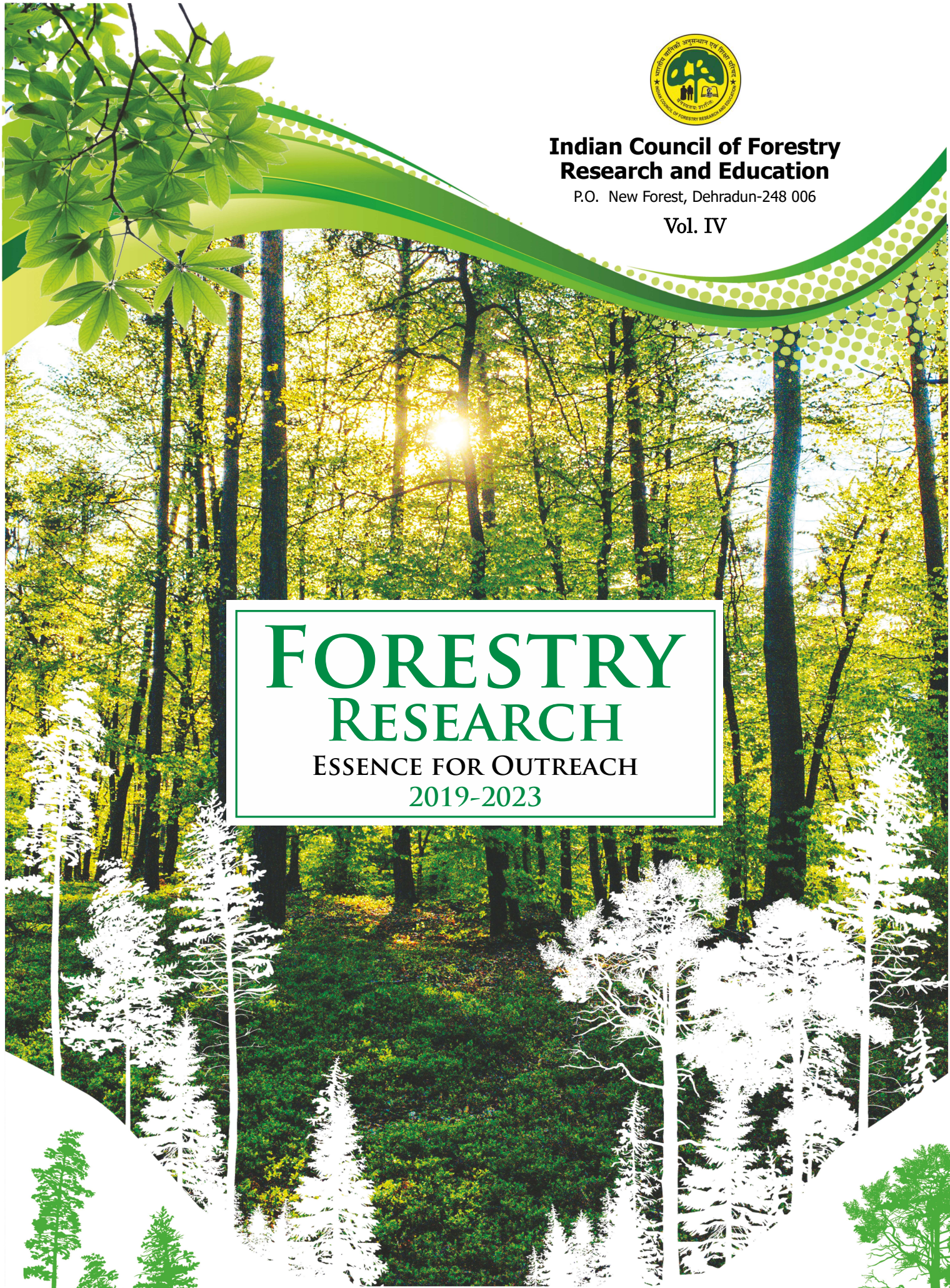
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun-248 006

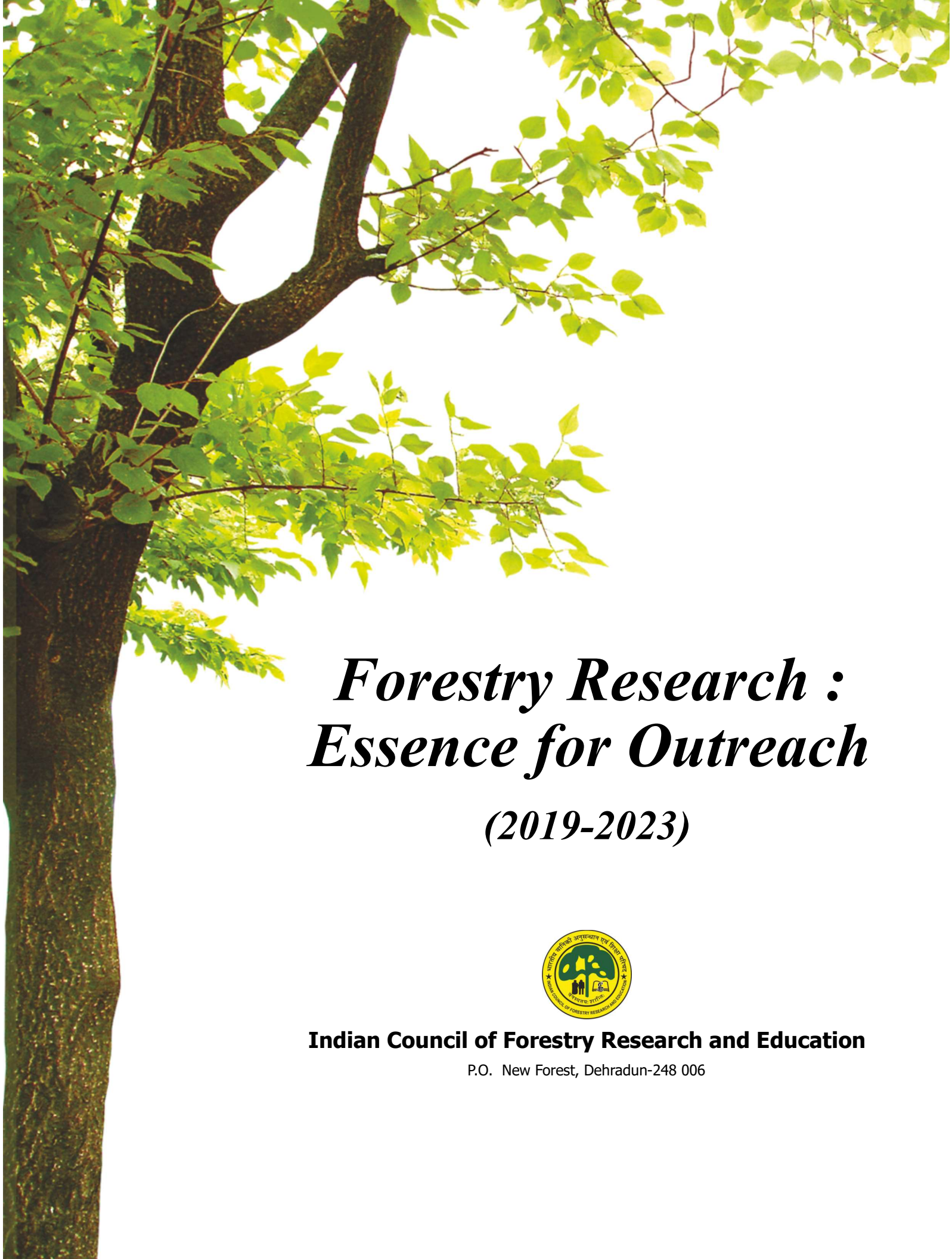
Vol. IV



FORESTRY RESEARCH

ESSENCE FOR OUTREACH

2019-2023



Forestry Research : Essence for Outreach

(2019-2023)

Indian Council of Forestry Research and Education

P.O. New Forest, Dehradun-248 006

Published by :
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun - 248006

Printed at :
Agarwal Adpro Pvt. Ltd.
36/1, Old Connaught Place, Chakrata Road,
Dehradun (U.K.)-248001

कंचन देवी, भा.व.से.
Kanchan Devi, IFS

कुलाधिपति, व.अ.सं. विश्वविद्यालय
Chancellor, FRI University

महानिदेशक
भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद्
न्यू फॉरेस्ट, देहरादून–248006
Director General
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun-248006

FOREWORD

Indian Council of Forestry Research & Education (ICFRE), Dehradun, India is known for its contribution in the field of forestry research, education and extension. It is the endeavour of ICFRE to serve humanity with advance research in the field of forestry, environment, climate change and ecosystem services.

Scientists at ICFRE and its institutes work on research projects covering themes such as Agroforestry, Biodiversity & Climate Change, Chemistry, Ecology, Soil & Land Reclamation, Extension, Forest Products, Genetics & Biotechnology, Hydrology, Protection (Entomology & Pathology) and Silviculture & tree improvement. During 2019-2023, 170 research projects have been completed under plan funds and project completion reports were submitted. This publication is a brief overview of the projects under 12 themes incorporating the summary, significant achievements and research gaps. It highlights the applications of these research projects to give a glimpse of the research work done by ICFRE institutes.

It is hoped that this publication will motivate the researchers to take up new and follow up projects on various subjects. It will also be useful for the public to know about the latest research in forestry and the institutions working on them.

I hope that the publication of compilation of abstracts would be beneficial for the forest managers and forestry professionals; motivating young researchers and forestry students in handling similar situations elsewhere

(Kanchan Devi)

डॉ. राजेश शर्मा
उप महानिदेशक (अनुसंधान)
अनुसंधान निदेशालय

Dr. Rajesh Sharma
Deputy Director General (Research)
Directorate of Research

दूरभाष नं./Phone No. 0135-2224836 (का.) (O)
ई.मेल / E-mail. ddg_res@icfre.org

भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद
(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार की एक स्वायत्त परिषद)
पो.ओ. न्यू फॉरेस्ट देहरादून – 248 006 (उत्तराखण्ड)

INDIAN COUNCIL OF FORESTRY RESEARCH & EDUCATION
(An Autonomous body under the Ministry of Environment, Forest and Climate Change, Government of India)
P.O. New Forest, Dehradun - 248 006 (Uttarakhand)

PREFACE

Research pursued and published is considered as the mouthpiece of a research institution. The researchers wish to excel in their respective fields and get recognized among their international counterparts. On completion of a research project, the Project Completion Report becomes an integral repository of knowledge for the organization. Most of the research results find their way in the form of publications in journals, books and articles.

This publication is a compilation of the efforts of the Scientists that includes abstracts of 170 projects on the themes of Agroforestry, Biodiversity & Climate Change, Chemistry, Ecology, Soil & Land Reclamation, Extension, Forest Botany, Forest Products, Genetics & Biotechnology, Hydrology, Protection (Entomology & Pathology) and Silviculture & tree improvement.

This publication will act as a source of inspiration and motivation to the researchers besides providing a platform to take up new research initiatives

(Rajesh Sharma)

एलन चोंग टेरोन, भा.व.से.
सहायक उप महानिदेशक
(अनुश्रवण एवं मूल्यांकन प्रभाग)

Alan Chong Teron, IFS
Assistant Director General
Monitoring and Evaluation Division

दूरभाष नं./Phone No. 0135-2224810 (का.) (O)
ई.मेल / E-mail. adg_me@icfre.org

भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद
(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार की एक स्वायत्त परिषद)
पो.ओ. न्यू फॉरेस्ट देहरादून – 248 006 (उत्तराखण्ड)

INDIAN COUNCIL OF FORESTRY RESEARCH & EDUCATION
(An Autonomous body under the Ministry of Environment, Forest and Climate Change, Government of India)
P.O. New Forest, Dehradun - 248 006 (Uttarakhand)

ACKNOWLEDGEMENT

This publication is the result of efforts and labour of many individuals of the Council. First, I express my heartfelt thanks and gratitude to Shri A.S. Rawat, former Director General of the Council for his moral and logistic support to pursue and complete this assignment. I am also grateful to Smt. Kanchan Devi, Director General, ICFRE for steering the assignment and guidance provided. I am thankful to both for their inspiration and leadership.

The time-to-time interventions by Dr. Ratnaker Jauhari, former Deputy Director General (Research) have made this work possible, for which I express sincere thanks. We appreciate his notable contributions, support and facilitation. Special thanks are also due to Dr. Rajesh Sharma, Deputy Director General (Research), ICFRE. I am thankful to Dr. Sumit Chakrabarti, former Assistant Director General, M&E Division, for his assistance and support.

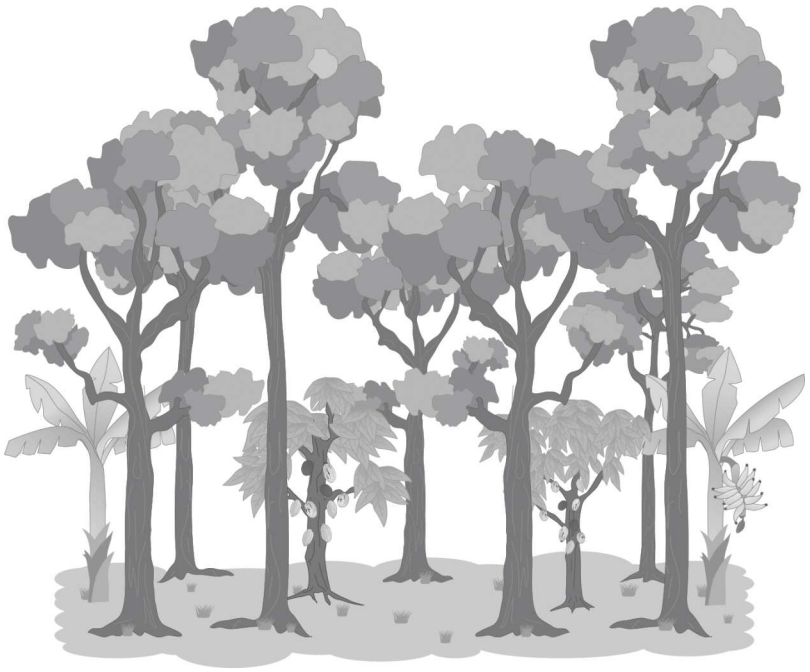
I am thankful to all the Project Leaders/Principal Investigators for providing information about the Abstracts of the research projects, their respective Directors and Group Coordinators (Research). This abstract compilation would not have been possible without their contribution.

I appreciate the efforts made by Dr. Jawaid Ashraf, Scientist, M&E Division, ICFRE for coordinating, liasoning and facilitating with all ICFRE institutes for collection of completed project information and designing the abstract of the completed projects for this publication and Dr. Anugrah Tripathi, Senior Technical Officer, M&E Division, ICFRE for coordinating with ICFRE institutes. I also wish to thank the consultant for editing this book.

Last but not the least, I wish to thank and acknowledge the team and personnel of Monitoring & Evaluation Division, ICFRE for their timely assistance and support.

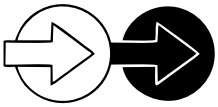
(Alan Chong Teron)

CONTENTS



AGROFORESTRY

AGROFORESTRY



1. **Title of the project:** Study on crop yield, soil fertility and gum production in *Acacia senegal* based traditional agroforestry system in arid region of Rajasthan

   Principal Investigator: Dr. Bilas Singh, CTO, ICFRE-AFRI Jodhpur

   Duration: 2017 - 2022

   Critical analysis of research theme and summary of the study:

   Senegalia senegal (= *Acacia senegal)* trees scattered on agricultural and other marginal lands and raised on farm boundary as live fence/hedge in western Rajasthan play important role in socio-economic upliftment. However, potential of this tree species has not been fully exploited in undulating landscape with poor sandy soil and harsh climatic condition of arid Rajasthan. Integration of *S. senegal* trees in farmlands or boundary hedge agroforestry system along with gum enhancing technology may enhance the resilience of the production system, income and employment to secure livelihood. Tree height, diameter at breast height (DBH), canopy diameter, basal area and canopy cover were measured and found in the range of 6.32-7.58 m, 17.80-26.30 cm, 5.95–6.59 m, 4993-11265 cm^2 per hectare and 413.7-1143.2 m^2 per hectare, respectively. Photosynthetically Active Radiation (PAR) and soil pH decreased, whereas Electrical Conductivity (EC) Soil Organic Carbon (SOC), Total Nitrogen (TN) available Phosphorus (PO_4-P) and exchangeable Potassium (K) increased beneath tree canopy than those in open area (5.0 m from canopy edge/boundary hedge) suggesting beneficial effects of trees on soil properties. However, competitive effects of trees affected crop yield negatively. Tree/hedge density played important role in influencing system productivity, where crop decreased but fodder, fuel and gum yield were additional benefits, which increased with increase in tree/hedge density. Seed and gum production was limited to 78% and 56% trees of *S. senegal,* respectively. But seed production increased with increase in tree dbh, whereas gum yield was highest in trees having medium size dbh.Thus, *S. senegal* based traditional agroforestry systems of varying tree/hedge densities were more profitable than sole agricultural crop in arid region of Rajasthan.

   Significant achievements/ findings of the project:

   Height and diameter at dbh of naturally growing scattered trees of *S. senegal* followed similar growth pattern during 2017-2021. However, percent increase in height was greater in 10-20 tree per hectare, whereas that of dbh was greater in 20-30 tree per hectare plots. Collar diameter of boundary hedge of *S. senegal* trees showed similar growth pattern, where collar diameter was greater at hedge density 50 plants per 100 running meters (RMT). Incremental growth of farm trees and hedge plants' dbh declined with increase in tree and hedge density, respectively. PAR was highest in control plots and decreased by 78% and 72% at 1 m distance from tree trunk and at canopy edge of *S. senegal* trees. PAR interception was highest beneath trees in 10-20 trees per hectare plot. Soil pH decreased, whereas EC and concentrations of SOC, TN, available PO_4-P and exchangeable K increased (P<0.05) beneath tree canopy in both the experiments. Average total yield (24.65 Q per hectare) and grain (7.73 Q per hectare) yields of agricultural crop was highest in open areas. Respective yield beneath canopy of *S. senegal* trees was 26.44% and 36.75% lower. Farmlands with tree density of 10-20 tree per hectare and 20-30 tree per hectare exhibited 21.24% and 43.08% higher total yield (TY) and 52.45% and 23.67% higher grain yield as compared to that in 30-40 trees per hectare plot (16.76 Q per hectare TY and 4.69 Q per hectare grain yield). Reduction in total yield decreased from 27.36% in 20-30 trees per hectare plot to 24.03% in 30-40 trees per hectare plot, whereas reduction in grain yield increased from 38.40% in 20-30 tree per hectare plot to 41.73% in 30-40 tree per hectare plot beneath tree canopy. Boundary hedge of *S. senegal* with density 30 plants per 100 RMT showed 31.13% and 30.91% enhancement in total yield and grain yield, respectively as compared to the yield along hedge density 50 plants per 100 RMT (24.03 Q per hectare TY and 7.02 Q per hectare grain yield). Application of Ethephon induced gum yield but limited to 56% of the total trees. Yield of gum arabic was positively influenced by tree density and was found highest in 30-40 tree per hectare plots. Net return from pearl millet crop was Rs. 14735 per hectare in 10-20 trees per hectare plots, whereas it was lowest (Rs. 3665/ha) in 30-40 trees per hectare plots in rain-fed system. The net benefit increased to Rs. 35482 per hectare and Rs. 5728 per hectare in respective system under irrigation during kharif season. In Rabi season, net return was highest (Rs. 34053/ha) for cumin inter-cropped in 10-20 trees per hectare plots, whereas mustard inter-cropped in 20-30 trees per hectare plots provided lowest net return (i.e., Rs. 9212/ha).

Suggestions/ advisory note for end users "To-do-techniques":

The study indicated that *S. senegal* based agroforestry systems of varying tree/hedge density were more profitable than pure agricultural crop systems in arid region of Rajasthan. This system demonstrated its potential in enhancing soil fertility and productivity of the system and hence the income of the farmers in this harsh environmental condition. It made the local people climate resilient and helped sequestering carbon and mitigating climate change effects. Motivating farmers in arid and semi-arid regions to establish *Senegalia senegal* plantations and live hedges/ fencing and creating infrastructure for processing, value addition and finding new application areas of gum Arabic will be taken up.

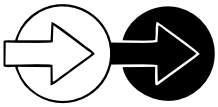
Research gaps:

Senegalia senegal is valued for its gum which generates a source of livelihood for people in Rajasthan. Many farmers grow this species in their field along with agricultural crops. Since tree density directly correlates with the gum yield per unit area and is also expected to greatly affect crop productivity, this project was formulated to work out appropriate tree density to increase the overall productivity of *S. senegal* based traditional agroforestry system in drought prone Western Rajasthan.

Uses of research outcomes:

Optimization of the tree density would ensure more gum Arabic production while also maintaining or improving crop production, thereby warranting livelihood security and employment to the desert dwellers, while also ensuring soil sustainability in Western Rajasthan.

\



2. **Title of the project:** Study on the effects of trees on soil fertility and crop production in Rajasthan

Principal Investigator: Dr. Bilas Singh, CTO, ICFRE-AFRI Jodhpur

Duration: 2016 - 2019

Critical analysis of research theme and summary of the study:

Existing literature on different agroforestry systems available were synthesized and elaborated for identifying best practices and maximum benefits. Field study was also conducted on line transect basis to document traditional and indigenous agroforestry models existing on the farmers' fields in each agro-climatic zones (ACZ) of Rajasthan covering 15 districts in the state. Study was conducted in both 'Kharif' and 'Rabi' seasons and data on trees height, diameter at breast height, canopy cover, crop yield under tree canopy, canopy edge and sole agriculture crop as control (well beyond the tree canopy) were recorded and analysed. There were 14 silvicultural, 7 horticultural and 21 agricultural crop species identified growing on farmlands in different agroclimatic zones of Rajasthan. This makes a total 115 tree-crop combinations in the state. However, 10 silviculture and 6 horticulture species were common. *Prosopis cineraria*-based agroforestry system was prominent in arid and semi-arid regions, whereas *Acacia nilotica* was prominent in semi-arid to sub-humid regions of Rajasthan. Grafted *Zizyphus mauritiana* and *Cordia myxa* were widely distributed, whereas *Kenzhoumandarin*, *Punica granatum*, *Psidium guajava, Mangifera indica* and *Citrus reticulata* were available in limited areas depending upon climatic conditions and the soil characteristics.

Significant achievements/ findings of the project:

Different ACZs had varying average tree density from 23.2 to 1.5 trees per hectare across the species, average tree height between 11.2 m in irrigated areas of ACZ Ib and 6.5 m in IIb, and canopy diameter from 9.03 m in zone Ib to 5.28 m in zone IIb. Basal area and tree canopy cover were highest in IIIb, and lowest in IIIa and zone Ic (177 m^2 per hectare). Densities of *Senegalia senegal* and *Tectona grandis* were 26.3 and 25.0 tree $ha^{-1,}$ whereas it was 1.77 and 2.15 tree per hectare for *P. juliflora* and *Vachellia tortilis,* respectively. Yield of agricultural crops varied from 21.75 q/ha in ACZ IIIa and 7.72-8.84 q/ha in ACZs Ia, Ic and IIa. All agroforestry systems reduced crop yield that ranged between 20% in *P. ceneraria*-based to 60% in *Salvadora oleoides*-based agroforestry system. Reduction in crop yield associated with *Punica granatum* was about 80%, whereas it was about 31% in association of *Citrus reticulata* system among the horticultural species. Soil pH, EC, SOC, total N, available P and K varied between different ACZs as well as silvicultural and horticultural species integrated in farmlands. SOC, total N and K were higher and lower in ACZ V and IIIb respectively. Available P ranged between 9.98 mg kg^{-1} soil in IIIb and 3.14 mg kg^{-1} in Ib ACZs. Soils of ACZs Ic, Ia and Ib were high in pH and EC, whereas they decreased in high rainfall ACZs IVa, IVb and V zones. Soil pH and EC were observed highest in *Z. mauritiana* (8.44) and *D. sissoo* (1.79 dSm^{-1}), respectively, but their lowestvalues were in soils of *T. grandis* based system, which was highest in SOC, total N and available P. Soils of *V. tortilis*-based system was lowest in total N, whereas *Dalbergia sissoo* based system was lowest in available P. Available K ranged between 209 mg kg^{-1} in *P. juliflora* and 96 mg kg^{-1} in soil of *Ailanthus excelsa*-based systems. Among horticultural species based systems, soil pH and EC were highest (8.09 and 1.478 dSm^{-1}) with *K. mandarin,* SOC, available P and K were high with *C. reticulata*, and total N was high in the soil with *M. indica*. Low values of SOC, total N, available P and K were observed lowest in the soils associated with *C. myxa*, *Z. mauritiana*, *K. mandarin* and *M. indica* species, respectively. Benefit-cost ratio indicates that*D. sissoo*-based agroforestry system was more remunerative by providing Rs 86,018/ha as net benefits than the other agri-silvi systems in Rajasthan exhibiting 2.68-fold high return over investment. Other equivalent systems are Ardu-based (Rs 75,016/ha) and teak-based (Rs 73,600/ha) systems. *V. tortilis* and *A. senegal*-based systems exhibited only B:C ratio 1.74 only. The economic return was Rs 132500/ha by paddy/wheat cultivation with *A. nilotica* in Kota, followed by cotton/wheat with *D. sissoo* system (Rs 114223/ha) in Sriganganagar. Hyper-arid region of Churu and Barmer districts showed lowest (Rs 1048-12922/ha) economic returns

Suggestions/ advisory note for end users "To-do-techniques":

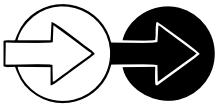
Development of different agroforestry systems with varying tree density ranging from 1.5 to 23.2 to trees per hectare is the output of prevailing environmental conditions, soil characteristics and most importantly is the social acceptance. All exiting agroforestry systems reduced crop yield that ranged between 20% in *P. cineraria*-based system to 60% in *S. oleoides*-based agroforestry system. However, such losses are compensated by additional benefits provided by the woody components in the form of fuelwood, fodder, fruit and vegetables that improves livelihood of the farmers in addition to the environmental services. *D. sissoo*-based agroforestry is most promising and profitable in agro-climatic zone Ib but only under irrigated condition. *A. nilotica*-based system performs better in agroclimatic zones IIIa, IIIb and V. *Prosopis cineraria*-based agroforestry is most promising and profitable in Ia, Ic, IIa, IIb agro-climatic zones. Competition between tree and crop is the main cause that affects crop production negatively. Integration of trees on farmlands not only helps to improve land productivity and alternative livelihoods but also help conserve biodiversity and mitigate the adverse effects of climate change and desertification.

Research gaps:

Farmers are maintaining this species on their farmlands randomly and thus have limited understanding about optimum density to maximize production whether to go for high density of *A. senegal* or low tree density. Thus, it was felt necessary to workout optimum tree density to improve productivity of *A. senegal* based traditional agroforestry system in Western Rajasthan.

Uses of research outcomes:

Higher tree density (30-40 tree per hectare) of *Acacia senegal* tree was most beneficial agroforestry system as well as ameliorate soil condition among the studied of tree density treatments in dry land of Rajasthan. This system improves soil fertility, productivity and income of farmers in this harsh environmental condition.



3. **Title of the project:** Assessment of suitable clones of Eucalyptus for promotion of Agroforestry in Eastern U. P.

Principal Investigator: Dr Anubha Srivastav, Scientist D, ICFRE - ERC, Prayagraj

Duration: 2016 - 2021

Critical analysis of the research theme and summary of study:

This project was executed with the objectives of assessment of promising clones of Eucalyptus in different agro-climatic zones of eastern Uttar Pradesh and extension–cum- training for promotion of promising clones to different target groups. Genetically improved clonal planting stock of eucalypts has transformed the productivity and profitability of plantations. Average yields from such clonal plantations are 20 to 25 times higher compared to the average productivity of forests in India. Eucalyptus clones, with average productivity of 25 m^3 per hectare per year produce 1.75 to 2 million cubic meters wood annually at 5 years rotation. Eucalypts are preferred commercial species of agroforestry for farmers/tree growers of Uttar Pradesh for their easy marketability and good returns in short time. Site specific clones in agro-climatic zones of the region were assessed and market linkages of species were also channelized under the project. On the basis of performance of 32 clones of Eucalyptus in selected districts of eastern Uttar Pradesh, promising clones were categorized in three series of clones *viz.* IFGTB, Coimbatore; FRI, Dehradun, and commercial clones of Punjab and were scored on the basis of growth performance in different districts covering different agro-climatic zones of Eastern Uttar Pradesh.

Significant achievements/ findings of the project:

The summarized results of different districts showed that in IFGTB series, the clones IFGTB 4, IFGTB 8, IFGTB 6, IFGTB 10 and IFGTB 1 performed superior over other clones, whereas in FRI series, the clones FRI 100 and FRI 124 performed superior over all the three clones. The overall performance of IFGTB clones was superior to FRI clones in Pratapgarh district. Here, all well performing clones of IFGTB series belonged to *Eucalyptus camaldulensis*. In IFGTB series, the clones IFGTB 4, IFGTB 1, IFGTB 6, IFGTB 9, IFGTB 10, in FRI series, FRI 104, and FRI 124 and in Punjab series, P-14, P-45, 07, K-25, 526, 2136 and 2013 clones performed superior over other clones in Gorakhpur district. Here, all well performing clones of IFGTB series belonged to *E. camaldulensis.* In Punjab series clones- P-13, P-50, P-23, 526, P-32, 3018 and P-45 performed superior over other treatments and all well performing clones of Punjab series belonged to *E. camaldulensis* except 3018, which belonged to *E. tereticornis* in Raebareilly. On the basis of height, gbh / dbh, basal area and volume of tree, clone P-32, 07, P-14, 288, P-23, P-50 and P-13 performed superior over all other treatments. All superior clones belonged to species *E. camaldulensis* except 288 and 07 which were of *E. tereticornis* in Mirzapur district. On the basis of height, gbh / dbh, basal area and volume of tree, overall, clone P-32, P-13, P-23, 526, P-50, 3018, 04 and P-50 performed superior over all other treatments. All superior clones belonged to species *E. camaldulensis* except 3018 which belong to *E. tereticornis* in Padilla, Prayagraj district. In Eastern plain region, the clones IFGTB 4,8,6,10,1, FRI 100, 124 and Punjab P13 , P50, P23, 526, P32, 3018, P45; in Vindhyan region, the clones IFGTB 4, 3, 6, 7, 10, FRI 100, 124, Punjab P 32, 07, P14, 288, P23, P50, P13 and in Eastern Tarai region, the clones IFGTB 4, 1, 6, 9, 10, FRI 104, 124, Punjab P14, P45, 07, K25, 526, 2136, 2013 performed superior over other clones.The ranking of 32 planted clones showed that Clone IFGTB 4, IFGTB 6 and IFGTB 10 in IFGTB series; FRI 124 in FRI series, and P-13, P-14, P-23, P-32, P-45, P-50 ,07 and 526 in Punjab series were consistently superior in all regions.

Suggestions/ advisory note for end users "To-do-techniques":

The results were extended to stakeholder groups for adoption of these site- specific clones. The farmers of eastern UP were linked to plywood/ veneer industries for sale of Eucalyptus trees for good returns (Rs. 1500-1800 per tree with 3.0 - 3.5 quintal). The results confirmed that the clones are best selected and tested in particular environment and may be deployed in larger area having similar environmental conditions. Therefore, clonal plantations, both on degraded forest lands and under agro-forestry system should be encouraged and integrated with planned development of wood-based industries through innovative policy changes.

Research gaps:

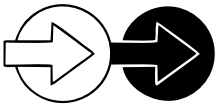
Identification of site-specific promising clones of Eucalyptus in field plantations/agroforestry in different regions of eastern Uttar Pradesh.

Uses of research outcomes:

Adoption of identified site-specific promising clones by farmers/tree growers/NGOs in region of Eastern UP will gain higher returns by the sale of Eucalyptus trees.

Publications:

- Srivastav Anubha 2020. Performance of Eucalyptus Clones in Trans- Ganga Region of Prayagraj, India. *Indian J. of Agroforestry* 22 (1): 43-47.
- Srivastav Anubha, Tomar Anita and Shukla S. D. 2018. Evaluation of Eucalyptus clones in Eastern Gangetic Plains of Uttar Pradesh, India. *Asian Journal of Research in Agriculture and Forestry* 2(4):1-6.
- Srivastav Anubha 2018. Early Growth Performance of Eucalyptus Clones in Vindhyan Region of Uttar Pradesh, India. IJARIIT 4 (2):549-*552.*
- Srivastav Anubha 2022. Suitability of Eucalyptus clones on salt affected areas of Eastern Gangetic Plains, India. *Indian J. Agroforestry* 45(2):87-91, https://doi.org/10.54207/bsmps1000-2022-S31VN
- Srivastav Anubha, Tomar Anita and Shukla, S. D. 2022. Clonal Eucalyptus – Suitability in Eastern Uttar Pradesh, p. 68-83 - a book chapter in *Clonal Forestry- Principles & Practices* published by Biotech Books, New Delhi.
- Srivastav Anubha 2021. A booklet in Hindi for extension purposes –पूर्वी उत्तरप्रदेश में यूकेलिप्टस कृषि वानिकी, published by ICFRE-ERC, Prayagraj



4. **Title of the project:** Development of Kachnar (*Bauhinia variegata*), Bhimal (*Grewia optiva*) and Kadam (*Neolmarckia cadamba*) based agroforestry models on farmers land under rainfed conditions in Uttarakhand.

Principal Investigator : Dr. Charan Singh, Scientist-F, ICFRE, FRI Dehradun

Duration: 2017 - 2022

Critical analysis of the research theme and summary of the study:

Neolmarckia cadamba, *Bauhinia. variegata* and *Grewia optiva* are fast growing species and fulfill the demand of timber, fuel wood and fodder and also helpful in enhancement of farmers' income and improvement of livelihood. In Tarai region of Uttarakhand State, these three species showed their potential of their survival with better growth performance in harsh conditions. These species did not show any remarkable antagonistic effect on the crop of wheat, millet, maize and drought resistant variety of sugarcane. Under 3 years old plantation, *N. cadamba* performed better in spacing of 6x8 m with a height of 951.00 cm with girth 55.60 cm followed by *Bauhinia variegata* of height 628.30 cm with girth 30.00 cm (spacing 6x6m) and *Grewia optiva* of height 611.00 cm with 24.00 cm girth (spacing 6x8 m). Crops like wheat, maize, millet, Sesame and Sugarcane (Drought tolerating variety-CoPant97222) were grown successfully by farmers. After experimentation on farmland 12 agroforestry models came out and out of these models, kadam based two models showed more economic viability. The model having the crop sequence as wheat (3crops) - finger millet (1crop) - sesame (1crop), these crops showed the yield as 124.23q/ha, 290q/ha and 2.03q/ha, respectively under plantation of Kadam having 280 plants/ha with spacing of 6x6m at 3-year rotation. The cultivation cost of crops and management of trees and sale calculated as Rs. 1.68 Lakh/ha and sale value of produce was calculated as Rs. 3.42 lakh/ha with a net profit Rs.1.74 Lakh/ha showing the B:C ratio as 2.03.

At 8 years rotation, the yield of wheat, finger millet and sesame were estimated as 186.34q/ha, 435.00 q/ha and 3.15 q/ha while the aspected timber from the *N. cadamaba* at the same rotation is 2010.23q/ha from 280 trees/ha with spacing of 6mx6m. The expected economic value of the model at 8 years rotation showed total cultivation and management cost Rs. 5.51 Lakh/ha and sale value of Rs. 18.48 with a net profit of Rs. 12.97 Lakh/ ha with B:C Ratio as 3.35. The other model having the sequence of under storey crops like Maize (1crop)-sugarcane variety-CoPant97222 (2 harvestings)-wheat (1 crop) grown with *N. cadamba* plantation having its spacing of 6x6 m, the crops maize, sugarcane and wheat showed the yield of 2.00 q/h, 694.03q/ha and 31.17q/ha with yield from Kadam as 98.53 q/ha. The total cost on crop and tree species was Rs. 1.47 Lakh/ha and sale value of produce obtained from crops and wood from *N. cadamba* was Rs. 3.55 Lakh/ha. The net profit at 3 year rotation was 2.08 with B: C Ratio as 2.41. Under study on Allelopathy, solution of Kadam leaves showed allelopathy/ Bioassay effects on maize (45.00% germination in 75% and 0.00% in 100% solution of Kadam leaves). In case of wheat, 35.67% germination in 75% and 21.67% in 100% stalk solution of Kadam leaves was recorded. Kachnar showed no remarkable allelopathic effect on maize, wheat and Til (Sesame). The germination of Til (Sesame) in Bhimal leave solution at 100% concentration was found 25.00%. In field conditions, no allelopathic effect was seen on crops under canopy management with 50% pruning of trees for light penetration on under-storey crops.

Significant achievements/ findings of the project:

N. cadamba performed better in spacing of 6mx8m with a height of 951.00 cm with girth 55.60 cm followed by *Bauhinia variegata* of height 628.30 cm with girth 30.00 cm (spacing 6x6 m) and *Grewia optiva* of height 611.00 cm with 24.00 cm girth (spacing 6mx8m). Kadam produced fuel wood @ 15.12 quintal with a sale value of Rs. 4536.00/ha from 280 plants planted at 6mx6m spacing. Kachnar produced fodder @ 15.68 quintal with a sale value of Rs. 1568.00/ha from 280 plants planted at 6mx6m. Bhimal produced fodder @ 14.26 quintal with a sale value of Rs. 1426.00/ha from 280 plants planted at 6x6 m. Based on Kadam, Kachnar and Bhimal, total 12 models have been developed. Out of these following 2 models showed higher return in 3 years as per recorded data and a viable economic value aspected at 8 year rotation:

- Kadam+Wheat +Finger millet +Sesame model showed sale value of Rs. 3.86 Lakh/ha with net profit of Rs. 2.18 Lakh/ha
- Maize+Sugarcane+Wheat model also showed sale value of Rs. 3.65 Lakh/ha with net profit of Rs. 2.18 Lakh/ha

Suggestions/ advisory note for end users "To-do-techniques"

The study revealed that Kadam, Kachnar and Bhimal can be grown with agricultural crops like wheat, finger millet, sesame and sugarcane in Tarai area of Uttarakhand. Kadam can be opted commercially for timber while Kachnar and Bhimal can be opted under agroforestry as fodder yielding species.

Research Gaps:

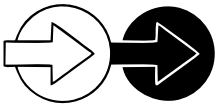
The project was initiated to establish diversifying agroforestry models based on species like *N. cadamba*, *G. optiva* and *B. variegata* in Terai area of Uttarakhand having potential to survive under rain-fed conditions as the land was degraded and no proper facilities of irrigation were available.

Uses of research outcome:

Kadam (*N. cadamba*) can be promising under agroforestry as timber species in Terai region of Uttarakhand, if retained for 8 years.*B. variegata* and *G. optiva* can also be grown as fuel and fodder species which can provide fodder in lean period and survive under rain-fed conditions as the land was degraded and no proper facilities of irrigation were available.

Publications:

- Singh Charan and Himshikha, 2018. *Grewia optiva* (Drumm.Ex Burr.) – A multi-purpose tree under agroforestry in Sub-Tropical region of Western Himalya, *Journal of Tree Science* 37(2):36-43.
- Singh Charan, Singh Rambir and Gulati Ajay 2021. Performance of *Anthocephalus cadamba* (Roxb.) Miq., B*auhinia variegata* Linn. and *Grewia optiva* Drumm. Ex Burr in Tarai Bhabar region of Uttarakhand, India. *Indian Forester* 147(2): 168-174.



5. Title of the project: Development of *Gmelina arborea* and *Emblica officinalis* based agroforestry models on fallow lands in Uttarakhand and Uttar Pradesh (2017-2022).

Principal Investigator : Sh. Rambir Singh, Scientist-E, ICFRE-FRI Dehradun

Duration: 2017 - 2022

Critical analysis of the research theme and summary of the study:

As a major output, it can be asserted that Gamhar (*Gmelina arborea*) is a fast-growing species, which is capable to fulfil the timber and fuel wood demand of farmers in Uttarakhand and Uttar Pradesh states without making adverse effect on under storey crops under fallow land agroforestry. Grafted Aonla (*Emblica officinalis*) variety of NA-7 is a short rotation cash crop and suitable for degraded lands in Uttar Pradesh and Uttarakhand. In an integrated way, both tree species can give a handsome income to the farmers in short rotation of 8 years and a long rotation up to 10 years in farmers' fields. Under the project agroforestry models were established at 4m x 5m and 5m x 5m spacing with rabi crops like Wheat-Barley-Mustard and kharif crops Groundnut-Til-Millet on fallow lands of Dhaluwala Majbata (Haridwar) of Uttarakhand and Fatehpur Pelio (Saharanpur) and Kodapur (Prayagraj) of Uttar Pradesh sites. The bund based agroforestry is more popular in the eastern part of the state of Uttar Pradesh and Uttarakhand due to marginal land holding. At present, after completion of three years planting of *G. arborea* and *E. officinalis* found maximum at 5x5m spacing of *G. arborea* (Ht. 8.76m & girth 20.2cm) in T3 (Gamhar+Agriculture)and *E. officinalis* (Ht. 4.75m & girth 11.7cm) in T1 control at Kodapur siteand well performing with agriculture crops on fallow lands. Aonla (*E. officinalis)* also performing well and found maximum in T1-control at both 4x5 m and 5x5 m spacing in all the sites. Attack of gall forming insect in *E. officinalis* and sap sucker insect in *G. arborea* was also observed.Treatment of Furadan for gall insect and Metacid/ Endosulphan for sap sucker insect was given to infested plants.

Economically, the estimated B:C ratio and Net profits of Gamhar and Aonla based Seven agroforestry models in 8 years rotation per hectare were calculated and found maximum (3.29 & Rs.19,15,320/ha) in model-1 (Gamhar-Groundnut-Wheat-Millet-Urd+til at 4x5m spacing) followed by model-2 (Gamhar-Groundnut-Wheat-Millet-Urd+til at 5x5m spacing) with (3.13 & Rs.17,54,028/ha), model-7 (Gamhar-Barley-Dencha-Mustard-Cauliflower-Cabbage at 3m on Boundary) with (2.99 & Rs.19,09,525/ha), model-5 (Gamhar+Aonla Mixed–Groundnut–Wheat–Millet - Urd+til at 4x5m spacing) with (2.60 & Rs.13,46,788/ha), model-6 (Gamhar+Aonla Mixed–Groundnut–Wheat–Millet -Urd+til at 5x5m spacing) with (2.47 & Rs.13,15,317/ha), model-3 (Aonla-Groundnut-Wheat-Millet-Urd+til at 4x5m spacing) with (1.94 & Rs.7,84,992/ha) and model-4 (Aonla-Groundnut-Wheat-Millet-Urd+til at 5x5m spacing) with (1.83 & Rs.6,83,352/ha), respectively.

Significant of the achievements/ findings of the project:

After three years planting of *G. arborea* and *E. officinalis* found maximum growth at 5x 5m spacing of *G. arborea* (Ht. 8.76 m & girth 20.20 cm) with agricultureand for *E. officinalis* (Ht. 4.75 m & girth 11.70 cm) in control at Kodapur siteand well performing with agriculture crops on fallow lands. Comparatively estimated economics as per Net profit (Rs.19,15,320) and Cost Benefit ratio (3.29) confirms that the model-1 (Gamhar-Groundnut-Wheat-Millet-Urd+til at 4mx5m spacing) and model-7(Gmelina-barley-mustard-wheat-vegetables on bund) were found more economic and viable than other models in expected 8 years rotation. The soil at Kodapur (Prayagraj) site was alkaline with 8.25 pH in comparison of sites at Dhaluwala majbata (7.11 pH) and Fatehpur Pelio (7.36 pH). But after three years of plantation soil pH was near to neutral at site Dhaluwala majbata (6.93) and Fatehpur Pelio (7.30) and slightly alkaline value changed at site Kodapur (8.10).Timber yield of *G. arborea* is expected about 198.008 tons/ha at 4x5 m spacing having 400 trees and 178.56 tons/ha at 5x5 m spacing having 320 trees at 80% survival in 8th year rotation. Similarly, the total yield of *E. officinalis* is expected about 22.2 tons/ha at 4x5 m spacing having 400 trees and 17.8 tons/ha at 5x5 m spacing having 320 trees at 80% survival in 8th year.

Suggestions/ advisory note for end-users "To-do-techniques":

An awareness and demonstration programs were organized by Extension Division, Forest Research Institute, Dehradun on "Gamhar (*Gmelina arborea*) and Aonla (*Emblica officinalis*) based agroforestry models on fallow lands in Uttarakhand and Uttar Pradesh" to the farmers on 23.12.2021 at Kudarikheda, Fatehpur Pelio (Saharanpur) in Uttar Pradesh and on 24.12.2021 at Dhaluwala majbata (Haridwar) in Uttarakhand. One day farmers' training program was also organized by Forest Research Centre for Eco-rehabilitation on "Aonla and Gmelina based Agroforestry" on 07.02.2022 in forestry and environmental awareness camp located at Magh Mela. Farmers and other stakeholders should be aware about availability and knowledge of existing marketing location and availability of quality planting material. Publicity materials like brochure, pamphlets and posters for popularization of the agroforestry models should also be prepared and published.

Research gaps:

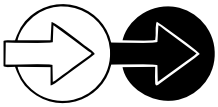
The project was initiated to establish suitable agroforestry models with an appropriate tree species on fallow land of farmers in Terai region of Uttarakhand and Central region of Uttar Pradesh where *Gmelina arborea* was introduced as new tree species and *Emblica officinalis* (variety NA-7) as value addition to the models with traditionally grown agriculture crops.

Uses of research outcomes:

The models established are economically viable and may be useful for all categories of farmers for enhancing the income from fallow and degraded farmland in a short rotation of 8 years with employment generation for associated industries including NGOs, SHGs, pharmaceuticals and local people.

Publications:

- Singh Rambir, Srivastava Anubha, Singh Charan and Gulati Ajay 2020.Performance of *Gmelina arborea* and *Emblica officinalis* under agroforestry on fallow lands in Uttarakhand and Uttar Pradesh. *Indian Forester* 146:353-358.
- Singh Rambir, Srivastava Anubha, Singh Charan and Gulati Ajay 2021. Growth and yield attributes of *Gmelina arborea* (*Roxb.)* and *Emblica officinalis* (Gaertn.) based agroforestry system on fallow lands in Uttarakhand and Uttar Pradesh. *Indian Forester* 147:680-686.
- Srivastava Anubha, Singh Rambir and Agarwal Yogesh Kumar 2023. Suitability of *Gmelina arborea* Agroforestry in Eastern Uttar Pradesh. *Journal of Tree Sciences* 40 (2): 1-8.



6. **Title of the project:** Survey and evaluation of Silvipastoral systems in Himachal Pradesh and its role in sustaining community livelihood

Principal Investigator: Dr. Swaran Lata, Scientist-D, ICFRE-HFRI Shimla

Duration: 2016 - 2021

Critical analysis of research theme and summary of the study:

Increasing human and livestock population on one hand and sustainability consideration shifts focus on research on silvipastoral systems. From the productive, ecological, economical, and social point of view, these systems are one of the most promising modalities of the agroforestry systems; however, these land use practices have not been studied scientifically considering the whole Himachal Pradesh as a single unit although it caters various domestic needs viz., fuel, fodder, etc. of the farming communities. The output of the research was resulted in generation of data on silvipastoral systems with respect to different agroclimatic zones of Himachal Pradesh viz. system units, floristic composition, community structure, soil physico-chemical properties, socio-economic dependency, carrying capacity and economics which can be used for future planning for productivity enhancement and sustainable management of these land use systems.

Significant of the achievements/ findings of the project:

Farmers of Himachal Pradesh are practicing traditional types of silvipastoral land use systems for fulfilling daily livelihood needs. Three system types and 72 system units (Zone-1=36, Zone-II=18, Zone-III=11, Zone-IV=7) are prevalent in silvipastoral systems of Himachal Pradesh. Agro-climatic zones I & II were more diverse with 36 and 18 system units, respectively, where as in zones III & IV system units were 11 and 7, respectively. Site 3- Roghi, Kinnaur in agro-climatic zone-IV was most diverse in terms of species composition with 103 species, 66 genera and 28 numbers of families followed by Site-3 Banalgi, Solan in agro-climatic zone-II with 92 species, 87 genera and 46 families. Maximum density of tree species recorded in *Myrica esculenta* (980.00 Ind/ha), *Grewia optiva* (660 Ind/ha)and *Bauhinia variegata* (630 Ind/ha) in agro-climatic zone-II.In zone I, most dominant tree species were *Pinus roxburghii* and *Acacia catechu*; in zone II *Myrica esculenta* and *Phoenix sylvestris*;in zone III *Quercus oblongata* and *Cedrus deodara*;in Zone IV *Cedrus deodara* and *Pinus wallichiana.* Among all farmer categories marginal farmers were having more diverse system units and maximum silvipastoral land holding 2.91 ha recorded in Banalgi (Solan) in medium farmer category followed by 1.45ha in Keela Kalanj (Sirmaur) in zone II. Marginal farmers were highly dependent on silvipastoral systems mainly for fodder and also having maximum number of livestock. Maximum biological yield 141.168q and net return Rs. 54129.58 recorded from Banalgi (Solan) and minimum biological yield 9.479 q recorded from Jarashi (Shimla) with net return Rs. 1427.55 agroclimatic zone- II. *Grewia optiva* and *Bauhinia variegata* inagro-climaticzone-I &II;*Quercusoblongata* and *Q.floribunda*inzone-III and *Salix* and *Populus* spp. in zone IV were the most preferred tree species irrespective to different farmercategory.Maximum herbage carrying capacity 1.36 ACU per hectare per year recorded form Banalgi, Solan with stocking rate 0.92 ACU/ha/year in agro-climatic zone II. Minimum carrying capacity 0.02 ACU/ha/year recorded fromKundi (Chamba) with stocking rate 15.9 ACU/ha/year in agro-climatic zone III. Among all studied sites Kundi (Chamba), Naun (Mandi), Jarsahi (Shimla), Muling (Lahaul & Spiti) and Bhakra (Bilaspur) has high stocking rate in comparison to carrying capacity.

Suggestions/ advisory note for end users "To-do-techniques":

To increase the productivity of silvipastoral systems introduction/ integration of fast growing multipurpose leguminous trees and high yielding nutritive grasses along with development and introduction of climatically suitable silvipastoral models suggested. In addition, most of the studied sites were infested by weeds (*Parthenium, Lantana* and *Ageratum*) which also reducing productivity thus integrated weed management practices viz., physical, chemical and biological weed control measures should be encouraged through organizing trainings and camps. Data generated from present study will contribute in laying out the field trials on introduction/integration of fast growing and nutritive fodder species, systematic long-term growth and suitability and palatability studies, development of improved silvopastoral models, establishment of demonstration models, degraded land restoration, commercial plantations and other agroforestry programmes and may be beneficial for farmers, SFDs, NGOs and entrepreneurs in terms of fodder, fuel and timber production.

Research gaps:

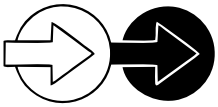
Increasing human and livestock population on one hand and sustainability consideration shifts our focus on research on silvipastoral systems. From the productive, ecological, economical, and social point of view, these systems are one of the most promising modalities of the agroforestry systems; however, these land use practices have not been studied scientifically considering the whole Himachal Pradesh as a single unit although it caters various domestic needs of the farming communities.

Uses of research outcome:

The data generated on various aspects of silvipastoral systems will act as baseline data for further in-depth studies on development and introduction of suitable demonstration/silvipastroal models, tree-grass suitability and compatibility studies, quantitative and qualitative improvement in livestock, restoration of degraded lands and silvipastoral system management improvement programmes. In addition the data generated on floristic composition and phyto-sociology of silvipastoral systems of Himachal Pradesh will help in conservation of native agro-biodiversity.

Publications:

- Lata, S., Chauhan V. and Paul, S. 2023. Prevalent silvipastoral system units among different farmer categories in Himachal Pradesh, North Western Himalaya, India. *Journal of Plant Development Science*, 15 (3):189-1
- Lata, S. and Varsha 2020. ब्यूलरू हिमाचल प्रदेश के निचले एवं मध्य पहाड़ी क्षेत्रों के वन चरागाह प्रणालियों में पाए जाने वाला महत्वपूर्ण एवं लोकप्रियवृक्ष, *Van Anusandhan* January-June.1-2
- Lata, S and Sharma, D. 2021. बौहिनियावेरिएगेटा (कचनार) : एक महत्वपूर्ण बहुउद्देशीय वृक्ष प्रजाति, *Van Anusandhan* (6): 22-24.



7. **Title of the project:** Evaluation of windbreaks for enhancing water use efficiency, crop productivity and climate change resilience in farmlands in semiarid regions of Tamil Nadu

Principal Investigator: Dr. C. Buvaneswaran, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2016-2020

Critical analysis of the research theme and summary of the study:

ICFRE-Institute of Forest Genetics and Tree Breeding (ICFRE-IFGTB) Coimbatore has successfully released five productive tree varieties (clones) of Casuarinajunghuhniana suitable for Windbreak Agroforestry system. These Windbreak clones of ICFRE-IFGTB showed high level of branch persistence with 40 to 50 thick and horizontal branches within 3 m height from the base of the tree. These clones have greater branch thickness, wider branch angle, greater height growth rate and faster diametrical growth rate of main stem. The efficacy of these windbreak clones in micro-climate moderation, enhancing of water use efficiency, agriculture crop productivity and soil moisture retention in the farm fields was assessed in the present study. The results revealed that there is a significant effect of windbreak on wind speed reduction and soil moisture retention inside the field with windbreaks, when compared to the adjoining open field. The percentage reduction in wind speed inside the windbreaks ranged from 25 to 65% when compared to the wind speed in the adjoining open field. Further, the cumulative soil moisture loss in five consecutive days ranged from 9.8% to 10.0% inside the windbreaks and the soil moisture loss in five consecutive days was from 25.0% to 26.9% in the adjoining open area. Thus, windbreaks were more effective in reducing water loss through evapo-transpiration. In short, Windbreaks can be one of the ways in achieving our national goal of "MORE CROP PER DROP".

Significant achievements/ findings of the project:

It was recorded that besides preventing the red gram crop from lodging due to heavy wind, the windbreaks enhanced the yield of the red gram. The yield of red gram was 600 kg per acre inside the windbreaks in comparison o only 400 kg per acre in the open field outside the windbreaks during 2018 and also in the second consecutive year (during 2019).

Suggestions/ advisory note for end-users "To-do-techniques":

Windbreak Agroforestry system can be promoted to make the agro-ecosystems as climate change resilient system through enhanced productivity, reduced evapo-transpiration and in turn increased water use efficiency of the agro-ecosystemas, reduced crop damage particularly in plantain cultivation and increasing carbon sequestration in biomass and in soil.

Research gaps:

In the context of ever-increasing unprecedented events of heavy wind storms associated with global warming, there is an imperative need to enhance the climate resilience in the agro-ecosystems. Of many strategies for increasing climate resilience, "Windbreaks" are one of the economically viable and ecologically sustainable agroforestry interventions. However, there are no studies on effect of windbreaks for enhancing water use efficiency, crop productivity and climate change resilience in farmlands – particularly with reference to clonal windbreaks.

Uses of research outcomes:

The end users are farmers who can use these results on reduced water loss due to evapo-transpiration inside the field with Windbreaks and also can be benefited from enhanced productivity of crop inside the field with windbreaks. Deploying of Windbreak clones of IFGTB can help the farmers in achieving the National goal of "More Crop Per Drop".

Publications:

- Buvaneswaran C., Kumar K. Vinoth, Velumani R., Senthilkumar S. 2018. Experimental Design for Evaluation of Clones of Casuarina for Windbreak Agroforestry System. Journal of Tree Sciences 37 (1): 11-18.
- Buvaneswaran C., Masilamani P., Senthilkumar S. and Prashanth R.S. 2017. Windbreaks and Agroforestry for Enhancing Carbon Sinks in Dry Lands. In: Agroforestry Strategies for Climate Change: Mitigation and Adaptation, pp. 301–315, Eds.: K.T. Parthiban, R. Jude Sudhagar, C. Cinthia Fernandaz and K.K. Suresh. Jaya Publishing House, Delhi, India.
- Buvaneswaran C., Masilamani P., Velumani R. and Vinothkumar K.. 2017. Short Rotation Windbreak Agroforestry systems – Case studies. In: Plantation and Agroforestry – Pulpwood Value Chain Approach, pp. 295 – 309, Eds.: K.T. Parthiban and R. Seenivasan. Scientific Publishers (India), New Delhi.

8. **Title of the project:** Agroforestry Interventions and Conservation of Tree Genetic Resources of *Acacia leucophloea* in traditional 'Korangadu' Silvi-pasture system towards fodder security

Principal Investigator: Dr. C. Buvaneswaran, Scientist-G & Dr. R. Anandalakshmi, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

A traditional silvipasture system in the western zone of Tamil Nadu locally termed as 'Korangadu' is dispersed in semi-arid pockets of Coimbatore, Erode, Tiruppur and Karur. The extent of area under this traditional agroforestry system has dwindled from 3.0 lakh acres to 1.5 lakh acres since 1960. This shrinkage of a traditional 'Korangadu' silvipasture system in Tamil Nadu will lead to loss of tree genetic resources of *Acacia leucophloea* (Reonja) and will also have bearing on 'fodder security' issues. This project aimed to enhance the productivity of the system and also to conserve important tree genetic resources of the system. In this effort, selected 78 CPTs of *Acacia leucophloea* and the progenies of these selected CPTs were raised and established in a germplasm bank in 1 ha area in Tuvarankurichi field station during August 2019 in 4 m x 4m spacing. The germplasm comprised a total of 546 plants representing 11 different populations. Evaluation of performance of progenies will be carried out and superior seed sources for the fodder tree - *Acacia leucophloea* – will be identified in near future

Significant achievements/ findings of the project:

Out of 78 CPTs identified, 28 high fruit yielding candidate trees of *Acacia leucophloea* were selected for half-sib progeny evaluation for three consecutive years at seedling stage. The results showed marked variation in germination percentage and which ranged from 2% in Half-sib family no. 24 to 71% in Half-sib family no. 2. The biomass production was also greater in Half-sib family No. 2 and least biomass production was recorded in Half-sib family No. 28. The variation in germination percentage was similar in the subsequent two years as well. Half-sib family no. AL-02 recorded greater germination consistently for three subsequent years by registering germination of 64 to 71%. While comparing the total dry matter production, again half-sib family AL-02 recorded highest grand mean value of 8.676 g per seedling. This marked variation observed in germination and growth among half-sib families of *Acacia leucophloea* warranted the need for conservation of superior phenotypes for enhancing fodder productivity in the traditional 'Korangadu' silvi-pasture system in Tamil Nadu.

The present project also attempted to study the potential of windbreaks as water conservation measures to enhance the fodder productivity in this traditional silvipasture system. The results clearly showed that wind speed was less inside the windbreaks when compared to open field and in turn aided in reducing water loss through evapo-transpiration and in turn will enhance the pasture productivity in the field with windbreaks.

Suggestions/ advisory note for end-users "To-do-techniques":

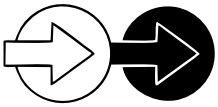
The fast-declin1ing tree genetic resources of *Acacia leucophloea* in the 'Korangadu' agroforestry system has to be conserved and the conserved elite germplasm need to be made available for enhancing productivity of the 'Korangadu' silvipasture system in near future.

Research gaps:

The shrinkage in extent of a traditional 'Korangadu' Silvi-pasture system in Tamil Nadu will lead to loss of tree genetic resources of *Acacia leucophloea* (Reonja) and will also have bearing on 'fodder security' issues. Hence, this project aimed to enhance the productivity of the system and also to conserve important tree genetic resources of the system.

Uses of research outcomes:

The end users are farmers who can use these selected phenotypes of *Acacia leucophloea* in the traditional Silvi-pasture system for increasing the pod yield, which in turn will increase fodder productivity in the system, more particularly during lean season. Also, by deploying Windbreak clones of IFGTB in Silvi-pasture system the pasture productivity can be increased through enhanced moisture availability by way of minimizing the evapo-transpiration loss.



9. Title of the project: Preparation of volume and yield table for indigenous tree species in Tamil Nadu

Principal Investigator: Dr. C. Buvaneswaran, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2018 - 2021

Critical analysis of the research theme and summary of the study:

Farmers are willingly participating in tree cultivation programme to overcome several problems associated in sole agriculture farming, particularly the shortage of farm labourer. When these plantations attain the harvesting age, there will be an imperative need for farmers to assess the standing wood volume and yield of the plantations. However, farmers are facing a practical problem of volume and yield estimation while felling of trees especially fast-growing tree species. Merchants and middle man estimate the volume and yield by ocular estimation and bargain with farmers, thus farmers are losing huge amount of money. Though data on productivity pattern and volume and yield table are available for plantation species like Teak, Eucalyptus and Casuarina, such data on volume and yield tables under different age, site condition and management regimes are not available for important fast growing indigenous species like *Melia dubia*, *Gmelina arborea* and *Ailanthus excelsa*. Hence, this project was executed for preparation of volume and yield table for these tree species to provide a tool to the farmers in estimation of volume and yield in the standing crop prior to felling.

Significant achievements/ findings of the project:

Growth parameters were recorded and volume production was estimated in 41 plantations of *Melia dubia,* 49 plantations of *Gmelina arborea* and 28 plantations of *Ailanthus excelsa* and data of growth parameters recorded and stem wood volume estimated for sample trees in these plantations. In turn, stem wood volume production on ha basis and also stem wood productivity was arrived at.

Among three species studied, at younger ages of 3 to 6 years, highest productivity of around 25 m^3 per ha per year was recorded in *Melia dubia* and *Gmelina arborea* and it was only 19.3 m^3 per ha per year in *Ailanthus excelsa.* When age of the plantations increased to around 15 to 21 years, the productivity recorded ranged from 13 to 18 m^3 per ha per year in these three species studied.

It was observed that per tree volume was highest under lower stand densities. In plantations of *Melia dubia,* while mean stem volume was 0.239 m^3 per tree under low stand density (200-400), it was only 0.05 m^3 per tree under high stand density (2500 trees per ha). Similar observation was also made in plantations of *Gmelina arborea, wherein* stem volume per tree was only 50% under high stand density (from 1111 to >2500 trees per ha), when compared to per tree volume production under low stand density plantations (400-600 or 600 to 800 trees per ha).

These volume prediction models for all three species were also used to develop Mobile Apps. These Mobile Apps will be made available in **"Tree Genie"** Digital Platform of IFGTB.

Suggestions/ advisory note for end-users "To-do-techniques":

The results on productivity under different spacing (stand densities) has clearly brought out optimum spacing requirements to attain the required per tree volume of all the three tree species studied *viz. Melia dubia, Gmelina arborea* and *Ailanthus excelsa.* The volume tables and Mobile Apps prepared under this project will provide a tool to the farmers in estimation of volume and yield in the standing crop prior to felling and will help the farming communities to value their plantations for better marketing. Farmers and other stakeholders are advised to get registered in **"Tree Genie"** Digital Platform of IFGTB to access these Mobile Apps for yield estimation.

Research gaps:

There is an imperative need for farmers to assess the standing wood volume and yield of the grown up plantations. This project was executed for preparation of volume and yield table for three fast growing indigenous tree species of Tamil Nadu viz., *Melia dubia, Gmelina arborea*, and *Ailanthus excelsa*.

Uses of research outcomes:

The end users are farmers who can use these results to have better understanding on yield potential of these three tree species - *Melia dubia, Gmelina arborea* and *Ailanthus excelsa* – under different ages as well as under different management regimes particularly under different spacing (stand densities). Further, Volume Tables and Mobile Apps those have been developed under this project, will be a ready reckoner for farmers, SFDs, wood-based industries and researchers for estimating the yield of standing crop

10. Title of the project: Biomass and Soil Carbon Sequestration in important plantation species of clonal and seedling origin in Tamil Nadu

Principal Investigator: Dr. A.C. Surya Prabha, Scientist-E, ICFRE-IFGTB Coimbatore

Duration: 2020 - 2022

Critical analysis of the research theme and summary of the study:

The objective of the study was to determine soil organic carbon (SOC) pool and carbon stock in biomass of important plantation species viz, Eucalyptus, Casuarina, Teak, and Melia in different agro-climatic zones of Tamil Nadu. It is important to have a good knowledge of the current global SOC stock and its spatial distribution to inform various stakeholders to make the best use of available land and provide the best opportunities to mitigate and adapt to climate change. Also, plantations are efficient sequesters of carbon and can mitigate the predicted rise in atmospheric CO2 concentration and future climate change. Information on the carbon sequestration potential of these plantations of clonal and seedling origin is not available, particularly in Tamil Nadu. The project was undertaken to study the carbon stock in biomass and soil carbon sequestration in important plantation species of clonal and seedling origin in Tamil Nadu.

Significant achievements/ findings of the project

The project has enabled generation of base line data on soil carbon sequestration and carbon stock in biomass of Eucalyptus, Casuarina, Melia and Teak plantations of clonal and seedling origin in different agro-climatic zones of Tamil Nadu. The observations made in the study demonstrated that, among the four species studied, the total carbon stock was maximum in >5 years aged Casuarina clonal plantation (CH-5) followed by Eucalyptus clonal plantation (EC-4) of >6 years. The findings explained the ability of clonal plantations of Casuarina and Eucalyptus in accumulating maximum biomass carbon stock and carbon storage potential. The data generated provided valuable information on the scope of afforestation and reforestation projects for sustainable livelihoods and also encourage the farming communities to contribute to mitigating global carbon emissions and expanding forest and tree cover.

Suggestions/ advisory note for end-users "To-do-techniques"

The various stakeholders *viz*, farmers and State Forest Departments will be benefitted from the results of the study by having better understanding on the biomass carbon stock of the four tree species Eucalyptus, Casuarina, Teak, and Melia. Brochures and pamphlets on the research results need to be published.

Research gaps:

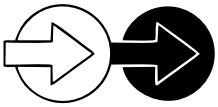
Information on the carbon sequestration potential of these plantations of clonal and seedling origin of *Eucalyptus, Casuarina, Teak,* and *Melia*is not available, particularly in Tamil Nadu. By considering the above facts, the project was undertaken to study the carbon stock in biomass and soil carbon sequestration in important plantation species of clonal and seedling origin in Tamil Nadu.

Uses of research outcomes:

The study's findings will help several stakeholders, *viz*, farmers' and state forest departments by providing a better understanding of the biomass carbon store of the four tree species namely*Eucalyptus, Casuarina,* Teak and *Melia*. The data generated in this study will encourage farming communities to contribute to reducing global carbon emissions and increasing the amount of forest and tree cover, as well as offering important insights on the scope of afforestation and reforestation programmes for sustainable livelihoods.

Publications:

- Surya Prabha, A. C., Rajkamal, A., Senthivelu, M. and Pragadeesh, S. 2022. Soil carbon stock and physico-chemical properties in important plantations of Tamil Nadu. *International Journal of Environment, Agriculture and Biotechnology* 7 (6): 99-107.
- Surya Prabha, A. C., Rajkamal, A., Senthivelu, M. and Pragadeesh, S. 2023. Carbon Stock in Biomass of Important Plantations in the Southern Zone of Tamil Nadu. *Ecology, Environment and Conservation* 29 (2):197-201.



11. Title of the project: Agroforestry capacity building project of Bihar State & Development of productive clones and economic evaluation of Poplar based agroforestry for North Bihar.

Principal Investigator: Dr. Aditya Kumar, Scientist – E, ICFRE-IFP Ranchi

Duration: 2021

Critical analysis of the research theme and summary of the study:

Successful introduction of poplar cultivation in the state of Biharwas achievedby planting more than 76 lakhs plants in the farmer's field. This programme immensely contributed in sensitizing the farmers of Bihar towards adopting agroforestry models in their crop land. The poplar species gained tremendous attention among the farmers and helped farmers in strengthening their livelihood through additional income by growing and selling of the species. The stem cuttings of commercial clones (Kranti and G-48) and 18 different accessions including hybrids, variant selections and naturalized open pollinated populations were collected from G. B. Pant University of Agriculture & Technology Pantnagar. The collected accessions were propagated and planted under multi-location field trial and observed for their growth and productivity. The trials were also observed for the incidence of diseases and insect-pests. Apart from the genetic evaluation, different poplar-based agroforestry models have also been developed which are being practiced by the farmers in the state. Out of sixteen entries of Poplar against two checks, five (5) clones viz. Kshitij (IFP-BPA-30) and Rohini (IFP-BPA-33) and three Poplar hybrid clones viz. Khushi (IFP-BPA-34), Arambh (IFP-BPA-38) and Lakshmi (IFP-BPA-41) were developed and released for cultivation in Middle Gangetic Plains Region especially in Bihar. The developed clones are of higher productivity, ranging from 36.72 m^3 per hectare per year to 43.11 m^3 per hectare per year (35.55 Tonnes per hectare per year to 41.86 Tonnes per hectare per year) in 6-year rotation. The monitory gain estimated from the developed clones ranging from Rs. 3.21 to Rs. 3.77 Lakh per hectare per year. Poplar based agroforestry models viz. Poplar-Litchi, Poplar-Wheat, Poplar-Sugarcane and Poplar-Maize-Jute were established in Muzaffarpur, Narkatiyaganj and Araria for estimating the economics of the model.

Significant achievements/ findings of the project:

Five outperforming clones of poplar (*Populus deltoides* Bartr) for Bihar viz. IFP-BPA-30(Kshitij), IFP-BPA-33(Rohini), IFP-BPA-34(Khushi), IFP-BPA-38 (Arambh), IFP-BPA-41 (Lakshmi) were approved by the Variety Releasing Committee (VRC) for clonal release in Bihar region. The productivity of the recommended accessions of poplar was varied from 36.72 m^3 per hectare per year (IFP-BPA-38) to 43.11 m^3 per hectare per year (IFP-BPA-41). License agreement was signed between ICFRE-IFP, Ranchi and 7 farmers/nursery growers of Bihar for mass multiplication of poplar clones developed by the ICFRE-IFP, Ranchi on 01.02.2023. Promotion of Poplars in farmers field in Bihar was done and developed different Agroforestry models.

Suggestions/ advisory note for end-users "To-do-techniques":

The developed clones have been commercialized and non-exclusive licenses have been given to farmers and nursery growers of Bihar for mass propagation of ETPs for planting under agroforestry. The advisory has been provided to SFD of Bihar to promote Poplar based agroforestry for North Bihar.

Research gaps:

There was lack of information on performance of poplar clones in agroforestry in Bihar.

Uses of research outcomes:

Successful clones have been given to farmers and nursery growers for mass propagation of ETPs. SFD of Bihar was given a package to promote Poplar based agroforestry in North Bihar.

Patent:

- Released 5 clones viz. Kshitij (IFP-BPA-30), Rohini (IFP-BPA-33) Khushi (IFP-BPA-34), Arambh (IFP-BPA-38) and Lakshmi (IFP-BPA-41)

12. Title of the project: Impact Assessment of Agroforestry systems existing in farmer's fields of Madhya Pradesh

Principal Investigator: Dr. Nanita Berry, Scientist-F, ICFRE-TFRI Jabalpur

Duration: 2018 - 2020

Critical analysis of the research theme and summary of the study:

The aim of the project was to assess the impact of adoption of Agroforestry system on the livelihood of farmers of Seoni and Hoshangabad (Now Narmadapuram) districts of Madhya Pradesh. The study was conducted by extensive surveys carried out in the different agro-climatic zone of Madhya Pradesh and finalized two sites for the study i.e. Seoni and Hoshangabad districts. The study showed that the farmers who had adopted Agroforestry system on their farm field, get increased income by 25 - 30%. Out of the total sampled farmers, majority have indicated Agroforestry is a source of an additional income. The study will be helpful to take new schemes for the farmers who are interested to scale up the innovative agroforestry models which are site specific and need based for the improvement of livelihood security for them within short period besides maintaining their land sustainably.

Significant achievements/ findings of the project:

The income generated by the Teak based AF system is increased maximum (28 % after 20 years of its plantation) followed by Eucalyptus based AF system (25% within 4 year), fruit based system (Grafted Aonla, Mango, Custard apple, Guava within one year except Aonla). While some farmers retain arjun trees on their paddy field bund getting income in terms of fuelwood and leaf as fodder and sometime selling bark to pharmaceutical industry and local healer. Farmers who had adopted bamboo on their field bunds, they are utilizing its benefits only as fencing material, staking for climber crops, and other household tools. The other factors of Agroforestry as pointed out by the farmers are source for emergency cash (20%), supplemental employment (15%), fuelwood and fodders (12%) and soil conservation (5%).

Suggestion/ advisory note for end-users "To-do-Techniques":

The study will be helpful to take new schemes for the farmers who are interested to scale up the innovative agroforestry models which are site specific and need based for the improvement of livelihood security for them within short period besides maintaining their land sustainably.

Research gaps:

This project was prepared for Database generation on impact of adoption of Agroforestry system by the farmers to increase their income.

Uses of research outcomes:

The study showed that the farmers who had adopted Agroforestry system on their farmfield, get increased income by 25 - 30 %. Out of the total sampled farmers, majority have indicated Agroforestry is a source of an additional income.

Publication:

- Berry Nanita, Dilraj I.T.K., Dubey Sourabh and Rai Nikita 2021. Agroforestry system adopted by farmers of Hoshangabad district of Madhya Pradesh. *The Pharma Innovation Journal* SP-10(10): 72-79.

BIODIVERSITY
AND
CLIMATE CHANGE

BIODIVERSITY AND CLIMATE CHANGE

1. **Title of the project**: Diversity of insect pollinators and their role in fruit/ pod production of *Acacia senegal, Capparis decidua* and *Prosopis cineraria* (Tricuta) in Rajasthan

Principal Investigator: Dr. Shiwani Bhatnagar, Scientist-D, ICFRE-AFRI Jodhpur

Duration: 2016 - 2020

Critical analysis of the research theme and summary of study:

The objective of the research was to study the diversity of pollinators on *Prosopis cineraria*, *Capparis decidua* and *Acacia senegal* and their role in fruit production and fruit quality. As the indigenous fruits play an important role in the nutrition of children in rural and urban areas alike therefore, in this project three important tree species of Rajasthan *Capparis decidua, Acacia senegal and Prosopis cineraria* were undertaken for studying diversity of insect pollinators. The fruits and pods of *P. cineraria*, *C. decidua* and *A. senegal* are the most important ingredients of the famous panchkuta and Trikuta Marwari vegetable prepared from five and three types of dried fruits or seeds respectively. Incredibly, kair, sangria and kumtia is rated as one of the mainstays of the Marwari kitchen. The dried green sangria from khejri tree, fruits of *C. decidua* and seeds of *A. senegal*is very costly in market. These trees/shrubs are very important species of Rajasthan and are cross pollinated in nature and require pollination by insect. Therefore, present study emphasized on the diversity of native insect visitors pollinating theses three tree/shrubs. Also, as beekeeping for pollination is a 'double benefit approach' therefore augmentation of *Apis mellifera* was done to study the effect on production of fruits of *Capparis decidua* and pods of *Prosopis cineraria*. The results of present findings documented diversity of insect visitors and their foraging behaviour on the*P.cineraria*, *C.decidua* and *A.senegal*. Augmentation of *Apis mellifera*resulted in positive pollination effect of honey bees *Apis mellifera* L. on fruit weight and considerable increase in number of fruit/pods panicle-1 when natural pollination was augmented with honeybees (*Apis mellifera* L.).

Significant achievements/ findings of the project:

Present study deals with documentation of diversity of insect pollinators of *A. senegal, C. decidua* and *P. cineraria*; foraging behaviour of insect pollinatorsand effect of augmentation of *Apis mellifera* (honey bees) fruit/pod on fruit /pod setting, weight of fruit, TSS%. Based on above work, it was observed, diversity of insect visitors identified on these species was: *P.cineraria* (41), *C.decidua* (44) and *A.senegal* (50). The most frequent insect visitors were bees. The abundance of insect visitors was highest in the forenoon when the flowers are filled with nector and has abundant pollen for forage. Of the insect species identified visiting on the flowers of *P. cineraria*, *C.decidua* and *A. senegal* only *A. dorsata*, *A. florea* and *Amegilla sp.* carried high pollen loads. However, of these species *A.dorsata* and *A.florea* were found to be most abundance and frequent visitor, implzying they were the most reliable pollinators at the sites utilized during this study. The average numbers of fruit/ pod setting panicle-1, fruit weight, germination and vigour index and TSS% were found more in natural pollination with augmentation of honey bees followed by pollination by honey bees only and least in natural pollination.

Suggestions/ advisory note for end users "To-doing-techniques":

Outcome of the research is useful and field usable. Training programmes for forest officials, NGO's and progressive farmers and other stake holders. It is advised, to do not spray pesticides at the time of flowering in fields to save native pollintaors. Augmentation of managed honeybee colonies (*Apis mellifera*) for enhancing fruit /pod setting in trees. Conservation of native pollinators for better fruit/pod yield in cross pollinated trees.

Research gaps:

Documentation of biodiversity of insect pollinators is important for assessing the potential impact of climate change on the abundance and behaviour of insect pollinators. This project was undertaken to document the diversity of insect pollinators of *Acacia senegal, Capparis decidua* and *Prosopis cineraria* in Rajasthan and to decipher the role of local communities in pollinator conservation and management.

Uses of research outcomes:

This study can be beneficial for field foresters, NGOs and farmers for increasing yield of fruits/pods by augmentation of *Apis mellifera* L. in their fields, as well as for conservation and management of insect pollinators.

Publications:

- Bhatnagar Shiwani, Khan Ameen Ullah, Rathore Lokendra Singh, Sharma Neha and Tak Prem Singh 2018. New insect record of *Julodis* spp. on *Acacia Senegal*. *Journal of Entomology and Zoology Studies* 6 (4):1628-1630.
- Bhatnagar Shiwani, Sharma Neha, Suman Raj Kumar and Sankhla Mamta 2021.Seasonal abundance of oriental hornet in *Apis mellifera* L. colonies.*Journal of Entomology and Zoology Studies* 9 (1): 1550-1553.
- Bhatnagar Shiwani, Suman Raj Kumar, Sharma Neha and Sankhla Mamta 2020. Infestation of greater wax moth *Galleria mellonella* in *Apis mellifera* colonies in Jodhpur (Rajasthan).*Journal of Entomology and Zoology Studies* 8 (5): 1194-1197.
- Bhatnagar Shiwani, Khan Ameen Ullah, Rathore Lokendra Singh, Kumar Bundesh and Vishnoi Geeta 2018. First record of the jewel beetle *Sternocera* spp. (*Coleoptera: Buprestidae*) on *Acacia senegal* in Jodhpur. *The Bioscan* 13(2):679-681.

2. **Title of the project**: Documentation of flora and fauna of both Raj Bhawan and publish a coffee table book

Principal Investigator: Dr. G. Singh, Scientist-G, ICFRE-AFRI Jodhpur

Duration: 2016 - 2019

Critical analysis of the research themes and summary of the study:

Raj Bhawans (Governor Houses) of Rajasthan are situated at Jaipur and Mount Abu both are such important biologically rich places. These areas have lush green lawns with variety of tall trees and flower beds blooming with seasonal flowers. Both the Raj Bhawans are situated in climatically contrast places with varying soils and topographical conditions and hence supports a wide variety of flora and fauna. While areas of Raj Bhawan Jaipur support semiarid type of vegetations, Mt. Abu supports vegetations ranging from xeromorphic to subtropical evergreen species. Because of luxurious vegetation many birds and other fauna are also visible in these areas. Varying levels of development activities at these two places have led advancement of differing ecosystem and these treasures of nature go unnoticed in absence of proper documentation and access to the public as well as academician. Hence, this work was planned to monitor biological diversity by documenting flora and fauna, observe diversity indices and offer possibilities to improve this urban habitat.

Significant achievements/ findings of the project:

A coffee table book book has been handed over to state forest department covered in 8 chapters. First chapter starts with a general background on urban forest environment and the methodology adopted in documenting and presenting the diverse range of flora and fauna of the Raj Bhawan areas. The second chapter describes enumerated and measured data on height and diameter as well as status of the trees and shrubs, existing number of species of different life forms like trees, shrubs, lianas, climbers, herbs, grasses, sedge and ferns and their phenology, and diversity indices of different plant forms in 10 blocks demarcated in Raj Bhawan Jaipur and 11 blocks delineated in Raj Bhawan, Mount Abu areas. Third to fifth chapters present digital information on classification, local names, distribution, uses and characteristic features of the trees, shrubs including lianas and herbaceous species (herbs, grasses, climbers and ferns), respectively and their pictorial presentation. It is followed by Chapter 6 that covers diversity of birds and other fauna observed in both the Raj Bhawans areas and their characteristics. Entomological and pathological signs recorded on different plants of the Raj Bhawan Jaipur and Mount Abu areas and their control measures are provided in Chapter 7. It is following by conclusion and recommendation chapter.

Suggestions/ advisory note for end users 'To do techniques":

This coffee book will be beneficial to the visitors of both the Raj Bhawans as well as public. This will also be useful to policy makers, academician and researchers in devising further developmental activities in the areas. This coffee table book will also help in extending knowledge on biological diversity of Raj Bhawan areas of Jaipur and Mount Abu and contribute to academic and scientific knowledge in promoting, conserving and managing the ecological and socioeconomic services delivered by such urban ecosystem

Research gaps:

Both Rajbhawan of Rajasthan are rich in floral and faunal diversity but lacking scientific documentation and proper seasonal record. These are also Biodiversity rich areas where many native and exotic species of plants are maintained and preserved.

Uses of research outcomes:

The diversity indices calculated and their relations together may be of use in managing and improving the quality of this urban landscape, and conserving ecological integrity of this important micro ecosystem. This study will contribute towards managing, protecting and deciding future planting programme and enhance its aesthetic value further.

3. **Title of the project:** Evaluation of plant growth promoting (PGP) activity of *Rhizobium* from native legumes and development of consortia with other PGP rhizobacteria.

Principal Investigator: Dr. Sangeeta Singh, Scientist-F, ICFRE-AFRI Jodhpur

Duration: 2017 - 2021

Critical analysis of research theme and summary of study:

Plant growth-promoting rhizosphere bacteria (PGPR) are a group of bacteria that can be found in the rhizosphere. The term PGPR refers to bacteria designated to be introduced in the roots (rhizosphere) of plants to promote growth. The rhizosphere is the area with the greatest microbial activity, forming a closed nutrient pool, in which essential macro- and micro-nutrients are extracted. Due to the existence of root exudates as a nutrient source for microbial growth, the microbial populations existing in the rhizosphere are relatively different from the microbial populations in the surrounding environment. It was proved that as compared to bulk soil, the narrow rhizosphere is rich in nutrients for microorganisms; this can be demonstrated by the number of bacteria present around the roots of plants, which is usually higher than in bulk soil 10 to 100 times. The microorganisms that colonize the rhizosphere include bacteria, fungi, actinomycetes, protozoa, and algae. PGPR are not only related to roots and have a beneficial effect on plant development, but also have a positive effect on the control of plant pathogenic microorganisms. According to the interaction with plants, PGPR can be divided into symbiotic bacteria, which live inside plants and directly exchange metabolites with plants, and free-living rhizosphere bacteria, which live outside plant 3 Cells. The direct mechanism is biological fertilization, stimulating root growth, rhizosphere repair and plant stress control. On the other hand, rhizosphere bacteria serve as an indirect biological control mechanism to promote plant growth by reducing the effects of diseases, including antibacterial, inducing systemic resistance, and competition for nutrients and niche. Certain bacteria can create symbiotic relationships with the host and infiltrate plant cells in the intercellular spaces of host plants. Furthermore, a select number have the ability to integrate their physiology with that of the plant, resulting in the creation of specialized structures. Rhizobia, well-known mutualistic symbiotic bacteria, can form symbiotic relationships with leguminous crop plants, fixing atmospheric nitrogen in nodules on the plant's roots. Therefore; PGPR are one of the active ingredients in biological fertilizer formulations.

Significant achievements/ findings of the project:

Eighty-four isolates of *Rhizobium* were obtained from Khejri (*Prosopis cinerea*) nodules using trapping technique. Characterization experiments showed that most of the strains showed adaptability in the range of pH 5 to pH 11 some strains can tolerate up to 3% NaCl, three strains can solubilise phosphorus apart from fixing atmospheric nitrogen, 3 strains showed positive chitinase activity. Phenotypic, biochemical and molecular characterizations of these isolated formed 23 groups based on similarity. One isolate from each group was selected and nursery experiment with compatible isolates of *Azotobacter* and *Bacillus* was laid out in combination as well as singly. The results showed that consortia (T_3) of the isolates (Rhizobium + Bacillus) were performing better as compared to single isolate. Because of their various plant growth promoting (PGP) properties and high symbiotic efficiency, these rhizobial isolates could act as excellent biofertilizers/microbial inoculants in semi-arid and dry regions of the country. In view of environmental pollution due to excessive use of fertilizers and high costs of the fertilizers, PGPR strains will have potential to be used for the sustainable and environmentally friendly development of quality planting material of khejri as well as in raising the soil fertility which in turn will result in increased production

Suggestions / advisory note for end users "To- do- techniques":

Rhizobium was isolated from soil collected from different agroclimatic zones from the rhizosphere of khejri and characterized using physical, biochemicals and molecular methods. Based on the characterization, groups was formed and one isolate from each group was selected and subjected to field testing in combination of one Azotobacter and one Bacillus strain. The results showed that the combination of Rhizobium with Bacillus was best and can be used as consortium for production of quality planting material

Research gaps:

Work on identification and characterization of *Rhizobium* through biochemical and molecular techniques had been conducted for Khejri and other legumes by different workers but the work on consortia development and its application in production of quality planting material was not done earlier for Khejri.

Uses of research outcomes:

The consortia of *Rhizobium* and *Bacillus* that were found to be the best combination for growth of Khejri (*Prosopis cineraria*) seedlings in nursery and can be used as a package of practice for production of quality planting material. Moreover, their application can also help enrich soil quality and therefore minimize application of synthetic fertilizers.

Publications:

- Singh Sangeeta, Bhoi Tanmaya Kumar, Vyas Vipula, Sharma Kuldeep, Singh Indar and Nirwan Bindu 2022. Variation in Sturdiness Quotient of Khejri Seedlings. *Indian Forester* 148 (5): 516-519, DOI: 10.36808/if/2022/v148i5/167155
- Singh Sangeeta, Bhoi Tanmaya Kumar, Choudhary Sunil, Vyas Vipula and Sharma Kuldeep 2023. Pheno-morphological, and Biochemical Characterization, of Rhizobium sp associated with Khejri Seedlings Isolated from, different Geographical locations of Rajasthan. *Indian Forester* 149: 728-736, 2023. DOI: 10.36808/if/2023/v149i7/169455

4. **Title of the project:** Impact of harvesting on soil nutrients and carbon stock in canal side plantations of Indira Gandhi Nahar Pariyojana (IGNP)

Principal Investigator: Dr. G. Singh, Scientist-G, ICFRE-AFRI Jodhpur

Duration:2017 - 2022

Critical analysis of research theme and summary of the study:

Plantations of IGNP area have now been converted into lush green forest and have become an important carbon sink in the region with an additional benefit of combating desertification. There were wide variations in population density, height and diameter at breast height and hence biomasses in stem, branches and leaves between the studied species depending upon soil resource availability and climatic conditions in the region. Recorded above-ground biomass of *Eucalyptus camaldulensis* and *Vachellia tortilis* in stem, branches and leaves were strongly related to height and diameter at breast height (DBH). The best fit allometric models $Y= a \times (DBH)^b$ and $Y= a \times exp^{b\times DBH}$ for predicting standing above-ground dry biomasses of *E. camaldulensis* and *V. tortilis*, respectively showed DBH as the best predictor of biomass in the region as inclusion of height in the models did not improve the estimated biomass in both the species. Per tree biomass was greater in *E. camaldulensis* than *V. tortilis* by 3.3% only, but it was 3-fold for the estimated biomass per unit land highlighting the importance of species characteristics on yield variations. Hence species characteristics, DBH, population density and site conditions appeared important factors influencing growth pattern, biomass yield and carbon storage. These factors were also responsible for variations in C, N, S contents and C: N ratio in different components of these species leading to variations in stress tolerance and decomposition rates of litter and the woods of these species. However, decrease in C content and increase in N and S contents in stem and branches with increase in DBH was associated with increased accumulation of N and S containing secondary metabolites with increase in tree age. Impact of species characteristics was shown by C storage of 150.13 Mg C ha^{-1} in *E. camaldulensis* and 53.64 Mg C ha^{-1} in *V. tortilis* whereas edaphic factors influenced the site-wise variations in carbon storage both in biomass and soil. The study showed increase in SOC and nutrients in plantations, which showed a positive impact of these species in soil improvement by way of adding litters and root turnover linking soil characteristics with above-ground productivity and carbon storage. Reduction in EC, SOC, carbon stock and soil nutrients (NH_4-N, NO_3-N and PO_4-P) after clear felling suggested negative impact of tree harvesting. Increased anthropogenic disturbances and trampling and exposure of soils to increased temperature and solar radiations in this arid climatic condition also had negative impact on soil water status, carbon stock and salt/nutrients and highlight the importance of avoiding clear cutting or cutting of high intensity in view of sensitiveness of carbon stock to the local climate. Utilization of these allometric equations reliably by the researchers and forest managers to calculate the standing above-ground biomass and its components in these species for improved carbon accounting and reporting.

Significant achievement/ findings of the project:

Eucalyptus camaldulensis and *Vachellia tortilis* were harvested between 736RD and 1364 RD in Bikaner and Jaisalmer forest divisions along the IGNP covering a distance of about 170km. Model was developed on basis of above ground biomass and DBH of selected trees species. Models- $AGB=0.505(DBH)^{2.040}$, $SB=0.471(DBH)^{1.956}$; $BB=0.044Dbh^{2.353}$ and $LB=0.021(DBH)^{1.841}$ were best fit for estimating dry biomass of different components of *E. camaldulensis*, whereas the models $AGB = 38.058*exp^{(0.087*DBH)}$, $SB = 12.588*exp^{(0.082*DBH)}$, $BB =24.543*exp^{(0.089*DBH)}$ and $LB = 1.264*exp^{(0.055*DBH)}$ were best fit to determine dry biomass of different components of *V. tortilis* trees. Because of high rates of carbon sequestration and reduced cost of reestablishment, this study also highlights the importance of promoting regeneration of *E. camaldulensis* through coppice, though early silvicultural practices like thinning of coppice shoots and pruning are required to increase stem quality and to promote growth as well. The carbon sequestration in the 28 year old stands of *E. camadulensis* was found 150.13 Mgha^{-1} and in *Vachellia tortillis* 53.64 Mg ha^{-1}. Coppice of *E. camaldulensis* produced only 23.1% of the biomass of the main crop, but rate of carbon sequestration in these coppices were 12.65 Mg C ha^{-1} $year^{-1}$ in 39 months old and 10.41 Mg C ha^{-1} $year^{-1}$ in 28 months old

coppice, that was significantly higher than the rate of carbon sequestration in main crop (5.36 Mg ha^{-1} $year^{-1}$) and highlights the importance of maintaining *E. camaldulensis* regeneration through coppice. While increased carbon stock in such degraded desert region highlights the importance of these plantations in climate change mitigation, clear felling leads to depletion of SOC stock and nutrients. Promoting plantations of suitable site-specific tree species in less or unproductive lands appeared a recognized management action by long duration C storage both in biomass and soil. To enhance carbon storage potential and to maintain the soil nutrient status of these plantations, retention of some trees, monitoring and management of invasive species and irrigation and fertigation are required to maintain growth of new plantations and the coppice in case of *E. camaldulensis*.

Suggestion / advisory for end users "To-do-techniques"

A massive plantation forest established in canal command area of Indira Gandhi Nahar Pariyojana (IGNP) in arid western Rajasthan, India for environmental, economic and livelihood benefits to the local people also requires assessment for understanding their contribution in climate change mitigation. Because of sensitiveness of soil organic carbon and increased Aeolian activities under clear felling, the impact of clear felling trees on soil characteristics and carbon storage brought about by these plantations also requires to be assessed.

Research gaps:

Evaluation of the impact of clear-felling on soil characteristics and carbon storage brought about by plantations in the IGNP canal, in arid western Rajasthan, India, was not done. This project was framed to assess these impacts so as to aid in devising effective management strategies for these plantations.

Uses of research outcomes:

The project aimed to assess standing biomass and carbon stored in these plantations and monitor and quantify different soil fertility parameters both pre- and post-harvest. The project findings can be taken into consideration while formulating appropriate management strategy for this valuable natural resource.

5. **Title of the project:** Molecular characterization of selected medicinal plants of Uttarakhand

Principal Investigator: Mrs Ranjana Negi, Scientist-E, ICFRE-FRI Dehradun

Duration: 2017 - 2020

Critical analysis of research theme and summary of the study:

Aconitum heterophyllum wall. Ex Royle (अतीश), *Aconitum balfourii* Stapf. (मीठा), *Dactylorhiza hatagirea* (D. Don) Soó (हथजड़ी/सालमपंजा), *Paris polyphylla* Sm. (सतवा) and *Saussurea costus* (Falc.) Lipsch. (कुथ) are threatened species of Indian Himalayan Region with declining status demanding conservation. Taxonomically authenticated samples of Selected species in Uttarakhand were collected. Gene diversity and Genomic relationship among different genetic populations of these selected medicinal plant species evaluated using molecular markers (ISSR) and Popgene software. Molecular phylogenetic relationship amongst different populations of a particular species evaluated using four DNA barcode regions (rbcL, rpoC2 and psbA–trnH from the chloroplast genome, and ITS from the nuclear genome) and Molecular Evolutionary Genetics Analysis (MEGA X) software. The study will be helpful in authenticating the species identity mainly addressing police queries where, underground parts and fragments are usually received thus, will be helpful in curbing illicit trade in these medicinal plant species.

Significant achievements/ findings of the project:

Contribution in worldwide DNA library of investigated species through barcode sequence submission was made in GenBank database of NCBI (National Center for Biotechnology Information), at the U.S. National Library of Medicine (NLM), located at the National Institutes of Health (NIH). First time sequences were submitted in GenBank database of *A. balfourii* for barcode region, database for rbcL region for *A. balfourii,* for rpoC1 region for *D. hatagirea.* Genetic diversity studies by using molecular markers from India for were done for the first time for species *Aconitum heterophyllum, A. balfourii, Dactylorhiza hatagirea, Paris polyphylla* and *Saussurea costus*.

Suggestions/ advisory note for end-users "To-do-techniques":

Study shall be useful in conservation of threatened medicinal plants of Indian Himalayan Region. DNA barcode study shall be useful in pharma-forensics investigation for illicit trade in endangered medicinal plants and adulteration. Genetic diversity study shall be useful while designating IUCN conservation status as well as identification of conservation areas of investigated species.

Research Gaps:

Uttarakhand being the part of Indian Himalayan region, one of the biodiversity hotspots is house of immense treasure of rare species of medicinal plants so is this also hub for illicit trading of these invaluable resources. These offenders often go unpunished in the absence of authentic identification. New trends in R &D mainly the molecular techniques/genomics enable us to find more accurate results which needs to be fully used to draw inferences in this field.

Uses of research outcome:

The results shall be of important use while addressing biopiracy cases and have wide application in the field of sequence based authentic identification of medicinal plants, identification and development of universal barcode for medicinal plants, pharma-forensic investigations of these medicinal plant species and phylogenetic studies of plant species at various ranks (species, family etc.) and thereby contributing in understanding of evolutionary history

Publications:

- Negi, R.K., Nautiyal, P., Rawat, J.M. and Bhatia R. (2022). Assessment of genetic diversity of Aconitum heterophyllum Wall. ex Royle using ISSR markers: an endangered medicinal herb of Himalaya. Vegetos 35: 942-952. https://doi.org/10.1007/s42535-022-00369-4
- Negi, R.K., Nautiyal, P., Bhatia, R and Verma R. (2021). rbcL, a potential candidate DNA barcode locus for aconites: conservation of Himalayan Aconites. Mol Biol Rep 48: 6769–6777. https://doi.org/10.1007/s11033-021-06675-5

6. **Title of the project:** Butterflies associated with different forest types/sub-types in Uttarakhand

Principal Investigator: Dr. Arun Pratap Singh, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2021

Critical analysis of research theme and summary of the study:

Four year field surveys (2017-2020) revealed 370 taxa of butterflies which accounted for ~75% of the species so far recorded from the state and 21% of the species found across India. A total of 65 taxa recorded accounted for 14 % of the total butterfly taxa that are listed as protected in India under Indian Wildlife Act 1972 and 58 taxa identified as "rare" in terms of rarity and species of conservation priority in the state. Over 60 species showed preference to single forest type and 90 species for 2 forest sub-types and were thus specialists while the number of species showing preference for 4 or more forest sub-types i.e generalists were less. At least 7 different types of hierarchial forest sub-type clusters were identified in the state that have unique assemblage of butterfly species (communities). These were i. 3C/C2a Moist Shiwalik Sal Forest; ii. 12/C2c Moist Temperate Deciduous Forest; iii .12/C1a Ban oak Forest; iv. 3C/C2c Moist Terai Sal Forest; v.9/C1b Upper or Himalayan Chir Pine; vi. 5B/C2 Northern Dry Mixed Deciduous Forest and 5B/C1a Dry Shiwalik Sal Forest; vii.12/C1b Moru Oak; 12/C2bWestern Himalayan Upper Oak Forest/Fir; 12/C1dWestern Mixed Coniferous; 12/2S1Low level Blue Pine; 12/C2a Kharsu Oak Forest; 14/C1a West Himalayan Sub-alpine Fir;14/C1best Himalayan Sub-alpine Birch/Fir/ 14/1S2Deciduous Sub-alpine Scrub & 15/C1 Birch/Rhododendron Scrub.

Significant achievements/ findings of the project:

Important forest sub-types evaluated in the state in terms of rich butterfly diversity and species of conservation priority were '12/C1a Ban oak Forest' followed by '12/C2cMoist Temperate Deciduous forest' in the Western Himalayan zone and '3C/C2 Moist Shiwalik Sal Forest'and '3C/C2c Moist Terai Sal Forests', respectively in the Shiwalik zone, that hold maximum number of butterfly species including rare ones. Many of the species of conservation concern were located in forested areas our side the existing Protected Area (PA) Network of the state which consist of 17 PA's. It was recommended that 10 clusters of butterfly sites which harbour butterfly species of conservation concern outside the PA network may be taken up for long term conservation as biodiversity rich habitats and corridors that form a link to fill the remaining gaps in the protected area network of the state. This will ensure long term conservation at a landscape level in the state before forests outside the PA network become more degraded. A GIS database created gave forest sub-types distribution maps for each of the 370 butterfly taxa in 20 different forest types found in the state along with baseline information on their seasonality, larval host plants, relative abundance, altitudinal distribution taxonomic nomenclature and coloured images of each butterfly for identification published in the form of a book online at ICFRE website at the following link - https://icfre.gov.in/books-file/book25.pdf

Suggestions/ advisory note for end users "To-do-techniques":

The database created in the form of GIS based maps for each butterfly taxa with site specific locations in each forest sub-type can be used as baseline/reference data for comparison in the future for changing range margins of species due to climate change and shrinkage of habitat sensitive species due to fragmentation and destruction of forests. Identification of biodiversity rich habitats outside the PA network can also be used for promoting ecotourism with butterflies and also identification of habitats to be included for restoration of corridors and filling gaps in the current PA Network.

Research gaps:

It is not known if the species composition and community structure of lower groups of animals i.e. butterflies, is also similar within each forest-sub-type or different ineach forest sub-type. Each forest sub-type harboring rare species can betaken as unique habitat or unit of conservation at the lower level on a regional scale and can be used to identify gaps in the current protected area network of the state.

Uses of research outcomes:

The identified butterfly species in the state, communities and forest subtypes and forest areas that are of conservation priority having rich and unique in the Uttarakhand state, can be included in conservation planning at landscape level to further enhance the protected are network. The database developed gives GIS distribution maps of individuals species in the region along with information on their seasonality, forest type association, altitudinal distribution, protection status, food plants, their nomenclature and images for identification which will help in conservation of biodiversity in the region and also study the influence of climate change on butterflies based on comparison with past distributions and life histories of each taxa. Besides, identification of hotspots of butterfly diversity and locations of species of conservation priority outside the PA network along with their seasonality, will help in promoting butterfly inclusive eco-tourism and identify new sites for conservation in the state outside the PA Network.

Publications:

- Singh, A.P. and Seal S. 2019. Occurrence of Dark Sapphire *Heliophorus indicus* Fruhstorfer (Lepidoptera: Lycaenidae) in Garhwal Himalaya, Uttarakhand, India. *Bugs R All* #175, *Zoo's Print* 34 (7): 33–34.
- Singh, A. P. and Singh T. 2019. Recent records of the rare Mountain Tortoiseshell *Aglaisrizana* Moore (Lepidoptera: Nymphalidae) in the upper Garhwal, western Himalaya, India, after 100 years. *Journal of Threatened Taxa*, 11(15): 15068-15071.
- Singh, A.P. and Singh T. 2020. Occurrence and association of the Scarce Lilac fork *Lethedura gammiei* Moore (Lepidoptera: Nymphalidae: Satyrinae) with Woolly-leaved Oak *Quercus lanata* Smith (Fagaceae) forest in the Kumaon region of the Indian Himalaya. *Journal of Threatened Taxa* 12(3): 15387–15390.
- Singh, A.P. 2020. Blank Swift *Caltoris kumaramoorei* Evans (Lepidoptera: Hesperiidae) in Dehradun Valley, Uttarakhand, India: a new record for the western Himalaya. *Journal of Threatened Taxa* 12(17): 17380-7382. https://doi.org/10.11609/jott.6694.12.17.17380-17382
- Singh, A.P. and Singh T. 2021. Habitat association and hybridization in wood browns (*Lethe nicetas, L. sidonis and L. dakwania*) (Lepidoptera: Nymphalidae: Satyrinae) in Kedarnath Musk Deer Reserve, western Himalaya. *Journal of Threatened Taxa*13(3):18045–18049. https://doi.org/10.11609/jot.6517.13.3.18045
- Singh, A.P. and Singh T. 2021. First record of White-ringed Meadow brown, *Hyponephele davendradavendra* Moore (Lepidoptera: Nymphalidae) from inner valleys of Garhwal, Uttarakhand, India. *J. Bombay Nat. Hist. Soc*. 118 (2): 1-5 http://dx.doi.org/10.17087/jbnhs%2F2021%2Fv118%2F152490.7**.**
- Singh, A.P., Singh T. and Ramola G.C. 2021. Outbreak of Himalayan Yellow Coster, *Acraea issoriaissoria*, Hubner (Lepidoptera: Nymphalidae) on Daar, *Boehmeriarugulosa* Wedd. (Urticaceae) in the foothills of Garhwal, Western Himalaya. *Indian Forester* 147 (12):1131-1133.https://doi.org/10.36808/if/2021/v147i12/157231.
- Singh, A.P. 2022. Associations of butterflies across different forest types in Uttarakhand, western Himalaya, India: implications for conservation planning. *Journal of Threatened Taxa* 14(1):20346–20370. https://doi.org/10.11609/jot.7711.14.1.20346-2037
- Singh, A.P. and Singh T. 2022. Occurrence of the little known Dubious Five-Ring, *Ypthima parasakra* Eliot in Garhwal Himalaya. *Indian Journal of Entomology*. 84(1):1-3.

  Singh, Arun Pratap 2021. *Butterfly-Forest Type Associations in Uttarakhand*. Forest Research Institute (ICFRE), Dehradun. 414 pp.

7. **Title of the project:** Assessment of Floristic Diversity in Tundah Wildlife Sanctuary of District Chamba, Himachal Pradesh for its Long-Term Ecological Monitoring

Principal Investigator: Dr. R. K. Verma, Scientist-G, ICFRE-HFRI, Shimla

Duration: 2016 - 2020

Critical analysis of the research themes and summary of the study:

The diverse climate and the varied environmental conditions prevailing in the lap of Himalaya support diverse habitat ecosystems and life forms. The assessment of plant wealth in a particular ecosystem may provide a key for its conservation. Keeping this in view and in absence of any detailed documentation on this account, attempts were made to assess the plant diversity including documentation of the medicinal plants found in Tundah Wildlife Sanctuary in Chamba district of Himachal Pradesh. The objectives of the study were: to ascertain the extent of species richness through community identification and their structure; demarcate plant diversity rich areas and their status; identify species of ethno-botanical importance; and identify threatened or abundant species in the Sanctuary.

Significant achievements/ findings of the project:

In Tundah wildlife sanctuary, total 233 plant species belonging to 176 genera and 76 families was recorded. The dominant families were Asteraceae, Apiaceae, Fabaceae, Lamiaceae, Rosaceae, Geraniaceae, Polygonaceae, Pinaceae, Ranunculaceae and Acanthaceae. The maximum number of plant species were in Lambapahad site (145 spp.) followed by Dughi Dhar (132), Tarun Dhar (128), Tandi Dhar (125), Thanala (123), Janu Dhar (117), Mumber Dhar (116), Chharola (105) and Liyundi Dhar (75). Out of 113 medicinal plant species recorded from the Sanctuary, 20 species viz., *Arnebia benthamii, Bergenia stracheyi, Betula utilis, Dactylorhiza hatagirea, Dioscorea deltoidea, Fritillaria roylei, Heracleum lanatum, Juniperus communis, Jurinea dolomiaea, Meconopsis aculeata, Podophyllum hexandrum, Polygonatum verticillatum, Rheum australe, Rhododendron campanulatum, Rhododendron anthopogon, Rhododendron lepidotum, Roscoea alpina, Selinum tenuifolium, Taxus wallichian* and *Trillium govanianum* fall under threatened category of plants. Ethnobotanical study was conducted in fourteen villages falling in and around the Sanctuary and documented 107 plant species used for different purposes.

Suggestion/ advisory note for end users"To-do-techniques":

The data generated from this study on various sites/ areas of the Sanctuary can be used by State Forest Department of Himachal Pradesh for conservation and management of the area. The data can also be used as base line data for future studies by various researchers, Universities, Institutes, Non-Governmental Organizations, etc.

Research gap:

No concerted efforts towards assessment and status of flora including population structure of ecosystem have been made in this high-altitude Tundah wildlifesanctuary. The study was conducted to assess the plant diversity including documentation of the medicinal plants found in this sanctuary for suggesting suitable conservation measures and for protection of plant wealth of the areas.

Uses of research outcomes:

The data generated from the study on plant diversity in the various sites/ area of the sanctuary can be used by State Forest Department of Himachal Pradesh for conservation and management of the area. The data can also be used as base line data for future studies by various researchers, Universities, Institutes, Non-Governmental Organizations etc.

Publication:

- Verma, R.K.,Dushyant and Kumar, Jai 2020. Tundah Wildlife Sanctuary Chamba, Himachal Pradesh: An Appraisal to its Plant Diversity. Himalayan Forest Research Institute, Shimla. 116 p.

8. **Title of the project:** Carbon Sequestration Potential of Existing Land-use Systems in Lahaul Valley, Himachal Pradesh

Principal Investigator: Dr. R. K. Verma, Scientist-G, ICFRE-HFRI, Shimla

Duration: 2016 - 2022

Critical analysis of the research themes and summary of the study:

The land-use can be a source or sink for carbon depending on the process experienced by the system. Land-use management can contribute to carbon sequestration through promoting growth and biomass accumulation and hence, the average carbon sequestration in the system. It may be pointed out that more accurate and reliable estimates of continental CO_2 emissions from land use/ cover change can only be obtained from extrapolation of reliable local estimates. Therefore, comprehensive information on the spatial and temporal distribution of land-use is a pre-requisite for understanding the carbon flux by the local estimates. Besides, soils are also an effective sink for carbon and to be most effective, CO_2 must be fixed into long lived pools. The soil organic carbon invariably depends on the land use and its management. Further, the study on carbon sequestration potential gains importance in the context of carbon credit systems, as afforestation and reforestation were added as eligible activities under the Clean Development Mechanism of Kyoto protocol. Accordingly, there is an imperative need to provide an assessment on biological mitigation potential of various land use systems under different site conditions. With this backdrop, the present study was carried out to assess the carbon sequestration potential of existing land use systems in Lahaul valley of Himachal Pradesh. The objectives of the study were to determine net CO_2 fixation and uptake by soil-plant systems and to prepare carbon inventory for assessing the mitigation potential of the different land-use systems.

Significant achievements/ findings of the project:

Among the 15 land use systems studied in Lahaul valley,total mean biomass carbon stock was maximum in Kail forest (318.21tC/ha) followed by Deodar forest (255.41 tC/ha), Mixed forest (188.72 tC/ha), Juniper forest (111.51 tC/ha), Poplar plantation (108.87 tC/ha), Salix plantation (94.11 tC/ha), Agri-Silviculture system (91.73 tC/ha), Bhojpatra forest (33.67 tC/ha), pure Horticulture system (33.40 tC/ha), Agri-Horticulture system (32.42 tC/ha), Sea buckthorn shrubs (23.25 tC/ha), Medicinal plant crop system (14.75 tC/ha), pure Agriculture system (4.36 tC/ha), Degraded area (3.47 tC/ha) and lowest value was found in Alpine pasture system (2.53 tC/ha).

Total mean soil carbon stock up to 30 cm depth was maximum in Bhojpatra forest (70.14 tC/ha) followed by Kail forest (69.23 tC/ha), Mixed forest (68.69 tC/ha), pure Agriculture system (67.85 tC/ha), Agri-Silviculture system (66.09 tC/ha), Juniper forest (63.58 tC/ha), Alpine pasture (60.19 tC/ha), Salix plantation (59.81 tC/ha), Sea buckthorn shrubs (59.48 tC/ha), Agri-Horticulture system (59.21 tC/ha), pure Horticulture system (58.84 tC/ha), Medicinal plant crop system (57.75 tC/ha), Poplar plantation (55.96 tC/ha), Deodar forest (50.39 tC/ha) and lowest value was found in Degraded area (28.88 tC/ha).

Total mean carbon stock was maximum in Kail forest (387.45 tC/ha) followed by Deodar forest (305.81 tC/ha), Mixed forest (257.41 tC/ha), Juniper forest (175.09 tC/ha), Poplar plantation (164.84 tC/ha), Agri-Silviculture system (157.82 tC/ha), Salix plantation (153.92 tC/ha), Bhojpatra forest (103.81 tC/ha), pure Horticulture system (92.24 tC/ha), Agri-Horticulture system (91.63 tC/ha), Seabuckthorn shrub (82.73 tC/ha), pure Agriculture system (78.14 tC/ha), Medicinal plant crop system (72.50 tC/ha), Alpine pasture system (62.72 tC/ha) and lowest value was found in Degraded area (32.25 tC/ha).

Suggestion/ advisory note for end users "To-do-techniques":

The carbon pool inventory of different land use systems has revealed that forest land use system (Kail, Deodar, Mixed-forest, Juniper) had the higher potential for sequestering carbon in biomass and soil up to 30 cm soil depth than Poplar plantation, Agri-Silviculture system, Salix plantation, Bhojpatra forest, pure Horticulture system, Agri-Horticulture system, Sea buckthorns shrubs, pure agriculture, medicinal plant crop system and alpine pasture.

Research gaps:

The forest of particular species and different land use systems can contribute to carbon sequestration through promoting growth and biomass accumulation and hence, the average carbon sequestration in the system. The accurate and reliable estimates of continental carbon dioxideemissions can only be obtained from extrapolation of reliable local estimates.The information for carbon stock and carbon sequestration potential of various land use systems of North west Himalayan region was not known/ available.

Uses of research outcomes:

The data generated from this study for biomass, biomass carbon stock and soil carbon pool for different land use systems of Lahaul valley of Lahaul &Spiti of Himachal Pradesh can be used by State Forest Department and other agencies for formulating sustainable forest management plans in the mountains thereby putting some strategies in place for combating the issue of climate in Himalayan Zone.

Publications:

- Verma R.K., Verma Rahul and Chauhan Harish 2022. Assessment of biomass and soil carbon stock in different forest land use systems of Lahaul valley, Himachal Pradesh, India. *Indian Journal of Forestry* 45(1): 14-19.
- Verma R.K. and Kumar Ranjeet 2022. Estimation of Biomass and Soil Carbon Stock in Alpine Pastures of Lahaul valley of District Lahaul & Spiti, Himachal Pradesh. *Environment & Ecology* 40 (4C): 2638-2641.

9. **Title of the project:** Ecological Monitoring and GIS mapping of Microlepidoptera diversity of Deodar (Cedrus deodara) Forests of Himachal Pradesh

Principal Investigator: Dr. Pawan Kumar, Scientist-F, ICFRE-HFRI Shimla

Duration: 2019 - 2023

Critical analysis of the research theme and summary of study:

The major aim of the study was to assess the diversity of microlepidoptra of Deodar forest of Himachal Pradesh and to study environmental impact and habitat association of micro moths. In this study 1097 specimens of microlepidoptera (Lepidoptera: Insecta) were collected from Deodar Forest of Chopal (Sarain, Deha), Shimla (Sargheen, Badagaon, and Summerhill), Theog (Kandyali and Shilaru), Jogindernagar (Kathyaru, Barot and Multhan), Gohar (Janjhaili, Thunag and Kandha),Karsog (Snarali), Chail, Jhungi, Charkhadi, Kharapather, and Banethi areas. The data on various parameters like associated flora, GPS information, altitude, temperature, rainfall, humidity, etc. was also taken simultaneously for diversity and habitat association analysis. The specimens of micromoths were segregated into different taxa leading to identification of 102 species belonging to the 20 families. Some of economically important identified species were *Stegasta variana* Meyr. *Parectopa bathracma* Meyr. *Plutella xylostella* Linn. *Stathmopoda auriferella* Walker, *Onebala hibisci* Staint ,*Promalactis* sp.,*Edosa strepsineura* Meyr., *Archips machlopis* Meyr., *Thisizima bubalopa* Meyr.,*Edosa opsigona* Meyr. and *Endotricha denticostalis*. Quadrate sampling to study the floral diversity of the area was carried out to assess the habitat preference of the moths of the selected sites. Vegetation (trees, shrubs and herbs) of selected sites was studied by laying out quadrates of different sizes. The present study has aimed to identify the distribution patterns of Micro Lepidoptera and their ecological diversity with their mapping and geo-referencing on a GIS platform and correlate their distribution with environmental parameters to study the impact of biotic and non-biotic pressures on biodiversity.

Scientific achievements/ findings of the project:

Investigation of taxonomical significant traits of 102 micromoths species was carried out to update the taxonomic status of micromoths of Deodar forests of Himachal Pradesh. Diversity status of micromoths in different study sites was evaluated to establish the threat status using different diversity indices. Floral diversity status of study sites was calculated to assess the preferred habitats of micromoths in the region. Thirty two species of micromoths were reported as a new record from Deodar forest of Himachal Pradesh GIS mapping of micromoths distribution was conducted using ArcGIS software to develop permanent distribution database for future use in analyzing the variation in micromoth diversity.

Suggestions/ advisory note for end users "To-do techniques":

The study will provide information on the micromoth diversity of deodar forest of Himachal Pradesh and act as a baseline for more detailed and comprehensive studies of the moths of this region. Research should be done to comprehend the biology and behavior of the native insects. To help the conservation of the Lepidoptera population, it is advised to grow and conserve the host food plants of the rare and endangered species. Geospatial maps based on the GIS mapping provide a database for future studies in this direction. The geographic distribution of the butterfly flora in Himachal Pradesh must be updated in light of these findings.

Research gaps:

Correct identification of the species is a prerequisite for any endeavour made for the study of ecology, behaviour, control of pest species and conservation of biodiversity.The systematic arrangement and the nomenclature of insect species including butterflies needed to be updated in accordance with recent progress made in systematics research.GIS mapping and biodiversity of butterflies of Subalpine Forest were not studied earlier by any worker.

Uses of research outputs:

The study has set a trend for forecasting future distribution patterns of selected species and their food resources/plants,throughevolving habitat conservation strategy and identify other insect species including insect pollinators and bioindicatorspecies sensitive to environment/climate change in other parts of the globe and particularly of the Himachal Pradesh especially of the Sub-Alpine Forests. These findings can be used by SFDs and Biodiversity specialists to devise conservation plan and effective management of important biodiversity of the region. The study will also help to the Naturalist/Conservationists, researchers or Taxonomist working on the same or other groups of the area as a reference during such endeavor in this direction.

10. Title of the project: Ecological Studies in Alpine Pastures of District Shimla, Himachal Pradesh

Principal Investigator: Dr. R. K. Verma, Scientist-G, ICFRE-HFRI, Shimla

Duration : 2016 - 2020

Critical analysis of the research themes and summary of the study:

The pastures in alpine zone occupy about 1.52% of the total land area in the country, and are mainly found in the Himalayan states. In Himachal Pradesh, one of the largest states of the Indian Himalayan region, alpine pastures cover about 10,052 km^2 which constitute 17% of the total geographical area of the state. The productivity of alpine pastures is quite low because of presence of alpine scrubs and herbs. Overgrazing has also added to the woe, which is the principal cause of degradation. With the ever-increasing human and cattle population, it becomes quite pertinent to have in-depth knowledge of all the alpine pasture ecosystems with respect to floristics and productivity. Keeping this in view, studies on assessment of plant diversity, identification of population structure of the communities along with biomass and nutrient status of the high-altitude pastures occurring in the Shimla district of Himachal Pradesh were carried out. The objectives of the study were: to carry out comparative studies for floristic composition and phytosociology in the diversely located alpine pastures; assess the production potential of the alpine pastures, and study the flux of major nutrients in biomass and soil of the pastures.

Significant achievements/ findings of the project:

Total 158 species belonging to 110 genera and 46 families were recorded from the selected alpine pastures of Shimla district.Out of 87 medicinal plants recorded from the pastures, 11 species fall in the threatened category of plant species. Total 60 unpalatable plant species were found in the pastures. Study of biomass provides useful information about the quantity of organic matter produced under given climatic conditions. Among the four sites, total above ground biomass was maximum 3.81 t/ha and 3.86 t/ha during monsoon season at Mural Danda pastures in first and second year, respectively. The values of below ground biomass were highest 6.45 t/ha and 6.98 t/ha in monsoon season at Mural Danda pasture during respective years. The standing dead vegetation was maximum 1.01 t/ha and 1.09 t/ha during winter season at Mural Danda and Hatu pastures in first and second year, respectively. Whereas, values of litter biomass were highest 0.78 t/ha and 0.85 t/ha in winter season at Mural Danda and Hatu pastures during respective years. The annual aboveground net production values varied from 2.15t/ha to 2.96t/ha during the first year and 2.22t/ha to 3.00t/ha during second year. The annual belowground net production values ranged from 2.85t/ha to 3.48t/ha and 2.87t/ha to 3.73t/ha during first and second year, respectively. Total net production values varied from 5.00t/ha to 6.44t/ha during the first year and 5.11t/ha to 6.73t/ha during second year of the study. The maximum value for total net production (6.73t/ha) observed at Mural Danda site while minimum value of total net production recorded at Talra (5.00t/ha) site during the study period. The values of turnover rate varied from 0.45 to 0.54 during first year and 0.46 to 0.53 during second year. The data on status of major nutrients (Nitrogen, Phosphorus, Potassium, Calcium and Magnesium) and standing state of nutrients in various components viz, above ground biomass, below ground biomass, standing dead vegetation and litter biomass was also generated from the study.

Suggestion/ advisory note for end users "To-do-techniques":

The data generated from this study on various aspects like plant diversity, phytosociology, biomass production, standing state of nutrients in different pastures of Shimla district can be used by State Forest Department of Himachal Pradesh for conservation and management of the alpine pastures. The outcomes can also be used as baseline data for future studies by various researchers, Universities, institutes, Non-Governmental Organizations, etc.

Research gaps:

Due to unscientific management of pastures, a large number of pasture lands had been converted or in the process of conversion to the degraded lands thereby bringing a shift in the natural equilibrium and plant diversity as well. In this scenario, it has become quite pertinent to carry out the ecological studies of these precious resources for assessing the loss of plant diversity including assessing the production potential of the pastures to devise some strategies for their management.

Uses of research outcomes:

The data generated from this study on various aspects like plant diversity, phytosociology, biomass production, standing state of nutrients in the different pastures of district Shimla can be used by State Forest Department of Himachal Pradesh for devising strategies for conservation and better management of the alpine pastures.

Publications:

- Verma R. K. 2017. Variation in biomass and soil carbon stock in Alpine Pastures of district Shimla, Himachal Pradesh. *Environment and Ecology* 35 (4E): 3698-3701.
- Verma R.K.,Shilpa and Chauhan Harish 2020. *Alpine pasture of District Shimla, Himachal Pradesh: An Appraisal to its Ecological Studies*. Himalayan Forest Research Institute, Shimla. 158 p.
- Verma R. K. and Chauhan Harish (2022). Floristic Diversity in Alpine Pasture of Mural Danda of District Shimla, Himachal Pradesh.*Biological Forum – An International Journal* 14(1): 1641-1646.
- Verma R. K., Kumar Ranjeet and Chauhan Harish 2023. Status of Plant Diversity in Alpine Pasture of Chansel of District Shimla, Himachal Pradesh. *Eco. Env. & Cons*. 29 p. (S378-S386)

11. Title of the project: Innovative Technologies for Climate Change Mitigation and Biodiversity Conservation with alternate livelihood opportunities for mountain communities in North Western Himachal Himalayas.

Principal Investigator: Dr. Vaneet Jishtu, Scientist-E, ICFRE-HFRI Shimla

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:
Encouraging results with involvement of total 335 households (HH) and saving of 40% fuel wood with mountain solar heating systems in 307 households were observed. Each unit mitigated average 2.70 t Carbon emission/HH/annum and mitigate women drudgery in fuel wood collection. Rural artisan earned revenue from fabrication of solar water heating system. At the same time button mushroom cultivation model for forest communities provided immediate cash and generated Rs. 5,20,898/- for 131 HH in two years with 40000 kg spent compost for improved composting for agriculture without collecting forest biomass. Skill development of 335 HH for sustainable harvesting and *ex situ* propagation of selected NTFPs e.g., *Swertia cordata, Taxus wallichiana and Picrorrhiza kurroa*. A total of 3000 rooted cuttings of *Taxus wallichiana* were planted and harvesting of *Swertia cordata* (Chirayita) produced 300 g seeds and distributed among farmers for increasing propagation. A total number of 307 women participants were provided with vermiculture 2 Kg each for initiating improved composting, 80-100 improved fodder tufts for bund plantation and 40 plants each of *Quercus oblongata* for plantation around their houses. These inputs were provided with proper demonstration for preparation of compost and planting details.

Significant achievements/ findings of the project:
Consumption of fuelwood was observed maximum in winter season (17.6417.640.96 Kg/household/day at Kullu and 16.850.87 Kg/household/day at Mandi). Demand is summer seasons was 12.450.81 and 4.940.50 Kg/household/day at Mandi and Kullu sites, respectively. During rainy season demand of fuelwood /household/day was 12.510.98 and 8.970.59 at Kullu and Mandi villages surveyed for the study.
Quantity harvested from forests was maximum 38.210.50 and 33.060.71 Kg/household/day in Kullu and Mandi villages respectively. Collection of fodder from forests during summer was estimated 27.030.43 and 23.730.61 Kg/household/day in Kullu and Mandi villages, respectively. Although the village livestock graze in the natural forests throughout the year. Collection of data for NTFPs was difficult and figure emerged in selected villages of Mandi and Kullu was 14.270.80 and 7.820.72 Kg/household/annum appeared to be on the lesser side. This contains mixture of medicinal plants and mushrooms (Morels) species mainly of market value/demand.

To reduce dependence on forest for fodder a simple technology of planting improved green fodder Tall Fescue on bunds was popularized. Among the villagers 12000 Oak (*Q. oblongata*) and 25000 improved fodder slips planted. 4980 Oak (1000 at HRG), 2200 *Celtis*, 12000 *Salix*, 700 *Robinia*, 1200 *Quercus floribunda* and 2000 *Robinia* were distributed.

Trainings and information on improved composting and vermiculture were also provided to the stakeholders. Earthworms were also distributed to the villagers to start their own units. Skill development of 335 households was oriented three times during the project duration in sustainable harvesting and *ex situ* propagation of selected NTFPs e.g., *Swertia cordata*, *Taxus wallichiana* and *Picrorhiza kurroa*.

Suggestions/ advisory note for end users "To-do-techniques":
Project activities addressed most stressing demand of rural households in mountains. Activities not only addressed conservation needs but also helped in community empowerment and livelihood generation. Scaling of activities through financial institution linkages and commercialization are expected to address the issues of conservation of biodiversity, livelihood, and mitigation of CO_2 from degradation of Himalayan Ecosystem. Replicability of project activities is very high keeping in view the high dependence on forests in mountains of IHR. Technology models of all the activities implemented are available for immediate replication by any individual, organization, department, and funding agencies.

Research gaps:

The area under study was very remote and their livelihood cantered around the natural resources in the nearby forests. The study was conducted for capacity building and community orientation of the stakeholders for the sustainable management of the available natural resources in the region. Moreover, the study also brought forth the impact of solar energy used in domestic needs of water heating through solar water heating system for mitigating household carbon emissions, forest degradation and women drudgery.

Uses of research outcomes:

Activities not only addressed conservation but also helped community empowerment and livelihood generation through skill development of 335 households for sustainable harvesting and ex situ propagation of important NTFPs (*Swertia cordata, Taxus wallichiana, Picrorhiza kurroa*, etc.). Mountain solar water heating system were provided to households and thus a decline in dependence on fuel wood in the area was observed.

Publications:

- Singh L., Kaur M.J., Jishtu V., Kumar D., Kumar P. and Kumar R. 2022. Forest Based Livelihood Enhancement with Technology Innovations in North Western Himalaya. In: Proceedings of Workshop on Forestry Research, Sustainable Forest Management and Livelihood; Himalayan Forest Research Institute-ICFRE. pp. 238-247.
- Jishtu V., Singh L., Kumar P., Kumar R., Waman S. and Kaur M.J. 2020. Traditional use of Non-Timber Forest Products in Kwar region of Shimla, Himachal Pradesh, NW India. *Journal of traditional Knowledge and folk practices* 7(1&2):14-28.
- Jishtu V., Singh L., Kumar P. and Kumar R.2020. Pamphlet on "Major basketry products from hill bamboo in Dodra Kwar, Shimla District, Himachal Pradesh.
- Jishtu V., Kumar D. and Kumar P. 2019. केंचुआ खाद : एक अवलोकन
- Jishtu V.,Kumar P., Kumar R. and Sharma D.2018. डोडरा क्वार की उपयोगी औषधीय वनस्पतियाँ
- Jishtu V., Kumar P., Kumar R.2020.Sustainable harvest of non-timber forest products.

12. **Title of the project:** Invasion impacts of *Acacia mearnsii* on changes in soil fertility status of shola forests in the Western Ghats

Principal Investigator: Dr. A.C. Surya Prabha, Scientist-E, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2018

Critical analysis of the research theme and summary of the study:

The study was conducted with an aim to study the invasive impacts of *Acacia mearnsii* on physico-chemical characteristics and microbial population of soils in shola forests. Invasive plant species can modify physical or chemical attributes of soil, including inputs and cycling of nitrogen and other elements. Studies on the soil physico-chemical properties and microbial population of soil in invaded shola forests are required for proper management of the forests and utilization of resources.

Significant achievements/ findings of the project:

The baseline data on the various physico-chemical properties as well as microbial population in *A. mearnsii* invaded shola forests was generated. Soil properties such as pH, available nitrogen and the amount of base cations in the soil varied significantly under *A. mearnsii* invaded shola forests compared with native vegetation. In the present study, soil organic carbon was highest under shola forest in the Kodaikanal range followed by *A. mearnsii* invaded shola. Available nitrogen, available phosphorus, exchangeable calcium, magnesium, DTPA-Zn and DTPA-Mn in the Kodaikanal range were highest under *A. mearnsii* invaded shola forest. The availability of micronutrients viz, DTPA-Cu, Zn Mn and Fe were higher under shola forest compared to other study plots in Poombarai range. The population of bacteria, fungi and actinomycetes was highest under shola forests in all the three ranges of Kodaikanal Forest Division.

Suggestions/ advisory note for end-users "To-do-techniques":

The project has contributed to the understanding of soil physico-chemical characteristics and microbial population in *A. mearnsii* invaded shola forests. The user groups viz., State Forest Departments will have added benefit in undertaking appropriate decision making in the management of forests to control the invasive menace of *A. mearnsii* thereby improving the soil quality.

Research gaps:

The study was conducted with an aim to study the invasion impacts of *A. mearnsii* on physico-chemical characteristics and microbial population of soils in shola forests. Invasive plant species can modify physical or chemical attributes of soil, including inputs and cycling of nitrogen and other elements. Studies on the assessment of soil properties under shola forests invaded by *A. mearnsii* in the Western Ghats of Kodaikanal are scanty. Hence, the present work was undertaken to study the soil physico-chemical properties and microbial population of shola forests invaded by *A. mearnsii* plantations in the Western Ghats.

Uses of research outcomes:

The project has contributed to the understanding of soil physico-chemical characteristics and microbial population in *A. mearnsii* invaded shola forests. The user groups *viz.,* State Forest Departments will have added benefit in undertaking appropriate decision making in the management of forests to control the invasion menace of *A. mearnsii* thereby improving the soil quality.

Publications:

- Surya Prabha A. C., Arulmani K., Senthivelu M., Velumani R. and Padmini S. 2020. *Acacia mearnsii* Invasion on Soil Microbial Population of Shola Forests in the Western Ghats. *International Journal of Current Microbiology and Applied Sciences* 9(08): 3421-3425.
- Surya Prabha A. C., Arulmani K., Senthivelu M., Velumani R. and Pragadeesh S. 2021. Soil properties of shola forests invaded by black wattle (*Acacia mearnsii*) in the Western Ghats of Tamil Nadu, India. *Applied Ecology and Environmental Research* 20(1): 251-263.

13. Title of the project: Taxonomic study of Orthoptera of Tamil Nadu

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Orthopterans are excellent indicators since they are strongly influenced by landscape changes. Some orthopteran species respond to the changes positively and their population increases, sometimes reaching pest status levels. Therefore, the present study has been conducted to understand the Orthoptera of Tamil Nadu in terms of systematics, diversity, habitat preferences, population dynamics, disturbance impacts, and conservation. There are about 13, 6 and 9 Subfamilies of Acrididae, Tettigoniidae and Gryllidae are represented in India, respectively. However, in the present study, we have recorded 116 species of Orthoptera belonging to 59 genera and 4 families. There are about 28 subfamilies recorded in the present survey with 14 subfamilies of Acrididae; 6 subfamilies of Tettigoniidae; and 2 subfamilies of pryrgomorphidae and one subfamily of Gryllidae. Short-horned grasshoppers were recorded with greater diversity in all the habitats followed by long-horned grasshoppers, Pyrgomophids and gryllids were represented poor. Forestland ecosystem harboured greater number of Orthoptera species followed by arablelands, grassland and wasteland. Thirteen species of Orthoptera were recorded first time in Tamil Nadu. Host range, host preference and host selection studies were conducted to identify the potential species to become pest status, if any. They fed on a wide range of host plants belonging to unrelated families and so are polyphagous. Population dynamics studies revealed that they were known to occur in a wide variety of habitats, ranging from the low, mid altitude to high altitude. It was predicted that at middle altitudes, there was a significant reduction in diversity of grasshoppers. It was evident that the tropical high altitudinal stunted wet evergreen forests locally known as sholas provided refuge when lowland sites are subject to anthropogenic pressure and climatic fluctuations. High altitude zone is under severe biotic threat due to anthropogenic disturbances due to urbanization, climate change, eco tourism etc. The results demonstrated that there was a little to strong changes in the assemblage of Orthopterans in the disturbed grassland and forestlands. However, there was statistically significant decline in the densities of orthopteran species in disturbed forestland after impact.

Significant achievements/ findings of the project:

Totally 116 species of Orthoptera belonging to 59 genera falling under 22 subfamilies with 4 families were recorded in Tamil Nadu during the survey period of three years. Maximum number of species were recorded in the family Acrididea with 53 spp., followed by Tettigoniidea with 44 spp. The family Prygomorphidea was represented by 13 spp. and Gryllidea with only 6 spp. Maximum richness was observed in forestlands with 79 species followed by the arablelands with 49 species, the grassland with 40 species and the wastelands with 25 species, respectively irrespective of the agroclimatic zones. Key to species of the recorded Orthopterans were prepared and web enable data base was also developed. Three new species of Orthoptera have been described.

Suggestions/ advisory note for end users "To-do-techniques":

This study indicated that distribution, diversity and richness of orthopterans in different habitat types under seven agroclimatic zones of Tamil Nadu were related to the vegetation types and availability of host plants, subject to the prevailing ecological conditions. Few species were unique to Tamil Nadu especially in Western Ghats because of the ecological uniqueness of the region, one of the mega biodiversity hot spots of the world. Therefore, given the need for conserving the Orthoptera faunal diversity of Tamil Nadu, the habitats viz., Forestlands, montane grasslands and shola forests have to be protected.

Research gaps:

There is a paucity of information on Taxonomy of Orthoptera (Insecta) in India with reference to biodiversity conservation of fauna and hence scientific intervention has been made.

Uses of research outcomes:

The research outcome will help the forest department to develop sound management strategies for healthy maintenance of forest ecosystem.

Publications:

- Divya G., Senthilkumar N. and Senthamarai Selvan P. 2021. Altitudinal gradients and species richness: A study on diversity of orthoptera in Nilgiris Shola Forests and Grasslands. *Rec. zool. Surv. India* 121(4): 465–472, DOI: 10.26515/rzsi/v121/i4/2021/157081
- Senthilkumar N. and Divya G. 2020. A new species of the genus *Trigonocorypha* (Orthoptera: Tettigoniidae: Phaneropterinae) from Tamil Nadu, India. *Zootaxa*, 4802(1):189-195DOI: https://doi.org/10.11646/zootaxa.4802.1.13
- Divya G. and Senthilkumar N. 2020. Description of new species of the Genus, *Trigonocorypha* (Orthoptera: Tettigoniidae: Phaneropterinae) from Tamil Nadu, India. *Journal of Entomology and Zoology Studies* 8(2):1736-1739 **DOI:** http://dx.doi.org/10.22271/j.ento
- Divya G. and Senthilkumar N. 2019. Rarity and prioritization of Tettigoniid species and selection of sites for conservation of Tettigoniidae in Tamil Nadu. *Journal of Global Biosciences* 8(10): 6481-6499.
- Divya G. and Senthilkumar N. 2018. Influence of courtship feeding on fecundity of *Conocephalus maculatus* (Le Guillou, 1841) (Orthoptera: Tettigoniidae: Conocephalinae). *Journal of Entomology and Zoology Studies* 6(5): 612-617.
- Divya G. and Senthilkumar, N. 2017. Record of grasshopper fauna (Orthoptera) in forest campus, Coimbatore, Tamil Nadu, India. *Current Biotica* 10(4): 296-301.

14. Title of the project: AICOPTAX on Tettigoniidae of India

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Inventory of Tettigoniids has been conducted in different habitat type viz., forestlands, grasslands, arablelands and wastelands under the different agroclimatic zones of Tamil Nadu, Kerala and Karnataka states. Total 47 species of Tettigoniids belonging to 17 genera falling under 6 subfamilies were recorded in southern India during the survey period. Maximum 34 species were recorded in the sub family Phaneroptera. The subfamily Conocephalinae was represented by 6 spp. and Pseudophyllinae with only 4 spp. Maximum richness was observed in forestlands with 25 species followed by the arablelands with 11 species, the grassland with 8 species and the wastelands with 3 species, respectively irrespective of the agroclimatic zones. Key to species of the recorded Tettigoniidae was prepared. Seasonality of Tettigoniids was also studied in various season with selected 28 sites falling under different agroclimatic zones of Tamil Nadu, Kerala and Karnataka. Identification of Tettigoniidae specimens using image scope software confined the species. Sites were selected for each habitat type in different agroclimatic zones to study the impact of disturbances on assemblage and diversity of Tettigoniids to prioritize the sites and habitats for conservation. Forestlands stood first rank for conservation of Tettigoniids followed by grasslands and arable lands.

Significant achievements/ findings of the project:

A new species of Tettigoniid was described. It was found that the distribution, diversity and richness of Tettigoniids in different habitat types under different agroclimatic zones of Tamil Nadu, Kerala and Karnataka were related to the vegetation types and availability of host plants, subject to the prevailing ecological conditions. Few species were unique to Tamil Nadu especially in Western Ghats because of the ecological uniqueness of the region. Therefore, given the need for conserving the Orthoptera faunal diversity of Tamil Nadu, Kerala and Karnataka, the habitats viz., Forestlands, montane grasslands and shola forests have to be protected.

Suggestions/ advisory note for end users "To-do-techniques":

Grasshoppers are one of the major components of ecosystem; their assemblage in the ecosystem will be the indication for maintenance of the ecosystem health. The study provided information on diversity of tettigoniids insects in different habitat types under seven Agroclimatic zones of India since there is paucity of information on this aspect. Results from the impact assessment studies will provide vital information on the stress and strain encountered by the indicator species in the ecosystem. The proposed project will provide technologically authentic database for designing appropriate strategies towards management of ecosystems/habitats in a holistic way.

Research gaps:

Tettigoniids are a lesser known group of Insects globally and a concern on conservation of this group of insects and hence the study has been attempted to enrich the biodiversity status of this group of insects.

Uses of research outcomes:

The research outcome will help the forest department to include in the management plan for conservation of fauna vis-à-vis habitat.

Publications:

- Divya G. and Senthilkumar N. 2020. Contributions to the knowledge of the genus *Phaneroptera* (Tettigoniidae: Phaneropterinae) with a new record from Tamil Nadu, India. *Zootaxa* 4860(3): 425-434. DOI: https://doi.org/10.11646/zootaxa.4860.3.7
- Rajaganesh R. and Senthilkumar N. 2020. Diversity and distribution records of Orthoptera (Insecta) in Nagarhole Tiger Reserve, Karnataka, India". *Proceedings of the Zoological Society* (PZOS), 73:362-379 https://doi.org/10.1007/s12595-020-00339-1

15. **Title of the project:** Managing Critical Ecosystems: Tree Improvement and Biotechnological interventions capture Genetic and Adaptive variations in *Rhizophora* to mitigate climate changes

Principal Investigator: Dr. B. Nagarajan, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2018 - 2022

Critical analysis of the research theme and summary of the study:

Rhizophora is a keystone taxon that is abiotically pollinated (anemophilous) and abiotically dispersed (hydrochorous). Flowers are long lived, protandrous, dichogamous and functionally anemophilous. *R. mucronata* is an obligatory cross breeder while, *R. apiculata* shows both self and cross breeding behavior. Mating behaviors of the said taxon, anemophilous pollination syndrome and overlap in their reproductive phenology brings about the putative hybrid *R.* × *annamalayana*, a morphological intermediary to *R. apiculata* and *R. mucronata*. The hybrid shows heterosis in terms of morphology, biomass, carbon stock exhibiting their enhanced productivity and also has a higher genetic diversity. However, it is the lowest in terms of frequency of occurrence within Pichavaram. The study identified that *Rhizophora apiculata* in Pichavaram was vulnerable due to lower frequency in the vegetation, low reproductive fitness and low genetic diversity. Elimination of one of the parental species could negatively influence the natural hybridization.

Significant achievements/ findings of the Project:

Floristic surveys were completed in Pichavaram (Deltaic type). About 73 putative *Rhizhophora* hybrids (*Rhizhophora x annamalaiyana*) were identified and tagged. Biomass productivity hybrids (above and below ground) were higher in hybrids compared to either parent. Studies on genetic diversity (fourteen microsatellite markers) of are indicative that some most genotypes were closer to *R. mucronata*.

Suggestions/ advisory note for end-users "To-do-techniques":

The study suggests that, *R. apiculata* in Pichavaram needs of human assisted species recovery. Future afforestation programs should include both the parental species representing the holistic vegetation could improve the ecosystem structure function and services. Conventional breeding technologies could also be adopted to generate intra specific hybrids with pedigrees, perhaps this could aid in improving the hybrid population and create an avenue for tree breeding research on carbon capture and climate change mitigation, if appropriate tree breeding and (or) improvement approaches are deployed. A technology entitled Automated Mangrove Incubation Nursery Technology (AMINT) has been standardized and transferred to Tamil Nadu Forest Department for propagation of mangrove Rhizophoras. The said method was defended to the IPR committee of IFGTB during February, 2023 and currently in the process of obtaining Patent.

Research gaps:

Baseline data on biomass and adaptive variations and regeneration at species and population levels (*Rhizhophora* sp.) in criticalecosystems across varying (*insitu*)salinity levels were not available for handling management and conservation aspects.

Uses of research outcomes:

About one hundred and twenty *Rhizophora* putative hybrids geo-tagged for long term observations.The findings have been extended to the TNFD for making suitable management measures as a follow up research program at Pichavaram, Cuddalore District, Tamil Nadu.

Publications:

- Utchimahali M., Shanthi A.., Maheswari P., Nithishkumar K., Haritha S. and Nagarajan B. 2022. Molecular Characterization and Phylogenetics in the *Rhizophora* Species Complex at Pichavaram, Tamil Nadu: A Potential Resource for Phyto Pharmacology. *International Journal of Life Science and Pharma Research* 13(1), L202 -

L208. https://doi.org/10.22376/ijlpr.2023.13.1.L202-208.

- Utchimahali M. and Nagarajan B. 2022. Floral Biology and Pollination Ecology of *Rhizophora mucronata* Lam. in Pitchavaram, Tamil Nadu. *Indian Journal of Applied and Pure Biology* 37 (2): 332-339.
- Nagarajan B., Utchimahali M., Balasubramaniam A. and Jesubalan D. 2019. Population studies on two species of *Bruguiera* of *Rhizophoraceae* in selected areas of Kerala and Tamil Nadu. *Journal of advances in Biological Sciences* 6 (1): 23-26.
- Utchimahali M., Silambarasan R., Priyatharshini S. and Nagarajan B. 2022. A review on the Recent changes in the Indian Mangrove cover. Lulu Publication, 3101 Hillsborough St, Raleigh, NC 27607, United States.
- Nagarajan B., Karthikeyan A., Shanthi A., Ragavan P., Siva Priya N. B., Utchimahali M. and Haribabu K. 2020. Indian Mangroves Insight, Interventions and Implications: A Hand Book. ICFRE Publication, 46 p.
- Nagarajan B., Utchimahali M. and Selvam M. 2021.vkykspuk: पुनर्प्राप्ति के लिए एक मार्गदर्शिका (Sirukandal: Meetuadukkum Kuritha oru Kaiedu) (*Ceriops decandra:* A Brochure on species recovery), 8 p.
- Utchimahali M., Nagarajan B., Chitra P., Aswin Y. and Haribabu K. 2021. Habitat Changes?! Habit Changes!!: Mangroves in Critical State? *IFGTB Newsletter 3* (1) 2 -3.
- Nagarajan B., Aswin Y. and Utchimahali M. 2021. Automated Mangrove Incubator Nursery Technology (AMINT) *IFGTB Newsletter 3* (1): 3.
- Utchimahali M. and Nagarajan B. 2022. Controlled Pollination and Hybridisation in *Rhizophora*: Targeting Hypersalinity and Productivity *IFGTB Newsletter* 3 (2): 2.

Patent:

- A technology entitled Automated Mangrove Incubation Nursery Technology (AMINT) was defended before the IPR committee of IFGTB during February, 2023 and currently in the process of obtaining Patent.

16. **Title of the project:** Spatial mapping and Assessment of Phenological Responses of Teak to Changing Climate

Principal Investigator: Dr. A. Rajasekaran, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 – 2023

Critical analysis of the research theme and summary of the study:

Land use and Land cover (LULC) including the spatial extent of Teak in selected areas of Tamil Nadu and Kerala was prepared. A WebGIS layer containing various teak plantations in the study area was developed. Phenological responses of Teak to changing climate was assessed using 19 years (2001 to 2019) MODIS satellite data. Normalized Difference Vegetation Index (NDVI) Time series was constructed for various study sites and used for calculating phenological metrics like Start of Season (SoS), End of Season (EoS) and Length of Season (LOS) using TIMESAT software. The phenologcial metrics were correlated with annual mean temperature and annual cumulative rainfall data. The climatic data was downloaded from the India Meteorological Department (IMD) website. Among the study sites, SoS was early in Salem (April – July), SoS was delayed in Wayanad (August-September) and in other sites SoS is during July-August. However, the delay in SoS could be due to the Latitudinal difference. The LoS was positively correlated with annual cumulative rainfall. The LoS got reduced during the year 2003-2004 in Parambikulam, Malappuram and Wayanad which received less cumulative annual rainfall. However, LoS of teak was not affected in Siruvani and Valparai study sites which also received less cumulative annual rainfall during the year 2003-2004. This could be due to the the resilience of the teak and also could be due to the microclimatic factors including the soil moisture in these areas.

Significant achievements/ findings of the project:

The phenological responses of Teak to changing climate was assessed using 19 years (2001 to 2019) MODIS satellite data. The study revealed that though there were minor shifts in the teak phenology (SoS, EoS and LoS) across the study sites during few years of the study period (2001-2019), no significant shifts in the overall phenological cycle of teak was observed.

Suggestions/ advisory note for end-users "To-do-techniques":

Techniques for monitoring the impact of changing climate on the phenological responses of Teak has been standardized. The research outcome can be used to formulate strategies for the management of Teak. Further, the results of the project will help the Council to develop techniques for monitoring the impact of changing climate on the phenological responses of other forest tree species.

Research gaps:

Information on the phenological responses of Teak to climate change was not available across various landscapes in Tamil Nadu and Kerala.

Uses of research outcomes:

Though there were minor shifts in the teak phenology (SoS, EoS and LoS) across the study sites during few years of the study period (2001-2019), no significant shifts in the overall phenological cycle of teak has been observed. The outcome of the study is being shared with the State Forest Departments.

17. Title of the project: Survey and documentation of Phytodiversity in and around Singanallur Lake, Coimbatore. Phase-I (S-Lake)

Principal Investigator: Dr. C. Kunhikannan, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2017 - 2019

Critical analysis of the research theme and summary of the study:

As the part of the initiatives, IFGTB took up work of documenting the Phytodiversity in and around the Lake. A total of 453 plant species, mostly terrestrial ones, belonging to 304 genera and 84 families were enumerated. Life form wise analysis of flora indicated the dominance of herbaceous species in the vegetation around the lake with 193 species followed by trees with 144 species, 56 species of shrubs, 55 climbers and 5 lianas. On the basis of utility, 328 species found to be medicinal, 86 ornamental, 72 edible and 46 fodder species. Out of 84 families, Leguminosae was found to be with the most 64 species followed by Poaceae (45 species), Malvaceae (32 species). The top ten families contributed almost 60% of the species in the Lake area. Thirty-nine families represented by only one species. Quantitative analysis of the vegetation on all the bunds revealed that *Brachiaria mutica* (Para grass, Buffalo grass, Dutch grass) was the highly frequent and dominant grass spread along the lake shore garlanding the inner bunds helping in protecting the bunds. The vegetation around the lake also acted as the nesting or hiding places for the birds, herpetofauna and small mammals. The Lake supported an array of fauna including 116 species of resident and migrating birds with a few near threatened species like Spot-billed Pelican, Painted Storks and Oriental White Ibis, reptiles including soft shelled turtle, several butterflies, moths, dragon flies, etc. During the study, certain weeds could be recorded in the vicinity of the lake such as *Parthenium hysterophorus, Prosopis juliflora, Xanthium strumarium, Desmanthus virgatus, Croton bonplandianus* and some climbers which disturb the vegetation.

Significant achievements/ findings of the project:

A total of 453 plant species were documented in and around the Singanallur lake; Herbarium specimens of all the species were prepared and preserved in ICFRE-IFGTB Herbarium. The information brought out through this project serves as a baseline for further monitoring of the vegetation.

Suggestions/ advisory note for end users "To-do-techniques":

It was suggested that invasive species such as *Parthenium hysterophorus, Prosopis juliflora, Xanthium strumarium, Desmanthus virgatus, Croton bonplandianus* would be gradually removed without affecting overall functioning of the lakeshore vegetation.

Research gaps:

The Singanallur Lake, Coimbatore, Tamil Nadu is one of the urban lakes with rich plant diversity, but baseline data on plant diversity of this urban lake was not available.

Uses of research outcomes:

The findings of the study were shared with local Panchayats and others stakeholders including school students and nature enthusiasts to raise awareness about the plant diversity. The Singanallur lake has been declared as Urban Biodiversity Conservation Zone by Coimbatore City Corporation based on this study report.

Publications:

- Kunhikannan C., Prasanna R., Balaji R., Thamilarasi R, Peter Vinny R. and Joseph Reginald L. 2023. Plant Diversity of Singanallur Lake-An Urban Wetland in Coimbatore, Tamil Nadu. *Indian Forester* 149 (1) : 23-34.
- Prasanna R., Balaji R., Thamilarasi A. and Kunhikannan C. 2022. Grasses in the environs of Singanallur Lake in Coimbatore district, Tamil Nadu, India and their ecological and economic uses. *Journal of Economic Taxonomic Botany* 46 (3&4): 143-146.
- Prasanna R., Balaji R., Thamilarasi A. and Kunhikannan C. 2020. Phytodiversity in and around Singanallur Lake. *IFGTB Newsletter* 2(2): 5.

18. Title of the project: Assessment of plant biodiversity of Silent Valley Buffer Zone (KFD- III)

Principal Investigator: Dr. C. Kunhikannan, Scientist-G, ICFRE-IFGTB Coimbatore

Duration:2017 - 2022

Critical analysis of the research theme and summary of the study:
Considering the importance of the richness of the area, and opinion came out during the meeting held for preparation of management plan for the buffer zone of Silent Valley National Park, it became important to know the present status of the species richness and population status of important species in the buffer zone. Complete survey was carried out in 35 different locations in Buffer zone and enumerated and documented 1019 plant species belonging to 642 Genera and 136 families. All the collected plant samples were processed into herbarium specimens. The study also recorded 121 wild edible and 290 potential ornamental species. The identified wild edible and ornamental species can be further domesticated for commercial uses.

Significant achievements/ findings of the project:
Documented 1019 plant species belonging to 642 Genera and 136 families. All the collected plants samples were processed into herbarium specimens. The study also recorded 121 wild edible and 290 potential ornamental species.

Suggestions/ advisory note for end users "To-do-techniques":
It is suggested to the Forest department to have special schemes to conserve the threatened species and also domesticate and multiply native ornamental and wild edible species. The information brought out through this report will serve as a baseline for further monitoring of the vegetation and also helpful in preparation of management plan for the buffer zone of Silent Valley National Park.

Research gaps:
For the management plan for the buffer zone of Silent Valley National Park, the present status of the species richness and population status of important species in the buffer zone are to be known.

Uses of research outcomes:
The information will be used by the State Forest Department for the management of the buffer zone of Silent Valley NationalPark.

19. Title of the project: Assessment, Documentation and Characterization of Lichen diversity of Tripura, North – East India.

Principal Investigator: Sh. Sandeep Yadav, Scientist-D, ICFRE-RFRI Jorhat

Duration: 2017- 2020

Critical analysis of the research theme and summary of the study:
Lichens play an essential role in many ecosystems. They are a food source for various animals, including reindeer, caribou, and insects. Lichens also help to fix nitrogen in the soil, making it available to other organisms, and are essential contributors to soil formation. Tripura's lichens were not studied thoroughly so to fill this research gap, this project was initiated. The documentation of 124 species of lichens under this project indicated that there is a moderate diversity of lichen in the state of Tripura.

Significant achievements/ findings of the project:
Low lying areas of altitudinal range 0 – 500 m amsl are predominantly characterized by crustose lichen communities with genera such as *Arthonia, Bacidia, Buellia, Caloplaca, Chrysothrix, Cryptothecia, Glyphis, Graphis, Pertusaria, Pyrenula,* etc. Genera such as *Bulbothrix, Caloplaca, Cladonia, Coccocarpia, Collema, Dirinaria, Flavoparmelia, Haematomma, Heterodermia, Lecanora, Leptogium, Letroutia, Parmotrema, Pyxine*, etc. are of common occurrence in the altitudinal range of 500 – 1000 m amsl. *Cryptothecia striata* was one of Tripura's most abundant crustose lichens occurring on bark, leaves, iron poles, cement walls etc. *Dirinaria aegialita* is another dominant sub-foliose species. Leaves of under-storey plants in thick forests were occupied by folicolous lichen genera such as *Strigula elegans, Calopadia,* etc.

Suggestions/ advisory note for end-users "To-do-techniques":
The results of this project will be helpful for further lichenological studies in the state. The data generated in this project would be helpful for forest managers, researchers, front-line forest staff, students etc.

Research gaps:
Since, Tripura's lichens were not studied thoroughly; a clear research gap was evident.

Uses of Research Outcomes
The data generated in this project would be helpful for forest managers, researchers, front-line forest staff, students, etc.ICFRE can take up consultancy services in lichen taxonomic studies.Lichens have long been recognized as good air quality and good environment indicators and will help conduct environmental studies in future.

20. Title of the project: Micro propagation of rare and endangered species of orchids of Mizoram and their re-introduction in wild.

Principal Investigator: Sh. Sandeep Yadav, Scientist-D, ICFRE-RFRI Jorhat

Duration: 2017- 2020

Critical analysis of the research theme and summary of the study:

Orchidaceae is one of the largest families of flowering plants in the world. India is home to 1,256 species of orchids under 155 genera; of these, 307 species are endemic. Northeast India harbours 714 species of orchids under 125 genera, of which 73 are endemic. Globally, orchids are among the most threatened plant groups due to the increased scale and extent of threats, inherent rare biology and specific conservation needs. Habitat destruction and degradation are among the most pertinent threats to orchids today. Despite having a large forest cover, Mizoram does not harbor a rich diversity of orchids, totaling 287 species. The traditional shifting cultivation or Jhuming is mainly responsible for the extensive scale depletion of natural habitats of orchids of Mizoram. This situation is compounded by the illegal wildlife trade of orchid plants in Myanmar. About 15,000 orchid seedlings of the targeted five species were re-introduced in four locations in Mizoram. Extension pamphlets on the propagation of orchids via the seed-flasking method were prepared in English and Mizo. A DVD on the Artificial Pollination of Orchids was designed and released.

Significant achievements/ findings of the project:

Five rare and endangered orchids of Mizoram, viz., of *Aeride sodorata*, *Dendrobium primulinum*, *Paphiopedilum spicerianum*, *Renanthera imschootiana* and *Vanda coerulea* var. *semi-alba*, were cultivated through tissue culture and 15,000 plants were reintroduced in wild for their conservation.

Suggestions/ advisory note for end-users "To-do-techniques":

The study will help in conserving orchid bio-diversity. Orchid society of Mizoram was identified as a suitable agency for transfer of technology. The Orchid Society of Mizoram was selected as a suitable party for transferring technology for orchid micro-propagation.

Research gaps:

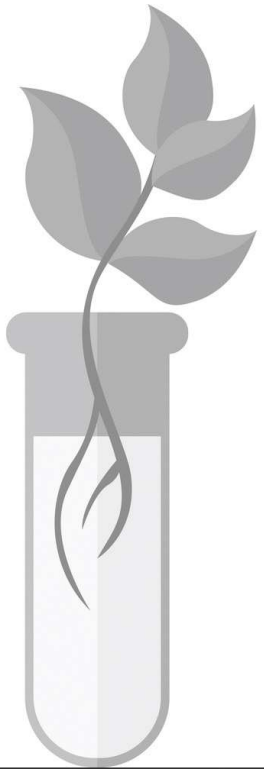
Despite having a large forest cover, Mizoram stands second last in the number of orchid species reported (287) among the northeastern states and only about 44% of orchids present in Mizoram are having large populations; the rest fall under different categories of threat as envisaged in the Red Data Book published by the International Union for Conservation of Nature and Natural Resources (IUCN). The traditional shifting cultivation or Jhuming is mainly responsible for the extensive depletion of natural habitats of orchids of Mizoram and is compounded by the illegal wildlife trade of orchid plants in Myanmar.

Uses of Research Outcomes

1The data generated in this project would be helpful for forest managers, researchers, front-line forest staff, students etc. The outcome of the study will help ICFRE to give consultancy services in Orchid Micro-propagation and re-introduction. The package of practice developed under this project can be transferred to public/private orchid tissue culture labs.

Publications:

- DVD on the Artificial Pollination of Orchids.
- Pamphlet on Micro propagation of orchids via seed-flasking method.



CHEMISTRY

CHEMISTRY

1. **Title of the project**: Utilization of forest biomass through value added application as source of natural dyes

Principal investigator: Dr. Y.C. Tripathi, Scientist-F, ICFRE-FRI Dehradun

Duration: 2017 - 2021

Critical analysis of the research theme and summary of the study:

The objective of the project was to explore new plant sources of natural dyes for safe and ecofriendly textile finishing. A number of species though ethnically used for dyeing purpose, a few of them only have so far been scientifically accessed and validated as a viable source of natural dyes. Screening of renewable plant parts of ten plant species was undertaken and based on their dye yield and dyeing performance on silk, wool and cotton fabrics, three of them namely *Cassia occidentalis, Mimosa himalayana* and *Prosopis juliflora* were systematically investigated for development of best possible dye extraction and dyeing protocols, colour fastness properties and color strength on silk, wool and cotton fabrics. The results highlighting specific analysis of dyes and their dyeing characteristics on different parameters recognized *Cassia occidentalis, Mimosa himalayana* and *Prosopis juliflora* as a potential and commercially feasible source of natural dyes thus affirming notable additions in the existing source of plant inventory of natural dyes.

Scientific achievements/ findings of the Project:

Optimization of conditions for the extraction of dye from the leaves of *Cassia occidentals* (CO)*, Mimosa himalayana* (MH) and *Prosopis juliflora* (PJ) led to achieve significantly high yield of these dyes CO,18.50%; MH, 19.33%; PJ,16.35%). Optimization of dyeing parameters and appropriate mordanting afforde- range of attractive and acceptable shades have been developed on silk and wool fabrics. The colourfastness of CO, MH and PJ dyes against light, washing, rubbing and perspiration were found to be excellent (4-5) on silk and wool fabrics. However, performance of dyes on cotton was observed to be average (2-3) to good (3-4). Most appropriate fibre-dye-mordant combinations were determined for all the extracted dyes based on CIEL*a*b* and K/S values. An estimate of cost in terms of energy and labour for dye extraction and dyeing at laboratory scale through batch extraction and subsequent dyeing as well as simultaneous extraction and dyeing showed that the cost of energy and labour for drying could be saved in simultaneous dyeing so the process is particularly beneficial for professional dyers, weavers and cottage industries engaged in weaving and dyeing. On the other hand-batch extraction is suitable for production of marketable products like dye concentrates or dye powder.

Suggestion/ advisory note for end users "To-do-techniques":

The users of the natural dyes are dyers, NGOs engaged in using of natural dyes, researchers, industries of natural dyes etc. The research findings may encourage these users to use natural dyes from the leaves (renewable parts available round the year) of *Cassia occidentalis, Mimosa himalayana, and Prosopis juliflora* for natural dye production and fabric dyeing. Training programmes for dyers / users should be organized to acquaint them about the investigated plants as economically viable source of natural dye. Brochures, pamphlets etc. for popularization of plants as promising source of natural dyes and extension of related technical know-how should also be prepared and published. Findings of the project should be extended to the SFDs for promotion and utilization of these dye yielding plants.

Research Gaps:

Despite the textile industry's increasing interest in eco-friendly alternatives, only a limited number of plant species have been scientifically evaluated and validated. This leaves a significant gap in our knowledge and utilization of the diverse range of plant resources available.

Uses of research outcome:

The research outcomes are field usable and benefit dyers, NGOs, researchers, and natural dye industries. Encouraging the use of natural dyes from *Cassia occidentalis, Mimosa himalayana,* and *Prosopis juliflora* through training programs and awareness materials facilitate their adoption. Extending findings to SFDs promotes the utilization of these dye-yielding plants.

Publications:

- Kumar R. and Tripathi Y. C. 2022. Exploring leaves of *Lannea coromandelica* as a renewable source of natural dye for textile applications. *The Indian Forester* 148 (4): 407-414. 10.36808/if/2022/ v148i4/169091.
- Kumar R., Lijina L.N. and Tripathi Y.C. 2020. Dyeing Behaviour Assessment of Fruit Pulp Extract as a Source of Textile Dye. *Asian Dyer* 17(3): 27-30.

2. **Title of the project:** Chemical examination and value addition of edible mushroom *Astraeus hygrometricus*

Principal investigator: Dr. V.K. Varshney, Scientist-G, ICFRE-FRI Dehradun

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

One of the important groups of NWFPs, collected all over the world and used for subsistence purposes as well as sold on local markets and restaurants, are wild mushrooms. Generally, edible mushrooms possess all three properties of food-nutrition, taste and physiological functions Edible mushrooms contain not only high nutritional and culinary values but also show medicinal effects which are attributed to their diverse primary and secondary metabolites including bioactive low- and high molecular weight compounds. Most mushroom derived preparations and substances find use as a novel class of products named as dietary supplements, tonics, functional foods, neutraceuticals, phytochemicals, mycochemicals, biochemopreventives, and designer foods. *Astraeus hygrometricus* (AH), commonly known as 'Earth Star', '*Rugra*', '*Matitara*', or '*Phutphut*', is one of the ectomycorrhizal edible mushrooms growing wild in association with Chir pine and Sal trees in the forests of Jharkhand, West Bengal, Odisha, Madhya Pradesh and Uttarakhand. Collection of young fruit bodies from the forests by the tribal and local people and their selling in local market is an alternative source of their income. Fruit bodies are revered for their delicacy, earthy aroma and meaty flavour, however, their shelf life is very poor which limit their marketability. The objective of the project was to examine the detailed nutritional and chemical profile of *A. hygrometricus* in order to expand its nutritional and therapeutic benefits and also to develop practice (s) for preservation of its fruit bodies for their increased utilization and marketability. Detailed chemical examination of the fruit bodies was undertaken and their proximate nutritional composition, taste imparting components, and bioactive compounds were determined. Overall *A. hygrometricus* proved its edibility in terms of tasty and nutritional food and also reflected its therapeutic potential. To add value to the fruit bodies, their canning in a 20% brine solution containing 0.1% citric acid was demonstrated to enhance their shelf life for duration up to 360 days without altering their color, organoleptic properties and content of protein, carbohydrates and fat.Determined nutritional and chemical composition of the fruiting bodies indicated their significant potential in maintaining good health and boosting immune system of the human body and might, therefore, act as good nutraceuticals. Being simple and economical, this method was also suitable to be adopted by local / tribal people for augmenting their income.

Scientific findings/ achievements of the project:

Proximate nutritional composition of the fruit bodies of *A. hygrometricus* with respect to moisture, total carbohydrates, protein, fat, dietary fibers, ash, pro vitamin D2, *in vitro* digestibility and energy values, fatty acids (palmitic acid, stearic acid, oleic acid, linoleic acid, minerals (K, Ca, Mg, Na, Fe, Mn, Se), taste imparting components [soluble sugars (glucose, mannose, trehalose), sugar alcohols (mannitol, arabitol), free amino acids (8.20%, aspartic acid, serine, glutamic acid, glycine, histidine, threonine, alanine, proline, tyroline, valine, methionine, lysine, isoleucine, leucine, phenylalanine) and 5'-nucleotides (5′-UMP and 5′-GMP) was determined. GC-MS and LC-MS assisted analyses of the extracts of different polarity isolated from the fruit bodies led to establish the composition of their low molecular weight secondary metabolites. Altogether thirty six chemical constituents, belonging to different chemical classes, including five sterols, nine triterpenoids, five phenols, one alkaloid, one unsaturated fatty acid, one saturated fatty acid, three unsaturated fatty acids esters, three saturated fatty acids esters, one unsaturated fatty acid amide, five unsaturated hydrocarbons, one saturated hydrocarbon and one lactone were characterized. Molecular structure of the polysaccharide isolated from the fruit bodies was established with the help of modern and classical techniques. Shelf-life experiments of the fruiting bodies revealed that canning of the fruit bodies in a 20% brine solution containing 0.1% citric acid was the best process which can effectively enhance the shelf life of the fruit bodies for duration up to 360 days without affecting their colour, organoleptic properties and content of protein, carbohydrates and fat.

Suggestion/ advisory note for end users "To-do-techniques":

A good amount of scientific data and new knowledge has been generated in the project which led to understand the taste, nutritional, and chemical attributes of the wild edible mushroom *A. hygrometricus* which is an effective approach for expanding its nutritional and medicinal benefits. Developed practice for preservation of fruit bodies can lead to increased utilization and marketability of this mushroom. Thus, the findings of the project are seen to have an impact on scientific advancement in the area of promotion and utilization of wild edible musrooms.Findings of the project are useful for various stakeholders including researchers, SFDs, entrepreneurs, NGOs, and local communities, engaged in collection of the fruit bodies of *A. hygrometricus* from the wild, for promotion of utilization and marketability of the mushroom. Preserved fruit bodies can be processed at various scales hence entrepreneurs may utilize the findings in value addition of these fruit bodies in form of various marketable products such as dietary supplements, functional foods, antioxidants, mushroom extract, mushroom concentrate, mushroom powder, soup, biscuits, low calorie products, etc.

Research gaps:

Wild mushroom *Astraeus hygrometricus* (Earth Star), is economically important for local communities. The limited knowledge on the nutritional, taste, and chemical attributes of this mushroom, coupled with its poor shelf life causing restricted marketability, presented challenges that the research aimed to address.

Uses of research outcomes:

The research outcomes benefit diverse stakeholders, including researchers, SFDs, NGOs, and local communities involved in collecting *Astraeus hygrometricus*. Entrepreneurs can leverage findings for mushroom based value-added products. Developed practice for enhancing the shelf life of the mushrooms facilitate their increased utilization and marketability.

Publications:

- Singh Pankaj, Varshney V. K., Jayaram Kumar K. and Singh Sanjay 2019. A review on nutritional and biological potential of *Astraeus* spp. of wild edible mushrooms. *International Journal of Medicinal Mushrooms* 21 (6); 523-536.
- Singh Pankaj, Kumar Arvind, Varshney V.K., Stashenko Elena E. 2019. GC-MS Analysis of Different Extracts of Wild Edible Mushroom *Astraeus hygrometricus* (Pers.) Morgan from Jharkhand, India. *Proceedings of 10th International Medicinal Mushroom Conference*, 19-22/09/ 2019, Nantong, China, pp. 452-464.
- Singh Pankaj, and Varshney V. K. 2020. Nutritional Attributes and Nonvolatile Taste Components of Medicinally Important Wild False Earthstar Mushroom, *Astraeus hygrometricus* (Agaricomycetes), from India. *International Journal of Medicinal Mushrooms* 22(9), 909-918.

Extension:

Research out comes on the investigated wild edible mushroom were disseminated through a Webinar on "Potential and Prospects of Value Addition in Wild Edibles" organized on 26th November, 2021. This event was attended by more than 60 participants including representatives from academia, research, NGO, Industries such as Krishivan Doon (P) Ltd., Dehradun; Doon Eagle Organics (P), Ltd, Dehradun; Han Agrocare, Dehradun; R.K. Industries, Dehardun; Jaunsar Organics, Sahiya, Dehardun; Godavari Gramodhyog, Bageshwar; Bagwan Gramodhyog Samiti, Shyampur, Dehradun; Diamond Shiksha Prachar Samiti, Dehardun; mushroom growers, aspirant entrepreneurs and other stakeholder groups.

3. Title of the project: Utilisation of *Pinus roxburghii* needles for value-added products

Principal investigator: Dr. Vineet Kumar, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

Pinus roxburghii Sarg. is the most abundant species in the Himalayan region. Pine needles largely contribute to forest biomass and are the major cause of forest fires leading to climate change, biodiversity loss, etc. Non-utilization of the abundantly available needles has multifarious disadvantageous. Firstly, the raw material remains unutilized even though it may be a good bioresource for valuable products. Secondly, it is also responsible for the destruction of forests due to forest fires. The needles also do not allow access to other important species for their growth. Despite enormous harmful effects, the logical strategy for sustainable and effective management of the utilization of the needles is still being explored due to multiple complex factors like collection, affordability of the machinery, sustainability, environment friendliness, process cost, translation to pilot scale, availability of raw material in remote areas, etc.

In search of a scientific solution for the utilization of pine needles and protection of the Himalayan forests from fires, studies on utilization of needles were undertaken and a novel process has been developed in the laboratory for the isolation of natural fiber from pine needles. The isolated fiber can be spun into handloom cloth and a series of useful handicraft products can be made from the isolated fiber.

Scientific achievements/ findings of the Project:

Pine fiber despite being a non-traditional fiber, is fairly long (~20cm) and shiny that can be spun into coarse, strong threads and is one of the cheapest natural fibers. It is composed of 55-60% cellulose, 20-22% hemicellulose, and 24-26% lignin. Microscopic studies indicate uniform long strands having stomatal pores that contribute to good water absorption capacity. The fiber is generally smooth, with few dislocations. Pine fiber is a moderately strong fiber. The water absorption and moisture content of pine fibers are 600% and 15% respectively, which is fairly good. The pine strand is composed of many short fibers (length between 4-20 cm, diameter 100-200 μm) and can be spun into ropes, mats, etc. by spinning. It has the potential to become a versatile, eco-friendly, natural, and moderately durable fiber. Being compatible with diverse natural fibers, pine fiber can be mixed with other natural fibers to harness complementary benefits for diverse applications.

Suggestion/ advisory note for end users "To-do-techniques":

The technology could be a way to fix several problems at once and offer an opportunity for the utilization of biomass to prepare commercially important products which are important for the viability, sustainability, livelihood support, and hence wider acceptability of the *Pinus roxburghii* plantations in the Himalayan region. The technology for isolation of natural fibre has been transferred to Uttarakhand Bamboo and Fiber Development, Dehradun and Himachal Pradesh State Forest Department, Nahan, Himachal Pradesh. Training on 'Utilization of Pine Needles as a Source of Natural Fiber' has also been given to Officers, Rangers, Foresters, Forest Guards, and villagers. The adoption of this technology will help prevent forest fire and also generate livelihood options at the local level from the locally available abundant bioresource.

Research gaps:

Pine needles largely contribute to forest biomass and are the major cause of forest fires leading to climate change, biodiversity loss, etc. Non-utilization of the abundantly available needles has multifarious disadvantageous. In search of a scientific solution for the utilization of pine needles and protection of the Himalayan forests from fires, studies on the utilization of needles were undertaken.

Uses of research outcomes:

A novel process has been developed for the isolation of natural fiber from pine needles. The identified stakeholders for use of the project outcome are people living in and around pine areas, NGOs, self-help groups, and SFDs, etc.

Patent:

- Vineet Kumar and Pradeep Sharma. Natural fibre from *Pinus roxburghii* (Chir Pine) needles and a process of preparation thereof. Indian Patent Application No. 202011051242 dated 25.11.2020.

4. **Title of the project:** Nutritional and quality evaluation of selected wild edible plants as a source of functional food

Principal investigator: Dr. Y.C. Tripathi, Scientist-F, ICFRE-FRI Dehradun

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

The objective of the project was to evaluate the nutritional and bioactive compoistion as well as bioefficay of selected wild edible fruits in order to recognize them as a potential source of functional food. In recent years, wild fruits have attracted greater attention as potential source of nutrients than conventional horticultural fruits. Evaluation of nutritional and bioactive content as well as disease- preventing and health promoting antioxidant efficacy of edible fruits of selected plants namely *Rhus parviflora, Rubus ellipticus, Rubus niveus, Ficus palmata,* and *Coriaria nepalensis* of Uttarakhand were investigated. Research work under the project involved proximate and nutritional analysis of fruits, qualitative and quantitative estimation of bioactive chemical constituents (total phenolic, flavonoid and anthocyanin contents) and evaluation of antioxidant activity fruit extracts through multifunctional approach. All investigated wild fruits were found to contain varying but substantial amount of nutrients viz: carbohydrate, protein fat, fiber and vitamin C and bioactive polyphenols which were found to be positively correlated with antioxidant activity. Since the study revealed significant quanity of polyphenolic compounds vis-à-vis antioxidant activity, it can be speculated that the investigated wild edible fruits can be potentially useful as source of natural antioxidants.

Scientific achievements/ findings of the project:

The physicochemical and nutritional values of the fruits of *Rhus parviflora* (RP)*, Rubus ellipticus* (RE)*, Rubus niveus* (RN)*, Ficus palmata* (FP)*,* and *Coriaria nepalensis* (CN) of Uttarakhand and their diverse bioactive chemical composition were revealed through physicochemiocal and qualitative phytochemical screening, which provided useful information for their botanical identification and may help in quality control. Evaluation of the phenolic, flavonoid, anthocyanin and ascorbic acid contents of the fruits of RP, RE, RN, FP, and CN suggested the presence of significant but varying amounts of these bioactive compounds in all the species. Fruits extracts of RP, RE, RN, FP, and CN showed significant antioxidant activities in a concentration dependent manner. The activity however found to vary according to the total phenolic content. A direct correlation between total phenolic content and radical scanvenging efficacy has been established.

Suggestion/ advisory note for end users "To-do-techniques":

Nutritional and phytochemical profiles coupled with antioxidant activity can be beneficially utilized in value addition of these wild fruits. Farmers, tribals, NTFP collectors, NGOs, SHG may find opportunity for additional income generation through collection, preservation, primary value addition and supply of raw materials. The scientific knowledge on nutritional profile and healthcare attributes may encourage people to use wild fruits as nutritious dietary supplement. Brochures, pamphlets, etc. for popularization of studied wild fruits as promising source of nutrition and extension of project findings among user groups should be prepared and published. Awareness should be generated among local people about the health benefits of consumption of wild fruits through publication of popular articles, radio talks, and dissemination through mass media. The outcome of study may encourage SFDs towards protection, conservation and largescale plantation of these fruit plant species.

Extension:

With the aim to disseminate research out comes on the investigated wild fruits, a Webinar on "Potential and Prospects of Value Addition in Wild Edibles" was organized on 26th November, 2021 which was attended by more than 60 participants including representatives from academia, research, NGO, Industries such as KrishivanDoon (P) Ltd., Dehradun; Doon Eagle Organics (P), Ltd, Dehradun; Han Agrocare, Dehradun; R.K. Industries, Dehardun; Jaunsar

Organics, Sahiya, Dehardun, Godavari Gramodhyog, Bageshwar, BagwanGramodhyogSamiti, Shyampur, Dehradun; DaimondShikshaPracharSamiti, Dehardun; mushroom growers, aspirant entrepreneurs and other stakeholder groups.

Research gaps:

Limited research on nutritional and bioactive content in wild edible fruits hinders their recognition as sources of nutraceuticals and functional foods. Extensive studies on commercialized fruits contrast with the insufficient exploration of wild fruits, leaving a gap in understanding their potential as natural antioxidants and health-promoting compounds.

Uses of research outcomes:

The outcome of the project will benefit **f**armers, tribals, NTFP collectors, NGOs, SHG by offering additional income opportunities through collection, preservation, primary value addition and supply of raw materials. Entrepreneurs can use findings for value addition. Scientific knowledge promotes wild fruits as nutritious supplements, encouraging conservation and, large-scale plantation of identified fruit plant species by the SFDs.

Extension through Mass Media

- A Radio Talk was delivered on the topic "Nutritional and Functional Significance of Wild Edible Fruits of Uttarakhand" on 11th Feb., 2019 from All India Radio (AIR), Dehradun.
- A Radio Talk was delivered on the topic “Employment and income generation opportunities in wild fruits processing” on 27th Feb., 2020 from All India Radio (AIR), Dehradun

ECOLOGY, SOIL AND LAND RECLAMATION

ECOLOGY, SOIL & LAND RECLAMATION

1. **Title of the project:** Rehabilitation of salt affected soil with amendments of biofertilizer (AM fungi)

Principal Investigator: Dr. Bhawana Sharma, Scientist-E, ICFRE-AFRI Jodhpur

Duration: 2016 - 2019

Critical analysis of the research themes and summary of the study:

This project includes a systemic attempt on Arbuscular Mycorrhizal (AM) association with *Salvadora persica* an important multipurpose tree species of western Rajasthan in biomass production. A series of field survey and laboratory experiments were carried out for isolating and identifying the predominant fungal species in different edaphoclimatic conditions of arid regions of Rajasthan. The information on the diversity of AM fungi was derived from the abundance and types of spores and AM root colonization. These data were further correlated with soil parameters. Survey was done in Jodhpur, Bikaner, Jaisalmer, Nagur, Barmer, Jalore, Pali and Jaipur districts of Rajasthan for *S. persica* (Kharajal, Pilu) tree population. Rhizosphere soil and root samples were collected from different selected sites of above mentioned seven districts. Five genera identified were *Glomus, Acaulospora, Scutellospora, Gigaspora* and *Sclerocystis.* Among these five genera *Glomus* was dominant and diffferent *Glomus* species were identified as *G. aggregatum, G. microaggregatum*, *G. constrictum*, *G. fasciculatum* and *G. mosseae.* High diversity of AM fungi was observed that varied between sites and districts. The nursery experiments were laid out to select the efficient strains of AM fungi for best growth of *S. persica* seedlings. Effect of AM fungi on inoculated seedlings of *S. persica* was observed. Dual inoculated *(G. fasciculatum+ G. aggregatum*.) seedlings performed better as compared to un-inoculated ones (control).

Significant achievements /findings of the project:

The spore population varied between the sites from 96 and 448 propagules per 100 g soil. Per cent colonization in the roots of *S. persica* also varied from 35 to 71%. The pH of the study area ranged between 7.3 and 8.7, EC was 0.99 to 6.03 (dSm-1), per cent organic carbon (OC) ranged from 0.09 to 0.67 and available phosphorous (P) content varied from 2.18 to 7.12 kg^{-1}. A high diversity of AM fungi was observed that varied from site to site. Total 19 AM fungal species were isolated and identified. The maximum numbers (15) of AM fungal species were isolated from Pali whereas, only 9 species were found from Jaisalmer. Maximum spore density was recorded in tree rhizosphere from Sambhar (448 spores 100 g^{-1} soil) and minimum (96 spores 100 g^{-1} soil) from Jodbeed, Bikaner. The trend of AM population was in the decreasing order - Jaipur > Nagaur > Jodhpur > Jalore > Pali > Barmer> Jaisalmer > Bikaner > Barmer. Maximum per cent root colonization (71%) was recorded in Neembli, Jodhpur whereas, the minimum root colonization of (35%) was recorded from Ramdevra, Jaisalmer. Decreasing order of per cent root colonization was Jodhpur > Pali >Jaipur > Bikaner > Jalore > Nagaur > Barmer > Jaisalmer. Result of nursery experiments showed that the dual inoculated (*G. fasciculatum+ G. aggregatum*) seedlings performed better as compared to un-inoculated ones (control). The inoculated seedlings were better in growth and biomass in nursery conditions.

Suggestions/ advisory note for end users "To do techniques":

The findings of this study can be successfully utilized by state forest departments of Rajasthan in afforestation of salt affected soils using *S. persica*. Selected AM fungi may be used for fortifying seedlings in nursery before taking them for plantation in salt affected areas. Selection of best strains of AM fungi will certainly help in enhancing the productivity of *S. persica*. the inoculation with AM fungi especially *Glomus fasciculatum* had a strong impact on seedling growth of *S. persica* and can be applied in rehabilitation of salt affected lands.

Research gaps:

Salvadora persica survives in salt-affected areas but is not used in plantation due to its slow growing nature. If the growth of this species can be augmented by the use of effective measures, this species can be a boon for restoration of salt-affected lands.

Uses of research outcomes:

The inoculation with AM fungus especially *Glomus fasciculatum* had a strong impact on seedling growth of *Salvadora persica*, hence, it can used for fortifying seedlings in nursery before taking them for plantation in salt-affected areas. These findings can be successfully utilized by state forest departments of Rajasthan in afforestation of salt-affected soils using *S. persica*.

Publication:

- Sharma B., Verma N., Gupta R. K. and Lohara R. R. 2021. Effect of Arbuscular Mycorrhizal Fungi on Growth of *Salvadora persica* L. Seedlings under the Nursery Condition. *Biological Forum – An International Journal* 13(3): 000-000.ISSN No. (Print): 0975-1130.

2. Title of the project: Selection of efficient AM fungi, PSBs and *Azospirillum* for productivity enhancement of *Dendrocalamus strictus* and *Bambusa bambos*

Principal Investigator: Dr. Neelam Verma, CTO, ICFRE-AFRI Jodhpur

Duration: 2016 - 2021

Critical analysis of the research theme and summary of the study:

The objective of the project was to explore an eco-friendly method for optimum growth and good quality of *Dendrocalamus strictus* and *Bambusa bambos* and to find out efficient strains of bio-inoculants, viz., Arbuscular Mycorrhizal (AM) fungi, Phosphate Solubilizing Bacteria (PSB's) and *Azospirillum.* Bamboo occurs in relatively moist area of Rajasthan and Gujarat particularly in hilly tracts. However, these hilly tracts are under degradation because of over-exploitation and vegetation removal affecting land productivity. In such a condition there is need to improve land productivity utilizing available natural resources like AM fungi, PSBs and *Azospirillum*. A series of field survey and laboratory experiments were carried out for isolating and identifying the AM fungal species in different edapho-climatic conditions of Rajasthan and Gujarat. The information on the diversities of AM fungi was derived from the abundance and types of spores and AM root colonization. These data were further correlated with different soil parameters. Periodical surveys of eight districts (Alwar, Banswara, Chittorgarh, Dungarpur, Pratapgarh, Rajsamand, Sirohi and Udaipur) for *D. strictus* and four districts (Banswara, Chittorgarh, Pratapgarh, and Udaipur) for *B. bambos* were done in Rajasthan. Similarly, periodical surveys of six districts (Chhota Udaipur, Dahod, Dang, Narmada, Navsari and Valsad) for *D. strictus* and four districts (Dahod, Dang, Navsari and Valsad) for *B. bambos* were done in Gujarat. Rhizosphere soil and root samples were collected from different selected sites of above mentioned districts. A high diversity of AM fungi was observed and it varied at various sites in Rajasthan and Gujarat. The important genera were identified as *Acaulospora, Gigaspora, Glomus, Sclerocystis* and *Scutellospora*. Among these five genera, *Glomus* occurred most frequently and dominant in nurseries as well as in plantations. The different species of *Glomus* were recorded as *G. aggregatum, G. fasciculatum, G. mosseae,* etc. The nursery experiments were laid out to select the efficient strains of AM fungi, PSB's and *Azospirillum* for best growth of *D. strictus* and *B. bambos* seedlings. Inoculated seedlings of both bamboo species were tested and the effect of bio-inoculants was observed. The inoculated seedlings performed better as compared to un-inoculated ones (control) at nursery stage and were also survived better in field/stress conditions. Under this project one day online training was also organized on "Application/Importance of different biofertilizers in Bamboo" on 15th March, 2021 at AFRI, Jodhpur to promote the use of biofertilizers among progressive farmers, foresters and other stake holders.

Significant achievements/ findings of the project:

The maximum number (31) of AM fungal species were isolated and identified from Banswara (Raj.) whereas, only 18 species were identified from Alwar (Raj.) for *D. strictus,* while in case of *B. bambos,* maximum species (30) were isolated and identified from Banswara (Raj.) whereas, only 23 species from Udaipur, Rajasthan. Similarly, in Gujarat, maximum 33 species were isolated and identified from Valsad whereas, only 18 from Dahod for *D. strictus*. In case of *B. bambos,* maximum 34 species were isolated and identified from Valsad whereas and only 23 from Dahod, Gujarat. The number of AM propagules present in the rhizosphere soil, may be the resultant effect of various climatic, physical and chemical properties of soils. In case of *D. strictus* a significant correlation of AM population was observed with number of rainy days, while in case of *B. bambos* it was observed with number of rainy days and rainfall from Rajasthan. Similarly, from Gujarat state a significant correlation was observed with annual rainfall, number of rainy days and % mean soil moisture in case of *D. strictus*, while in case of *B. bambos* it was observed with (%) root colonization, rainfall (mm), and number of rainy days while other variables under study had a non-significant correlation with total AM population. The inoculated seedlings (with a consortia involving *Glomus fasciculatum* + *Glomus mosseae* + *Bacillus thuringiensis* + *Azospirillum brasilense*) performed superior to individual ones in case of *D. strictus* seedlings, while a consortia involving *G. aggregatum* + *G.mosseae* + *B. thuringiensis* + *A. brasilense* performed the best in *B. bambos* seedlings. Maximum biomass ranged from 14.86 to 26.27 g for *D. strictus* and 17.03

to 29.43 g for *B. bambos*. The quantum of increase was 1.8 fold as compared to control for *D. strictus* and 1.73 fold for *B. bambos*. The inoculated seedlings had higher nutrient accumulation as compared to uninoculated ones (control) in both bamboo seedlings at nursery stage. These results indicated that consortia of different biofertilizers help in acquisition and accumulation of relatively immobile nutrients of phosphorous. A consortium involving *G. fasciculatum* + *G. mosseae* + *B. thuringiensis* + *A. brasilense* has been developed for improved quality of *D. strictus* seedlings at nursery stage, while a consortium involving *G. aggregatum* + *G. mosseae* + *B. thurengensis* + *A. brasilense* has been developed for improved quality of *B. bambos* seedlings at nursery stage. The inoculated seedlings treated with all biofertilizers sp. were survived better in field/stress conditions. This study can benefit the field foresters, NGO's, and progressive farmers for reducing the use of expensive chemical fertilizers by application of most efficient strains of AM fungi/PSBs/*Azospirillum* for improvement of the two bamboo species for quality canes, increased yield causing losses in various stages of plant development.

Suggestions/ advisory note for end-users "To-do-techniques":

Outcome of the research is useful and field usable. Training programmes can be organized for forest officials, NGO's and progressive farmers and other stake holders to inform them about the eco-friendly uses of bio-inoculants for improvement of bamboo.

Research gaps:

Biofertilizers are known to improve the growth and survival of plants and are often employed to give a boost to the growing seedlings and plants. Testing the efficacy of different consortia of biofertilizers in improving quality of *D. strictus* and *B. bambos* seedlings at nursery stage will help improve the growth and survival.

Uses of research outcomes:

Best biofertilizer consortia can be used by nurseries for production of quality plant material to ensure production of quality canes, increase yield as well as prevent losses incurred at various stages of development. The findings can also be utilized by the state forest departments while undertaking afforestation programmes with bamboos for their better survival and growth in harsh and stress conditions of both the states.

3. **Title of the project:** Evaluation of Indigenous Tree Species for Reclamation of Salt Affected Lands in Agro-Climatic Zones of Eastern Uttar Pradesh

Principal Investigator: Sh. Alok Yadav, Scientist-E, ICFRE-CSFER Prayagraj

Duration: 2020

Critical Analysis of the research theme and summary of the study:

Project aimed to study the constraints being faced by the plants in adverse soil conditions such as low nutrient availability, sodicity as well as mechanisms of adaptation with particular emphasis on plant nutrition. The pilot study was initiated with the plantation of indigenous tree species on the sodic land and biological approaches were adapted to assess their effect on survival and growth of the species in Gorakhpur, Pratapgarh and Prayagraj. Total six plant species (*Ficus glomerata, Tamarindus indica, Carissa carandus, Moringa oleifera, Dalbergia sissoo, Aegle marmelos*) of local importance were selected for plantation. Sodic soils are considered as harsh site and survival is normally low in such sites therefore treatments of FYM, vermicompost and rice husk were given in different ratios and their effect was studied on survival and growth parameters. Application of treatments was repeated two times during the year. Data pertaining to height, collar diameter and survival were recorded biannually. After 3 years, the maximum survival was recorded in *Dalbergiasissoo, Tamarandus indica* and *Ficus glomerata* at all the sites

Significant achievements/ findings of the project:

Sodic soils are considered as harsh sites and survival is normally low in such sites. During first six months the survival (85%) of all the species was reasonably good but it declined after 9-10 months. Treatments with FYM/Vermicompost with rice husk have resulted in maximum survival. It was found that survival of species varied from 11-88% and height of the plants varied from 32 to 199 cm which was very high in range. The average height attained by *Ficus glomerata* and *Tamarindus indica* in salt affected land was very less as compared to normal soil in three years. The increase in height of species, over a period of 3 years, from the initial height of plants differed between the applied treatments. Maximum increase over initial height was recorded for *Moringa oleifera* and *Dalbergia sissoo.*

Suggestions/ advisory note for end-users "To-do-techniques":

Amelioration of salt affected soils is essential for sustaining food, fuel, fodder, fiber, and timberproduction for an ever-increasing human population. A large tract of common lands (either government lands or village panchayat lands) is not in any productive use. Hence the demonstration plots may be developed for awareness generation of farmers, SFDs and NGOs. Planting of trees and grasses along with suitable treatments such as FYM/Vermicompost/rice husk on sodic soils provides an alternative to control further deterioration of these soils and to maintain soil health.

Research gaps:

A huge chunk of salt affected land is distributed in the Indo-Gangetic alluvial plains of northern India. It has become imperative to develop the wastelands under productive land use system and fulfill the requirement of the growing population.

Uses of research outcomes:

Planting of trees on sodic soils provides an alternative to control further deterioration of these soils and to maintain soil health. It would also help in fulfilling the demand for food, fodder, fuel and timber.

4. **Title of the project :** Evaluation of carbon regulating services and soil health of restored limestone mine overburden areas

Principal Investigator: Sh. N. Bala, Scientist-G, ICFRE-FRI Dehradun

Duration: 2019 - 2023

Critical analysis of the research theme and summary of the study:

Limestone mining was rampant in Doon valley and Mussoorie hills till the early eighties with 105 working mines in the region. Ecological restoration of these mined areas in the Doon- Mussoorie region started almost three decades back by various agencies, including the state forest department. Lambidhar and Chunakhala limestone mine area in Dehradun District of Uttarakhand are two such sites where restoration work was done by UP State Mineral Development Corporation (UPSMDC) from 1988 to 1989. An attempt was made to assess the success of mine land restoration work in terms of improving various ecosystem functions and carbon regulating services in these limestone mine areas in comparison to the adjoining natural forests. The work is based on a detailed survey, collection of data on various vegetation parameters, litterfall production, litter decomposition, litter nutrient dynamics, carbon assimilation, soil respiration, soil microbial biomass and carbon stock. The results contributed to the advanced understanding of various ecosystem functions and carbon regulating services in the restored limestone mine area and suggested that various ecosystem functions of the mine degraded lands have taken their recovery trajectory close to the adjoining natural forest following restoration efforts.

Significant achievements/ findings of the project:

The number of species of various life forms was high in the restored mine areas of Lambidhar and Chunakhala compared to the adjoining natural forest but the estimated total basal cover (TBC) was much lower compared to the natural forest. Though the carbon assimilation rate recorded in the vegetation of the restored areas is at par at Lambidhar and higher at Chunakhala than that of vegetation of adjoining natural forests at species level, at community level, the restored area may have lower assimilation owing to lower total basal cover (TBC). It was observed that microbial activity in the topsoil layer has increased substantially given the fact that the plantation was done on an extremely degraded limestone mine area having large boulders and loose rock fragments that are devoid of moisture and nutrients. Comparable litterfall production, litter nutrients, decomposition rate, microbial biomass carbon, soil respiration, C:N ratio, and carbon assimilation estimated for the two sites points towards a favourable environmental conditions and decomposer community composition that is developing in the restored mine areas, improving various carbon regulating services.

Suggestions/ advisory note for end-users "To-do-techniques":

A very low total basal cover (TBC) and biomass in the restored mine area compared to the adjoining natural forest is a concern that needs further attention. It is obvious that during the initial stage of restoration, because of the unfavourable strata, the choice of species was limited. However, significant improvement in topsoil that has taken place after 30 years of restoration provided opportunities for further interventions. More species could be reintroduced into the area to increase the TBC. A sequential restoration approach, once there is improvement in soil conditions, may help accelerate the recovery process.

Research gaps:

While significant progress has been made in quantifying the carbon sequestration potential of forests, grasslands and agricultural land, the long-term changes in carbon pools in reclaimed mined areas are still poorly documented and understood. This will foster a clearer understanding of the many forms of Forest Landscape Restoration that are possible, and enable us to achieve a more precise balance of objectives for projects, suited to the circumstances of people and place.

Uses of research outcome:

The research findings have been published in the form of papers in journals for dissemination of knowledge. These will be shared with the state forest department of Uttarakhand along with the abstract of the significant findings and way forward. The findings are also being disseminated to different stakeholders through presentations/talks/deliberations at various forums like Regional Research Conference, World Soil Day celebration, etc.

Publications:

- Bala N., Panwar V.P., Nautiyal S., Kumar A., Chand T. and Verma P.K. 2023. Recovery of ecosystem functions on a restored limestone mine area in the foothills of Himalaya. *Indian Forester* 149(2): 207-214.
- Nautiyal S., Singh H., Kamboj S., Kumar A., Panwar V. P. and Bala N. 2022. Carbon Regulating Services of A 30-year-old Reclaimed Limestone Mine Area in Foothills of Himalaya. *Indian Forester* 148(3): 338-343

5. **Title of the project:** Identification and Characterization of important bacterial groups from salt affected soils of Haryana and Punjab

Principal Investigator: Dr. Parul Bhatt Kotiyal, Scientist-F, ICFRE-FRI Dehradun

Duration: 2018 - 2021

Critical analysis of the research theme and summary of the study:

Only limited attempts have been made to study the diversity of salt tolerant group of bacteria from extreme Indian environments. Survey, site selection and collection of soil samples were done from Muktsar and Bhatinda in Punjab and Fatehabad and Kaithal in Haryana. Soil samples were collected from predetermined depth of 0-30, 30-60, 60-90 cm in pre and post monsoon season from different landuses in the above said districts. Soil bacteria were isolated from the soils of these land uses and isolates were characterized using cultural and biochemical tests. Most of the isolates were rod-dshape and some were cocci. Out of these isolates, 62% were Gram positive while 38% were Gram negative. Gram's staining showed that 0-30 cm depth is occupied by majority of Gram negative bacteria in Haryana. There is a slight but significant difference in the bacterial population and majority are Gram positive at 30-60 cm depth.

Significant achievements/ findings of the project:

On the basis of the results obtained from biochemical tests, the possible bacterial genera were confirmed as *Streptococcus* sp., *Bacillus* sp., *Staphylococcus* sp., *Klebsiella* sp., *Enterobacter* sp., *Clostridium* sp., *Rhizobium* sp., *Azospirillum* sp., *Escherichia coli* and *Pseudomonas* sp.

Studies were conducted to investigate that how different combinations of bacterial inocula, chemical fertilizers and compost would affect the growth of *Prosopis cineraria (Khejri)* and *Toona ciliata (*Toon*)* in sodic and saline soil condition. *Prosopis ceneraria* is native to arid portions of Western Asia and the Indian Subcontinent. *Toona ciliata* timber is very valuable and various parts of the plant are used medicinally throughout its geographical range, it is a fast-growing tree and can tolerate extreme heat ranged from 8 - 48°c (2), even it can moderately tolerate drought conditions. Four best bacterial isolates were selected and carrier- based inoculants of bacterial species were prepared by growing in 50 ml nutrient broth for 2 days on rotary shaker. The cell suspension was then mixed with sterile charcoal containing 12.5 p cent (pH 7.2) in 1:2 ratio. Integrated dose of chemical fertilizer, bacterial inoculums in combination with compost were applied in soil and seeds of *Toona ciliata* and *Prosopis ceneraria* were sown in a complete randomized block design in glass house conditions and observation on growth parameter and soil properties were recorded.

Suggestions/ advisory note for end-users "To-do-techniques":

Remediation through microorganisms basically involves the stimulation of microbial population in sodic soils to produce acid, or acid producing microbial population in sodic soils, thereby decreasing the soil pH and releasing calcium, which helps in soil aggregation and prevent soil dispersion. Biofertilizers, applied along with compost release many byproducts inclusive of $NH4^{+}$ and Ca^{++} ions into the soil solution. The formation of aggregate structure by the release of organic acid and humus by the effective microorganisms in combination with organic manure improved the structure of the upper soil and also increases the permeability of the rhizosphere. These isolates can show potential for plant growth promotion in salt affected soil regions, so it is suggested to conduct further studies with multiple field trials in different location for various suitable forest trees species under salt stressed conditions.

Research gaps:

Only limited attempts have been made to study the diversity of salt tolerant group of bacteria from extreme Indian environments and particularly from salt affected forest areas. So, isolation and characterization of bacteria from salt affected soils will provide better understanding of the composition and diversity of the bacterial community across a variety of soils in different climates and different soil conditions and will lead to better management practices to be followed in these types of soil.

Uses of research outcome:

Remediation through microorganisms basically involves the stimulation of microbial population in sodic soils to produce acid, or acid producing microbial population in sodicsoils, thereby decreasing the soil pH and releasing calcium, which helps in soil aggregation and prevent soil dispersion. The microbial isolates can show potential for plant growth promotion in salt affected soil regions.

Publications:

- Kotiyal P.B., Dimri B.M., Soni. A and Devi U. 2019. Relationship between soil bacterial population and chemical properties under Poplar and Eucalyptus plantation at Haryana. *International journal of science environment and technology* 8:418-425.
- Kotiyal P. B., Singh S., Rawat S., Vyas V. and Negi H. 2021. *Lysinibacillus acetophenoni* and *Pseudomonas stutzeri* with High Salt Effect, Recovered from High Salinity Soil Area (Indo-Gangetic Plain of India). *International Journal of Plant and Soil Science*. 33:14
- Kotiya P.B., Singh S. and Vyas V. 2023 Distribution and correlation of Soil bacterial population and chemical properties in salt affected landuses of Kaithal and Fatehabad district of Haryana. *South Asian J Agric Sci* 3(1): 133-139. DOI: 10.22271/27889289.2023.v3.i1b.80

6. **Title of the project:** Carbon sequestration and carbon dioxide emission from the soils under different forest covers in Uttarakhand

Principal Investigator: Dr. Vijender Pal Panwar, Scientist-F, ICFRE-FRI Dehradun.

Duration: 2017 - 2021

Critical analysis of the research theme and summary of the study:

Soil plays a vital role in the global carbon cycle, sequestering carbon in soil and emitting carbon dioxide into the atmosphere through soil respiration. To understand the role of soils in the global carbon cycle, it is necessary to estimate the spatially distributed SOC pools and flux and estimate the potential biospheric responses to change in climatic factors. In Uttarakhand, Sal (*Shorea robusta*) and Chir pine (*Pinus roxburghii*) are amongst the major forestry species composing 29 per cent of the total forest area and thus needs quantification of carbon sequestration and carbon dioxide emission from the soils under these forest covers. The findings of this project have provided accurate, scientific and comprehensive estimates of soil CO_2 emission and soil organic carbon stock in these forests of Uttarakhand state. It will serve as benchmark information for future investigations on this essential aspect of climate change.

Scientific achievements/ findings of the project:

Soil CO_2 efflux rates differed among ecosystems and also varied with environmental conditions. The total understorey carbon showed higher understorey biomass carbon in sal study sites (1.92 t ha^{-1}) than chir pine sites (0.58 t ha^{-1}). CO_2 emissions from soil under different vegetation covers were recorded higher in *S. robusta* (3.10 µ mol CO_2 $m^{-2}sec^{-1}$)than compared to *P. roxburghii* (2.83 µ mol CO_2 $m^{-2}sec^{-1}$). Higher CO_2 emission was observed in broadleaved vegetation followed by coniferous vegetation. The total CO_2 emission from both the vegetation in Uttarakhand state according to the total recorded forest area was about 11.10 mt (*S. robusta*) and 12.86 mt (*P. roxburghii*). Likewise, the total SOC pool was found to be higher in *P. roxburghii* (53.84 mt) and lower in *S. robusta* (22.74 mt). Higher SOC in vegetation may be due to higher litter production in the vegetation, which increases organic carbon. The study concludes that CO_2 emission and carbon sequestration were varied amongst different vegetations density.

Suggestions/ advisory note for end-users "To-do-techniques":

This study should be extended to other vegetations to estimate carbon, sequestered and emission rates to address climate change related issues and mitigation.

Research gaps:

There is a significant gap in estimation of SOC pool and CO_2 emissions under Sal and Chirpine forest covers in Uttarakhand, following IPCC guidelines. Understorey and vegetation carbon need to be envisagedand uncertainties on SOC stock data by including bulk density and coarse fractions in calculating results need to be minimized. The comprehensive information generated through this study will serve as a benchmark for future investigations on this essential aspect of climate change.

Uses of research outcomes:

Results of this study would be helpful for SFDs, Non-Governmental Organizations and Plantation companies for the formulation of strategies for better management of CO_2 emission and SOC stock in forests so that emissions from different forest ecosystems can be reduced. The study will helpselect the appropriate vegetation to facilitate the storage of more organic carbon in the soil and reduce the CO_2 emission from the soil to the atmosphere. In addition, SFDs could create awareness to the local people about the need to protect litter on the forest floors.

7. **Title of the project:** Impacts of nutrient loading from droppings of nesting migratory waterfowl in the wetland ecosystem of *Nelapattu* Bird Sanctuary, Andhra Pradesh

Principal Investigator: Dr. D. Jaya Prasad, ICFRE-IFB Hyderabad

Duration: 2016 – 2019

Critical analysis of the research theme and summary of the study:

In wetland ecosystems, faecal droppings from birds that feed outside the system, but roost and/or breed within are a natural source for nitrogen (N) and phosphorus (P). Migratory birds, especially the roosting ones form the important nutrient contributor in wetland ecosystems. The present study undertaken to evaluate the nutrient dynamics of Nepalapattu wetland ecosystem revealed spatio-temporal variation in important nutrient parameters possibly associated with the bird migration activity. The seasonal sampling of water immediately preceded to bird migration activity showed variation in orthophosphate and dissolved oxygen, respectively high and low owing to possible biological oxygen demand of decomposers as well as enhanced algal growth and other biological activities due to phytoplankton, chlorophyll, zooplankton and benthos. These results are in consonance with the studies conducted earlier that nutrient addition leads to increase biological production. The important sediment/soil nutrient parameters *viz*., Organic Carbon (OC), Nitrogen (N), Phosphorous (P) and Potassium (K) of the wetland ecosystem showed seasonal as well as spatial variations, which were in general was high in the Nelapattu pond compared to that of the downstream agriculture field and the control fields. The outcome of the study indicated increased importance of bird migration activity in providing provisioning services in terms of nutrient addition to the wetland ecosystem of the sanctuary.

Significant achievements/ findings of the project:

A study on nutrient level variation in the aquatic ecosystem of Nelapattu Bird Sanctuary (NBS) with respect to the activities of wintering migratory waterbirds was attempted. It was observed that rainfall and consequent availability of water in the tanks has profound impacts on the arrival of birds in the Sanctuary and due to acute rain deficit in the area (annual average rainfall of 28.73 mm), no bird migration happened during 2016. According to the bird census data, Little Cormorant, Open billed Stork, White Ibis and Grey Pelicans were the most abundant birds in the Sanctuary. The grey/spot-billed pelican (*Pelecanus philippensis*), recorded earlier in from few to hundreds in number in NBS during the past has now been increased to 2168 and 3568, respectively during 2015-16 and 2017-18.

All the biological parameters *viz*., phytoplankton, chlorophyll, zooplankton and benthos varied between seasons from relatively high in summer samples as compared to those of the winter. The important physico-chemical parameters *viz*., pH, Electrical Conductivity (EC), Organic Carbon (OC), Nitrogen (N), Phosphorous (P) and Potassium (K) of soil/sediment of the wetland ecosystem significantly varied between seven sampling months (Sep. 2016 - Sep. 2018), while the significance in variance between three sampling locations (pond, influenced and control fields) was observed only in case of four (OC, N, P and K) out of six parameters. In general, the pH of the soil/sediment samples observed to fall under strongly acidic-moderately acidic (5.0-6.4) and slightly acidic (6.8) categories; all Electrical conductivity measurements (soluble salts in soil) were observed to be normal (<1.0); the OC content of the soil samples observed to vary from medium 0.5% to high 0.8-1.5%; the available nitrogen in most of the soil samples were low (<240 Kg/ha) than that of medium (240-480 Kg/ha); the available phosphate of the samples ranged between 30-68 Kg/ha and was found to be high (>22 Kg/ha) in all the samples collected and the available potassium in three out of seven samples were found to be medium (110-280 Kg/ha) and that of the rest of the four samples were high (>280 Kg/ha). Overall, the results in the light of the studies conducted earlier indicate possible impacts of bird driven nutrient loading in the ecosystem.

Suggestions / advisory note for end-users "To-do-techniques":

The results of the study may be useful in devising suitable strategies for better management of the area. It is apparent that more holistic studies required for understanding the functional roles played as well as ecosystem services provided by the birds in the ecosystem and that such approach offer positive force for management and conservation of the area.

Research gaps:

Waterbirds play a major role in regulating nutrient level of aquatic ecosystem both by acting as consumers by removing the aquatic insects and macrophytic vegetation and by contributing nutrients by their faecal matter deposition, food remains and decaying carcasses. Out of the above; the latter mentioned role of waterbirds is more pronounced and is relatively less investigated.

Uses of research outcomes:

The results of the study is useful in devising suitable strategies for better management of the Nelapattu Bird Sanctuary by Andhra Pradesh Forest Department, Irrigation department and local villagers of Nelapattu.

8. **Title of the project:** Assessment of visitor carrying capacity of Kuruva Island, Wayanad, Kerala.

Principal Investigator: Dr. A. Rajasekaran, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2018 - 2019

Critical analysis of the research theme and summary of the study:

The study was based on primary data collected through field inspection, discussions and interactions with officials of Forest Department and various stakeholders of Pakkom - Kuruva Ecotourism site in South Wayanad Division, Kerala. The draft guidelines provided by the Ministry of Environment, Forest and Climate Change, Govt. of India on 2nd June, 2011 for Ecotourism in and around protected areas have been followed for assessing the visitor carrying capacity of Pakkom – Kuruva ecotourism site. Visitor carrying capacity was assessed at the following three levels namely; a) Physical Carrying Capacity (PCC), b) Real Carrying Capacity (RCC) and c) Effective Carrying Capacity (ECC). Correction factors such as soil erosion, Elephant movement and human-elephant conflict, Mugger crocodile breeding time and Smooth coated Otter were considered as limiting factors for this study to ensure minimum ecological impact, biodiversity conservation and safety of the visitors. The study found that the present management capacity of area is optimum. Based on the outcome of the study, it may be concluded that the number of visitors entering the area was high for the years 2014-15 to 2016-17 and it was well within the limits of carrying capacity for the last year, i.e. 2017-18.

Significant achievements/ findings of the project:

The short-term study was taken up to assess the Visitor Carrying Capacity of Kuruva Island, Wayanad, Kerala. The outcome of the project was shared with the State Forest Department to regulate the entry of visitors in the ecotourism destination and it is being implemented at the site.

Suggestions/ advisory note for end-users "To-do-techniques":

The suggestions given for reducing the impact of visitors on the ecotourism site may be followed and periodical assessment of the visitor carrying capacity may be carried out.

Research gaps:

Information on the number of permissible visitors to the Kuruva ecotourism site in South Wayanad Forest Division, Kerala was not available.

Uses of research outcomes:

The recommendations of the study are being implemented in the ecotourism sit by the Kerala state forest department.

9. **Title of the project:** Assessment of visitor carrying capacity of Chembra Peak, Wayanad, Kerala.

Principal Investigator: Dr. A. Rajasekaran, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2020

Critical analysis of the research theme and summary of the study:

The study was based on primary data collected through field inspection, discussions and interactions with officials of Forest Department and various stakeholders of Chembra Ecotourism site in South Wayanad Division, Kerala. Visitor carrying capacity was assessed at the following three levels namely a) Physical Carrying Capacity (PCC), b) Real Carrying Capacity (RCC) and c) Effective Carrying Capacity (ECC). Correction factors such as Landslides, fire, Elephant movement, breeding time of Banasura Laughing Thrush, Dhole, Sambar Deer, Nilgiri Langur and Leopard were considered as limiting factors for this study to ensure minimum ecological impact, biodiversity conservation and safety of the visitors. The study found that the present management capacity of area is optimum. It was found that the number of visitors entering the area was highest for the year 2016-17 and it was above the present estimated level of carrying capacity.

Significant achievements/ findings of the project:

The outcome of the project was shared with the State Forest Department to regulate the entry of visitors in the ecotourism destination and it is being implemented at the site.

Suggestions/ advisory note for end-users "To-do-techniques"

The suggestions given for reducing the impact of visitors on the ecotourism site may be followed and periodical assessment of the visitor carrying capacity may be carried out.

Research gaps:

Information on the number of permissible visitors to the Chembra Peak ecotourism site in South Wayanad Forest Division, Kerala was not available.

Uses of research outcomes:

The recommendations of the study are being implemented in the ecotourism site.The suggestions given for reducing the impact of visitors on the ecotourism site may be followed and periodical assessment of the visitor carrying capacity may be carried out.

10. Title of the project: Assessment of visitor carrying capacity of Banasuramala-Meenmutty, Wayanad, Kerala.

Principal Investigator: Dr. A. Rajasekaran, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2020

Critical analysis of the research theme and summary of the study:

Visitor carrying capacity was studied at the three levels namely a) Physical Carrying Capacity (PCC), b) Real Carrying Capacity (RCC) and c) Effective Carrying Capacity (ECC). The study found that the present management capacity of area is optimum. It was found that the number of visitors entering the area from 2009 to 2019 was within the limits of carrying capacity.

Significant achievements/ findings of the project:

The outcome of the project was shared with the State Forest Department to regulate the entry of visitors in the ecotourism destination and it is being implemented in the site.

Suggestions/ advisory note for end-users "To-do-techniques":

The suggestions given for reducing the impact of visitors on the ecotourism site may be followed and periodical assessment of the visitor carrying capacity may be carried out.

Research gaps:

Information on the number of permissible visitors to the Banasuramala-Meenmutty ecotourism site in South Wayanad Forest Division, Kerala was not available.

Uses of research outcomes:

The recommendations of the study are being implemented in the ecotourism site by the Kerala state forest department.

11. **Title of the project:** Assessment of visitor carrying capacity of Soojippara, Wayanad, Kerala

Principal Investigator: Dr. A. Rajasekaran, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2020

Critical analysis of the research theme and summary of the study:

Information based on observations of the relevant stakeholders from the area was taken into consideration. The visitor arrival statistics in Soojippara site and other available data was collected from the Divisional Forest Officer, South Wayanad Division. The possible impact of visitors in the Soojippara site was assessed through field survey in the area and discussion with local people and field staff. Correction factors such as heavy floods, reduced water flow, landslide, soil erosion, disturbance to wildlife breeding, etc. were considered as limiting factors for this study to ensure minimum ecological impact, biodiversity conservation and safety of the visitors. It was found that the number of visitors entering the area was high for the years 2010-11 to 2012-13, 2015-16 and 2016-2017 while it was highest in the year 2012-2013 but well within the limits of carrying capacity. The study found that the present management capacity of the area was optimum.

Significant achievements/ findings of the project:

The Study assessed the visitor carrying capacity at three levels i.e., Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC) and Effective Carrying Capacity (ECC) and submitted possible recommendations. The outcome of the project was shared with the State Forest Department to regulate the entry of visitors in the ecotourism destination and it is being implemented at the site.

Suggestions/ advisory note for end-users "To-do-techniques"

The suggestions given for reducing the impact of visitors on the ecotourism site may be followed and periodical assessment of the visitor carrying capacity may be carried out.

Research gaps:

Information on the number of permissible visitors to the Soojippara ecotourism site in South Wayanad Forest Division, Kerala was not available.

Uses of research outcomes:

The recommendations of the study are being implemented in the ecotourism site by the Kerala state forest department.

12. Title of the project: Investigation on factors responsible for Sal Mortality in Jharkhand State

Principal Investigator: Dr. S. N. Mishra, CTO, ICFRE-IFP Ranchi

Duration: 2019

Critical analysis of the research theme and summary of the study:

A study was undertaken to generate spatial data of healthy and infected *Shorea robusta* as well as to generate spatial distribution map of potential sites under present and future climate change scenario. The study would also include associated species, edapho-climatic and biophysical parameters contributing in potential cause for sal mortality in Jharkhand.

The mortality suitable habitat of Sal (*Shorea robusta)* in Jharkhand using MaxEnt species distribution models have been identified and classified into four groups namely; Highly; Moderately, Poorly and Unsuitable habitats. MaxEnt results, depicts that a "Highly suitable area" in term of sal mortality was predicted 7574.96 sq. km (9.50 %) of the total geographical area, which is a very good sign for forest health. Similarly, the model depicts Moderately, Poorly and Unsuitable habitats for sal mortality were 19.17%, 23.93% and 47.40%, respectively. Field survey analysis depicted some of the significant factors that could be responsible for Sal mortality including stag-headed (dieback), lightning, waterlogging, anthropogenic stress, soil erosion, and injury. The study helps to develop effective management and conservation strategies for forest managers, ecologists, landowners, and policymakers to restore the economically important IUCN Red list plant *S. robusta*.

Significant achievements/ findings of the project:

The probability distribution map of seven to eight different types of mortality in Sal has been prepared in Jharkhand and advisory has been provided to SFD, Jharkhand.

Suggestions/ advisory note for end-users "To-do-techniques":

The outcome of the research will be helpful for the State Forest Department of Jharkhand for research purpose.

Research gaps:

The mortality factors and development of suitable habitat model for Sal (*Shorea robusta)* has not been enumerated in Jharkhand. Therefore, a study was undertaken to generate spatial data of healthy and infected as well as to generate spatial distribution map of potential sites under present and future climate change scenario.

Uses of research outcomes:

Data pertaining to Sal tree mortality will be helpful for forest managers, ecologists, land owners and policy makers as it provided critical information about the health and condition of the these forest. The information generated in the project enabled identification of areas under stress, facing threats such as pests, diseases and climatic factors thus leading to timely appropriate mitigation measures. The data will assist forest management in decisions such as thinning or selective harvesting for better understanding of overall health and condition of the forest, distribution of tree species with different measurements, dynamics of forest ecosystems, reforestation efforts and the potential impacts of different management strategies on the productivity of the forest ecosystem.

13. **Title of the project**: Reclamation of coal mined land of North Eastern Coalfields, Assam through soil amendment and revegetation with native plant species using integrated biological approach.

Principal Investigator: Dr. Prosanta Hazarika, ACTO, ICFRE-RFRI Jorhat

Duration: 2018 - 2021

Critical analysis of the research theme and summary of the study:

Positive effect of inoculation of AM fungi along with other microorganism such as nitrogen fixing bacteria, phosphate solubilizing micro-organism (PSM), plant growth promoting rhizobacteria (PGPR) has been reported for reclamation of coal mined area. Therefore, there is a need for revegetation of post coal mined areas with native plant species to restore native biodiversity and ameliorate environmental issues. Taking into consideration of the above background, the study was conducted at a backfill area of coal mine overburden dump (OBD) in Tikak Colliery, North Eastern Coal Field, Margherita, Assam, India to evaluation of the performance of 42 native plant species in a revegetation experiment with integrated biological approach. After a series of pot experiments and field trial it was revealed that spores 100 per g soil + PGPRs @ concentration 10^{-6} in culture broth + Lime @ 15 g per pit + FYM @ 2 Kg per pit was the best treatment combination among the treatments evaluated for plant growth and to obtain desired soil microbial status. Pot culture experiments were undertaken to obtain the best treatment combination for the field trail. The seed ball technology was also adopted in the initial year to stabilize the area with green herbaceous cover and to improve soil parameters. The result revealed that herbaceous species growing from seed ball sowing could survive in the OBD area. Out of a total of 42 native planted species on the OBD area, 17 were recorded for 60- 70 % survival after 2 years of planting on the OBD site. A total of 26 naturally colonizing plant species dominated by Poaceae family were also recorded from the site 3 years after sowing of seed balls. *Callicarpa arborea* and *Schima wallichii* were tree species and *Chromolaena odorata* and *Lantana camara* were invasive species naturally colonized on the OBD. The best performed treatment combination was AMF + PGPR + Lime + FYM. Out of a total of 42 native plant species 17 attained 60- 70 % survival after 2 years of planting on the OBD site. These practices completely replaced the application of topsoil in the revegetation programme of coal mine site and the technology is replicable to adopt for reclamation of coal mine degraded sites for successful plantation programme in other parts of India and abroad.

Significant achievements/ findings of the project:

The study illustrated the advantages of the plantation technology in coal mined area as it does not require application of top soil and/or application of chemical fertilizers on the plantation site. The study could identify 17 native plant species and also 5 native PGPR isolates) which were trialed in the restoration of coal mined land in Tikak Colliery Margherita, Assam and recorded 40 % to 70 % survival rate when planted inoculated with the treatment combination of AMF+ PGPR+ Lime+ FYM. The study also provided a package of practices to the Coal mining authority to establish plantation with integrated biological approach. Inoculation of arbuscular mycorrhizal fungi (AMF) @ 220 spores per 100 g soil (obtained by mass multiplication of AM fungi in nursery bed) and 10 ml aliquot to PGPR consortia at the dilution 10^{-6} in the rhizosphere to each polybag seedlings at least 3 months before plantation along with application of Lime @ 15g per poly bags soil media and FYM @ 5 Kg per pit was found most suitable for establishment of plantation with native plant species.

Suggestions/ advisory note for end-users "To-do-techniques":

It is also expected that the plantation trial illustrated in the study would be useful for the stakeholders and government agencies particularly coalmining authorities dealing with similar restoration programmes elsewhere in India and abroad. The technology could be transferred through trainings to the end users/desired agencies and also follow the RFRI- Technical Reports published as '*Package of Practices for Restoration of coal mined land*' and 'Seed ball

technology for restoration of coal mined land'. The technology is now replicated in restoration of abounded coal mining area of Saipung Block, East Jaintia Hill District, Meghalaya in a pilot study of 5 ha in project mode. Results of the restoration technology applied in Meghalaya so far are encouraging and supported its replicability.

Research gaps:

The coal mining activities severely disturb the land by removing vegetation; alter the topography, consequent dumping of subsoil and also lost biodiversity of the area. Natural invasion of plant species in such areas is difficult and also takes time. Revegetation of such area does not become successful through normal plantation techniques

Uses of research outcomes:

The plantation trial illustrated in the study would be useful for the stakeholders and government agencies dealing with similar restoration programmes.

Publications:

- Hazarika P., Dutta D. and Talukdar N.C. 2018.Microbial technology for revegetation in overburden dumps of coal mined area of Assam, India – a review.*Int. Res. J. Environmental Sci.*7(12): 56-62. (SJIF 6.016; GIF 0.675)http://www.isca.in/IJENS/
- Hazarika P., Dutta D. and Hazarika Protul 2022.Reclamation of coal mined land with integrated biological approach. *Indian Forester* 148(3): 313-321.
- Hazarika P., Dutta D., Hazarika Protul, Giri K. and Dutta S.P. 2023.Seed Balls Accelerate Succession of Plant Species in Degraded Coal Mined Land Restoration: A Case Study on Tikak Colliery, Margherita, Assam, India. *Indian Forester* 149 (2): 197-206. DOI: 10.36808/if/2023/v149i2/169719

14. Title of the project: Assessing the impact of pruning of *Diospyros melanoxylon* bushes on its yield, quality and natural regeneration of tree species in Maharashtra

Principal Investigator: Dr. Avinash Jain, Scientist-F, ICFRE-TFRI Jabalpur

Duration: 2016 - 2018

Critical analysis of the research theme and summary of the study:

Diospyros melanoxylon (Tendu) is one of the most important NTFP species in central India. A total of seven Tendu collection villages were selected in Maharashtra after thorough surveys with the officers of respective State Forest Departments. Evaluation of traditional practices for harvesting of Tendu in the selected sites was studied by laying 03 quadrats of 0.1 ha each in each of the selected site which consisted villages from both State Forest Department (SFD) controlled forests and Community Forest Rights (CFR).

Significant achievements/ findings of the project:

It was observed that SFD controlled sites (except East Gurwada site) had pruned Tendu bushes, while CFR controlled sites had non-pruned Tendu poles. The yield of healthy leaves in pruned bushes was found five times more as compared to non-pruned poles. Non-pruned poles yielded higher gall infested diseased and defoliated leaves as compared to pruned bushes. SLA, depicting quality of leaves, was found higher in pruned bushes than non-pruned poles showing better quality of leaves collected from the former. SLA of healthy leaves was recorded higher than diseased or insect attacked leaves in both pruned bushes and non-pruned poles.

Suggestion/ advisory note for end-users "To-do-Techniques":

The best practices for producing better quality Tendu leaves included pruning of Tendu bushes of medium girth (2–4 cm) at ground level annually to maximize the leaf surface area thereby enhance the quality of leaves. First pruning i.e., first week of March including control fire was found to be the most effective for minimizing the incidence of leaf gall forming insect, *Trioza obsoleta* and increasing the leaf weight and area of leaf.

Research gaps:

Forest canopies provide goods and services to support diverse human communities and closed forest canopies are fragmenting and disappearing at a faster rate than any other habitat throughout the world. Conservation of this unique habitat needs to be required including the studies focused on interactions among forest canopy cover, under storey vegetation and atmosphere for phytodiversity conservation.

Uses of research outcomes:

The results of the project will help in conservation of biodiversity and increase in productivity, sequestering more carbon from the atmosphere and improving environmental quality. The findings of this research project will be useful for Maharashtra state forest department, especially forest divisions concerned to Western Ghats.

Publication:

- Mehta N., Jain A. and Rajkumar M. 2020. Impact of pruning of *Diospyros melanoxylon* Roxb. (Tendu) bushed on yield and quality of leaves in Maharashtra. *Journal of Pharmacognosy and Phytochemistry* 9(1): 1360-1365

15. Title of the project: Carbon sequestration through afforestation at Rourkela Steel Plant, Odisha

Principal Investigator: Dr. Avinash Jain, Scientist-F, TFRI Jabalpur

Duration: 2014 - 2019

Critical analysis of the research theme and summary of the study:

Burning of fossil fuels adds about 5.4 billion tonnes of carbon each year to the atmosphere and deforestation adds another 1.6 billion tonnes of carbon each year among anthropogenic activities. These two activities are primarily responsible for fast increase in CO2 emission levels. The problem of global warming is of dire concern and industries are adopting methodologies to mitigate contribution in the same. Extensive plantation has been done at all SAIL plants and mines over the years with a purpose aimed at either enhancement of aesthetics; restoration of degraded land; compliance to statutory requirement; making of barriers for air and noise pollution; or utilization of its medicinal, timber and fruit value. In this process, considerable amount of carbon has already been sequestrated over the years automatically. However, neither a quantitative assessment of this carbon getting sequestrated nor an accounting of the emission of carbonaceous gases generated through different processes and activities has been attempted so far. In this regard, RDCIS, SAIL Ranchi had approached TFRI, Jabalpur and consequently to execute the research project at Rourkela Steel Plant.

Significant achievements/ findings of the project:

On thorough vegetation survey and monitoring, it was found that 42.12 lakh trees planted at RSP during 1958-59 to 2013-14 covering an area of 1013 ha stocked 220.33 t/ha carbon with an annual carbon sequestration of 5.69 t/ha. Carbon in shrubs and herbs was calculated to be 0.22 t/ha and in litter and deadwood 2.85 t/ha. Whereas, soil reported 35.48 t C/ha with an annual increase of 0.91 t/ha. Three training programmes for the officers of SAIL were also conducted at RSP and TFRI on different aspects of plantations and their management.

Suggestion/ advisory note for end-users "To-do-Techniques":

Suggested to raise plantations of high carbon sequestering tree species in future plantation programmes with proper spacing between trees. Also suggested to cut the trees either attaining their rotation age or with significantly low annual girth increment and raise plantations of trees having higher growth rate.

Research gaps:

The information on quantifying carbon stock in the form of vegetation and soil, annual sequestration and valuation of plantations raised by industries and PSUs for tangible and intangible benefits is lacking. Biodiversity assessment for selecting suitable species for industrial plantation purposes is the urgent need of the hour.

Uses of research outcomes:

The outcomes of the project will be useful for industries and PSUs for raising large scale plantations of suitable tree species and their assessment in and around the industries.

Publication:

- Jain A., Rao G.R., Mehta N., Verma S. and Mahiske V. 2022. Mitigation impacts of disasters through carbon enhancement in natural forests and plantations. Indian Journal of Tropical Biodiversity 30(1&2): 67-72.

EXTENSION

EXTENSION

1. **Title of the project:** Livelihood improvement through sustainable utilization of *Grewia optiva* (Bhimal) in Uttarakhand

Principal Investigator: Dr. Devendra Kumar, Scientist-E, ICFRE-FRI Dehradun

Duration: 2018 - 2022

Critical analysis of the research theme and summary of the study:

Bhimal trees are multipurpose and give fodder for livestocks, fibre and medicines for human. These trees can be lopped either 100% or 75%. Lopping of trees up to 75% are better option to obtain the fodder in lean period and fibre too in sustainable manner for livelihood improvement. Many chemical treatments, eco-friendly materials and combinations of mechanical treatments were tried to obtain fibre and saponin. Saponin was observed on average 45%. When the bhimal twigs were treated with chemicals then either fibre or saponin was obtained not both. So advance technology for extraction of bhimal (*Grewia optiva*) fibre using Modified Steam Explosion Treatment Machines (MSETM) and shampoo collection has been developed. MSETM was fabricated and with the help of MSETM, both saponin and bhimal fibre were obtained within one day without any bad smell and harm for environment. Traditionally bhimal fibre takes more than 90 days in process. Demonstration of this technology for bhimal fibre extraction has been shown in the field and was appreciated by participants. In bhimal grown areas, people can earn money by using this technology and lopping of bhimal tree sustainably for improvement of their livelihood.

Significant achievements/ findings of the project:

Socioeconomic surveys and estimation of existing population of *Grewia optiva* in study area were carried out. It was observed that higher nos of medium size (5-10 holding land acres) and sufficient number of youths were available including Agricultural laborers in all the sites. The residents of Chandau, Jasau Kharaya, Malhau and Tipauin Kalsi Block, Dehradun were interviewed and status of *Grewia optiva* was collected and analyzed. *G. optiva* was observed 33.10%in Chandau, 46.95% in Jasau Kharaya, 47.30% Malhau and 57.66% in Tipau as compared to other species such as Banj (*Quercus leucotrichopra*), bamboo (Bambusoideae), Burans (*Rhododendron arboreum*), Deodar (*Cedrus deodara*), Kachnar (*Bauhinia varigata*), Khadik (*Celtis australis*), Gorial, Keemu and Padink. Most of the fodder species were noticed in the area. There were four selected villages viz. Aamgaon, Dung dhar, Kandi and Thangarin Yamkeswar block, Pauri Garhwal. Local residents of villages were interviewed and status of *Grewia optiva* data was collected and analyzed. *G. optiva was observed* 45.39*% in* Aamgaon, 74.13% in Dung dhar, , 76.54% Kandi and 62.45% in village Thangar of Yamkeswar block, Pauri Garhwal as compared to other species such as Cheer (*Pinus roxburghii*), Anola (*Emblica officinalis*), Githi (*Dioscorea bulbifera*), Guava (*Psidium guajava*), Gullar (*Ficus racemosa*), Khadik (*Celtis australis*), Kolan (*Pterichis triangularilabia*), Mango (*Mangifera indica*), Nashpati (*Pyrus communis*), Orange (*Citrus sinensis*), Shahtoot (*Morus alba*) and Kavach.

Suggestions/ advisory note for end users "To do techniques":

Fibre yielding species like bhimal is contributing to both domestic requirements and income generation for livelihood. Demand for fibre of bhimal in Himalayan region was observed growing and small factories are entering in production process, which has created good economic value for the species. There was an urgent need to encourage fibre making and shampoo from bhimal plant which was abundantly available in the area.

An ecofriendly method for extraction of fibre, and collection of shampoo from bhimal plant of Himalayas along with sustainable and economically viable harvesting technique has been developed. This fibre extraction of technique give fibre within one day with the help of modified steam explosion treatment machine (MSETM) and collect shampoo too for their livelihood improvement.

This kind of work can also generate the employment for local people where other resources of income are not available. It may be a sustainable source of income for local people. Above technology has been demonstrated in experimental site, obtained appreciable feedback and Uttarakhand Forest Department also procured one unit of MSETM for rural people. NGOs, Panchayat, SHGs and other stakeholder may be invited to take technology.

Research gaps:

Traditionally retting method of fibre extractionb from *G. optiva* twigs consumes more than 90 days whereas saponin (Shampoo) cannot be collected by this method. New less time taking methods appealing to younger generation need to be worked out.

Uses of research outcomes:

The ecofriendly method for extraction of fibre, and collection of saponin (shampoo) from bhimal plant of Himalayas collected within one dayalong with sustainable and economically viable harvesting technique will be useful for livelihood improvement of the rural people.

Publication:

- भीमल (ग्रेवियाऑप्टिवा) का रेशा निकालने की उन्नत तरीका (Brochure)

2. **Title of the project:** Awareness training for conservation of *Pinus gerardiana* (Chilgoza) through scientific intervention in Kalpa and Pooh Forest ranges of district Kinnaur, Himachal Pradesh.

Principal Investigator: Dr. Swaran Lata, Scientist-D, ICFRE-HFRI Shimla

Duration: 2020 - 2022

Critical analysis of research theme & summary of the study:

Pinus gerardiana (Chilgoza)is the only conifer of India which provides edible nuts.Itsdistribution is very sparse in the world and restricted only in dry temperate regions of Afghanistan, Baluchistan, Pakistan and India at elevations of 1600-3300 m amsl.Total Chilgoza forest area in Himachal Pradesh is 2060 ha of which majority of area 2040 ha falls in Morang, Pooh and Kalpa ranges of Kinnaur district. In India major indigenous supply (approx. 80-100 tons) comes from Kinnaur and approximate value of its annual produce is Rs. 18 crores. It is one of the most important cash crops of tribal people residing in Kinnaur district of Himachal Pradesh and its current market rate is Rs.2000-2200/kg. Apart from economic benefits it also contributes significantly in maintaining their rich traditional culture of *Kinnaura* tribes and ecological stability of the region. Currently destructive harvesting practices of Chilgoza is major problem of the region which affects its natural regeneration and cone/crop production. In addition, intensive grazing, conversion of Chilgoza forest into orchards, construction of hydropower projects and other developmental activities also affecting its natural habitats and populations. In view of its dwindling population, it is also listed in the "Near Threatened" category as per IUCN threat category. Considering these there is an immediate need to protect this species through scientific intervention and community awareness. Considering these for conservation and sustainable harvesting of Chilgoza ICFRE-HFRI, Shimla established demonstration plot (1 ha) near Pangi village of Kalpa Forest Range of Kinnaur Forest Division and also conducted eight field demonstrations and awareness training programmes on topic "*Conservation and Sustainable Management of Chilgoza*" for the farmers and front line forest field staff of Kalpa, Roghi, Duni, Pangi, Barang, Tangling, Powari, Meeru and Urni panchayats of Kalpa Forest Range and Dubling, Spillow, Kanam and Labrang panchayats of Pooh Forest Range. Multi-angular long reach pruners (5 each) were also distributed to each panchayat for sustainable harvesting of Chilgoza.

Significant achievements/ findings of the project:

Through field demonstration and awareness programmes project activities contributed in generating awareness on conservation and sustainable management of Chilgoza and also brought attitudinal changes in 357 farmers of Pooh and Kalpa Forest Ranges of Kinnaur Forest Division towards destructive harvesting of Chilgoza. Locals became familiar with new cone harvesting tool Multi-angular-long-reach pruner and each participant also got hands on training on its handling in nearby Chilgoza forest and they accepted thatin comparison to traditional harvesting tools viz., Axe (Lasta), Sickle (Bhotya) and Adze (Basing) new cone harvesting tool was less damaging to trees and easy to handle. Currently local communities are using Multi- angular-long-reach pruners for Chilgoza harvesting from forest as well as private lands and also leaving 4-5 cones on trees for natural regeneration which will definitely contribute in conservation, sustainable management and improving natural regeneration of Chilgoza in project area (1408.7 ha).

Suggestions/ advisory note for end users "To-do-techniques":

In Kinnaur district of Himachal Pradesh, rights of Chilgoza crop harvest are with local inhabitants, hence, there is no role of State Forest Department in regulation of harvesting of Chilgoza crop. The officials of Kinnaur Forest Division are putting sincere effort to increase the Chilgoza forest cover by carrying out plantation activities in the region but due to various anthropogenic pressures and extreme climatic conditions of the region, the survival per cent of plantation was not so satisfactory. The community awareness is the only way to bring attitudinal change in locals to give up destructive harvesting practices and for adoption of sustainable harvesting practices. In order to ensure better survival of plantations, involvement of local communities also need to be ensured.

Research gaps:

Currently destructive harvesting practices of Chilgoza is major problem of the region affecting natural regeneration and cone/crop production. In addition, intensive grazing, conversion to Chilgoza forest into orchards, construction of hydropower projects and other developmental activities also affecting its natural habitats and populations. In view of its dwindling population, it is also listed in the "Near Threatened" category as per IUCN threat category.

Uses of research outcomes:

It is essential to create awareness among the local communities for conservation and sustainable management of Chilgoza like the Kinnaura tribal communities, front line forest field staff, Panchayat representatives, Yuvak Mandals, etc.

Publications:

- Lata S., Negi P. S., Samant S. S., Seth M. K. and Varsha 2020. Indigenous uses and traditional practices of endemic and threatened Chilgoza Pine *Pinus gerardiana* Wall. ex D. Don by tribal communities in Kinnaur District, Himachal Pradesh, North Western Himalaya. *Journal of Threatened Taxa* 13(12): 16891-16899.
- Lata S. and Sharma D. 2021.चिलगोजाजिलाकिन्नौर का पारिस्थितिक,सामाजिक एवं आर्थिक रूप से महत्वपूर्ण वृक्षरू वर्तमान स्थिति एवं प्रबंधन की आवश्यकता, 28 p. (Booklet)

3. **Title of the project:** Transfer of products/technology on biobooster to Irular tribes in forest fringe villages of Coimbatore, Tamilnadu: An alternate source of livelihood support

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Forest fringe villages at Palamalai, Paraliyar and Pillur surrounding area in Coimbatore district were selected for this study. Interactions were made with the Irular tribes and selected members for Women Self Help Groups (WSHG) and 13, 8 and 12 women were selected from the WSHGs in Palamalai, Paraliyar and Pillur, respectively. The details of the members were collected in the prescribed format and they were explained about the product developed by IFGTB, Tree Rich Biobooster - and its utility in Forestry and Agriculture. The product will be transferred to tribal group in Palamalai and Pillur for livelihood improvement. Coir pith was procured and processed to bring down its EC value, followed by composting with Phosphobacterium, PPFM, Azospirillum and VAM to improve their properties for product development. Decomposed coir pith was analyzed for its bulk density (0.135), pH (6.78), and EC (0.551) in order to make it suitable for making of Tree Rich Biobooster discs. Seeds of tree species viz., Eucalyptus, Casuarina and *Gmelina arborea* were processed and evaluated in Tree Rich Biobooster for their germination performance. About 35-45% increment in germination was observed in coir pith media than conventional potting mixture.

Significant achievements/ findings of the project:

As an outcome of the project a "Home Garden Kit" was developed and released during "Inventor User Meet 2018" held on 1st October, 2018. The home garden kit consisted of an ecofriendly cloth bag with Tree rich biobooster (an organic potting mixture developed from waste), Tulsi sapling (medicinal plant); Sorgamaram (vastu tree) sapling; Bhendi sapling; Bhendi seeds, organic insecticide along with user pamphlet. The home garden kit was sold to the end users.

Suggestions/ advisory note for end users "To-do techniques":

The technology on development of "Tree Rich Biobooster" was transferred to tribals inhabiting forest fringe villages of Coimbatore who wholly depend on forest for livelihood.

Research gaps:

Tribes inhabiting forest fringes depend on forest for their livelihood and the transfer of technology developed through R&D intervention would help them as an alternate source of income thereby supports their livelihood. However, easy to understand and adopt technology is lacking.

Uses of research outcomes:

The research outcome will help the tribes inhabiting near forest fringes as an alternate source of income to reduce their dependency on forests.

Publications:

- Special issue on the oil based biopesticides: Tree PAL and HyACT and the growth promoter Tree Rich Biobooster. IFGTB News Vol. 1, No. 2, October, 2019.
- Murugesan S., Mohan V., Senthilkumar N., Lakshmidevi R., Suresh Babu D. and Sumathi R. 2016. Effects of growing media with bioinoculants on quality seedlings production of *Eucalyptus tereticornis* in nursery conditions. *European Journal of Experimental Biology* 6(3):86-93.

Patent:

Obtained "Organic Certificate" to the bioproduct, "Tree Rich Biobooster" from Tamil Nadu Organic Certification Department (TNOCD) as quality control measure. N0. NPOP/IM/7121980 dt. 7.1.2021; Trade mark for Tree Rich Biobooster®: No. 4582291

4. **Title of the project:** Development of compost out of waste involving tribal for their livelihood support: a part of Swachh Bharat Mission

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

Participation in Swachh Bharat Mission of India with effective utilization of municipal organic solid wastes collection and handling into valuable products/wealth (composts/fertilizers) involving Irular Tribes/ ST poor in Tamil Nadu for their poverty alleviation was achieved. "Tree rich biobooster" (TRB), an organic growth promoter consisting of coconut coir pith base medium was nutritionally enriched with addition of composts made out of municipal solid wastes like flower and vegetable waste, weed waste, tea waste and using as an alternate to conventional potting mixture (Sand: Soil: FYM) in the nursery, gardens for quality agriculture, forestry and horticultural crops production. In addition, sugarcane bagasse, casuarina leaf needles, paddy straw were used as alternate base material instead of coir pith and to that municipal solid waste composts were added in appropriate composition for use in the agro-silviculture models. Capacity building/training of Irular tribes/ST poor women from various forest fringe villages on the manufacturing of "Tree Rich Biobooster" discs and commercialized products was continued which were sold by establishing marketing channel for their livelihood improvement. Abandoned/wasted maize straw was collected and with addition of organic materials such as oil cake, cotton seeds, etc., was pressed into compact disc and used as an animal fodder for animals. In the Coimbatore forest fringe villages 39 tribal settlements were selected and training was imparted to 19 Women Self Help Groups comprising 295 members and 520 tribal women.

Significant achievements/ findings of the project:

Nineteen WSHGs with 520 women were trained to develop TRB. Established Infrastructure at their premises for production of TRB. Established infrastructure in IFGTB such as Southern Regional Tribal Welfare Center, Training and Demonstration center, Products sale counter, Compost Shed etc.

Suggestions/ advisory note for end users "To-do techniques":

Tribal WSHGs were given trainings for capacity building to develop the products and marketing channels were also established. The TRB has been empanelled in TRIFED for marketing.

Research gaps:

Municipal solid waste and tree biomass residue management is one of the challenging tasks in urban areas and effective conversion of these waste into compost as commercial viable products with the involvement of Tribal WSHGs was attempted.

Uses of research outcomes:

The research outcome is the development of commercial product from municipal waste and tree biomass residue in urban city thereby reducing the waste and help the tribal WSHGs income as well.

Patent

Filed Copyright no. 8922/2023-CO/CF dt. 05.04.2023

5. **Title of the project:** Developing and Popularizing Digital Interactive Platform for Tree Growers and Other stakeholders of Tamil Nadu.

Principal Investigator: Dr. S. Saravanan, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 – 2023

Critical analysis of the research theme and summary of the study:

Tree growers and other stakeholders of agroforestry-based systems need a significant amount of information. Information and Communication Technologies (ICTs) play a key role in knowledge exchange, targeted recommendations, market integration and probable access to finance institutions to make tree farming a profitable enterprise especially for the youth. Integration of multiple stakeholders on a common virtual platform would pave the way to bring about a positive attitude towards tree farming among all stakeholders.

This project envisages creating "TreeGenie" a digital platform for tree growers, planting stock suppliers, industries, research institutions and forest departments to integrate information flow on research and markets for the benefit of tree growers. IFGTB intends to develop a Digital (Software) Platform (interactive web and mobile applications) to connect tree growers and other stakeholders of Tamil Nadu. This Software Platform will consist of Mobile applications, Web Portal, SMS Communication systems to connect stakeholders.

Significant achievements/ findings of the project:

"Tree Genie" a digital platform to bring tree growers, planting material growers, industries and research institutions on a single platform where flow of research inputs and produce market information would be made available for benefit of tree growers. The new digital platform would serve as a single window service for aggregating information viz., commercial technologies from forestry research, availability of quality planting material, plantation area under different tree species, location and tree grower details, prevailing market price of wood/timber as offered by the wood-based industries, etc. The tree growers would also have access to the nationwide market and prices commensurate with quality of the produce. This application will work both on a mobile device (tablet or smart phone) as well as on the web, both in Android and iOS devices and will facilitate data gathering and uploading as well as sharing of information with farmers.

Suggestions/ advisory note for end users "To-do-techniques":

The consumer facing components of this Software Platform (e.g., Mobile App, Website) are bilingual (English & Tamil). The mobile app has texts, photos, audio clips as well as video clips for the convenience of the farmers. It also provides options to share information towards social media streams seamlessly to serve farmers. This app is available on both Google's Play Store and Apple's App Store.

Research gaps:

Digital user interface modules or apps are not available with the accessibility to farmers and other stakeholders. Hence this project was proposed to develop one stop solution for the nursery and plantation needs of forests tree species.

Uses of research outcomes:

The Tree genie app developed is utilized by the farmers, nursery growers, paper industries and forest departments to address all the issues from quality planting stock to marketing the wood produce. The multiple stakeholders involved in forestry are integrated in a single digital platform.

Publication:

- Rajesh G., Chandrasekeran P. C and Saravanan S. 2022. TreeGenie App. Pasumai Vikatan, 56-58.

6. **Title of the project:** Extension of biological control of teak defoliator and skeletonizer through egg parasitoid, *Trichogramma raoi* (TFRI-Trichocards) in plantations

Principal Investigator: Dr. Mohan C., Scientist-B, ICFRE-TFRI Jabalpur

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

The native population of egg parasitoid, *Trichogramma raoi* had been isolated in the past and being continuously maintained in the laboratory for use as biological control agents against teak defoliators and skeletonizers in plantations and forests. Their efficacy has also been investigated against defoliators in a few previous projects. However, it is felt that the technique is required to be extended to the major stakeholders through training programmes and field demonstrations. This will help popularize this ecofriendly and biorational biological control technique as well as the TFRI product TFRI-Trichocard.

Significant achievements/ findings of the project:

During the project period seventeen trainings were conducted in six circles of different forest divisions i.e. Kawardha, Raipur, Bilaspur, Katghora, Korba, Kawardha, Gariyaband, Bastar, Dantewada, Kondagaon, Korba, Katghora, Sarguja (Lundra), Balrampur, Khiragad, Rajnangaon, Chhattisgarh and disseminated Biological Control of Teak Defoliator/ Skeletonizer through TFRI-Trichocard to frontline staffs of State Forest Department Chhattisgarh. Feedback was also taken from the participants of the training programme to compile valuable and important suggestions for improving the efficiency of future training programs.

Suggestion/ advisory note for end-users "To-do-Techniques":

The developed technologies (TFRI-Trichocard) will popularize the biological control method for the eco-friendly and biorational management of teak defoliator and skeletonizer in teak plantations, thereby saving losses in terms of incremental growth in teak due to reoccurring incidences, without using chemicals. This will also facilitate introduction of the parasitoids in the areas of release by the stakeholders and might help their further establishment and help in maintaining natural balance in the pest and natural enemies. The results will be disseminated to user groups like progressive farmers, NGOs, SHGs and State Forest Departments, Forest Corporations and Federations through regular training programmes organized by the Institute, demonstration, scientific publications and extension materials.

Research gaps:

Teak is an important wood yielding species of Central India but severely infested by Teak defoliators and Teak skeletonizers, which are affecting growth of teak.

Uses of research:

Biological Control of Teak Defoliator/Skeletonizer through TFRI Trichocard was disseminated to frontline staff of State ForestDepartment of Chhattisgarh with demonstrations of the releasing technique of Trichocard in the field.

FOREST PRODUCTS

FOREST PRODUCTS

1. **Title of the project:** Performance evaluation of imported timbers after treatment with conventional (CCA, CCB and environmental-safe (ZiBOC) preservative in prototype cooling tower.

Principal investigator: Sh. Ajmal Samani, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2020

Critical analysis of research theme and summary of the study:

Cooling tower is important and inevitable part of any high energy consuming and heat generating industry. Industries like petrochemicals, fertilizers, oil refiners etc cannot think of dispensing with cooling towers. Various materials like concrete, steel, aluminum alloy, fiber glass were tried in cooling towers in different countries. But timber has been one of the best accepted materials for doing this job. However, not all timbers perform equally well. The Bureau of Indian Standard (BIS) had listed out only *Abies pindrow* (Fir), *Cedrus deodara* (Deodar), *Picea smithiana* (Spruce), *Pinus kesiya* (Khasi Pine), *Pinus roxburghii* (Chir), *Pinus wallichiana* (Kail), *Pseudotsuga taxifolia* (Douglas fir), *Tectona grandis* (Teak) for use in cooling tower. Later on *Pinus radiata* (Radiata Pine) was also included in the list. Due to the limited availability of indigenous natural grown species, the focus is now hugely shifting either to imported timbers like Radiata Pine from New Zealand and Australia, *Pinus elloti* from South Africa and Douglas fir from Europe since 1996-1997 or plantation grown timber. It is rather disturbing to note that a few of the cooling towers have started collapsing and failing in recent years. The durability of timber is improved by wood preservatives. European countries have place CCA in most hazardous category and suggested its replacement with CCB. Further CCB may also be scrutinized in future because of chromium which is carcinogenic in nature. Keeping this in view ZiBOC was developed in FRI Dehradun tested and found comparable with CCA in exterior ground condition. In this project southern yellow pineandimported teak were investigated for performance in prototype cooling tower after treatment with conventional (CCA and CCB) and new preservative (ZiBOC).

Significant achievement/ findings of the project:

The performance of imported timber Southern Yellow Pine (SYP) was evaluated after treatment with ZiBOC preservative and conventional preservatives i.e. CCA and CCB in prototype cooling tower. Samples were treated with CCA, ZiBOC and CCB preservatives at 2%, 4% and 6% concentration by pressure method as per IS 401carried out. Total 42 frames (21 frames for each species) were installed in prototype cooling tower. Each frame consisting of 20 samples (six samples of each conc.) and two control. Total six frames were removed from the prototype cooling tower after each quarter for up to seven quarters (three frames of each species) samples were oven dried and preservative analysis of the samples was carried out for the assessment of preservative leached out and the weight loss of the samples. The results showed maximum retention of 38.5, 35.8 and 33.2 Kg/m^3 in order of CCA >CCB > ZiBOC preservative in SYP whereas in imported teak maximum retention of 13.8 Kg/m^3, 12.8 Kg/m^3 and 12.7 Kg/m^3 was obtained in order of CCB > ZiBOC > CCA. However, after exposure in prototype cooling tower the dry salt retention loss of preservatives was observed in order of ZiBOC > CCB > CCA in both the species.

After twenty-one months of exposure Control samples of SYP showed weight loss of 30.5% as compared to 4.7% to 7.6% weight loss in different preservatives treated samples demonstrating 75% - 84.5% protection over the control samples. Similarly control specimens ofimported teak exhibited average weight loss of 22% after 21 months of exposure whereas treated samples have shown weight loss in the range of 6.8% to 8.6% within the samples treated with different preservatives, which is 60% - 69% protection over the control samples.

Suggestion/ advisory note for end users "To-do-techniques":

Preservative treatment of wood results in increase in its service life which reduces the demand for replacement wood and thus results less pressure on forests. The outcome of the project will be extended to the users/industry through short term training programs.

Research gaps:

Cooling tower industry is facing acute shortage of availability of timbers as recommended in IS 2372. However, not all timbers perform equally well in cooling towers. Due to the limited availability of indigenous natural grown species, thus the focus is now hugely shifting either to imported timbers or plantation grown timbers.

Uses of research outcomes:

Cooling tower industry/users may use the research outcome.

2. **Title of the project:** Studies on the Radio Frequency Curing of adhesives in manufacturing of Plywood

Principal investigator: Sh. D. P. Khali, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2020

Critical analysis of research theme and summary of the study:

In composite wood manufacturing, hot pressing is a critical step for production of diverse range of panels and products. Hot platen pressing requires extremely long times for heat to transfer from surface to the core, particularly when pressing thick composites. In recent years the radio frequency (RF) is being attempted for obtaining heat to cure thermoset resin in composites as well. The RF electrical impulses are transmitted through material, polarized parts such as thermoset resin and moisture vibrate along with the field. This motion of the thermoset resin and moisture generates a large amount of frictional heat facilitating better and rapid curing of thermoset adhesives. RF current gives a very fast uniform temperature rise and materials with any volume and cross-sectional dimensions can be heated in a very short time. RF curing may thus constitute a good alternative to improve production by drastically reducing curing times, yield thicker boards, make year-long operating conditions more uniform through penetrating and uniform heating, high energy efficiency, and increased operational flexibility to optimize processes.

Significant achievements/ findings of the project:

In this project, plywood of poplar and combiply of poplar and eucalyptus prepared with different duration of RF application for curing of adhesives and pressure levels using urea formaldehyde (UF) adhesives and phenol formaldehyde (PF) adhesives. The prepared plywood and combi ply were tested for their properties (Moisture Content, density, Glue Shear Strength in dry and wet conditions; Modulus of rupture along and across the grain; Modulus of elasticity along and across the grain) and process parameters for general purpose MR grade poplar plywood, general purpose BWR grade poplar plywood, general purpose MR grade combi plywood of poplar and eucalyptus and general purpose BWR grade combi plywood of poplar and eucalyptus were optimised. It was found that plywood using poplar veneers and combi plywood (PEPEP) moisture resistant (MR) grade for general purpose can be made at 14.0 kg/cm^2 and 17.5 kg/cm^2 specific pressures and combi plywood (EPEPE) moisture resistant (MR) grade for general purpose can be made at higher pressure level 17.5 kg/cm^2 with 9 minutes of RF application for curing of adhesives during pressing with meeting all properties as per IS specifications including glue shear strengths. Plywood boiling water resistant (BWR) grade using poplar veneers for general purpose can be made at 14.0 kg/cm^2 and 17.5 kg/cm^2 specific pressures and both combi plywood (PEPEP) and combi plywood (EPEPE) boiling water resistant (BWR) grade for general purpose can be made at higher pressure level 17.5 kg/cm^2 with 15 minutes of RF application for curing of adhesives during pressing with meeting all properties as per IS specifications including glue shear strengths.

Suggestions/ advisory note to end users "To do techniques":

FRI has leadership in wood composites and the RF curing technique has added new knowledge into it. The outcome of research is useful to all wood-based industries who manufacture plywood, particle boards, fibre boards, furniture etc. Findings can be disseminated to the end users through various short term training programs conducted by the institute.

Research gaps:

During the conventional hot platen pressing, heat is sequentially transferred from the platen to the panel core through heat conduction and convection resulting varied time of thermoset resin curing. Due to which densities of the pressed composites across the vertical direction are usually non uniform. Hot platen pressing requires extremely long times for heat to transfer from surface to the core, particularly when pressing thick composites.RF current gives a very fast uniform temperature rise and materials with any volume and cross-sectional dimensions can be heated in a very short time.

Uses of research outcomes:

The outcome of research is useful to all wood based industries who manufacture plywood, particle boards, fibre boards, furniture etc. Findings can be disseminated to the end users through various short term training programs conducted by the institute.

Publication:

- Khali D.P. 2019. Radio frequency (RF) curing of adhesives in manufacturing of composites. *Indian Wood & Allied Panels* April –June 2019

3. **Title of the project:** Study on the effect of fire-retardant chemicals on internal bond strength of particle board

Principal investigator: Sh. D. P. Khali, Scientist-G, ICFRE-FRI Dehradun

Duration: 2019 - 2022

Critical analysis of research theme and summary of the study:

Wood composite panels such as particle boards, fibre boards, plywood, block-board etc. are widely used in building industry. They are mainly used as non-structural components such as wall partition, flooring and ceilings. These untreated composite panels being combustible in nature do not comply with the fire safety requirements. In order to overcome this weakness, particle boards may be impregnated with fire retardant chemicals. Combinations of fire retardants may produce a synergisticeffect, which is of considerable practical importance, as it can allow the loading of one or more of the retardants to be reduced without compromising performance. This study was conducted to explore the possibility of impregnating particle board with fire retardant chemical compositions and to evaluate their effect on mechanical and fire-retardant properties of the treated particle board.

Significant achievements/ findings of the project:

The particle boards of lops and tops of poplar were prepared using urea formaldehyde resin with 110^0C pressing temperature. One set of particle boards were kept as control particle boards and remaining boards were treated with five different combinations of fire-retardant chemicals at 10% and 20% conc. by dipping method for 15 minutes and 30 minutes duration. The control prepared boards as well as fire retardant chemical compositions treated boards were tested in accordance with IS 3087, IS 2380 and IS 5509 for their various properties viz modulus of rupture (MoR), modulus of elasticity (MoE), internal bond strength, rate of burning test, flammability test and flame penetration test. It was found that particle board treated at both concentration (10%, 20%) and both duration (15 minutes, 30 minutes) of dipping with all five compositions passed the mechanical test viz. MoR, MoE and internal bond strength whereas particle board treated at lower concentration (10%) and both duration (15 minutes, 30 minutes) of dipping with all five compositions do not passed the fire retardant properties viz. time taken (Weight loss from 70% to 30%) under rate of burning test, flammability test and flame penetration test as per relevant IS specifications. The particle board treated at higher concentration (20%) and both duration (15 minutes, 30 minutes) of dipping with all five compositions passed the fire-retardant properties viz. time taken (Weight loss from 70% to 30%) under rate of burning test, flammability test and flame penetration test as per relevant IS specifications. However, at higher concentration and higher duration of dipping the internal bond strength reduced significantly but still all mechanical properties viz, MoR, MoE and even internal bond strength met as per relevant IS specifications. Therefore, following five different fire-retardant combinations were found suitable for the treatment of particle board as per relevant IS specifications.

- Di ammonium phosphate + Ammonium sulphate+ Borax + Zinc chloride
- Sodium silicate+ Phosphoric acid+ Boric acid
- Borax + Boric acid + Ammonium sulphate
- Sodium Silicate+ Boric acid
- Borax + Boric acid + Silicic acid

Suggestions/ advisory note to end users "To-do-techniques":

FRI has leadership in wood composites and the fire-retardant compositions developed have added new knowledge into it. The outcome of research is useful to all wood-based industries who manufacture plywood, particle boards, fibre boards, furniture etc. Findings can be disseminated to the end users through various short term training programs conducted by the institute.

Research gaps:

Wood composite panels such as particle boards, fibre boards, plywood, block-board etc. are widely used in building industry. These untreated composite panels being combustible in nature do not comply with the fire safety requirements. In order to overcome this weakness, particle boards may be impregnated with fire retardant chemicals.

Uses of research outcomes:

The outcome of research is useful to all wood based industries who manufacture plywood, particle boards, fibre boards, furniture etc. Findings can be disseminated to the end users through various short term training programs conducted by the institute.

Publication:

- Khali D.P. and Bisht Laxman Singh 2021. KarnPhalak (Particle Board). *Van Anusandhan E Patrika* 5:6-7.

4. **Title of the project:** Characterization and Extraction of Eco-friendly Natural Dyes from Eucalyptus, Casuarinas and Melias - leaves and bark; their application in Textile Industry

Principal Investigator: Dr. D. Thangamani, Scientist-D, ICFRE-IFGTB Coimbatore

Duration: 2018 - 2022

Critical analysis of research theme and summary of the study:

The objective of the project was to develop and characterize cost effective eco-friendly natural dyes from *Eucalyptus, Casuarina* and *Melia* species for the use in small scale dyeing industries. The main aim of the project is to utilize the waste resource from pulp and paper industries. The natural dyes were successfully extracted from *Eucalyptus camaldulensis, Casuarina equisetifolia* and *Melia dubia* leaves and bark samples and dyed on different fabrics (cotton, silk, wool and linen). They gave different shades and some unique colours with the use of different mordants. This consequently provides additional income to farmers who cultivate these species and also generates employment opportunities in small scale dyeing industries. Aromatic face mask was developed and tested for Bacterial Filtration Efficiency (BFE) as per the Bureau of Indian Standard and showed 85.2% of filtration efficiency. The natural dye extracted from these species can be very useful in developing sanitized fabrics for medical applications and protective clothing against common infections.

Significant achievements/ findings of the project:

The extracted natural dyes were successfully dyed on different fabrics (cotton, silk, wool and linen) with combination of natural mordants. Aromatic face mask named "DYECOP" was developed. The natural dye extracted can be used in developing sanitized fabrics for medical applications and protective clothing against common infections. Incense sticks and Bio-compost were developed from the waste leaves and bark of Eucalyptus. IFGTB has designed "Pilot Natural Dye Extractor" where 20 litres of natural dye can be extracted at desired temperature at a time. This equipment is recommended for small scale dyeing industries and self-help groups.

Suggestions/ advisory note for end-users "To-do-techniques":

Natural dye extraction from the plantation wastes provides additional income to farmers who cultivate these species and also generates employment opportunities in small scale dyeing industries.

Research gaps:

The improper management of plantation wastes for productive utilization is required throughappropriate technology in natural dyes extraction and its applications in textile industry.

Uses of research outcomes:

Effective utilization of plantation wastes for natural dye extraction thereby incineration of the plantation waste can be controlled. It provides additional income to the farmers.Small scale natural dyeing industry can be benefited using dye extractor unit developed through this project.

Publications:

- Thangamani O.M., Nawas Mohamed and LalithaS. 2021. Sustainable utilization of betalains rich *Rivina humilis* L. berries as natural mordant for dyeing silk and wool with eco-friendly natural dye. *Indian J. Applied & Pure Bio*. Special Vol. 159-169.
- Thangamani O.M., Nawas Mohamed and LalithaS. 2021. Utilization of *Melia dubia* Cav. leaves as a source of Natural dye for Textile Industry. *Indian J. Applied & Pure Bio*. Special Vol. 2(1): 187-193.
- Thangamani O.M., Nawas Mohamed and LalithaS. 2020. Extraction of eco-friendly natural dye from leaves and barks of *Eucalyptus camaldulensis* on cotton, silk, wool and linen fabrics using soy milk. *International Journal for Science and Advance research In Technology* (IJSART); ISSN: 2395-1052; Volume 6, Issue 4; pp. 561-564.

Patent: The patent for this equipment is in progress.

5. **Title of the project:** *Ailanthus excelsa*: as a potential of fodder in terms of nutritive value and qualitative assessment of other secondary compounds for alternate protein.

Principal Investigator: Smt. R. Sumathi, CTO, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Ailanthus excelsa Roxb. is a fast-growing multipurpose indigenous tree species for safety match industry in Tamil Nadu. Apart from the wood, the leaf is also an excellent source of quality protein which is superior to soya bean. There is a tremendous scope to develop value added products for animal feed, since the tree species has already used as fodder in Rajasthan and Gujarat. Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore has *A. excelsa* germplasm assemblage. The proximate analysis of the leaves of *A. excelsa* showed that it can be considered as the potential fodder tree and as a good source of crude protein, which may be considered as cattle feed. *In Vitro* Dry Matter Digestibility (IVDMD) analysis of selected accessions showed digestibility was greater than 50% and Metabolizable Energy (ME) and Total Digestible Nutrients (TDN) were found promising in all the accessions and hence the selected accessions of *A. excelsa* may be promoted exclusive for animal fodder.

Significant achievements/ findings of the project:

Five accessions were shortlisted based on nutritive and antinutritive analysis as per BIS norms, as promising accessions for use as a cattle feed. The major bioactive compounds present in the extracts contained antioxidant properties with health benefits in livestock. IVDMD analysis of selected accessions showed digestibility was greater than 50% and ME and TDN were found promising in all the accessions. During summer season five accessions met BIS specifications for animal feed whereas during winter season sixteen accessions were at par with BIS specifications.

Suggestions/ advisory note for end users "To-do-techniques":

The leaves collected during winter season found to have all required constituents at par with BIS specifications recommended for cattle and found promising as animal feed/livestock production, hence the selected accessions of *A. excelsa* may be promoted exclusive for animal fodder.

Research gaps:

The research gaps exist n improper management of plantation wastes for productive utilization, appropriate technology in natural dyes extraction and its applications in textile industry.

Uses of research outcomes:

Effective utilization of plantation wastes for natural dye extraction thereby incineration of the plantation waste can be controlled. It provides additional income to the farmers.

Publications:

- Sumathi R., Brindha B., Suresh Babu D. and Senthilkumar N. 2021. Determination of *Ailanthus excelsa* Roxb., leaves collected from different agro climatic zones of Tamil Nadu as fodder with reference to amino acid composition. *Journal of Science and Technology* 6(2): 123-131.
- Brindha B., Sumathi R., Lakshmidevi R., Suresh Babu D., Senthilkumar N. and Murugesan S. 2019. Profiling bio-active compounds of Ailanthus excelsa leaves roxb. (Simaroubaceae) for livestock health. *International Journal of Science, Environment and Technology* 8(1): 218 – 228.

6. **Title of the project:** Biocolourant:Bioprospecting of selected accessions of Red tamarind as ecofriendly and protective natural dye in textiles/ foods

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

The red tamarind, *Tamarindus indica* var. *rhodocarpa* is a rare variant with limited distribution in southern states of India that contains rosy red pigments which are responsible for its red colour and the unripen stage of the fruits provides anthocyanins. The anthocyanins content of the unripen fruits of red tamarind is high compared to other anthocyanin rich fruits. Hence, the research on red tamarind unripe fruit pulp has been carried out towards extraction, purification, characterization, and functional finishing of anthocyanin for use in food, cosmetic and textile industries and the development of eco-friendly products. The anthocyanins pigment, cyaniding-3-glycoside in unripen fruit of red tamarind was found to be more and is responsible for red colour. The extract contains high level of protein and carbohydrates; rich in minerals and vitamins with low level of fat and hence can be used in food. As an outcome of the project IFGTB, Coimbatore has developed the product "Tara Red" for use in food, cosmetic and textile industry. It has advantages over other natural pigments from grapes, cherry, berry, red cabbage and other vegetables with high colour strength; stability against microbes, varied pH, light and temperature; high specific gravity and osmotic pressure; long shelf life; low fat/cholesterol; rich in vitamins and minerals; cost effective and high antioxidant values.

Significant achievements/ findings of the project:

The Natural colourant "Tara Red" was successfully added into jam preparations, cake topping and lipstick preparations. The natural colourant from red tamarind would be cost effective if the yield increases and hence the cultivation of red tamarind may be promoted for agroforestry and dry land farming which may support rural livelihood.

Suggestions/ advisory note for end users "To-do-techniques":

The Natural colourant "Tara Red" from red tamarind can be added into jam preparations, cake topping and lipstick preparations. It is organic and natural colourant and, therefore, it would be of great utility for food and cosmetic industry.

Research gaps:

Use of synthetic colorants as food additives lead to carcinogenic and in search of colourant from natural source is warranted and hence attempt has been made to extract natural colorant from renewable forest source for use in food, cosmetic and textile industries.

Uses of research outcomes:

As an outcome of the projecta natural colourant has been developedfor use in food, cosmetic and textile industry. It has advantages over other natural pigments. It has successfully added into jam preparations, cake topping and lipstick preparations.

Publications:

- Senthilkumar N., Ramasamy Sumathi, Lourdhuswamy Marianayagam, Durairaj Lenora and Govindaraj Divya 2021. Phytochemical properties and antioxidant activity of natural colourant extracted from Red tamarind *Tamarindus indica* var. *rhodocarpa* in Tamil Nadu. *Research Journal of Chemistry and Environment* 25 (3), Pp 79-88.
- Sundarraj Rampriya, Senthilkumar. N. 2019. Characterization of Anthocyanins from Red Tamarind, *Tamarindus indica* var. *rhodocarpa* using Spectral Analysis. *International Journal of Pharmacy and Biological Sciences* 9 (3): 926-931.
- Lenora L.M., Suresh Babu D., Sumathi R., Mayavel A., Murugesan S. and Senthilkumar N. 2017. Anthocyanin from red tamarind, *Tamarindus indica* var. *rhodocarpa* as a potential natural pigment for use in textile industry. *International Journal of Recent Trends in Science and Technology* 23(1):15-17

Patent: FSSAI License has been obtained for manufacture of Natural colourant FSSAI lic. No. 30230706113842962.

7. **Title of the project:** Bioprospecting potential of Red sanders, *Pterocarpus santalinus* Linn. f., with special reference to health care and skin care properties.

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2020 - 2022

Critical analysis of the research theme and summary of the study:

Leaf, bark and heartwood samples of red sanders were collected from 38 trees located in 11 districts of 3 southern states of India namely Tamil Nadu, Andhra Pradesh and Karnataka. Yield of extract was high in heartwood than leaf and bark. Methanol gave high yield than acetone. Qualitative analysis revealed that heartwood contained more phytochemicals. The plant samples collected from Karaikudi, Thiruvannamalai, Tirupati and YSR District contained more phytochemicals. Heartwood sample from Tirupati contained more phytochemicals than Rajampet and YSR district. Presence of phenols, flavanoids, and alkaloids was found. Alkaloids and terpenoids were present in leaf, bark and heartwood. Quantitative estimation revealed high content of phenols followed by flavonoids and alkaloids. Heartwood contained more of phenols, alkaloids compared to bark and leaves. especially in acetone extracts other than methanol extract samples. Phenol content was high in Dharmapuri (T8) samples. GCMS analysis of leaf, bark and heartwood gave the profile of secondary metabolites with antimicrobial and antioxidant activities. Methanol extract of plant samples showed high free radical scavenging activity than acetone extracts, especially in leaf samples. Leaf collected from Andhra Pradesh showed high antioxidant activity. GC/MS/MS analysis revealed that heartwood contained more compounds followed by bark and leaf had the least. Maximum 24 compounds in heartwood collected from Dharmapuri Molecular docking of the phytocompounds against the targeted ligand protein indicated that the 3 compounds Lup-20(29)-en-3-ol, (3.beta.)- (CAS), Viminalol and Lup-20(29)-en-3-one with highest docking score for anti-inflammatory, anti-diabetes and anti-microbial activities.

Significant achievements/ findings of the project:

Skin care cream has been developed and passed the pH, Total fatty matter, heavy metals as lead and Arsenic are in below detectable level and total microbial counts were within the permissible limits as per standard norms. The skin care cream had enough ingredients for smoothening of skin without any side effects. Lipstick has been developed and tested showed that it meets all requirements prescribed by the national standard. A natural handmade soap named "Royalseema ICFRE-Red Sanders Soap" has been developed and released.

Suggestions/ advisory note for end users "To-do techniques":

The bark of red sanders is having antimicrobial, antioxidant properties and hence it has a potential to make use of the bark extract for development of cosmetics products.

Research gaps:

Red sanders wood has different uses in traditional and folklore medicines for the treatment of various ailments. Therefore, scientific evaluation of red sanders with special reference to health and skin care properties was studied.

Uses of research outcomes:

It is identified that Red sanders is a source of naturally occurring antioxidants, antimicrobial and antidiabetic agents especially accounts for its anti-inflammatory activity.Value added products viz., Red Sanders soap, skin care cream and lipstick were developed as an outcome of the study. The study concludes that the plantation grown red sanders in farmer's field can be considered as a potential source for the development of value added products without exploiting the natural stand.

Publication:

- Nithya Priya S., Sumathi R., Suresh Babu D. and Senthilkumar N. 2022. *Pterocarpus santalinus* L. f: A study on phytochemical constituents and biological properties of bark and heartwood extracts. *International Research Journal of Plant Science* 13(4) pp. 01-07. DOI: http:/dx.doi.org/10.14303/irjps.2022.026 (IF: 1.785)

Patent:

Filed an application to obtain trade mark for the natural handmade soap named "Royalseema ICFRE-Red Sanders Soap".TM application No. 5870030 dt. 29.03.2023

8. Title of the project : Estimation of important wood quality parameters and identification of timber species by rapid and non-destructive technique using Near Infrared Spectroscopy (NIRS)

Principal Investigator: Dr. S.R. Shukla, Scientist-G, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

The research was aimed at using rapid and non-destructive methods for assessing wood quality of important timber species.

Significant achievements/ findings of the project:

Near infrared spectroscopy (NIRS) was used for assessment of different wood quality parameters of *Tectona grandis* (Teak), *Shorea robusta* (Sal) and *Pterocarpus santalinus* (Red sanders). Various physical, mechanical, chemical and anatomical properties were evaluated using conventional or wet chemistry methods. NIR spectra of wood samples were collected before measuring various properties. PCA and PLS regression techniques were applied to develop the calibration models between measured values of wood properties and NIR spectral data points. Separate clusters corresponding to three timber species were observed on the score plots and PLS-DA analysis clearly demonstrated the separation and identification of three species with high accuracy and low error of prediction. Validation models for predicting different wood quality parameters were developed with high values of coefficients of determination and other performance parameters. These models may be applied in routine testing and evaluation procedures to estimate different wood properties.

Suggestions/ advisory note for end users "To-do-techniques":

Wood identification as well as material characterization is always laborious, time consuming and requires relatively large size samples. Finding a reliable alternative and less time-consuming method is always welcome. In this endeavour, the use of NIR spectroscopy was explored and it was found that the method can be utilised for estimating different wood properties.

Research gaps:

Convention methods of assessing wood quality are resource intensive and destructive in nature. NIR spectroscopy is one of the tools reported to be used for estimating certain wood properties. However, it applicability for tropical hardwood species have not been explored.

Uses of research outcomes:

The results of the study are being utilized for wood quality assessment and identification of certain important wood species.

9. **Title of the project**: Studies on acoustical behaviour of different types of natural fibers for their utilization as sound absorbing materials.

Principal Investigator: Dr. S.K. Sharma, Scientist-G, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Natural fibres are abundantly available and are also cheaper than manmade fibres. This study assesses the acoustical behaviour of selected natural fibres (bagases, banana, bamboo, coir and corn) for their utilization as sound absorbing materials.

Significant achievements/ findings of the project:

The composite boards of five types of fibres were prepared in three different density range. The porosity was found to vary from 50 to 79% depending upon the types of fibres and density of board. The damping coefficient (tan δ) was determined using dynamic mechanical analyser and found maximum (0.09) in banana and corn husk fibre boards having density 280-297 kg/m3). The noise reduction coefficient, which was calculated as an average of sound absorption coefficient values at 250, 500, 1000 and 2000 Hz, was found to decrease with the increase of board densities for all the five types of boards. The maximum NRC value of 0.40 was found for banana fibre boards having density of 280 kg/m3 and therefore found comparatively more suitable as sound absorbing material.

Suggestions/ advisory note for end users "To-do-techniques":

Natural fibers are environmentally friendly materials. Boards made from natural fibres such as Banana fiber, Bamboo fiber and corn fibers exhibited higher noise reduction coefficient values and are more suitable for their use as sound absorbing materials.

Research gaps:

Agro-based lignocellulosic fibers are not used for developing sound absorbing panel products which have significant potential as an alternative of conventional material and wood fibers.

Uses of research outcomes:

It was an exploratory study and publication on the same has been made which could be used by academia and researchers working in the field.

Publication:

- Sharma S. K. 2020.Acoustical behaviour of natural fibers based composite boards as sound absorbing material. *Journal of the Indian Academy of Wood Science* 17(1): 66-72.

10. Title of the project: Efficacy of Nano Metal Oxides as Wood Preservative.

Principal Investigator: Mrs. D. Venmalar, Scientist-E, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

The study assesses the efficacy of nano metal zinc oxide as a wood preservative against decay and termite attack and also its fixing ability in the wood. Nano zinc oxide showed more antifungal property than normal zinc oxide.

Significant achievements/ findings of the project:

Hevea braziliensis (rubberwood) wood specimens treated with nano metal zinc oxide by pressure and non-pressure methods showed that nano zinc oxide is well absorbed by the wood specimens and gets fixed (92% fixation in leaching experiments). The efficacy of nano zinc oxide against termites in the field, and brown rot and white rot fungi in the laboratory was evaluated and compared with normal zinc oxide. Nano zinc oxide showed more antifungal property than normal zinc oxide. The pressure treated wood specimens were found to be in sound condition against termites after 24 months of field exposure. The study revealed that nano zinc oxide could potentially be used as an effective wood preservative.

Suggestions/ advisory note for end users "To-do-techniques":

The study showed that nano zinc oxide was well absorbed by the wood specimens and well distributed in all the wood elements. The nano particles were also very well fixed (92%) in the wood and this tendency played a vital role in resisting wood against termites and fungi.

Research gaps:

Conventional preservatives are being phased out due to their environmental and health hazards. Wood preservatives developed from plants are not as effective as conventional wood preservatives. Nanotechnology presents opportunity to boost the field of wood preservation by implementing modern and unique metal biocides with improved properties.

Uses of research outcomes:

Using nontoxic chemicals to increase the life time of the wood for indoor and outdoor applications is required for ecofriendly measures.

11. Title of the project: Screening of High oleoresin yielding forest plants of Western Ghats and standardization of extraction methods.

Principal Investigator: Mr. B.S. Chandrashekar, Scientist – E, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study: Nil

Significant achievements/finding of the project:

Three potential species viz. *Cinnamomum zeylanicum, Cinnamomum tamala*, and *Zanthoxylum rhetsa* were screened for their potential yield of oleoresin. From *Cinnamomum zeylanicum* and *Cinnamomum tamala* oleoresin yield was highest, when extracted after shock wave treatment. Among the different parts of fruit of *Zanthoxylum rhetsa* studied, maximum phenolic content was found in whole fruit extract followed by its seed coat and seed. The high anti-oxidant activity of the oleoresin extracted from *Zanthoxylum rhetsa* shows that the oleoresin can be a potential food additive and also a natural preservative.

Suggestions/ advisory note for end users should include To-do-techniques: Nil

Research gaps:

Studies related to efficient use of the oleoresin from *Zanthoxylum rhetsa* as food additive and natural preservative are lacking.

Uses of research outcomes:

Stakeholders are food and beverage industries; pharmaceutical and nutraceutical industry.

Publication:

- Ravi Kumar G., Chandrashekar B.S., Lukose Olivia, Ravindra Mamata and Ravikumar Kavya 2019. Evaluation of *in vitro* antioxidant property and total phenolics content of *Zanthoxylum rhetsa* fruit extracts. *Journal of Pharmacogonosy and Phytochemistry* 8(3):1139-1144.

12. Title of the project: Nano cellulose Networked Natural Fiber Composites.

Principal Investigator: Dr. S.S. Chauhan, Scientist-G, ICFRE-IWST Bengaluru

Duration: 2017 - 2019

Critical Analysis of the Research Theme and summary of the study:

The research work opens-up a new area of developing completely "Green Composites" that might have application in developing new packaging materials which are bio-based and biodegradable. The properties of the composites could be tailored based on the end application. The approach also provides opportunity to utilize wood and agro-waste for value added products.

Significant achievements/ findings of the project:

The protocol to synthesize nanocellulose from pulp fibers was standardized and the unique property of nanocellulose to form a complex network was effectively used to develop completely biodegradable natural fiber based composite material. The nanocellulose film exhibited very high stiffness (storage modulus – 120 GPa) and negligible damping coefficient. Composites with density ranging from 0.100 g/cc to 0.800 g/cc were prepared by mixing nanocellulose suspension with fibers. Tensile strength, flexural strength, dynamic modulus of elasticity and electrical resistance of the composites increased with increasing density. The material can be tailored for the desired properties by varying the nanocellulose proportion and processing conditions. The developed material can be used as biodegradable packaging material**.**

Suggestions/ advisory note for end users "To-do-techniques":

The selected natural fibers were mixed with nanocellulose and formed into specific shape (plate or cylindrical), dried and hot pressed. Comparison of mechanical properties between only dried and compressed composites indicated significant differences, with pressed composites being the denser, stiffer and stronger. Thus by controlling compression parameters, properties of the material can be tailored. The thermal conductivity and electrical resistance characterization suggested that the compressed composites are suitable as thermal and electrical insulating material

Research gaps:

Synthesis and application of Nanocellulose is an emerging area of research and the potential of cellulose nanofibers as a sole binder for natural fibers have not been explored for developing composite materials.

Uses of research outcomes:

This was the exploratory study and the outcome of the research is being used for further research and development.

13. Title of the project: Identification, pattern of distribution, proportion of tension wood and study of certain physical and anatomical characters in *Melia composita* Syn. *Melia dubia* Cav. wood of two different ages.

Principal Investigator: Dr. M. Sujatha, CTO, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

This study assesses two age group trees (7 and 12 years) of *Melia dubia* in terms of tension wood and its impact on dimensional stability and wood processing.

Significant achievements/ findings of the project:

Tension wood is distributed as random patches, diffuse and in narrow bands. Proportion of tension wood varied from pith to bark. The values of three shrinkages (radial, tangential and volumetric) were higher in 7-year-old tree wood as compared to 12-year-old tree wood. The shrinkage values are much higher compared to teak. All the fiber morphological characters were higher in tension wood as compared to normal wood. Vessel morphological characters were found to be higher in normal wood. The drying rate was faster in 7-year-old tree wood as compared to wood from 12-year-old trees. There were no visible defects related to drying like deformation or end cracks in the microwave dried planks.

Suggestions/ advisory note for end users "To-do-techniques":

Wood from younger age trees (7 yr old) exhibited higher proportion of reaction wood and higher shrinkage values. Hence, such wood should not be recommended for utilization where high dimensional stability against changes in moisture levels is expected.

Research gaps:

Melia dubia is emerging as a prominent wood species for industrial application and no information on proportion and distribution of tension-wood, shrinkage and microfibrillar angle in this species and its effect on properties is available.

Uses of research outcomes:

The study was of academic in nature and the outcome are used in providing technical inputs to the users/stakeholders during training and different extension programmes.

14. Title of the project: Eco-friendly method of wood protection by hot oil treatment.

Principal Investigator: Dr. K.K. Pandey, Scientist-G, ICFRE-IWST Bengaluru

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

Thermally modified wood attained uniform dark colour and FTIR spectroscopic analysis showed degradation of cell wall polymers at higher temperatures. Hot oil treatment reduced equilibrium moisture content and increased dimensional stability (anti-swelling efficiency) and moisture exclusion efficiency of wood. Anti-swelling efficiency increased with heat treatment temperature. Weight percentage change of wood increased significantly with increasing post treatment cooling times. Hot oil treatment had adverse effect on mechanical properties (modulus of elasticity and modulus of rupture) of wood. Hot oil treated wood exhibited good resistance to brown- and white- rot decay fungi. Heat treated wood in vacuum was more susceptible to termite decay than untreated wood. However, heat treatment using hot pongamia and linseed oil enhanced termite resistance of wood. Vacuum pressure impregnation of wood samples using linseed oil and pongamia oil provided better protection than thermal modification under oil and vacuum. The performance of pongamia oil was best. The results of this study will be helpful in upgrading the properties of wood for outdoor applications in an ecofriendly manner.

Significant achievements/ findings of the project:

Thermal modification of *Hevea brasiliensis* (rubberwood), *Melia dubia* (Malabar neem) and *Populus deltoides* (poplar) using hot linseed and pongamia oil (at 170-210ºC) has significant effect on density, colour, moisture absorption, dimensional stability, and mechanical properties of wood. Hot oil treatment reduced equilibrium moisture content and increased Anti-swelling efficiency of wood. Hot oil treatment has adverse effect on mechanical properties (modulus of elasticity and modulus of rupture), particularly bending strength of wood. Hot oil treated wood exhibited good resistance to brown-rot and white-rot decay fungi. Thermal modification under vacuum completely failed to provide termite resistance. However, thermal modification using hot oil provided considerable resistance to termite attack. Increase in modification temperature adversely affected termite resistance. The performance of pongamia oil was better than linseed oil. Vacuum impregnation of pongamia oil and linseed oil at room temperature proved to be the best treatment procedure against termite attack and pongamia oil performed best. The results of this study will be helpful in upgrading the properties of wood for outdoor applications.

Suggestions/ advisory note for end users "To-do-techniques":

Thermal modification of rubberwood, *melia* and poplar wood using hot linseed and pongamia oil attained hydrophobicity and reduced swelling. Modification increased dimensional stability and moisture exclusion efficiency (MEE) of wood. Anti-swelling efficiency and MEE increased with increase in treatment temperature. Thermally modified specimens showed uniform darkening with decrease in lightness (L*) and corresponding increase in redness (a*) and yellowness (b*). Hot oil treatment had adverse effect on mechanical properties (modulus of elasticity and modulus of rupture) of wood. Thermal modification in hot linseed and pongamia oil provided brown-rot and white-rot resistance compared to untreated wood. With increase in temperature of treatment fungal resistance also improved. Thermal modification using vacuum oven completely failed to inhibit decay due to termites, ~100% destruction due to termites was observed within 3 months of exposure. However, thermal modification of wood using hot oils of pongamia and linseed oil was effective in restricting termite decay.

Research gaps:

Heat treatment is a simple, cheap and eco-friendly method of improving dimensional stability and decay resistance of low durability timbers. However certain properties are compromised. The hot oil treatment was expected to overcome these limitations.

Uses of research outcomes:

The findings of the project can have a significant and positive impact in the areas of scientific advancement, scientific leadership and development of environment friendly process. The research outcomes have been disseminated in workshops/conferences and industry-institute interaction meets.

15. Title of the project: Weathering of coatings on thermally modified wood.

Principal Investigator: Dr. K.K. Pandey, Scientist-G, ICFRE-IWST Bengaluru

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

Weathering performance of thermally modified *Hevea brasiliensis* and *Melia dubia* wood coated with transparent and opaque PU coating was evaluated by exposing the coated wood specimens to natural outdoor weathering. The weathering performance of thermally modified wood is species dependent. Thermal modification was not effective in enhancing service life of transparent coating and, therefore, need UV stabilizing additives for outdoor applications. The hydrophobic nature and good dimensional stability of thermally modified wood resulted in superior performance of pigmented opaque coating on it. Stabilization of UV degradation of heat-treated sapwood with application of an UV absorber (benzotriazole derivative) embedded coating has been illustrated. Wood treated with hot pongamia oil exhibited good weathering resistance and is excellent for outdoor applications.

Significant achievements/ findings of the project:

This study established role of heartwood extractives in the photo-stability of *Albizia lebbeck* and *Acacia auriculaeformis* wood. The extractive rich heartwood showed higher UV resistance as compared to sapwood. The high level of protection observed in heartwood of *A. lebbeck* was not observed in *A. auriculaeformis*. Thermally modified wood, particularly sapwood portion, is susceptible to photo-degradation, therefore, thermal modification has no beneficial effect in enhancing service life of transparent PU coating. However, hydrophobic nature and good dimensional stability of thermally modified wood results in enhanced service life of pigmented opaque coatings. UV resistance of thermally modified wood can be enhanced by application of coating containing UV absorber (e.g., benzotriazole derivatives). Heat treatment of wood using hot *pongamia* oil is very effective for inducing weathering resistance in wood.

Suggestions/ advisory note for end users "To-do-techniques":

The study indicated that UV degradation of thermally modified sapwood can be controlled by application of coating containing UV absorber (benzotriazole derivative). Thermally modified, particularly sapwood is susceptible to photo-degradation and hence needs polymer coating containing UV absorber for outdoor applications. Thermal modification of wood using hot *pongamia* oil was found to be very effective for inducing weathering resistance in wood. Therefore, wood treated with hot pongamia oil can be used for outdoor applications.

Research gaps:

There are inconsistent reports on UV resistance of thermally modified wood (TMW) with the majority of studies indicating its vulnerability to UV degradation.

Uses of research outcomes:

The results of this study indicate the limitation of uses of thermally modified wood for outdoor uses and recommend that additional protective measures against UV degradation is needed for its outdoor applications. Results are useful to wood based industries.

16. Title of the project: Pretreatment of *Pongamia Pinnata* seeds for deacidification and rapid oil extraction.

Principal Investigator: Dr. Ritesh Kumar D. Ram, Scientist-E, ICFRE-IWST Bengaluru

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

The present invention provides a process of deacidification of natural oil by doing simple pretreatment of seeds prior to oil extraction. It involves use of microwave as source of heating. With this pretreatment around 71% of deacidification was achieved. The acid value of control oil sample was found to be 1.68 mg KOH g-1. Acid value reduced significantly ($P < 0.05$) in pretreated seeds. The same may be attributed to the fact that in this invention, each water-soaked seed functions as an individual oil refining unit, where physical refining was underway. All other properties of oil remained intact under optimum condition.

Significant achievements/ findings of the project:

By adopting new seed pretreatment method oil extraction time has been reduced significantly. Due to prior treatment of seeds with microwave, almost 50% deacidification was achieved. Further, more gums were extracted, and the iodine value and saponification value did not vary due to microwave treatment. The peroxide value, oxidative stability and fatty acid composition of the oil remain unchanged under optimum condition.

Suggestions/ advisory note for end users "To-do-techniques":

This work relates to a development of novel technique of seed oil processing using microwave energy. In particular, the new process of microwave assisted seed pretreatment techniques offers seed oil extraction in short period of time as compared to conventional method. The novel pretreatment technique reduces FFAs (non-esterified) and other volatile impurities by almost 50%, without compromising other essential properties of natural oil. Furthermore, this new pretreatment technique is more environment friendly as it involves no chemical usage for deacidification.

Research gaps:

The two most commonly used methods for deacidification of vegetable oils (Vos) are chemical and physical refining method. Physical refining, which is also known as dry or steam refining, is based on the higher volatility of the FFAs as compared to the triglycerides. Factors that influence the stripping of volatile compounds from oil are temperature, pressure and amount of sparge steam. Alternative to these industrial practices, few new approaches are also taken up for deacidification such as aqueous oil extraction, miscellaneous deacidification, biological deacidification, enzymatic deacidification, solvent extraction, supercritical fluid extractionand membrane technology.

Uses of research outcomes:

Partial deacidification of seed oil prior to oil extraction from seeds may save cost of oil refining

17. Title of the project: Biological degradation and weathering behavior of wood-polymer composites.

Principal Investigator: Dr. Pankaj Aggarwal, Scientist – F, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research rheme and summary of the study:

The results of the study revealed the susceptibility of these composites against weathering degradations irrespective of fiber type, fiber content and coupling agent. Natural weathering for 12 months resulted in significant changes in colour, surface smoothness and also mechanical properties. The composite material became lighter in colour and lost up to 25% of its strength properties. The obtained data was statistically analyzed for effect of different parameters on weathering degradations. The composites were found to be resistant to both fungus and termites. In order to prevent weathering degradation, remedial measures have also been explored and use of UV stabilizer in combination with inorganic pigments was found to restrict the degradation process. Result of this study will help in deciding up on the composition and additives for their durability and performance depending the end-product

Significant achievements/ findings of the project:

Wood plastic composites were found susceptible of weathering degradation with change in colour during early stages of weathering followed by loss in mechanical strength on long term exposure to outside conditions. Among different fiber types, jute fiber reinforced composite exhibited maximum colour change. At low fiber content, the strength loss was ranging from 10 to 13% in composites after 12 months of weathering. At higher fiber content (50%), the strength loss was in the range of 13-18%. Weathering resulted in development of micro-voids on the surfaces of composite material. Presence of coupling agent though was not having any influence in colour change but had a positive impact on mechanical properties. Inorganic pigment namely ferric oxide along with UV stabilizers were found to be effective in maintaining the colour of the composites during outdoor exposure. Studies on biological degradation suggested natural durability of these composites against fungus and termites irrespective of the presence of coupling agent. Low moisture content in composites would have protected wood from fungal degradation. After 24 months of exposure to termite prone areas, mound was found to develop on few samples indicating the need for a long-term study on durability aspects.

Suggestions/ advisory note for end users "To-do-techniques":

The study indicated weathering as the most detrimental factor in WPC degradation and, therefore, need to be protected for enhancing service life and product performance. In the study, Hindered Amine Light stabilizers and inorganic pigments were evaluated for their efficiency in preventing weathering degradation. The combination of the stabilizer with inorganic pigments namely ferric oxide and titanium dioxide was found to maintain the colour of the composite and prevented weathering related loss in mechanical properties. The loss in strength values were reduced by more than 50% with the addition of 1% (wt%) pigment in the formulation. It is concluded that WPC with up to 50% fiber content prepared with coupling agent, UV stabilizer and inorganic pigments will give a product with superior mechanical properties and weathering resistance.

Research gaps:

Wood polymer composites are considered for many outdoor applications and products which are exposed to moisture and humid conditions. There are concerns regarding their resistance against weathering and biological degradation due to presence of wood component.

Uses of research outcomes:

Result of this study is to help in deciding up on the composition and additives for their durability and performance depending the end-product. The institute is already working in close association with few WPC based industries and the results can be shared with those industries.

Publication:

- Gunjal Jayashri, Aggarwal Pankaj and Chauhan Shakti (2020) Changes in colour and mechanical properties of wood polypropylene composites on natural weathering. *Maderas. Ciencia y tecnología*. http://dx.doi.org/10.4067/S0718-221X2020005000307.

18. Title of the project: Development of organo-metallic complex of *Eucalyptus* spp. and *Lantana camara* extracts and its evaluation as semi bio preservative

Principal Investigator: Ms. C.N.Vani, ACTO, ICFRE-IWST Bengaluru

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

The aim of this project is to develop alternative active organo-metallic complex by replacing arsenic component with natural preservatives derived from plant sources. These complex compositions are less toxic with natural botanicals and are safe for environment, renewable and biodegradable. In this study, extractives derived from *Eucalyptus camaldulensis* and *Lantana camara* (leaves, bark and wood) in combination with varying proportions of copper and chromium were used as preservative. The extracts of eucalyptus contained tannins and polyphenols which were toxic against wide range of microorganisms and insects. New formulations thus developed could be commercially formulated as efficient semi bio wood preservatives.

Significant achievements/ findings of the project:

Extractives from bark, wood and leaves were prepared using different solvents (viz, Hexane, acetone, alcohol and water) of varying polarity. Rubber wood samples were treated with extractives of the above species by pressure method and dipping method and were exposed to field test to study the toxicity of different extractives. Results of the initial experiment showed that alcohol and water extract after sequential extraction was performing better compared to other two solvents. This step was very important for selection of solvent extract for the preparation of organo-metallic complexes with inorganic salts i.e., Sodium dichromate and Copper Sulphate. Of the two extractives i. e. alcohol and water; water extractive performed better and solubility of this extractive and mixing with the inorganic salt was very good compared to alcohol extract. Fixation property of both the extractives was almost same. Both the extractives (Lantana and Eucalyptus) in combination are performing good. Eucalyptus bark and wood extractives are performing better compared to leaf extract.

Suggestions/ advisory note for end users "To-do-techniques":

The aim of this project was to develop alternative active organo-metallic complex replacing arsenic component with natural preservatives derived from plant sources. Excessive use of arsenic based preservative is posing serious problems to the environment. There is a need to reduce use of arsenic in wood preservatives and replace arsenic component with botanicals to make them less toxic to non-targets, more ecofriendly and applicable for industrial use.

Research gaps:

Conventional wood preservatives like CCA and CCB are considered to be unsafe for non-target organismsand therefore plant-based eco-friendly wood preservative needs to be developed.

Uses of research outcomes:

The study is very important from the point of view of environment improvement, as the use of CCA can be replaced with semi bio preservatives with low concentration of inorganic salts as they are more hazardous to the environment. Results from the study show that organometallic complexes of both the species separately and in combination were performing well under field conditions. New formulations developed could be commercially formulated as efficient semi bio wood preservatives.

19. Title of the project: Development of bamboo lumber using different bamboo species and evaluating its utilization potential as alternate to solid wood lumber for different structural applications.

Principal Investigator: Dr. S.K. Sharma, Scientist – G, ICFRE-IWST Bengaluru

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

The strength properties of these composite materials (Bamboo lumber) were found comparable or better than many commonly used conventional timber species. A few products have also been made using LBL and BSL for demonstration purpose. The project outcome has a great potential in today's market where there is scarcity of solid wood lumbers for utilization in various sectors and bamboo lumber may be an alternative for its use in furniture, construction and other sectors.

Significant achievements/ findings of the project:

In this research project, three low density plantation grown wood samples namely, *Maesopsis eminii*, *Ailanthus excelsa* and *Melia dubia* were impregnated with phenol formaldehyde (PF) and melamine formaldehyde (MF) thermosetting resins blended with nanoparticles (nano clay and nano silica). Blends of diluted resins and nanoparticles were prepared by dispersion process using ultra-sonication and high speed stirring. Testing of different physical and mechanical properties of treated and control samples was carried out as per IS standards. Improvements in density and flexural strength of ranging from 15-20% to 30-52% were observed after nano-resin impregnation. Dimensional stability and water resistance of impregnated wood have been enhanced. Flammability resistance was found to be increased due to presence of resin and nanoparticles in wood. Treated and control wooden stakes have been installed in graveyard test site and data collected regularly. Nano-resin treated wood samples have shown improved durability and decay resistance. Enhanced wood properties of nano-wood composites are of great importance for successful application of low-density woods in various value-added applications such as furniture, tiles, paneling, siding and other applications.

Suggestions/ advisory note for end users "To-do-techniques":

The effect of fire-retardant treatment on mechanical, bonding and fire resistance properties of LBL prepared from *Dendrocalamus brandisii* was evaluated during the study. The results showed that the fire-retardant treatment significantly improved the fire resistance of LBL prepared from treated strips of *D. brandisii*. However, the boiling treatment of strips in borax-boric acid solution was not effective as compared to the vacuum-pressure treatment of strips with 10% di-ammonium phosphate. The LBL prepared from treated strips with 10% di-ammonium phosphate solution passed the minimum requirements as recommended in IS 5509. The results also revealed that the mechanical properties namely, MOR, MOE and compressive strength parallel to grain were negatively affected by the fire-retardant treatments. Similarly, the bonding properties of the LBL prepared from treated strips of *D. brandisii* showed lower values as compared to LBL prepared from untreated strips of *D. brandisii*.

Research gaps:

The Laminated Bamboo Lumber can be manufactured into various sizes and shapes depending upon the availability of processing equipment. However, the performance of engineered bamboo composites is highly dependent on the species and processing parameters used for the production.

Uses of research outcomes:

The outcome of the project will be helpful for recommending the bamboo lumber as an alternative to solid wood for various applications such as in furniture sector, construction sector, etc. and are same being disseminated though workshops and conferences.

Publications:

- Kelkar B. U., Sharma S.K. and Shukla S.R. 2020. Optimizing pressing parameters of PF-bonded laminated bamboo lumber prepared using *Dendrocalamus brandisii*. *Journal of the Indian Academy of Wood Science* 17(2): 149-157.
- Kelkar B.U., Sharma S.K. and Shukla S.R. 2021. Comparative performance of phenol formaldehyde – bonded laminated bamboo lumber and bamboo strand lumber prepared from four different species. *Journal of Tropical Forest Science* 33(4): 418–429.

  Kelkar B.U., Sharma S.K. and Shukla S.R. 2021. Bamboo Lumber: a potential substitute to solid wood for various application. IWST Quarterly Magazine Wood is Good, Grow More-Use More 2(1): 41-46.

20. Title of the project: Value-addition of low-density woods by producing nano-wood-composites (NWC) with enhanced properties for high end applications

Principal Investigator: Dr. S.R. Shukla, Scientist – G, ICFRE-IWST Bengaluru

Duration: 2017 - 2021

Critical analysis of the research theme and summary of the study:
The aim of this work was to improve various properties of low-density wood material by impregnating polymeric thermoset resins blended with NC, NS and CNT nanoparticles. The planned treatments are likely to elongate the lifetime of treated wood and wood-based products, because the wood–water relations are essential at all utilization fields. The expected positive effect of investigated treatments is improvement of wood properties as a result of impregnation with hydrophobic nanoparticles fortified thermoset resins.

Significant achievements/ findings of the project:
In this research project, three low density plantation grown wood samples namely, *Maesopsis eminii*, *Ailanthus excelsa* and *Melia dubia* were impregnated with phenol formaldehyde (PF) and melamine formaldehyde (MF) thermosetting resins blended with nanoparticles (nano clay and nano silica). Blends of diluted resins and nanoparticles were prepared by dispersion process using ultra-sonication and high- speed stirring. Testing of different physical and mechanical properties of treated and control samples was carried out as per IS standards. Improvements in density and flexural strength of ranging from 15-20% to 30-52% were observed after nano-resin impregnation. Dimensional stability and water resistance of impregnated wood have been enhanced. Flammability resistance is found to be increased due to presence of resin and nanoparticles in wood. Treated and control wooden stakes have been installed in graveyard test site and data collected regularly. Nano-resin treated wood samples have shown improved durability and decay resistance. Enhanced wood properties of nano-wood composites are of great importance for successful application of low-density woods in various value-added applications such as furniture, tiles, paneling, siding and other applications.

Suggestions/ advisory note for end users "To-do-techniques":
Lower amount of nanoparticle (1%) fortified resin (20%) impregnated wood is recommended for interior applications; while comparatively greater amount of resin (30%) blended with 3% nanoparticle and impregnated in wood is observed to be more suitable for exterior condition. This easy and advanced process of producing nano-wood composites is advantageous towards value-added and successful applications of locally available fast grown low-density wood species in producing certain lifestyle products. A few prototypes such as centre and side tables, flooring tiles, etc. were fabricated using NWC for demonstration of utility products. Therefore, wood impregnation with water-soluble thermosetting resins fortified with nanoparticles by a vacuum-pressure method is an effective way to improve various wood properties of low-density timbers. The process has potential for scaling-up production and may be adopted by wood processing and product industry for value-added utilization of fast grown low density wood species.

Research gaps:
Short-rotation plantations typically produce wood with higher amount of sapwood and juvenile wood. While sapwood is non-durable, juvenile is associated with higher dimensional instability, lower density and mechanical propertieswhich seriously affect its potential for exterior applications.

Uses of research outcomes:
This study established the potential of nanoparticle-resin impregnation of potentially non-durable plantation species with standardized process parameters. These formulations are expected to open-up new frontiers of utilizing the fast-grown plantation resource of the country providing the value addition to these wood species. Knowledge generated is disseminated through publications, presentations in seminars, wood industry meets etc.

21. Title of the project: Evaluation of palm wood (*Borassus flabellifer* and *Areca catechu*) and their suitability for various applications.

Principal Investigator: Dr. S.K. Sharma, Scientist – G, ICFRE-IWST Bengaluru

Duration: 2019 - 2021

Critical analysis of the research theme and summary of the study:

The wood from both palmyra and areca palm are less in cost as compared to wood from other timber species. Palmyra palm timber can be classified as extremely heavy, very strong, tough, moderately steady and exceptionally hard. The wood can be efficiently utilized for tool handles, construction, furniture, wooden flooring, pallets, oars and paddles, door and window shutters and frames. The composite boards made from inner fibres as well as outer strips (after densification) will be less expensive as compared to other composite boards due to lower cost of raw material.

Significant achievements/ findings of the project:

Studies were carried out on wood quality of *Borassus flabellifer* (Palmyra palm) and *Areca catechu* (Areca palm) for their utilization as timber. The findings revealed that the timber of Palmyra palm can be classified as extremely heavy, very strong, tough, moderately steady and exceptionally hard. The wood can be efficiently utilized for tool handles, construction, furniture, wooden flooring, pallets, oars and paddles, door and window shutters and frames. The low-density core portion of both Palmyra palm and Areca palm was densified by impregnation of thermosetting resin and composite boards were made for value addition. The process can serve as a suitable method which can help in enhancing the utilization potential of inner soft portion of both the palms. Efforts are being made for finding industrial partners for mass production and utilization of Palmyra palm wood especially for furniture items.

Suggestions/ advisory note for end users "To-do-techniques":

The outcome of the project has a great potential in the market where there is scarcity of solid wood lumbers for utilization in various sectors and wood from palms (Palmyra and areca) may be an alternative for its use in furniture, construction and other sectors.

Research gaps:

There is a need to characterize the palm woods in terms of physical, mechanical, anatomical and durability properties and grade the material based on the properties for suggesting appropriate end uses. The value addition to the inner soft wood is also essential to realize its complete utilization potential.

Uses of research outcomes:

The outcome of the project will be helpful for recommending the palm wood as an additional source of material for various applications in furniture sector, construction sector, etc.

Publications:

- Sharma S.K., Shashikala S., Sujatha M. and Luies Harshitha 2021. Variation in specific gravity and vascular bundles in plantation grown *Borassus flabellifer* L. *Journal of Plant Development Sciences* 13(3): 93-97.
- Sharma S.K. and Kelkar B. U. 2021. Effect of densification on important physical and mechanical propertes of inner soft wood of *Borassus flabellifer* L. *Journal of the Indian Academy of Wood Science* 18 (1):39-44.
- Sharma S.K., Sujatha M., Shashikala S. and Jean Simon 2021. Utilization potential of Palmyra palm wood (*Borassus flabellifer* L.). IWST Technical Bulletin No. 24. PP 12.

22. Title of the project: Wood Plastic composites: Performance, sustainability, Environmental Impacts and life cycle assessment

Principal Investigator: Dr. Ritesh D. Ram, Scientist – F, ICFRE-IWST Bengaluru

Duration: 2019 - 2021

Critical analysis of the research theme and summary of the study:
The study aimed at less attempted gate-gate life cycle analysis which is important to study the environmental burden posed by any industry in the region at a microscopic level and gives an opportunity to reduce the negative impacts and correct the faults in the manufacturing units. The rise of the industries demands for the assessment of the production phase in order to ensure a livable environment and these results could help in the formation of better policies and industrial designs.

Significant achievements/ findings of the project:
There has been little literature on LCA on wood fiber filled thermoplastic composites although a significant scientific advancement has been made in production and utilization of WPC products. This may be due to the drive of using environmentally friendly materials. However, the literature shows a non-conclusive environmental effect when only the production phase of such composites is studied. During the cultivation stage, the use of pesticides and other types of chemical products can give a negative impact on the environment. On the brighter side, the use, recyclability and the disposal phase of such composites demonstrated a clear advantage from the environmental point of view. Sustainability analysis incorporating LCA will go a long way to understand societal and economic components as well.

Suggestions/ advisory note for end users "To-do-techniques":
The study concluded that higher environment impact from dependence on the coal-based energy source. Moreover, it can be concluded that the process units involving polymers resulted in higher energy consumption and CO_2 emission in comparison to the natural fibres, Therefore, introduction of natural fibre in the polymers can be regarded as sustainable with lesser environment impact.

Research gaps:
Life cycle analysis on production process involved in wood polymer composite are not many and therefore, this study was taken up.

Uses of research outcomes:
A life cycle assessment (LCA) according to ISO 14040 helps us in quantifying potential environmental impacts of product from to wood polymer composite industry.

Publication:
- Abhilash R.M., Gunjal J., Venkatesh G.S. and Chauhan S.S. 2022. Recyclability of bamboo polypropylene composites. *Journal of the Indian Academy of Wood Science* 11:1-7.

23. Title of the project: Development of natural fibre and charcoal filled hybrid polymer composites.

Principal Investigator: Dr. Ritesh D. Ram, Scientist – F, ICFRE-IWST Bengaluru

Duration: 2018 - 20201

Critical analysis of the research theme and summary of the study:

The present study was aimed at investigating the effect of charcoal which is obtained at different carbonization temperatures (300OC, 400OC, 600OC and 900OC) on thermal, mechanical and water absorption properties of BPCs. The charcoal was prepared from bamboo and coconut shell biomass. In general, better mechanical properties are obtained through BC as compared to CSC. The charcoal obtained at lower pyrolysis temperature (300OC and 400OC) enhances the strength properties of BPCs, whereas, strength properties reduces when charcoal prepared at elevated temperatures (600OC and 900OC) are added to BPCs.

Significant achievements/ findings of the project:

The incorporation of bio-fibers in thermoplastic composites as reinforcement has led to the emergence of wood plastic composites (WPCs). The inclusion of wood fibers into the polymer has resulted in increased stiffness and strength of composite material. The interfacial adhesion between bio-fiber and polymer is effectively improved and enhanced by use of coupling agent. Wood plastic composites (WPCs) have been widely used as interior automotive panel, garbage pails, crates, and garden equipment. WPCs have also made tremendous progress in exterior non-structural or semi-structural building products such as door and window frames, siding, decking, cladding, floor and roof tiles, fencing etc. The advantage associated with WPC is their excellent durability, dimensional stability, high rigidity, and relatively low density. However, the potential use of WPC is greatly restricted because of its poor fire resistance property and thermal degradation behaviour. Fire safety demand fire resistant material and therefore, incorporation of fire resistance agents in wood polymer matrix is essential to enhance the fire resistance properties of WPCs. In order to impart flame retardancy in WPCs, many fire retardants (FR) chemicals have been introduced.

Suggestions/ advisory note for end users "To-do-techniques":

Use of bamboo charcoal can increase the strength properties of wood polymer composite by 25 to 30%.

Research gaps:

Charcoal is an environmentally friendly material with excellent absorption properties. The unique properties of charcoal include its uniform composition and high porosity. Due to its tremendous adsorption capabilities, charcoal is used as adsorbents in water filters, gas masks, anti-bacterial/anti-fungal usages and antigastric tablets for people suffering from indigestion etc. Apart from these aforementioned benefits, charcoal is also used for enhancing properties of wood polymer composites (WPC). It has been reported that tensile modulus and flexural strength of resulting biocomposites increases by increasing the amount of biochar (up to 35%) in neat PP. However, no researcher in the past has evaluated exact quality of charcoal for property enhancement.

Uses of research outcomes:

The findings can be used to enhance the strength properties of wood polymer composite and to reduce the water absorption behaviour.

24. Title of the project: Study on flame retardancy and recyclability of natural fiber-polyethyline composites.

Principal Investigator: Dr. Ritesh D. Ram, Scientist – F, ICFRE- Bengaluru

Duration: 2018 - 2021

Critical analysis of the research theme and summary of the study:

In this study, bamboo polymer composite (BPC) was prepared by blending of high-density polyethylene (HDPE) with boric acid - borax (Ba-Bx) pre-treated bamboo fibers as reinforcement material and by using maleic anhydride grafted polyethylene as coupling agent. BPCs were incorporated with conventional flame retardants (FRs) additives such as ammonium polyphosphate (APP) along with nano particles such as silicon dioxide (nano-SiO2) and flame performance was investigated using cone calorimeter and limiting oxygen index analysis (LOI). While the flame and thermal properties of BPCs was improved significantly, the strength properties were marginally reduced due to application of FR additives. In general, APP as synergist with Ba-Bx improved thermal stability and flammability of BPCs.

Significant achievements/ findings of the project:

The incorporation of bio-fibers in thermoplastic composites as reinforcement has led to the emergence of wood plastic composites (WPCs). The inclusion of wood fibers into the polymer has resulted in increased stiffness and strength of composite material. The interfacial adhesion between bio-fiber and polymer is effectively improved and enhanced by use of coupling agent. However, wood being a lignocellulosic material is prone to water absorption and fiber swelling which ultimately affects its mechanical properties and durability. The development of micro cracks in the WPC due to fiber swelling also results in week interface of fiber-matrix. Thermal degradation while combustion is another area which requires improvement which has restricted the use of WPC in expansion into residential, furniture and construction sectors. Various physical and chemical routs have been explored to improve the water resistance and mechanical properties of WPCs, which has their own advantages and disadvantages.

Suggestions/ advisory note for end users "To-do-techniques":

The effect of FRs on BPCs is found to be statistically significant for FS, FM and TS. Compared to neat BPCs, the FS, FM and TS were reduced with addition of FRs, however, this reduction (FS and FM) was found to be more in samples containing nano-SiO2 2% along with Ba-Bx 5% and APP. The FS and FM of BPCs added with FRs (Ba-Bx 5% / APP 13% / nano-SiO2 2%) decreased significantly with each reprocessing cycle.

Research gaps:

Although the synergistic effects of the combination of APP with nanomaterials and APP with BCs on flammability of BPCs have been studied extensively, the synergistic effect of use of BCs along with APP and nano SiO_2 has not been investigated so far.

Uses of research outcomes:

The findings can be used to achieve flame retardancy in wood polymer composite

Publication:

- Kumar Ritesh, Gunjal Jayashri and Chauhan Shakti 2021. Effect of carbonization temperature on properties of natural fiber and charcoal filled hybrid polymer composite. *Composites Part B* 217: 108846.

25. Title of the project: Exploration of methods to enhance the shelf-life and fixative property of Neem based eco-friendly preservatives.

Principal Investigator: Sh. B.S. Chandrashekar, Scientist-E, ICFRE-IWST Bengaluru

Duration: 2017 - 2021

Critical analysis of the research theme and summary of the study:

The oil from the seeds and leave extractives were extracted. The leaf extract was subjected to precipitation to recover azadiractin and purified. The azadiractin was extracted from the leaves and compared with standard by TLC method for confirmation. The oil and extractives (with adjuvants) were observed weekly for deterioration under storage and the physical properties are evaluated. The oil and extracts were used for formulation with different adjuvants listed below in the combinations prepared.

Significant achievements/ findings of the project:

The extracted Phytochemicals was used in 13 different formulations and evaluated for shelf life. The physical properties like Refractive Index and specific gravity of the formulations are monitored regularly to evaluate their shelf life and fixative properties. The wood samples for field testing has been prepared and 6 short listed formulations were used to treat these samples and put got field test. (on Rubber, Melia and Mango wood).

The details of 13 formulations are as follows: -

1. Copper sulphate (1.25g) and Potassium dichromate (1.25g) in 100mL, 20mL neem oil, 1g *Prosopis juliflora* and 5ml Polysorbate 80.
2. Copper sulphate (1.25g) and Potassium dichromate (1.25g) in 100mL, 20mL neem oil and 5ml Polysorbate 80.
3. Ferric chloride (5g) in 100mL, 20mL neem oil and 5ml Polysorbate 80.
4. Copper sulphate (1.25g) and Potassium dichromate (1.25g) in 100mL, 20mL neem oil and 1g β-methyl cyclodextrin.
5. Ferric chloride (5g) in 100mL, 20mL neem oil and1g β-methyl cyclodextrin.
6. 10mL neem oil and 1g *Prosopis juliflora* complex.
7. 10mL neem oil and 1g *Acorus calamus* Methanolic extract.
8. 10mL neem oil and 1mL *Acorus calamus* oil.
9. 10mL neem oil and 1mL *Zanthoxylum rhetsa* oil.
10. 10mL neem oil and 1mL Patchouli oil (Pogostemon cablin).
11. 10mL neem oil and 1g *Acorus calamus* acetone extract.
12. Copper sulphate (1.25g) and Potassium dichromate (1.25g) in 100mL, 20mL neem oil 5ml Polysorbate 80 and 1g Gum acacia powder.
13. Copper sulphate (1.25g) and Potassium dichromate (1.25g) in 100mL, 20mL neem oil and 1g Gum acacia powder.

The wood samples were given prophylactic treatment with 2% Boric acid and 6 different neem-based formulations are prepared in bulk for treating the wood samples in replicates, so the same are put to graveyard test for evaluation. The wood samples have been given treatment with the six formulations along with control and standard preservative against termite attack as per IS 401 and IS 4833 (2001). The wood samples are placed in the field for accelerated test assessment. For accelerated test the experiment will be concluded in one year. The stakes will be monitored in regular time intervals and data will be collected. The accelerated test data is recoded in different time intervals.

Suggestions/ advisory note for end users "To-do-techniques":

As of now in accelerated wood treatment there is a significant efficiency shown by six different formulations. The efficient formulation can be further taken up for production of stable and eco-friendly wood preservative. As per suggestions by ICFRE the efficient formulation will be further evaluated and IPR will be applied for.

Research Gaps:

Long-termevaluation of efficient formulations in the fieldare required to be carried out.

Uses of research Outcomes:

Stakeholders are furniture industries, wood and panel industries.

26. Title of the project: Studies on propagation of a valuable timber species, *Diospyros ebenum* J. Koenig ex Retz. through seeds and *in vitro* techniques.

Principal Investigator: Smt. Tresa Hamalton, Scientist – D, ICFRE-IWST Bengaluru

Duration: 2017 - 21

Critical analysis of the research theme and summary of the study: Nil

Significant achievements/ finding of the project:

This research project addresses the development of propagation techniques for ebony through seeds and micropropagation. *D. ebenum* seeds were germinated *ex vitro*, after studying fruit and seed morphology. Protocols for surface sterilization and *in vitro* seed germination, and surface sterilization of leaf and nodal explants for in-vitro culture establishment were standardized. The effect of PGRs and additives on *in vitro* culture establishment from nodes and leaves were studied. *In vitro* shoot induction of 40% from nodes, and 80% callus induction from leaf were achieved. *Ex vitro* petiolar root induction was achieved in leaves treated with IBA.

Suggestions/ advisory note for end users "To-do-techniques":

In vitro seed germination, *in vitro* culture establishment of leaf and nodal explants followed by callus induction and axillary shoot induction, and petiolar root induction have been achieved for the first time for the highly valuable timber species, *Diospyros ebenum*. The technology can be used by the SFDs and tree growers.

Research gaps:

Further studies on the nature and germination behaviour of the seeds, is required to aid in artificial regeneration. There are no reports on the use of macropropagation and micropropagation techniques for this species till date.

Uses of research outcomes:

Propagation methods will be shared with SFDs and nursery growers.

Publications:

- Hamalton T., Jaganathan R. and Khanam A. 2020. *In vitro* culture establishment and seed studies of *Diospyros buxifolia* (Blume) Hiern - A slow growing timber species of Western Ghats. *European J. Biotechnol. Biosci*. 8 (1): 15-20.
- Hamalton T., Pooja S.J. and Khanam A. 2021. Propagation of the true ebony, *Diospyros ebenum* Koenig: A Review. *Jour. Pl. Sci. Res*. 37 (1) 231-236.

27. Title of the project: Development of transparent wood composite and evaluation of its properties.

Principal Investigator: Dr. K.K. Pandey, Scientist – G, ICFRE-IWST Bengaluru

Duration: 2019 - 2021

Critical analysis of the research theme and summary of the study:

The photostability of transparent wood composite (TWC) was evaluated by exposing TWC sheets to a UVA340 fluorescent lamp in an accelerated weathering tester. TWC was highly sensitive to UV light exposure and exhibited rapid photo-discolouration, chemical degradation and a decrease in optical transmittance. Incorporation of UV absorber in epoxy resin considerably reduced discolouration and photo-degradation of TWC. Moisture absorption behaviour (water uptake) of TWC was also evaluated by immersing it in water. The results indicated that TWC undergoes significant photo-degradation and needs application of UV stabilizer for its outdoor applications. Highly UV stable TWC functionalized with an UV-absorber was fabricated. Suggested potential application areas for scalable utilization of TWC are also discussed.

Significant achievements/ findings of the project:

Transparent wood composite with infiltration of epoxy resin in veneers of Poplar, Silver oak and *Melia* wood were prepared. Optically high transparent wood with high haze can be obtained through two step sequential approach of lignin modification bleaching followed by epoxy resin infiltration. Low density and highly porous wood supplement was easy and fast processing. Enlarging the thickness leads to decreased transmittance due to longer pathways for light transmission. Mechanical properties of transparent wood indicate a synergistic association with wood substrate and epoxy resin since the mechanical properties of transparent wood lies in between these two components. Thus, obtained transparent wood has shown low thermal conductively and good thermal stability. Moreover, low density and shatterproof nature makes it as an excellent choice for several application including light transmitting building materials, solar cells and illuminating objects.

Suggestions/ advisory note for end users "To-do-techniques":

The photostability of TWC was evaluated by exposing TWC sheets to a UVA340 fluorescent lamp in an accelerated weathering tester. TWC was highly sensitive to UV light exposure and exhibited rapid photo-discolouration, chemical degradation and a decrease in optical transmittance. Incorporation of UV absorber in epoxy resin considerably reduced discolouration and photo-degradation of TWC. Moisture absorption behaviour (water uptake) of TWC was also evaluated by immersing it in water. The results indicated that TWC undergoes significant photo-degradation and needs application of UV stabilizer for its outdoor applications. Highly UV stable TWC functionalized with an UV-absorber (2-(2H Benzotriazol-2-yl)-4, 6-di-tert-pentylphenol) was fabricated.

Research gaps:

Transparent wood composite (TWC) is an emerging material and very limited research is being done in this field.

Uses of research outcomes:

Developed process of transparent wood composite and evaluated UV stability of this material which is important for its outdoor applications particularly as building material and base material for solar cell.

Publication:

- Bisht P., Pandey K.K. and Barshilia H.C. 2021. Photostable transparent wood composite functionalized with an UV-absorber. *Polymer Degradation and Stability* 189: 109600.

Patent:

- Patent granted on invention titled "Transparent Wood Composite". Patent No. 376245

28. Title of the project: Distinguishing *Dalbergia latifolia* Roxb. and *D. sissoo* DC. woods using anatomy, chromatography, near infrared spectroscopy and molecular marker techniques**.**

Principal Investigator: Dr. Rakesh Kumar, Scientist – F**,** ICFRE-IWST Bengaluru

Duration: 2020 - 2023

Critical analysis of the research theme and summary of the study:

Wood anatomy has limitations as it is time consuming, and in some instances, identification is only possible up to genus level. Also, distinguishing between closely related look-alike wood samples of the same genus using anatomical tool is very difficult when most of the anatomical characters are overlapping.

Significant achievements/ findings of the project:

It is appropriate to integrate other tools of identification such as chemical finger printing using TLC, UV-Vis. and NIR spectroscopy, and DNA barcoding along with anatomy, since these techniques were found to potentially distinguish *D. latifolia* and *D. sissoo* woods. This study demonstrated that the integrated approach is able to distinguish wood samples of the two species from the same genus, despite their look-alike nature in the traditional wood identification process.

From analysis, it was observed that *D. latifolia* was difficult to distinguish from *D. sissoo* on the basis of anatomical features only as most of the features were overlapping. Fibre, vessel and ray characteristics did not show significant variation between the two species, although, sometimes colour and density of both wood species may differ slightly and may be treated as initial parameter.

From the TLC study it was observed that extract of *D. latifolia* showed yellow prominent spot which was completely absent in *D. sissoo*. From the UV study, a common peak was observed at ~290nm in both D. latifolia and D. sissoo where as a peak at around 350 nm was only observed in D. sissoo which is a distinguishable character.

The multivariate analysis (PCA and PLS-DA) of NIR spectra of *D. latifolia* and *D. sissoo* wood samples confirmed the potential of NIRS technique in distinguishing the two look-alike wood species. Based on the NIR spectra collected, the PLS regression models developed for estimation of a few physical and chemical parameters of these two commercially important wood species have shown potential of NIR spectroscopy as a rapid quality assessment tool, which may be used in wood-based industries.

On comparison of the nucleotide sequences of the barcode regions for *Dalbergia latifolia* and *D. sissoo*, their matK sequences were found to be clustered separately in the phylogenetic tree. Hence, it is concluded that phylogenetic analysis of the matK region can be used for species discrimination between the two species. From the nucleotide sequence alignment, species specific single nucleotide polymorphisms were observed in the matK and rbcL sequences, which can be used to distinguish *D. latifolia* and *D. sissoo* samples.

Research gaps:

Traditional methods of wood identification rely on macro- and micro-characteristics, which often closely resemble those of species within the same or related genera. This similarity poses a significant challenge in accurately distinguishing between species at the anatomical level.

Uses of research outcomes:

The outcomes of this research hold the potential to accurately discriminate between wood samples of *D. latifolia* and *D. sissoo*

29. Title of the project: Evaluation of coconut shell pyrolytic oil (CSPO) as wood preservative for industrial applications.

Principal Investigator: Dr. R. Sundararaj, Scientist – G, ICFRE-IWST Bengaluru

Duration: 2020 - 2023

Critical analysis of the research theme and summary of the study:

Wood is susceptible for insect and microorganism attack, though heartwood of some species is naturally durable. Rubber wood is cultivating as a plantation species and it is the second largest plantation crop. Rubber wood is less durable. Preservative application can make rubber wood more durable. Several timber preservation methods are used such as boron diffusion treatment, Vacuum pressure impregnation method, dipping method are the most common methods of rubber wood treatment. The main objective of this study is to develop an eco-friendly wood preservative formulation by extracting the coconut shell pyrolytic oil from the raw coconut shells through pyrolysis. Pyrolysis is a thermal decomposition technique which decomposes carbonaceous bio wastes into liquids, gases, and char (solid residue) in the absence of oxygen. As a result, it produces bio-oil which in turn can be used as an effective wood preservative.

Significant achievements/ findings of the project:

Raw CSPO was distilled at two temperatures 850 C and 1000 C and the distillates were formulated with copper sulphate, Boric acid, and $ZnCl_2$ and the formulations were evaluated. Bioefficacy studies were studied at six agroclimatic conditions and all the formulations were found effective up to one year after treatment in graveyard conditions. The developed formulations were found have miscibility, solubility and stability characteristics for one year. Data on the leachability were generated. For plywood purposes the formulations were found ineffective

Suggestions/ advisory note for end users "To-do-techniques":

Raw CSPO was distilled at two temperatures 850 C and 1000C and the distillates were formulated with copper sulphate, Boric acid, and $ZnCl_2$ and the formulations were evaluated. Bioefficacy studies were studied at six agroclimatic conditions and all the formulations were found effective upto one year after treatment in graveyard conditions. The developed formulations were found have miscibility, solubility and stability characteristics for one year. Data on the leachability were generated. For plywood purposes the formulations were found ineffective

Research gaps:

In case of panel products it can be further worked out to modify the resin systems to accommodate the coconut shell pyrolytic oil (CSPO) in glue line treatment as it is failed with convenient resin systems such as Urea Formaldehyde and Phenol Formaldehyde.

Uses of research outcomes:

Stakeholders were identified and discussions are going on to transfer the technology.

Publication:

- Vani C.N., Prajwal S., Sundararaj R. and Dhamodaran T.K. (2022). Chemical preservatives in wood protection. In: Science of Wood Degradation and its Protection Ed.: Sundararaj R., Springer https://doi.org/10.1007/978-981-16-8797-6_16.

30. Title of the project: Properties of cross laminated timber from plantation grown hardwoods.

Principal Investigator: Dr. Anil Sethy, Scientist – E, ICFRE-IWST Bengaluru

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Cross Laminated Timber (CLT) is an engineered wood composite and used in mass timber constructions. Mostly softwoods are commercially used for CLT production. This study assessed the suitability of selected locally grown plantation hardwoods for CLT, both in homogenous as well as in hybrid configuration.

Significant achievements/ findings of the project:

Cross Laminated Timber (CLT) produced from plantation grown hardwoods (*Hevea brasiliensis*; *Melia dubia*, *Grevillea robusta* and *Eucalyptus* hybrid) meets the delamination as well as block shear strength requirement as per the European Standard. The block shear strength values obtained were higher than the values reported for softwoods. Other mechanical properties of hardwood CLT were either comparable of better than that of softwoods CLT. Species mix did not affect the bonding behavior of the lamellas. Species mix provides opportunities to maximize resource utilization and control the density as well as mechanical properties of CLT. Bifenthrin was found very effective against both fungus and termite attack without having any negative effect on bonding efficiency of adhesives.

Suggestions/ advisory note for end users "To-do-techniques":

The technology of CLT provides opportunity to use small dimension plantation grown hardwoods to manufacture massive structural wood composites. Use of locally grown short rotation timber in CLT manufacturing not only minimizes the import bill, but also reduces the carbon foot print of the material associated with import.

Research gaps:

Cross Laminated Timber (CLT) is a massive multi-layer engineered panel wood product for structural application. There is very little information available on the properties and performance of CLT in Indian context.

Uses of research outcomes:

Development of process for CLT from plantation grown hardwoods be utilized as mass timber in building construction.

Publication:

- Maithani P., Chauhan S.S. and Sethy A.K. 2023. Polyurethane bonded cross-laminated timber prepared from *Pinus radiata*. *J Indian Acad Wood Sci*. https://doi.org/10.1007/s13196-023-00315-0.

31. Title of the project: Development of oriented natural fiber reinforced wood plastic composite panels.

Principal Investigator: Dr. Ritesh D. Ram, Scientist – F, ICFRE-IWST Bengaluru

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

The best mechanical properties can generally be obtained for composites when the fibre is aligned parallel to the direction of the applied load. However, it is more difficult to get alignment with natural fibres in extrusion. Some alignment is achieved during injection moulding, dependent on matrix viscosity and mould design. However, to get to higher degrees of fibre alignment, long natural fibre can be placed manually in sheets prior to matrix impregnation or alternatively traditional woven fibres can be employed. The project envisages the development of long fiber reinforced wood polymer composites with superior mechanical strength and stability using hot-pressing or compression moulding. Woven and non-woven fibers were used in the form of fabrics (jute, banana, etc.) with specific orientation and varying proportion along with WPC. The developed hybrid composites are characterized for physical and mechanical properties. The process provided an opportunity to tailor the properties of composites by altering the orientation of fibers and their proportions.

Significant achievements/ findings of the project:

This project was aimed to prepare an oriented long natural fiber panel product bonded with short natural-fiber reinforced thermoplastic composite and process thereof where in short natural fiber reinforced (NFRT) thermoplastic is used as a binding agent to bind long oriented fibers (such as from jute, banana, sisal) used in the form of fabric. The present invention further developed a layered composite product (3-layer, 5-layer, etc.) by admixing short natural fibers along with thermoplastic polymer (high-density polyethylene, polypropylene, and poly butylene adipate-co-terephthalate) and suitable coupling agent at optimum temperature, pressure and time. It also provided a combination of excellent bonding performance of NFRT to manufacture long natural fiber composite and improved mechanical properties to composite panel products.

Suggestions/ advisory note for end users "To-do-techniques":

Result of this study indicated that FS, FM and GS strength of hybrid plywood panels increased significantly with increase in fiber content in BPC, optimally up to 30%. TS increased marginally with increase in fiber content i.e., in PP/BPC and HDPE/BPC, whereas, its values increased significantly with fiber content in PBAT/BPC, optimally at 30%. Water absorption studies revealed that despite the addition of bamboo in polymers, the ultimate effect on water absorption and volumetric swelling in plywood was not very much affected by bamboo content. The plywood prepared with BPC prepared with different polymers absorbed 20-26% water after soaking the panels for 24 hours in water. SEM images confirmed proper flow of natural fiber reinforced thermoplastic adhesive over wood veneers and its penetration within the pours upon melting. It can be concluded that manifestation of mechanical interlocking between BPC and wood veneers, along with improved compatibility between BPC and wood veneer via suitable coupling agent and higher aspect ratio of bamboo fibers reinforced into the polymer matrix are the important reasons for improved strength properties (FS, FM, GS, Izod impact) in BPC bonded plywood panels.

Research gaps:

Wood polymer composites are characterized with low strength and stiffness as compared to wood but suffer from poor impact strength. Reinforcing WPC with oriented long fibers is the strategy to further improve the properties and also develop WPC based panel products. WPC based panel products are relatively less explored.

Uses of research outcomes:

Industrially scalable novel hybrid composite material has been developed for panel products having high strength and stiffness suitable for semi-structural applications.The developed composites could form an alternate to traditional wood-based composites.

Publications:

- Arya S. and Chauhan S. 2022. Preparation of plywood panels using waste milk pouches as an adhesive. *Maderas. Ciencia y tecnología*: 24.
- Arya S., Chauhan S. and Kumar R. 2022. Plastic bonded plywood using waste polypropylene container. *Materials Today: Proceedings* 67:471-7.
- Arya S., Kumar R., Chauhan S. and Kelkar B. U. 2023. Development of natural fiber reinforced thermoplastic bonded hybrid wood veneer composite. *Construction and Building Materials* 368:130459.

32. **Title of the project:** Management of Marihal bamboo (*Dendrocalamus stocksii* (Munro) M. Kumar, Remesh & Unnikrishnan) and *Dendrocalamus strictus* in agroforestry and block plantations

Principal Investigator: Dr. Syam Viswanath, Scientist-G and Dr. N. Ravi, Scientist- E, ICFRE-IWST Bengaluru

Duration: 2017 - 19

Critical analysis of the research theme and summary of the study:

The project was envisaged to develop methodologies to sustain the productivity of bamboo plantations and to have a better understanding on the feasibility of appropriate intercrops in bamboo agroforestry practices to increase the productivity of the bamboo plantations with intermediate income to the stake holders. The project was also focused to develop appropriate clump management schedule for *D. stocksii* and *D. strictus* in agroforestry and to assess the feasibility of *D. stocksii* and *D.strictus* as an alternate land use in semi-arid conditions with respect to soil carbon stock assimilation and carbon sequestration, a strategy for climate change mitigation. The intercropping of bamboo with red gram, field bean and ragi, increased the soil fertility and thus increased the growth of bamboo. The yield of the intercrops could not be ascertained due to failure of rainfall during the project period. The culm production can be increased by harvesting particular number of culms at regular interval. Over harvesting of culm affect the productivity of the clump. Growing of bamboo has to be encouraged more and more, as the species grows fast and playing important role in fixing the carbon through it high potential to convert in to biomass and stores more soil carbon through more litter production. The application of manure, intercropping and management need to be undertaken in all different forms of agroforestry model to increase the income of the farmers and also to meet the demand of the industries, and also mitigate the climate change.

Significant achievements/ findings of the project:

The experiment carried out in the rainfed area of Karnataka provided the possibility of increasing the production of *D. stocksii* and *D. strictus* by application of organic and inorganic amendments with different combination. Inter cropping in bamboo plantations increases fertility of the soil and also increases the growth of the culm. Intercropping also provides additional income to the farmers. Intercropping with bamboo in different spacing would give sufficient information for increasing the productivity of the bamboo and also to increase the livelihood of the farmers. Management of clump by removal of limited number of culms in a regular interval of time increase the culm productivity. The litter production of the bamboo clearly indicated the potential of the bamboo species in fixing the atmospheric carbon and making the soil in the bamboo plantations as a good source of carbon sink.

Suggestions/ advisory note for end-users "To-do-techniques":

Bamboo plantations are raised by farmers and the area under bamboo cultivation is increasing. The yield of the bamboo plantations comes down due to poor management after the initial planting, which resulted in decline in productivity. Proper management of bamboo clumps with sufficient nutrient application will increase the productivity. Adopting proper agroforestry model with intercropping will provide additional income to the farmers to increase the socio-economic status.

Research gaps:

Suitable methodology is lacking to increase the productivity of bamboo plantations in semi-arid areas using silvicultural and management practices, and also to study the soil carbon assimilation in bamboo plantation.

Uses of research outcomes:

Dendrocalamus stocksii and *D. strictus* are most suitable species for the semi-arid areas in Karnataka and their productivity can be increased by following management activities like spacing, application of fertilizers and culm management.The intercropping of bamboo with red gram, field bean and ragi, increased the soil fertility increased the growth of bamboo.The litter fall from the bamboo culms also fixes the atmospheric carbon and also increases the fertility of the soil.

Publication:

- Lubina P.A., Rajan Aparna, Pavithra G.M., Ravi. N., Anilkumar K.S and Viswanath S 2019. Assessment of Soil organic carbon stocks in *Dendrocalamus stocksii* and *Dendrocalamus strictus* plantations in three different agroclimatic zones. *J. Bamboo and Rattan* 18 (3): 55 – 62.

33. Title of the project: Establishment and evaluation of Provenance cum progeny trial of *Aquilaria malaccensis* (Agar) in Karnataka and Goa (Phase-I)

Principal Investigator: Dr. N. Ravi, Scientist- E, ICFRE-IWST Bengaluru

Duration: 2017 - 2022

Critical analysis of the research theme and summary of the study:

Aquilaria malaccensis, agar, is known for its agar wood, which has high demand for its fragrance. It is introduced in southern part of India as cash a crop. The search for profitable farming has made farmers/ companies of this region to choose Agar for its commercial value in the international market. The uncontrolled domestication of the species will lead to genetic loss and reduce the capability of the plant system to evolve itself to withstand the challenges caused by the introduced environment. Successful adaptation of the plant along with the success in methodologies to produce agarwood will make the introduction of this species beneficial to the farmer. The activities under this project aimed at establishment of provenance and progeny trial for the evaluation of their performances, and future utilization as seedling seed orchard to provide quality seeds for commercial utilization and to increase the productivity through organized research programme.

Significant achievements/ findings of the project:

Seeds from 42 seed lots from the natural distribution area of North East were collected. The progenies raised from the 42 known sources were established as provenance-cum-progeny trial in statistical design (CRBD) in two locations i.e. University of Agriculture and Horticulture Sciences (UAHS) Shimoga in Karnataka and Valkini (Goa Forest Dept.), South Goa in Goa with one control each from Karnataka and Tamil Nadu. The fruit and seed parameters showed considerable genetic variation among the seed lots. It showed positive correlation between fruit and seed characters except for fruit thickness which recorded a weak negative correlation with the seed characters. The established Provenance and Progeny trials were maintained for production of quality seeds for raising populations with known pedigree for future improvement program. The analysis of growth data at 1 year showed the seed lots from Assam and the local landraces performed better than other seed lots.

Suggestions/ advisory note for end-users "To-do-techniques"

Introduction of agarwood in south India will open the avenues for income generation through increasing the productivity.

Research gaps:

The natural habitat is to be conserved to collect fruits and to capture the variability exists among the selected trees, and to conserve them for establishment of base population.

Uses of research outcomes:

Provenance cum progeny trials of agar were established in Karnataka and Goa for long-term study on performance of different progenies and for further study on improvement in growth and agarwood production in Karnataka.

Publications:

- Ravi N., Hegde R., Salimath Supriya K., Rajan Aparna, Shilpa Shenoy S. and Bordoloi S. 2020. Variability Studies in Fruits and Seed Characters of *Aquilaria malaccensis*. *Int. J.Curr. Microbiol. App. Sci*. 9(11): 2096-2107.
- Ravi N., Rajan Aparna, Ravi Kumar G., Sunny A., Ravindra M. and Bordoloi S. 2020. A Preliminary study on physico-chemical evaluation of agar (*Aquilaria malaccensis*) seed oil from three different locations. *International Journal of Research in Applied*, *Natural and Social Sciences*, Vol. 8: 1–10

34. Title of the project: Development of Allometric Models for Estimating Volume and above-ground Biomass for Important Tree Species of Outside the Forest (TOF) in Assam.

Principal Investigator: Sh. Ajay Kumar, Scientist-D, ICFRE-RFRI Jorhat

Duration: 2018 - 2021

Critical analysis of the research theme and summary of the study:
Wood or timber is the principal tangible product of forest or Trees Outside Forest (TOF). Accurate estimation most important measurement for the management of any forest stand or trees outside of forests whether these are being managed for timber production or carbon sequestration or any other purpose. This estimation is done using different species specific volume equations or volume tables. There are standard methodologies including allometric equations available for tree growing in natural forests and naturalized plantation forests. There is a lot of variation in the site factors and treatment given to the forests and TOFs due to which the growth of trees and tree biomass accumulation in forest and TOF areas was also different. Details of the allometric equations vary with environmental conditions and tree growth, and these differences do matter. These differences generate uncertainty in the accurate estimation of wood volume of TOF. The present research project fills this knowledge gap by developing species-specific local and general volume equations for accurate estimation of volume, growing stock, biomass, and carbon content of the 10 most occurring trees outside forests in the state of Assam.

Significant achievements/ findings of the project:
Specific local and general volume equations for *Aquilaria malaccensis, Albizia* spp., *Tectona grandis, Artocarpus heterophyllus, Gmelina arborea, Bombax ceiba, Neolamarckia cadamba, Mangifera indica* and *Alstonia scholaris* were developed for TOF in Assam by using electronic Basal Area Factor Scope – Dendrometer. Study showed the volume equations developed for the trees growing in natural forests were not suitable for the same tree species growing in TOF as there was a variation in growth and biomass accumulation between the trees growing in natural forests and TOF.

Suggestions/ advisory note for end-users "To-do-techniques":
Methodology and equipment used in this project can be a very good guidance manual for the researchers who want to do research in forest biometry and allied subjects. Volume, biomass and carbon tables of the studied species can be prepared by using these volume equations for the use of state forest department of Assam. Besides this, the results of the study can be used further by the Forest Survey of India and other agencies in the estimation of above-ground biomass, carbon and carbon sequestration potential of TOF.

Research gaps:
The research project was designed to fill knowledge gap by developing allometric equations using non-destructive approaches.

Uses of Research Outcomes:
Results of the study can be used further in estimation of above ground biomass, carbon and carbon sequestration potential of TOF. It provides scientific advancementin economic valuation of ecosystem services of protected areas. Findings of the project will be of a great use in accurate estimation of growing stock and biomass as well carbon of TOF in Assam.

GENETICS AND BIOTECHNOLOGY

GENETICS AND BIOTECHNOLOGY

1. **Title of the project:** Clonal Propagation, Characterization and Biochemical analysis of *Leptadenia reticulata*- A Threatened Medicinal Plant

Principal Investigator: Dr. Sarita Arya, Scientist-G (Retd.), ICFRE-AFRI Jodhpur

Duration: 2016 - 2020

Critical analysis of the research theme and summary of the study:

Leptadenia reticulata, commonly known as Jivanti/Dodi/Dudi, is a valuable but threatened medicinal plant belonging to the plant family Apocyanaceae. This plant is medicinally important owing to its active constituent 'stigmasterol' which has lactogenic/galactogenic effect. It has also been documented as stimulant, eye tonic, astringent, used in controlling habitual abortion and maintaining pregnancy. It is an important ingredient of *Sudarshanchurna, Chyavanprassha*, and some other veterinary drug formulations. Due to its multipurpose uses, there is a huge demand for this species in the pharmaceutical industry which has led to its over-exploitation and caused the species to become endangered. There has been widespread habitat destruction which has also added to poor reproduction and propagation. Being an out breeding species, the seeds cannot be used to propagate true-to-type plant material. Hence, a need was felt to take up tissue culture for the species with the view that the technology so developed will help in mass-multiplication of high-yield genotypes and help in conservation of this species. The work undertaken under this project was aimed at standardizing the tissue culture conditions for *Leptadenia reticulata* using nodal segments as explants as well as through callus induction.

Significant achievements/ findings of the project:

It was found that 0.2% $HgCl_2$ provided the maintenance of highest degree of aseptic conditions (93.33%), but it also gave almost similar efficacy at 0.1% concentration (92.50% aseptic cultures). Pre-treatment with Bavistin and antibiotics streptomycin and tetracycline improved the sterilization during rainy season. Season played important role in successful establishment of nodal explants, with maximum bud break response (in %) achieved during March to June. Maximum bud break (90%) response, with 2-4 shoots, was observed in modified MS (containing ammonium nitrate and potassium nitrate in ½ amounts and KH_2PO_4 and $MgSO_4$ in 2x amounts, antioxidants (ascorbic and citric acids), adenine sulphate and ammonium sulphate) supplemented with 5.0 mg/L BAP. Additionally, the best *in vitro* shoot multiplication response was obtained with 2.0 mg/L BAP in a modified MS medium (also containing Arg and Asp). Best results for root induction in the *in vitro*-raised shoots were obtained on ¼ MS supplemented with 2.0 mg/L IBA and 100 mg/L activated charcoal, resulting in 82.50% rooting with an average of 7.83 roots. Under ex vitro conditions, 50% *in vitro* shoots were found to produce roots on IBA (2.0 mg/L) supplemented MS medium. Hardening was achieved by gradually opening the lid of culture jars and thereafter shifting the plantlets to polybags containing 1:1:1 sand: soil: FYM mixture after 4-5 weeks. Best results for callus induction and proliferation were observed for immature seeds on modified MS supplemented with 2,4-D (2.0 mg/L), and modified MS supplemented with 2,4-D and BAP, respectively. Callus was subjected to organogenesis as well as embryogenesis. Callus raised from leaves and internodal segments resulted in organogenic callus and callus raised from immature seeds and flowers resulted in embryogenic callus. Also, best embryo induction and germination was observed in embryos formed from calli obtained from flowers on hormone-free MS medium. Plantlets so formed were successfully hardened and shifted outside.

Suggestions/ advisory note for end-users "To-do techniques":

The project led to selection of superior plants of *Leptadenia reticulata* and development of tissue culture protocol for this important species. Future studies in this species may lead to produce improved planting stock with higher potential for its large-scale commercial uses.

Research gaps:

Protocol could not be scaled up for mass production of quality planting stock of of *Leptadenia reticulata*.Extensive research exploration is required to characterize active constitute from this plant for exploiting their therapeutic utility, using GCMS/LCMS.

Uses of research outcomes:

Developed protocol can used for cloning the high value germplasm and its further dissemination. Somatic embryos obtained in the study can be used in synthetic seed production, germplasm conservation and cryopreservation.

Publication:

- Kanwar N., Arya S., Kataria V. and Arya, I. D. 2018. *In vitro* studies on multiplication and *in vitro* plant regeneration from callus of *Leptadenia reticulata*. *Recent trends in plant propagation. Genetic Improvement & Industrial Applications* 195 pp.

2.. **Title of the project:** Development of Seed Production Areas and Haploid Plants of *Commiphora wightii* Arnott, a Rare and Threatened Medicinal Plant

Principal Investigator: Dr. U. K. Tomar, Scientist-F (Retd.), ICFRE-AFRI Jodhpur

Duration: 2016 - 2020

Critical analysis of the research themes and summary of the study:

Commiphora wightii also known as *guggul* has economic value and a wide array of medicinal importance. It is basically used for its oleo-gum resin commonly known as *guggul* gum. Exploitation of this species has led to decline in its population continuously making this plant vulnerable and categorised as data deficient in assemblage of IUCN. Seed viability and germination has always been a major setback for raising nurseries, mass scale production and domestication of this species. As a consequence of poor seed setting and further seed germination resulted in extremely low regeneration. Studies carried out at ICFRE-AFRI, Jodhpur provided information on density and distribution of *C. wightii* in Rajasthan. The study clearly indicated poor regeneration is due to the poor density of *C. wightii* at natural locations. Also there is high variation in seed vigour and viability due to genetic and climatic reasons. To strengthen the past work, more sources and superior mother trees need to be identified and reach to the uses. Keeping all this in mind the project was taken up to identify superior genotypes on the basis of seed quality and viability, potential seed production areas and conservation of important female genotypes and rare male plants.

Significant achievements/ findings of the project:

It was found that the ratio of two types of seeds (black and white) was greatly influenced by the season where winter season supported more viable black seed production. On the basis of seed quality, 25 superior genotypes and growth performance of 6 six superior families were shortlisted, having an asset of 7500 superior families, mother and male plants of *Commiphora wightii* as valuable FGRM.

Suggestions/ advisory note for end users “To-do-techniques":

The results of the study could be beneficial for stakeholders as resources available can be used for establishment of seed production areas in Rajasthan and Gujarat.

Research gaps:

The work was done primarily only in the states of Rajasthan and Gujarat. However, other states where Guggal is found have not yet been explored.SSR markers based study has not yet been conducted.

Uses of research outcomes:

AFRI identified superior genotypes and also identified few male plants of Guggul which are extremely rare. Seed production areas can be demarcated from Rajasthan and Gujarat. The superior genotypes have been multiplied through rooting of cuttings.

3. **Title of the project:** Development of Tissue Culture Protocol for Economically Important Bamboo - *Schizostachyum dullooa.*

Principal Investigator: Dr. Sarita Arya, Scientist-G (Retd.), ICFRE-AFRI, Jodhpur

Duration: 2016 - 2020

Critical analysis of the research theme and summary of the study:

Schizostachyum dullooa (dolu bamboo) is in large demand in kite making industry due to its long internodes. To meet the demand, it is imported in huge quantities from the North-East Indian region, which in turn, incurs huge transportation costs. This proposal was formulated on the requisition of the Gujarat Forest Department to develop rapid and large-scale multiplication of the bamboo species to cut down the demand and supply gap. The work undertaken under this project was aimed at standardizing the tissue culture conditions for *Schizostachyum dullooa*. The explants (nodal segments) were collected from Gujarat and AFRI nursery. Also, bamboo plantlets collected from Tripura were successfully planted in AFRI nursery. The nodal segments bearing axillary buds served as the source material for the establishment of cultures *in vitro*. Nodal segments were cultured on MS medium supplemented with hormones to promote shoot multiplication and the *in vitro* multiplication was assessed. Sub culturing was done every 4 weeks. *In vitro* rooting was also undertaken; however, it yielded no results. So, it was concluded that the species is recalcitrant as more time would be required to evaluate physical and chemical requirements to achieve rooting in *in vitro*-developed shoots.

Significant achievements/ findings of the project:

It was found that liquid MS medium was better than semi-solid medium for both bud break as well as *in vitro* shoot multiplication. Additionally, MS with 3% sucrose supplemented with 5.0 mg/L BAP gave the best bud break response (60.00±20.00 %) and was found to be optimum for bud proliferation with 1.20±1.20 mean shoot number and 3.47±1.11 mean shoot length. Whereas, 2.5 mg/L BAP was found to be (with 2.10±1.33 fold multiplication) ideal for shoot multiplication. Furthermore, success could only be achieved when a propagule containing 2-4 shoots was cultured and a single shoot failed to multiply.

Suggestions/ advisory note for end-users "To-do-techniques":

There is scope for further research, particularly with respect to *in vitro* rooting in this species.

Research gaps:

Schizostachyum dollooa is a bamboo species with long internodes and a favourite of the kite industry of Gujarat. But its fast propagation technology was not available.

Uses of research outcomes:

Development of an effective tissue culture protocol would be extremely useful for ensuring the availability quality plant material to the handicraft industry for weaving, basket making, kite making and other soft constructions and help top bridge the gap between demand and supply of this important bamboo species.

4. **Title of the project:** Non-destructive *in vitro* Production of Pharmacologically-active natural extract containing Guggulsterones – a Potent Cardio-protective and Anti-cancer Drug from *Commiphora wightii* (Guggul) using Bioreactor

Principal Investigator: Dr Tarun Kant, Scientist-G, ICFRE-AFRI, Jodhpur

Duration: 2017 – 2021

Critical analysis of the research theme and summary of the study:

Gum guggulu, secreted from the trunk of *Commiphora wightii* (Arn.) Bhandari is having medicinal importance and has been used for centuries in Ayurveda. This oleo-gum-resin is being extracted from plant by tapping, which ultimately leads to plant death causing destruction of guggal populations from natural habitat. Over-exploitation has led to large-scale destruction to the extent that the species is now listed under the critically endangered category of the IUCN Red Data Book. Efforts on non-destructive *in vitro* production of pharmacologically active natural extract containing guggulsterones are needed. ICFRE-AFRI, Jodhpur has developed a protocol for cyclic somatic embryogenesis for mass multiplication of the plant and using the same pathway the callus is subjected to liquid culture growth for guggulsterone-rich cell biomass production at bench top bioreactor level. A novel type solid-culture bioreactor has also been developed under the project for which a patent has been filed.

Significant achievements/ findings of the project:

Bioreactor conditions for growing the guggul cell suspension cultures was established in a 5L liquid culture bioreactor which can be easily scaled-up for commercial production. A novel type of solid culture bioreactor has been designed and tested to grow and bulk-up the Guggul cell biomass. HPLC and GCMS analysis were carried out on the cell biomass/callus indicating production of secondary metabolites under *in vitro* and bioreactor conditions.

Suggestions/ advisory note for end users "To-do-techniques":

The unscientific and excessive tapping of the main trunk of the Guggul plant for guggul gum should be avoided. Fast and efficient tissue culture protocol developed by ICFRE-AFRI utilizing the cyclic embryogenesis pathway should be used for multiplication of quality planting material of Guggul and used for species restoration programme and plantation for commercial purpose as the natural regeneration if poor. The ayurvedic formulation companies and pharma industry should come forward to invest in setting up liquid culture bioreactor for which technical know-how can be obtained from ICFRE-AFRI, Jodhpur. The bioreactor can be used to scale up the biomass production and this biomass having these compounds can be used in pharmaceuticals and nutraceuticals. This research is useful for secondary metabolite production from guggul callus without the destruction of natural population hence fulfil the goal of conservation of natural population of *Commiphora wightii.*(Guggul)

Research gaps:

Protocol for somatic embryogenesis for mass multiplication of callus and biomass production at benchtop bioreactor level has been developed under the project. However, the scaling up of the protocol to industrial scale needs to be further tested and optimized.

Uses of research outcomes:

The protocol for somatic embryogenesis can be used to grow embryogeniccalli having a good amount of guggulsterones. The bioreactor can be used to scale up biomass production and this biomass having these compounds can be used in pharmaceuticals and nutraceuticals. This research is useful for secondary metabolite production from guggul callus without the destruction of the natural population hence fulfilling the goal of conservation of the natural population of *Commiphorawightii*.

Publications:

- Mehra S. and Kant T. 2020. Pharmaceutically active cell biomass growth pattern under cell suspension culture of *Commiphora wightii* – a critically endangered medicinal plant. *J. Plant Develop.* 27: 71-81. https://doi.org/10.33628/jpd.2020.27.1.71
- Mehra S. and Kant T. 2021. Gum Guggulu – Oleogum Resin from *Commiphora wightii* (Arnot.) Bhandari: Source, Medicinal Importance and Biosynthesis. *LS-An International Journal of Life Sciences*, 10:214-224. http://dx.doi.org/10.5958/2319-1198.2021.00017.8

Patent:

- One patent has been filed for a solid culture bioreactor for culturing plant cells or tissue and a process thereof. Patent Application No : 202311020537, Date: 23.03.2023.

5. **Title of the project:** Screening of DNA Markers to Distinguish Male and Female *Ailanthus excelsa* Trees for Higher Biomass Production

Principal Investigator: Dr. U. K. Tomar, Scientist-F (Retd.), ICFRE-AFRI, Jodhpur

Duration: 2016 - 2020

Critical analysis of the research themes and summary of the study:

Ailanthus excela (Ardu) is a fast-growing multipurpose tree species. Female trees of *A. excela* are highly vigorous as compared to male trees and have a better potential for their exploitation for the timber value and success of the future improvement programmes. The characters on which male and female plants can be distinguished could be morphological (appearance), biochemical (isozymes) and molecular (genetic) basis. In the present study, attempts were made to differentiate male and female plants of *A. excelsa* on the basis of morphological, biochemical and genetic characters. Molecular (Random Amplified Polymorphism DNA-RAPD, Inter Simple Sequence Repeat-ISSR, Start Codon Targeted-SCoT) and morphological (tree height, DBH, clear bole height, leaf length, leaflet number, leaflet shape, leaflet surface area, leaflet trichome number, stomatal density, stomatal index, stomatal length and width) marker study was carried out at two sites in Rajasthan and Gujarat. Total five sub-populations were selected from these two selected sites. Overall, 232 genotypes were marked and identified as male (113) and female (119) for the study.

Significant achievements/ findings of the project:

Significant variation between and within male and female populations was observed in the morphological characters such as tree height, DBH, clear bole height, leaf length, leaflet number, leaflet shape, leaflet surface area, leaflet trichome number, stomatal density, stomatal index, stomatal length and width. Females have higher values for the stomatal index, stomatal length and width characters as compare to males. But in the case of males leaf length, leaflet number, leaflet shape, leaflet surface area and leaflet trichome density have a higher value. The leaf morphological parameter such as leaflet trichome number was found best marker to distinguish male and female trees of *A. excelsa* during the non-flowering phase. Total 45 RAPD, 20 ISSR and 23 SCoT primers were screened for DNA marker study. Out of which only 25 primers (13 RAPD, 6 ISSR and 6 SCoT) were found to be polymorphic. One of the RAPD primers showed a private band which was found in 73.07% females of CAZRI field, but not in male samples. Similarly, one private band was observed in female samples (68.42%) of Deesa block 1 using the SCoT primer. However, these private bands were found site-specific and not across all the population. Female genotypes in all five subpopulations were having slightly higher genetic diversity as compared to males. Cost estimates and its analysis revealed that the selected morphological marker (trichome density) is two times cheaper and more reliable as compared with the genetic marker. The estimated cost of the morphological marker is Rs. 140 per sample whereas DNA marker cost around Rs. 350.

Suggestions/ advisory note for end users "To-do-techniques":

This research is beneficial for identifying male and female trees in the juvenile and non-flowering stage, by using trichome number density as a strong morphological marker. Identification of female plants at the seedling stage can help the farmers to improve fodder and fuelwood productivity by selective plantation of female seedlings. The male and female *A. excela* seedlings identified through morphological markers need to be validated by growing them till maturity. Identification of the gender can be used by stakeholders to identify the genders in juvenile phase. The cost of a morphological marker is 2.5 times cheaper than a DNA marker.

Research gaps:

There was no method available to identify male and female trees of *Alianthus excelsa* during the juvenile non-flowering phase.

Uses of research outcomes:

By using trichome number density(morphological parameter), identification of male and female plants at the non-flowering phase/seedling stage can help the tree growers to select the female seedling and ensure planting a female tree of *Alianthus excelsa* which will be economically more lucrative.

Publication:

- Bano S., Ansari S., Choudhary M. and Tomar U.K. 2020. Gender based genetic variability of *Ailanthus excelsa* Roxb., Populations using RAPD, ISSR AND SCoT Markers. *Current Journal of Applied Science and Technology* 39(45):75-83.

6. Title of the project : Micropropagation of *Buxus wallichiana* - A Multipurpose Himalayan Tree

Principal Investigator: Dr Shambhavi Yadav, Scientist-B, ICFRE-FRI Dehradun

Duration: 2020 - 2022

Critical analysis of the research theme and summary of the study:

Buxus wallichiana Baill., commonly known as the Himalayan Boxwood, is found unevenly distributed across North-Western Himalayan region of Jammu and Kashmir, Himachal Pradesh and Uttarakhand states of India, and countries of Nepal and BhutanOwing to its multiple commercial as well as phytochemical uses, the population of *B. wallichiana* is been exploited and therefore facing threats in many parts of the Himalayan region. Therefore, concerted efforts are required to develop alternative methods to propagate and conserve such high valued multipurpose tree species to prevent it from extinction. The present research project aimed at development of a micropropagation protocol for boxwood species, *B. wallichiana*. *In vitro* methods were applied in order to get one-to-many propagules (shoots, in this case) and accordingly, method for aseptic establishment of nodal explants was described and axillary shoot proliferation was done. Shoot multiplication was reached and due to recalcitrance of the cultures towards *in vitro* elongation, rooting was severely affected and was not obtained. Also, shoot multiplication in the form of emergence of new lateral shoots was not observed in this species.

Significant achievements/ findings of the project:

Murashige and Skoog's (MS) medium containing 1 mg L^{-1} Benzylaminopurine (BAP) along with 0.5 mg L^{-1} Naphthalene acetic acid (NAA) was found best in terms of minimum mean number of days required to achieve bud break and best bud break response of 85.71 percent. Highest mean number of 9.77 leaves were also obtained in MS medium containing 1 mg L^{-1} BAP along with 0.5 mg L^{-1} NAA. Best treatment with respect to rate of shoot elongation was found to be MS medium containing 0.25mg L^{-1} BAP+0.2 mgL^{-1} NAA with 58.38 as rate of elongation. With respect to number of leaves, out of the 7 shoot multiplication/elongation medium tested, MS medium containing 0.25 mg L^{-1} BAP along with 0.1 mg L^{-1} NAA showed maximum mean number of leaves i.e. 14.33. For *in vitro* rooting, half strength MS medium was used and NAA in concentration of 1 mgL^{-1} was provided, but cultures did not show any root development and ultimately turned brown and died. *B. wallichiana* being extremely slow growing in nature probably showed similar behaviour under *in vitro* conditions. Poor shoot elongation and failure in root development were the major limitations observed with this species and affected the results and outcome of the project.

Suggestions/ advisory note for end-users "To-do-techniques":

There is always scope for further refinement of methods adopted in present work so as to overcome challenges faced during the present study. Method can thus be applied from lab to land through mass propagation efforts. The present study has provided a basic information of how the species responded under *in vitro* conditions and further process refinement can be carried out in future.

Research gaps:

The species, *B. wallichiana*, is facing anthropogenic pressure in natural habitats and no reports of *in vitro* propagation method available.

Uses of research outcomes:

The present study found the species to be highly recalcitrant towards *in vitro* culture hence requires further refinement of propagation methods (either vegetative or any other) in order to be made usable by any stakeholder.

7. **Title of the project: -** Characterization of the Hill Bamboo Species (Ringal) of the North-Western Himalayas for their Conservation and Genetic Improvement

Principal Investigator: Dr. Rajesh Sharma, Scientist-F, ICFRE-HFRI, Shimla; Dr. Maneesh Singh Bhandari, Scientist-C, ICFRE-FRI, Dehradun; Ms. Ranjana Negi, Scientist-C, ICFRE-FRI, Dehradun

Duration: 2017-2020

Critical analysis of the research theme and summary of the study:

The field surveys were conducted to explore the location of two species of hill bamboos i.e., *Drepanostachyum falcatum* and *Thamnocalamus spathiflorus* in Himachal Pradesh. The morphological traits (number of culms and culm height) for each selected population were taken and leaf samples were collected at a minimum distance of 50 m to avoid relatedness. The leaf sample were stored at - 20°C in the freezer till use. Thirty population of Ringal were recorded during the field surveys out of which samples from 22 population of *Drepanostachyum falcatum* and 3 population of *Thamnocalamus spathiflorus* were collected. Thirty representative leaf samples from each population with complete detail of sites and GPS coordinates were collected. DNA extraction of all 750 samples from 25 population were completed and the collected leaf samples and extracted DNA sample were deposited at Genetics and Tree Improvement laboratory, Forest Research institute Dehradun for further studies.

Significant achievements/ findings of the project:

DNA of all 750 samples from 25 population were extracted from the leaves of hill bamboo species (*Drepanostachyum falcatum* and *Thamnocalamus spathiflorus*) and were deposited at Genetics and Tree Improvement laboratory, Forest Research institute Dehradun and results are awaited.

Research gaps:

Ringal bamboo genetic resources are depleting at an alarming rate and the genetic base is narrowing down due to various reasons and eventually leads to degradation of the gene pool of the species. Therefore, there was a need to identify the exact distribution to study the genetic structure of species for its conservation.

Uses of research outcomes:

On the basis of distribution data 25 populations were identified for conservation and management and utilization of existing bamboo resources in Himachal Pradesh.

8. **Title of the project:** Exploring the potential of natural biostimulant on the growth and biochemical content in *Rauwolfia serpentina* (L.) Benth. ex Kurz

Principal Investigator: Dr Pankaj Singh, Scientist-C, ICFRE-IFB, Hyderabad

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

Biostimulants are the compounds, on application even in small amount, activate stress responses in tissues, improving the biosynthesis of desired secondary metabolites. These can be promoted among farmers as a possible supplement or substitute to inorganic fertilizers. Recent reports of *Moringa oleifera* leaf extract (MLE) and seaweed extracts (SWE) as promising natural biostimulants showed their potential for application in medicinal plant cultivation to ascertain their effect on growth and yield of crops. In the present study to evaluate the potential of natural biostimulants such as MLE and SWE as foliar spray on the growth and biochemical content particularly secondary metabolites of *R. serpentina* was achieved.

Significant achievements/ findings of the project:

R. serpentina was propagated through seed and seedlings were placed in RBD design in the field experiment in 16 treatments including control, MLE (3 to 21%), SWE (3 to 21%) and SGR (0.01%). Each plant was foliar sprayed to cover whole plant. The plants were harvested in January-2020 after 18 months. Spraying of MLE and SWE at different concentrations had a positive effect on increasing vegetative growth, yield and improving reserpine content of *R. serpentina* compared to the control. Among them, the 3-6 % SWE and 6% MLE lower dose were more effective treatments in terms of biomass yield and reserpine content. Further, SWE and MLE were low-cost, organic, safe, economical, eco-friendly, and sustainable solutions for production of healthy and safer medicinal plants.

Suggestions/ advisory note for end-users "To-do-techniques":

The project has strong utility value to use natural biostimulants such as MLE and SWE for increasing the biomass and production of desired chemical constituents in the medicinal plant as a value-added product. The findings of the project are useful for various stakeholders including SFDs, Medicinal plant boards, NGOs, Ayurveda companies and local communities engaged in cultivation, utilization and production of medicinal plants. There is enough scope of developing simple, organic, safe, cheap, eco-friendly, and sustainable solutions to produce the healthy and safer medicinal plants. This could be good organic practices for the cultivation of medicinal plants which help in the income generation of the farmers and others in terms of organic products.

Research gaps:

Moringa oleifera leaf extracts (MLE) and Seaweed extracts (SWE) have newly gained importance as foliar spray for lots of crops including various varieties of grasses flowers, cereals, vegetables and spices. The impacts of natural biostimulants including MLE and commercial SWE have not been explored on the medicinally important *R. serpentina* plant in field condition.

Uses of research outcomes:

Moringa LeafExtract and Seaweed extract are useful for various stakeholders including SFDsMedicinal Plant Boards, NGOs, Ayurveda Companies and local communities engaged incultivation, utilization and production of medicinal plants

Publication:

- A bilingual (English and Telugu) extension pamphlet has been published on "Seed quality improvement of *Rauwolfia serpentina* using natural biostimulant" under CAMPA-Extension by IFB, Hyderabad.

9. Title of the project: Strengthening of Tissue culture unit at IFGTB, Coimbatore

Principal Investigator: Dr. Rekha R. Warrier, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2018 - 2020

Critical analysis of the research theme and summary of the study:

In bamboo, availability of propagules is a limitation due to unpredictable and long interval of seed production. Comparatively, micro- and macro-propagation provides many folds multiplication per cycle and is established as an alternative method of propagation to sustainable supply of bamboo plants for planting. Not only this, vegetative as well as micro- propagation has distinct advantage of rapid and clonal multiplication of identified bamboo plant with superior characteristics so that plants identical to the parent plant can be produced in large numbers.

Significant achievements/ findings of the project:

An annexe to the existing tissue culture lab has been developed. All necessary infrastructure was procured, and the lab was made fully functional from January 2020 enhancing the capacity of the Tissue Culture (TC) lab from 25,000 to 35,000 plants. Based on the recommendations of the National Bamboo Mission, identified material available with RFRI Jorhat was procured through Material Transfer Agreement. The cultures obtained were mass multiplied. A shade net area for hardening of TC plants was constructed to house the plants in the vegetative propagation complex. Trainings were imparted on the development of protocols on bamboos to field staff. Hands-on training was imparted to staff from SFRI, Kanpur and RRC, Bhubaneshwar.

Research gaps:

Availability of propagules is a limitation in bamboos due to unpredictable and long interval of seed production. Micro propagation provides many fold multiplication per cycle to ensure sustainable supply of bamboo plants for planting which requires elaborate infrastructure.

Uses of research outcomes:

Protocol for large scale clonal multiplication of identified bamboo with superior characteristics was developed and being shared with stakeholders

10. Title of the project: *In vitro* production of secondary metabolites from tree species of Dasamoola through hairy root cultures

Principal Investigator: Dr. Rekha R. Warrier, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2014 - 2019

Critical analysis of the research theme and summary of the study:
The growing interest in commercialization of plant medicines leads to over exploitation of the plants. Hence, India has banned the export of several wild species in the form of raw materials, although the export of finished products containing the material is allowed. Despite this an estimated 95 % medicinal plants collected in India are gathered from the wild. Such destructive and non-sustainable collection methods coupled with low regeneration and habitat destruction have posed serious threat to the survival and availability of various medicinal plants in the wild. The scarcity of raw material leads to use of spurious substances resulting in decreased efficacy of the medicines. Targeting new methods to increase the availability of active metabolites would assure the presence of these compounds in medicinal preparations. Biotechnology provides scope for addressing the issue of non-availability of active principles and also enables conserving threatened medicinal plants.

Significant achievements/ findings of the project:
At IFGTB, hairy root initiation studies were carried out in *Aegle marmelos*, *Gmelina arborea, Oroxylum indicum, Premna interifolia* and *Nicotiana tabaccum* with nodal and leaf explants. Co-cultivation was carried out with different *Agrobacterium* strains. The roots produced were observed for GFP expression. Transformed roots showed fluorescence. *Aegle marmelos, Oroxylum indicum* and *Gmelina arborea* explants developed hairy roots when infected with A4wild, A4pHKN29, A4RS, A4RSpHKN29 strains. Hairy root transformation induced root proliferation. This enhanced root biomass production, thereby increasing the availability of secondary metabolites.

Suggestion/ advisory note for the end-users "To-do-techniques":
Alternative approaches should be explored for production of secondary metabolites technology so that the dependence on destructive harvest of bark, stem and roots of the selected tree species could be minimized, if not totally eliminated. The development of such methods needs to be encouraged in view of the dwindling natural resources in their natural habitats and because of increase in demands of these species in the Indian Systems of Medicine.

Research gaps:
Destructive and non-sustainable collection methods coupled with low regeneration and habitat destruction have posed serious threat to the survival and availability of various medicinal plants in the wild. Biotechnology provides scope for addressing the issue of non-availability of active principles and it also enables conserving threatened medicinal plants.

Uses of research outcomes:
Two patents for production of roots of medicinal trees thereby ensuring the availability of the trees in the wild.

Publications:

- MohanaPriya S., Indhu S., Kalaiselvi R. and Warrier Rekha R. 2020. *Agrobacterium* - mediated transformation in medicinal trees.*Annals of Phytomedicine* 9(1): 27-31.DOI: http://dx.doi.org/10.21276/ap.2020.9.1.4
- Warrier Rekha R., MohanaPriya S. and Kalaiselvi R. 2021. *Gmelinaarborea*– an indigenous timber species of India with high medicinal value: A review on its pharmacology, pharmacognosy and phytochemistry. *Journal of Ethnopharmacology* 267:1-22.https://doi.org/10.1016/j.jep.2020.113593

Patents:
- Hairy root culture protocols for the bio-production of secondary metabolites/ biomolecules Application No. 202041054370
- Cell culture protocol for in vitro production of secondary metabolites from *Aegle marmelos* Application No. 202041053835

11. Title of the project: Mass production of teak clones through tissue culture

Principal Investigator: Dr. Rekha R. Warrier, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2018 - 2020

Critical analysis of the research theme and summary of the study:

Teak is a valuable asset for which there is a huge international demand. The world's precious stocks are in very short supply and diminishing fast due to continuous logging. Extraction of best teak from forest has resulted in the loss of good genotypes. India has been identified as a centre of origin of diversity of teak and occupying large areas under teak (43 per cent of the world's total). In the absence of gene conservation plots and protected forests, the choice of protecting the identified superior genotypes for long-term conservation and future uses is limited. Identification of superior material bred over one generation will further tree improvement in the species by bringing together the best performing clones for the future generations.

Significant achievements/ findings of the project:

The clones of teak available at the IFGTB supplied to the Forest Development Corporation were tested across different locations (~20 ha). The clones showed high survival (~85%) and growth performance was 25-30 per cent greater than the stump-raised material. The Institute supplied 50,000 TC plants of teak raised through tissue culture to the FDCM.

Suggestion/ advisory note for the end-users "To-do-techniques":

There is a need to include seed raised material (At least 25% of the total plantation) to ensure diversity in the clonal plantations.

Research gaps:

The choice of protecting identified superior genotypes for long-term conservation and future uses is limited for teak, as the best resources have already disappeared. Identification of superior material and introduction into planting programmes would ensure productive plantations.

Uses of research outcomes:

The study indicates increase in area with identified planting stock of teak

12. Title of the project: Production of multi-parent inter-cross populations of eucalypts for salinity tolerance

Principal Investigator: Dr. R. Yasodha, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Soil salinization triggered by various factors including land clearing, poor drainage, irrigation water with high levels of salts and excessive use of fertilizers threatens food and wood production. In India, soil salinity is more widespread and is estimated to be 6.74 million hectare and it is likely to increase to 16.2 million ha by 2050. One way to improve productivity in the wake of increasing land salinization is to develop salt tolerant trees that can grow on salt-affected areas, which could be used to sustain and expand wood production. Some of the species of eucalypts have the ability to grow in saline soils. Introduction of breeding techniques such as selection of parents for salt tolerance and controlled hybridization with high yielding clones to combine the desirable traits would enhance the survival and productivity. In this project, the superior clones selected for productivity were subjected to different levels of salinity to identify the best performers. Based on the information on salt tolerance, four families of *E. camaldulensis* have been generated by controlled hybridization. These families were assessed for their hybrid purity and salt tolerance characteristics and would form the genetic resource for marker assisted breeding for salt tolerance in eucalypts.

Significant achievements/ findings of the project:

Grafting methods were optimized to induce early flowering and fruiting and at accessible height from the ground for controlled pollination. A genetic resource of eucalypts for salt tolerance breeding was generated. First and second-generation clones of eucalypts were assessed for their salt tolerance potential and 15 clones were identified to have different levels of tolerance. Four hybrid families were generated using a salt tolerant clone as pollen parent and one family (EC188 x EC7) with higher level of tolerance was identified. Specific leaf area (SLA) and root: shoot ratio was found to be the best indicators of salt tolerance in eucalypts.

Suggestion/ advisory note for the end-users "To-do-techniques":

Flowering height in eucalypts is challenging for breeders to take up controlled pollination and pedigreed seed production. The juvenile phase lasts for 3-4 years with no flowering or fruiting and height growth reaches more than 5 meters. This project developed methodologies to induce flowering at early age and height of 0.5 to 1.0 m through grafting techniques. Flowering branches as scion from identified trees were grafted on rooted cuttings which served as stock plants. Successful grafts favoured pedigreed seed production at large scale.

Research gaps:

In eucalypts, many countries have proved that hybrid vigor is good and hybrids have superior performance. In India hybrid production is not commonly practiced and hence the project addresses the gap in hybrid generation of eucalypts.

Uses of research outcomes:

This project established methods and protocols for production of inter and intra-specific hybrids. It paves the way for large scale production of hybrids in eucalypts. Currently field trials for hybrid eucalypts established for growth performance assessment.

13. Title of the project: Isolation and characterization of *CinnamoylcoA reductase* in *Casuarina equisetifolia*

Principal Investigator: Dr. A. Shanthi, Scientist-E, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Wood is the main raw material for paper and pulp industry and quality of wood determines its industrial use. This necessitates approaches to improve pulping quality of wood through understanding of lignin biosynthetic pathway at the biochemical and molecular levels. The present study was carried out to isolate and characterize Cinnaomoyl CoA Reductase (CCR), a lignin gene from *C. equisetifolia* to provide further leads for improving the species through development of markers for pulping trait or through genetic transformation. A full length CCR gene was isolated through wood transcriptome sequencing. The analysis of the wood transcriptome is the first report of genes involved in secondary growth in this species. The expression of nine major transcripts involved in lignin biosynthesis in secondary tissues was documented in four tissues and *CeCCR1* was found to show maximum expression in developing wood tissues. The pathway analysis of Casuarina transcriptome mapped 10.34% of the annotated unigenes to 31 pathways with majority under metabolic pathways, biosynthesis of secondary metabolites and biosynthesis of antibiotics. Putative Single Nucleotide Polymorphisms (SNPs) were identified in *CCR* gene between different provenances of *Casuarina equisetifolia.*

Significant achievements/ findings of the project:

Full length CinnaomoylcoA reductase gene was isolated in *Casuarina equisetifolia* through whole transcriptome sequencing study. Lignin biosynthesis genes were identified using transcriptome sequencing and *de novo* assembly. The *de novo* assembly of raw transcriptome data showed the minimum and maximum transcript length ranged between 224 bp and 6627 bp with an average length of 609 bp and the N50 contig size was 780 bp. The raw paired - end sequence data was deposited in NCBIs Short Read Archive with the study accession number SRP136154. 26,985 unigenes were identified and 15,952 were annotated. The expression of nine major transcripts involved in lignin biosynthesis pathway viz. Phenylalanine ammonia lyase (*CePAL*), Cinnamate 4-hydroxylase (*CeC4H*), 4-Coumarate: CoA ligase (*Ce4CL*), HydroxyCinnamoyl CoA Shikimate: quinate hydroxyl cinnamoyl transferase (*CeHCT*), Cinnamoyl CoA reductase1 (*CeCCR1*), Cinnamoyl CoA reductase1-like (*CeCCR1-like*), Ferulate 5-hydroxylase (*CeF5H*), Caffeic acid O-methyl transferase (*CeCOMT*) and Cinnamoyl alcohol dehydrogenase (*CeCAD*) in secondary tissues were documented in four tissues (wood, leaf, root and stem) and CeCCR1 was found to show maximum expression in developing wood tissues. The study also revealed that CeTUBA and CeH2A was the most stable transcript for normalization of qRT-PCR data. Transcripts from *C. equisetifolia* showed highest similarity with *Prunus persica* (935), *Morus notabilis* (738), *Vitis vinifera* (663), *Citrus clementina*, *Jatropha curcas* (614), and *Populus trichocarpa* (587). A total of 2392 SSRs were identified from 2082 sequences, with 259 sequences containing more than 1 SSR. Sixty putative Single Nucleotide Polymorphisms (SNPs) were identified among the international provenances. The identified alleles can be used for identifying markers tagging wood property traits in *Casuarina equisetifolia.*

Suggestions/advisory note for end-users "To-do-techniques":

The wood genomic resource developed in *C. equisetifolia* is the first report. It will form a base data for development of marker informed breeding using tagged wood property traits in this economically and ecologically important tree species and also be a valuable resource for further research on specific processes, structures, functions, and pathways in *C. equisetifolia.*

Research gaps:

The project was to identify CinnomoylcoAreductasegene markers tagging wood property traitsin *Casuarinaequisetifolia.*

Uses of research outcomes:

Wood genomic resource developed in *C. equisetifolia* was the first report and published in the high impact factor journal. The identified stakeholders would be tree breeders, researchers and paper industries.

Publication:

- Vikashini B., Shanthi A. and Ghosh Dasgupta M. 2018. Identification and expression profiling of genes governing lignin biosynthesis in *Casuarina equisetifolia* L. *Gene* 676: 37–46.

14. **Title of the project:** Transcriptome analysis of salt excluding roots of *Rhizophora mucronata*

Principal Investigator: Dr. Mathish N.V., Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2023

Critical analysis of the research theme and summary of the study:

India has around 6.73 Mha of salt affected lands. Such lands are laden with high concentration of sodium that causes toxicity in plants resulting in poor growth and productivity. Mangroves are a major group of marine halophytes that are well adapted to intertidal zones. *Rhizophora* spp. are categorized as salt excluders as they limit sodium uptake from the roots. To understand the genetic determinants that help in limiting salt uptake to the shoots, the root transcriptomes of salt tolerant *Rhizophora mucronata* and the relatively salt susceptible *R. apiculate* were compared. The early effects of salt stress (250 mM-24 h) on the root transcriptome of the two species were analyzed by RNA-seq using the Illumina platform followed by *de novo* assembly to identify key genes, functions, and pathways modulated during salt stress response in *Rhizophora*. This study thus provides a comparative and salt-induced root transcriptome resource in two species of *Rhizophora* providing a valuable resource for further research on dissecting the salt stress tolerance mechanism in *Rhizophora*.

Significant achievements/ findings of the project:

The shoot/ root ratio of Na^+ in propagules subjected to 250 mMNaCl for 24 h was found to be relatively higher at 0.97 for *R. apiculata* when compared to 0.83 for *R. mucronata* indicating relatively restricted Na^+ uptake by *R. mucronata*. The two species had 9216 differentially expressed genes under normal control conditions indicating inherent differences in gene expression. Salt induced transcriptome analysis of the roots of *R. apiculata* and *R. mucronata,* identified 3253 and 23 differentially expressed genes, respectively. The gene enrichment analysis identified key functions (ATP binding, metal ion binding, protein serine/threonine kinase activity, and water channel activity) and major pathways (biosynthesis of secondary metabolites, metabolic pathways, and phenylpropanoid biosynthesis) modulated during salt stress. The study identified candidate genes such as uncharacterized proteins, transcription factors, protein kinases, and other genes modulated during salt stress. Potential candidate genes for enhancing salt tolerance, Peroxidase-2 and Cation/ Calcium Exchanger-5, were identified and validated using RT-qPCR analysis.

Suggestions/ advisory note for end-users "To-do-techniques":

The genes identified to be modulated in response to salt stress in *Rhizophora* roots will be an invaluable resource for development of markers for salt tolerance and for generation of genetically modified / gene edited agricultural / forestry crops with enhanced salt tolerance.

Research gaps:

The project aimed to analyze the unique salt stress responses of the roots of salt tolerant *R. mucronata,* when compared to the relatively salt sensitive *R. apiculata*.

Uses of research outcomes:

Salt induced transcriptome sequence data generated for the first time from the roots of *Rhizophoramucronata*and *R. apiculata* were analyzed to identify deferentially expressed genes. *Peroxidase-2* gene driven by the root-preferential and salt-inducible promoter, *MsPRP2*, was cloned into a transformation vector. These genes could be used by researchers for development of markers and genome edited plants for improved salt stress tolerance

Publication:

- Manoj Kumar R., Vaishnavi J., Balasubramanian A., Shamili K., Sandhya M.C., Sivakumar, K., Kathiresan K. and Nambiar-Veetil M. 2022. Transcriptome evaluation of the salt-treated roots of *Rhizophoramucronata* and *R. apiculata.* IFGTB News, 4(2): 2-3.

15. Title of the project: Documentation of population demography and genetic structure of teak for developing sustainable conservation strategies and resource management

Principal Investigator: Dr. R. Yasodha, Scientist-G, IFGTB Coimbatore

Duration: 2016 – 2020

Critical analysis of the research theme and summary of the study:

Teak (*Tectona grandis* L. f.) is one of the premier tropical hardwood having qualities of durability, strength and visual pleasantries. Natural teak populations harbour a variety of characteristics that determine their economic, ecological and environmental importance. Genomic resources in this species are very limited to initiate DNA based breeding and conservation programs. Sequencing of whole nuclear genome of teak provided a draft genome of 317 Mb (151× coverage). Overall, 16,252 perfect SSRs showed *in silico* polymorphisms across six genotypes suggesting their promising use in genetic conservation and tree improvement programmes. Twenty-five genomic SSR markers developed in this study were utilized for genotyping thus advancing conservation and management of teak genetic resources. Phylogenetic studies confirmed the taxonomic position of the genus *Tectona* within the family, Lamiaceae. Interestingly, estimation of divergence time inferred that the Miocene origin of the genus *Tectona* to be around 21.4508 million years ago. Phenological observations on leaf flushing, flowering and fruiting variations across the populations were documented. The information generated under the project would provide leads to the state forest departments on prioritizing the teak populations for *in situ* conservation.

Significant achievements/ findings of the project:

Teak natural populations from South to Central India were selected to study the extent of genetic variation and local adaptive potential using genome wide SSR markers. Bottleneck effect along with genetic drift and local adaptation have played crucial role in designing the genetic structure of these populations, separating them into three gen-ecological zones namely Kerala, Tamil Nadu-Karnataka and Karnataka-Central India (Gujarat and Madhya Pradesh). Information on genetic variability, genetic structure, allelic richness, private and unique adaptive alleles of teak populations showed the presence of population specific diversity and revealed the basis of local adaptations. Significant association of genetic structure to environmental factors, temperature and precipitation was detected using linked neutral loci (SSR loci IFGTB285 and IFGTB479b). Population genetic structure of natural teak populations is influenced by isolation by distance (IBD) and isolation by environment (IBE), specifically the longitude showed greater correlation than latitude. Niche modeling identified Central Indian populations to be more vulnerable to climate change and probable shift in the distribution pattern of the species in the ensuing years.

Suggestions/ advisory note to the end users "To-do-techniques":

Several oldest teak trees in the states of Tamil Nadu, Kerala and Karnataka have been identified for conservation and the information shared with concerned state forest departments. Genomic resources of teak generated including identification of several thousands of microsatellite markers would find its use in tree improvement and conservation. Assessment of climate resilience need to be studied to prioritize the populations for assisted migration through provenance trails. Simple sequence repeat markers generated in this project can be used effectively to distinguish clones and germplasm accessions, trace timber origin, decipher provenance level genetic variations, identify seed sources, and other population specific parameters. The forest personnel (field staff) of Tamil Nadu Forest Department were trained on various aspects related to conservation of teak genetic resources.

Research gaps:

There was no genomic data available in teak and hence application of advanced breeding techniques was hampered. This project generated genomic resources and is used in various stages of molecular breeding.

Uses of research outcomes:

The microsatellite data generated in this project is used for various purposes including genetic diversity analysis, DNA fingerprinting, population structure analysis and genomic selection.

Publications:

- Yasodha R., Vasudeva R. and Balakrishnan S. 2018. Draft genome of a high value tropical timber tree, Teak (*Tectonagrandis* L. f): insights into SSR diversity, phylogeny and conservation. *DNA Research,* https://doi.org/10.1093/dnares/dsy013. **(IF: 5.404)**
- Balakrishnan S., Dev S.A. and Sakthi A.R. 2021. Gene-ecological zonation and population genetic structure of *Tectonagrandis*L.f. in India revealed by genome-wide SSR markers. *Tree Genetics & Genomes,* 17:33. https://doi.org/10.1007/s11295-021-01514-x. **(IF: 2.4)**
- Maheswari P., Kunhikannan C. and Yasodha R. 2020. Chloroplast genome analysis of Angiosperms and phylogenetic relationships among Lamiaceae members with particular reference to teak (*Tectonagrandis*L.f). *Journal of Biosciences*, DOI:10.1007/s12038-021-00166-2. **(IF: 2.7)**
- Kannan Patturaj M., Warrier N., Jacob R.R. and Yasodha R. 2021. Molecular diversity and functional prediction of foliar endophytic bacteria in *Tectonagrandis* (Teak) estimated by 16S rDNA sequence analysis. *Philipp. J. Sci.*, 150:1677–1687. **(IF: 0.2)**

16. **Title of the project**: Identification and Tagging of QTLs/Candidate genes for wood property and adventitious rooting traits in Eucalyptus and establishment of phenomics facility for water stress tolerance studies

Principal Investigator: Dr. Modhumita Dasgupta, Scientist-G; Dr. R. Yasodha, Scientist-G; and Dr. Shakti Singh Chauhan, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2021

Critical analysis of the research theme and summary of the study:

This network project in its second phase aimed at identifying markers for economically important traits in tropical Eucalypts. Three mapping populations were established across six locations and multiple wood property traits were evaluated in the populations across three environments. High density linkage maps were constructed and QTL analysis identified markers tagging adventitious rooting and wood property traits. Genome-wide association analysis predicted seven large effect markers for fibre area. Additionally, ten water stress tolerant *Eucalyptus* clones were identified for deployment in arid zones and future breeding programs. The project has generated the genomic platform essential for implementing marker assisted selection in *Eucalyptus*.

Significant achievements / findings of the project:

Two hybrid clones (IFGTB-EH01 and IFGTB-EH-02) were released for commercial purpose. An acetyl bromide based micro protocol was developed for large scale estimation of total lignin from *Eucalyptus* wood samples. Several stable hybrid clones were short-listed for superior wood property traits for inclusion in breeding programs. Genome-wide association analysis was conducted for 17 wood property traits using 13,610 polymorphic SNPs from 762 genes and a total of 45 significant SNP-trait associations were documented with seven markers explaining more than 80% phenotypic variance for fibre area. High density linkage map was constructed for the cross *Eucalyptus tereticornis* × *E. camaldulensis* with 4844 SNP markers, and parent specific linkage map for the cross *E. tereticornis* × *E. grandis* with 1951 (Et86) and 1527 (Eg9) SNP markers was developed. Six QTLs of adventitious rooting trait and sixteen QTLs of wood properties trait were identified. Screening of 160 *Eucalyptus* clones under progressive water retrieval condition was conducted and 10 drought tolerant clones were short-listed for future tree improvement program. The bacterial endophyte diversity in leaf tissues between susceptible and tolerant clones belonging to *E. camaldulensis* and *E. tereticornis* was documented and several taxonomic biomarkers were identified, which could differentiate the species and water stress tolerant genotypes. Identified two Drought Susceptibility Indices (SLA-DSI and RWC-DSI) for screening water stress tolerant/ susceptible clones of *Eucalyptus* under nursery condition.

Suggestions/ advisory note for end-users "To-do-techniques":

The stable hybrid clones identified with superior wood property traits from multi-environment data will be included in the *Eucalyptus* improvement program for variety release in future. The putative markers for wood property and adventitious rooting traits can be used for marker guided selection in tropical Eucalypts, subsequent to validation in larger number of genotypes. Several thousands of polymorphic SSR markers were developed for use in population genetics studies and marker assisted breeding in tropical Eucalypts. The drought tolerant clones short-listed in the project have been included in the multi-location trial under the All India Co-ordinated Project in *Eucalyptus* implemented with the funding support from MoEF&CC. Further, additional trials in arid zones are envisaged for future release of drought tolerant *Eucalyptus* clones.

Research gaps:

Productivity of *Eucalyptus* plantations in India is low with average productivity of 20 m^3 per hectare per year while in Brazil, intensively cultivated clonal plantations with hybrid clones have an average productivity of 45–60 m^3 per hectare per year. Hence, the present project was taken up to accelerate trait improvement in tropical *Eucalyptus* through marker-assisted selection.

Uses of research outcomes:

Two hybrid clones (IFGTB-EH01 and IFGTB-EH-02) were released for commercial purpose.An acetyl bromide based micro protocol was optimized for large scale estimation of total lignin from *Eucalyptus* wood samples.Stable hybrid clones with superior wood property traits were short-listed for inclusion in breeding programs. Ten drought tolerant clones were short-listed and specific leaf area (SLA) and relative water content (RWC) were identified as water stress tolerant indices for nursery screening of *Eucalyptus* clones.

Publications:

- Muthulakshmi E., Amrutha S., Sivakumar V. and Ghosh Dasgupta M. 2022. Development of physiological indices for screening dehydration tolerance in Eucalyptus clones under nursery conditions. *New Forests* https://doi.org/10.1007/s11056-022-09958-2. **(IF: 2.697)**
- Ghosh Dasgupta M., Abdul Bari M.P., Shanmugavel S., Dharanishanthi V., Muthupandi M., Kumar, N., Chauhan S.S., Kalaivanan J., Mohan H., Krutovsky K.V. and Rajasugunasekar D. 2021. Targeted re-sequencing and genome-wide association analysis for wood property traits in breeding population of *Eucalyptus tereticornis* × *E. grandis*. *Genomics* 113(6):4276-4292. **(IF: 5.736)**
- Muneera Parveen A.B., Muthupandi M., Kumar N., Chauhan S.S., Vellaichamy P., Senthamilselvam S., Rajasugunasekar D., Nagarajan B., Mayavel A., Bachpai V.K.W., Sivakumar V. and Ghosh Dasgupta M. 2021. Quantitative genetic analysis of wood property traits in biparental population of *Eucalyptus camaldulensis x E. tereticornis*. *Journal of Genetics* 100:46. **(IF: 1.166)**
- Amrutha S. Muneera Parveen A.B., Muthupandi M., Vishnu K., Bisht S.S., Sivakumar V. and Ghosh Dasgupta M. 2021. Characterization of *Eucalyptus camaldulensis* clones with contrasting response to short-term water stress response. *Acta Physiologia Plantarum* 43: 14. **(IF: 2.354)**
- Patturaj M., Munusamy A., Kannan N., Kandasamy U. and Ramasamy Y. 2021. Chromosome-specific polymorphic SSR markers in tropical eucalypt species using low coverage whole genome sequences: systematic characterization and validation. *Genomics & Informatics* 19(3): e33-e33.
- Patturaj M., Mayavel A., Dasgupta M. G., Nagarajan B., Rajasugunasekar D., Sivakumar V. and Yasodha R. 2021. Genome wide SNP identification in Eucalyptus and its application for linkage mapping and adventitious rooting related QTL analysis. *Indian Forester* 147(11): 1088-1102.
- Muthulakshmi V., Vijayam C.V., Bachpai V.K.W., Sivakumar, S., Muthulakshmi, E., Senthilkumar S., Muneera Parveen A.B., Yasodha R. and Ghosh Dasgupta M. 2020. Genetic control of adventitious rooting traits in bi-parental pedigree of *Eucalyptus tereticornis* X *E. camaldulensis*. *New Forests,* 52: 585-603. **(IF: 2.56)**
- Ghosh Dasgupta M., Burragoni S., Amrutha S., Muthupandi M., Muneera Parveen A.B., Sivakumar V. and Ulaganathan K. 2020. Diversity of bacterial endophyte in *Eucalyptus* clones and their implications in water stress tolerance. *Microbiological Research* 241:126579. **(IF: 5.415)**
- Muneera Parveen A.B., Lakshmanan D. and Ghosh Dasgupta M. 2020. Validation of variants using cost effective high resolution melting (HRM) analysis predicted from target re-sequencing in Eucalyptus. *Acta Botanica Croatica* 79 (2): 105-113. **(IF: 1.051)**
- Amrutha S., Muneera Parveen A., Muthupandi M., Sivakumar V., Nautiyal R. and Ghosh Dasgupta M. 2019. Variation in morpho-physiological, biochemical and molecular responses of two *Eucalyptus* species under short-term water stress. *Acta Botanica Croatica*, 78 (2): 125–134. **(IF: 1.051)**
- Sumathi M., Bachpai V.K.W., Mayavel A., Dasgupta M.G., Nagarajan B., Sekar D.R.S., Sivakumar, V. and Yasodha R. 2019. Genetic linkage map and QTL identification for adventitious rooting traits in red gum eucalypts. *3 Biotech,* 8:242. https://doi.org/10.1007/s13205-018-1276-1. **(IF: 1.361)**
- Dharanishanthi V. and Ghosh Dasgupta M. 2018. Co-expression network of secondary cell wall biogenesis genes in *Eucalyptus tereticornis*. *Silvae Genetica* 67: 72-78. **(IF: 0.63)**
- Dharanishanthi V. and Ghosh Dasgupta M. 2018. Co-expression network of transcription factors reveal ethylene-responsive element-binding factor as key regulator of wood phenotype in *Eucalyptus tereticornis*. *3 Biotech*

8(7):315. **(IF: 1.497)**

- Sumathi M., Bachpai V.K.W., Deeparaj B., Mayavel A., Dasgupta M.G., Nagarajan B., Rajasugunasekar D., Sivakumar V. and Yasodha R. 2018. Quantitative trait loci mapping for stomatal traits in interspecific hybrids of Eucalyptus. *J. Genet.* 97(1):323-329. **(IF: 0.995)**
- Dharanishanthi V. and Ghosh Dasgupta M. 2017. Isolation and characterization of homeodomain leucine zipper class-III transcription factor gene in *Eucalyptus tereticornis*. *Indian Journal of Biotechnology* 16: 334-339. **(IF: 0.289)**
- Ghosh Dasgupta M. and Dharanishanthi V. 2017. Identification of PEG-induced water stress responsive transcripts using co-expression network in *Eucalyptus grandis*. *Gene* 627:393-407. **(IF: 2.415)**
- Sumathi M. and Yasodha R. 2017. Microsatellite allele length variations in inter-specific hybrids of Eucalyptus. *Acta Botanica Croatica* DOI:10.1515/botcro-2016-0050. **(IF: 0.79)**

17. **Title of the project**: Assessment of adaptive genetic diversity in teak and sandalwood to guide conservation and genetic improvement efforts

Principal Investigator: Dr. R. Yasodha, Scientist-G and Dr. Modhumita Dasgupta, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2019 – 2022

Critical analysis of the research theme and summary of the study:

The genetic resources of both teak and sandalwood are depleting and hence, identifying, monitoring and managing the locally adapted genetic variation in both the species is essential for conservation and genetic improvement programs. The present project aimed to understand the adaptive potential of teak and sandalwood using the contemporary strategy of landscape genomics. This approach enhances the ability to quantify and explain the current patterns of adaptation and provide future predictions to categorize vulnerable or resilient populations along the natural distribution zone.

Natural populations of teak were studied at transcriptome and genome level to assess the adaptation potential in relation to precipitation and temperature. The major gene functions identified were stress related, signal transduction, secondary wall thickening and osmoprotectants. These results revealed that adaptation to drought conditions is occurring in areas receiving low levels of precipitation. The strong population adaptation variations in teak suggested that climatic conditions have shaped populations which are an essential source of knowledge to design tree improvement, plantation and genetic resources conservation prgrams.

In sandalwood, 23 natural populations from seven states were surveyed and data from morphological, phenological, physiological, biochemical and leaf spectral indices distinguished in Odisha, Kerala and Andhra Pradesh populations. Pan-transcriptome analysis clustered genotypes from wet, dry and monsoon locations, and environmental association analysis using genome-wide SNP markers predicted several probable genes governing environmental adaptation in sandalwood. The study identified adaptive populations of sandalwood which will assist in devising strategies for genetic resource management and conservation in the species.

Significant achievements/ findings of the project:

Natural populations of teak from 11 states were surveyed and species distribution map was constructed. Ecological niche modeling predicted that annual mean temperature, isothermality, temperature seasonality and annual precipitation contributed to the distribution of teak in India. Transcriptome and genome level analysis identified that the major gene functions governing adaptive potential in teak were stress related, signal transduction, secondary wall thickening and osmoprotectants (e.g., Homeobox-leucine zipper protein ATHB-7; Inositol 3-alpha-galactosyltransferase; Beta-D-xylosidase 1; ABI five binding protein 2; Putative DNA binding protein; Hydroxyproline-rich glycoprotein family protein; MLP-like protein 423). Whole genome sequencing of 35 populations from 12 states generated a total of 1,03,869 SNP markers and were used for population structure analysis. Genotype environment association analyses identified 4116 SNPs as outliers, with 80% (3289) found in intergenic region and 20% (827) of SNPs identified in genic region.

The spatial distribution map of sandalwood was developed and mean diurnal range, precipitation of the driest month and predicted as the most significant variables contributing to the distribution of sandalwood populations.Whole genome sequencing in 29 individuals across five states predicted 1.1 million SNPs and spatial genetic structure analysis revealed that natural population from Jawadhu hills, Tamil Nadu was distinct from other populations. Environmental association analysis using genome-wide SNP markers identified several genes including HMG-CoA

synthase, strictosidine synthase, transcriptional regulator SLK2, RNA binding protein 18, heat stress transcription factor B-2a-like protein (*HsfB2a*), ubiquitin ligase SUD1 and zinc finger protein ZAT10 governing environmental adaptation in sandalwood. Abundance of PGPRs which belong to genus *Mesorhizhobium, Bradyrhizobium, Sphigomonas, Nocardioides, Rhizobacter, Candidatussolibacter, Rhodoplanes* were recorded in the rhizosphere of healthy trees when compared to trees infected with sandal spike phytoplasma which can be used as potential biocontrol agents. Diagnostic marker to detect the presence of phytoplasma causing sandal spike disease was developed and validated.

Suggestions/ advisory note for end-users "To-do-techniques":

Molecular signatures (SNPs) linked to adaptive potential identified through the study can be used to understand the response of teak to abiotic stress and most importantly its influence in wood formation, which can then be used to design strong molecular breeding strategies. Environmental cues responsible for the expression of target genes (upregulation / down regulation) involved in wood formation can help in identifying the gene environmental interactions responsible for variation in the wood characteristics in teak.

The diagnostic marker developed for detecting sandal spike disease can be used for screening sandalwood germplasm and guide forest departments and farmers in taking appropriate measures to control the spread of the disease. The putative markers governing sandalwood adaptation when validated in larger number of individuals can assist forest departments in designing/ improving the conservation strategies of the species under future climate challenges. The PGPRs identified from rhizosphere of healthy trees using metagenomics can be used as potential biocontrol agents to control sandal spike disease.

Research gaps:

Climate change effects influence the natural distribution range of many of the forest tree populations including sandalwood and teak. However their adaptation potential was not known. This project targeted to understand the genes responsible for drought tolerance and their role in wood formation and to identify populations vulnerable for climate change effects to guide the conservation and tree improvement activities.

Uses of research outcome:

Genes involved in adaptation of teak were shortlisted. Seed zones of natural populations were identified in the peninsular region of the country. Diagnostic marker for detecting sandal spike disease was developed to screen sandalwood germplasm and suggest measures to contain the spread of the disease by the sandalwood growers.

Publications:

- Balakrishnan S., Ramasami Y. and Dev S.A. 2023. An overview of teak genetic improvement towards conservation of genetic resources in a changing climate with special emphasis on India. *Tree Genetics and Genomes* 19:29. https://doi.org/10.1007/s11295-023-01604-y. **(IF: 2.398)**
- Balakrishnan S., Unnikrishnan R., Yasodha R. and Dev S.A. 2023. Teak genomics for conservation and timber verification. *TEAKNET Bulletin* 16(1): 2-6.
- Muthulakshmi E., Madhuvanthi K.C. and Dasgupta M.G. 2022. Genomic resources in Indian Sandalwood: Implications in conservation and breeding. *The Sandalwood Genome. Springer.* https://doi.org/10.1007/978-3-030-93394-4.
- Muthulakshmi E., Thangaraj K., Aiyar B., Dev S.A., Balakrishnan S. and Dasgupta M.G. (2022). Development of a sensitive and single step PCR based assay for detection of sandal spike phytoplasma. *Current Science* 122(12):1454-1458.

18. Title of the project: Genome wide and geospatial approaches for enhancing the adaptive potential of threatened rattan resources in India

Principal Investigator: Dr. Modhumita Dasgupta, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2019 – 2022

Critical analysis of the research theme and summary of the study:

Rattans are one of the most precious non-timber forest produce having wider distribution in India. The enormous extraction pressure and changing climate have had its impact in terms of extreme reduction of the available resources, altered sex ratio and reduced regeneration. Being dioecious, the resource management in critically threatened rattan species demands a viable sex ratio, adaptive allele rich germplasm, and microclimate to support long term survival in the changed climate. This network project aimed at generating information on adaptive and rare alleles, population sex ratio, gender specific markers and viable ecological niches of threatened rattan species. In this project, the whole genomes of *Korthalsia laciniosa* and *Calamus brandisii* were generated and gender specific nucleotide variations (SNPs) in two gender linked genes (*FCMO*&*FCMO3*) were validated in *C. brandisii.*

Significant achievements/ findings of the project:

The draft genome of *Korthalsia laciniosa* and *Calamus brandisii* (female and male) was sequenced, assembled and functionally annotated. Comparative genomics across the male and female genomes of *Calamus brandisii* was conducted and gender-specific genes were identified. Two SNP markers in gender-specific genes, *FCMO* and *FCMO-3*were validated in male and female individuals of *C. brandisii.*

Suggestions/ advisory note for end-users "To-do-techniques":

The gender specific SNP markers identified and validated can facilitate gender identification in seedling stage which will support efficient restoration programs and assured seed stock for future plantation programs in *Calamus brandisii.*

Research gaps:

Gender determination in seedling stage prior to establishment of plantation or restoration programs can help in maintaining a viable population and enhance reproductive efficiency in *ex situ* conservation programs. Gender-linked markers can thus support restoration and conservation efforts in an endemic and endangered rattan like *C. brandisii.*

Uses of research outcomes:

Identified gender-specific SNP markers for gender determination at seedling stage in *C. brandisii.*

Publications:

- Sarath, P., Dev S.A., Sreekumar V.B. and Dasgupta M. 2022. Anthropogenic threats and habitat degradation challenge the conservation of palm genetic resources-an appraisal of current status, threats and look-ahead strategies. *Biodiversity and Conservation* https://doi.org/10.1007/s10531-022-02512-8. **(IF: 4.296)**
- Ghosh Dasgupta M., Dev S.A., Muneera Parveen A.B., Sarath P. and Sreekumar V.B. 2021. Draft genome of *Korthalsialaciniosa* (Griff.) Mart., a climbing rattan elucidates its phylogenetic position. *Genomics* 113: 2010-2022. **(IF: 4.4)**

19. Title of the project: Establishment of second generation seed orchards and selection of clones for high productivity in Eucalyptus

Principal Investigator: Dr. V. Sivakumar, Scientist-E, ICFRE-IFGTB Coimbatore

Duration: 2012 - 2019

Critical analysis of the research theme and summary of the study:

Genetically superior seeds of Eucalyptus are required in large quantity which can improve the productivity of the plantations by 10-15% more yield when compared to the local seed sources. About 150 trees were identified and seeds were collected for establishment of broad genetic base (BGB) population. The infusion population has been received from Thailand and tested for infusion. The progeny trials established were analyzed statistically and appropriate methods of culling to maximize the genetic gain were developed. About 7-8% genetic gain could be achieved when culling 70% of the poor trees considering the adjusted row means and sibling neighbourhood. As part of the breeding programme, 367 second generation plus trees were selected based on BLUP estimates for the families and individual tree superiority.

Significant achievements / findings of the project:

The established progeny trials were analyzed using mixed models /spatial models through advanced methods used to predict various components of the experiments viz., row, column, plot, replication, treatment and residual. The spatial analysis was efficient. The Multi-environmental trait (MET) analysis showed that the genotype by site interaction variance was higher than the genotype component. The study could shortlist families for inclusion in further breeding programmes based on breeding values. The families with high BLUP values can be used for planting programmes. Similarly, the female parents with high BLUP values can be used for establishment of Clonal Seed Orchard and cull the inferior families in seed orchards.The method of culling was optimized based on the advanced statistical tools and breeding principles and carried out in Marakkanam progeny trial and converted in to Seedling Seed orchard for getting about 7-8% genetic gain. Second generation plus trees (367 number) were selected on morphological traits viz., girth, height, clear bole height, branching habit, axis persistence, stem straightness, presence of pest and diseases and assembled in VMG for further mass multiplication and conduct of clonal trials.

Suggestions/ advisory note for end-users "To-do-techniques":

Multi-environmental trait (MET) is efficient in considering the GxE interaction of MLTs. The spatial variation can be modelled and appropriate result can be obtained. Families with high breeding value can be identified and used for establishment of seed orchards.

Research gaps:

Establishment of next generation seed orchards with infusion from within and outside the country need to be established.

Uses of research outcomes:

Under the project, seed orchard management strategies have been developed and used for management of the orchard of Eucalyptus. The plus trees selected under the project have been multiplied and planted under multilocational trials across the country under AICRP4 on Eucalyptus improvement. Once testing is completed the same can be released for commercial cultivation.

Publications:

- Chandrasekar R., Vinothkumar A., Nair Smitha G., Sivakumar V. and Nicodemus A. 2017. Additive main effects and multiplicative interactions (AMMI) analysis of growth of half-sib families of Eucalyptus camaldulensis across environments. *Madras Agric. J*. 104 (4-6): 197-202.
- Chandrasekar R., Vinothkumar A., Nair Smitha G., Sivakumar V. and Nicodemus A. 2017. Height growth of half-sib families of Eucalyptus camaldulensis across environments using additive main effects and multiplicative interactions (AMMI) analysis. *Shanlax Int. J. Arts Sci. Humanit.* 5 (2): 148-157.

20. Title of the project: Development of descriptors and DUS testing guidelines for indigenous forest tree species (*Tectona grandis* and *Melia dubia*) and establishment of Field Gene Bank

Principal Investigator: Dr. V. Sivakumar, Scientist F and Dr. Rekha Warrier, Scientist F, ICFRE- IFGTB Coimbatore

Duration: 2013 - 2020

Critical analysis of the research theme and summary of the study:

The project aims at developing DUS test procedures for *Tectona grandis* (Teak) and *Melia dubia*. For developing DUS test guidelines of teak, studies were undertaken in Seed Production Area (SPA) and Permanent Preservation Plot (PPP) in Kerala and Tamil Nadu and studied the natural and planted teak plantations in Cherupuzha, Nellikutha, and Parambikulam. The morphological characters in the Clonal Seed Orchard of teak at Top Slip, Tamil Nadu and Walayar, Kerala were recorded. Observations in the natural forests and plantations of teak showed that the variability within a plantation was found to be low with respect to all the leaf, bark, flower and fruit characters. Some amount of variability was observed in the natural populations. The tree stem form, leaf, branching habits and reproductive characters were found to be discriminating characters. Characterization of clones present in the National Germplasm Bank of Teak at Chandrapur was carried out. Leaf, flower and fruit characters were assessed and created an image data base. Similar studies were conducted in the farm lands for developing DUS characters in *Melia dubia* and about 40 characters were identified as DUS characters.

Significant achievements/ findings of the project:

A draft DUS descriptor for Teak with 33 characters and *Melia dubia* with 40 characters were prepared under the project. The same was presented before the Task Force established for these two crops by Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA). The same was approved and published in the gazette of India.

Suggestions/ advisory note for end-users "To-do-techniques":

New clonal varieties of these species shall be registered with PPV&FRA for IP protection.

Research gaps:

Poor quality seeds are mostly used for raising seedlings, hence the yield from these plantations are low when compared to clonal plantations. Genetically superior seeds are required in large quantity which can improve the productivity of the plantations by 10-15% more yield. Hence the project aims at increasing the availability of quality seeds.

Uses of research outcomes:

Different statistical analysis tools were compared to estimate the expected genetic gain that can be achieved through breeding programmes. The method of culling was optimised based on the advanced statistical tools and breeding principles and carried out in Marakkanam progeny trial and converted in to Seedling Seed orchard for getting quality seeds with about 7-8% genetic gain. In addition, Second generation plus trees (367 number) were selected and assembled in VMG for further mass multiplication and conduct of clonal trials.

Publication:

- Lakshmi M. A., Sivakumar V. and Nicodemus A. 2020. Notes on numerical taxonomy in DUS (Distinct, Uniform and Stable) Testing under the Protection of Plant Variety and Farmers Right Authority (PPV FRA). *NeBIO* 11(1): 40-41.

21. Title of the project: Screening of International Germplasm of *Casuarina equisetifolia* for Enhancing Productivity and Rural Livelihood in Tamil Nadu.

Principal Investigator: Dr Kannan CS Warrier, Scientist-F, ICFRE-IFGTB, Coimbatore

Duration: 2016 - 2021

Critical analysis of the research theme and summary of the study:

A project was undertaken for the genetic improvement of *Casuarina equisetifolia* through multi locational testing of new germplasm from CSIRO, Australia leading to selection of superior phenotypes with the funding support of Tamil Nadu State Planning Commission. The major thrust given in the project is to develop genetically superior planting stock for enhancing wood production from plantations. Three provenance trials were established at Thuvarankurichi, Neyveli and Gudalur near Chennai in Tamil Nadu covering one ha each with 23 common international provenances across the three locations. Six monthly observations on biometric traits were recorded from all the trees in these experiments and interim reports submitted.

Significant achievements/ findings of the project:

Total height ranged between 2.93± 4.42 m and 5.50±1.38 m at Thuvarankurichi at 4 years of age. At Neyveli, provenance 18586 CHINA registered the maximum value for total height (10.58 m) among the 23 provenances studied and 14 other provenances were found at par with it. The minimum value was recorded by provenance 18122 EGYPT (6.55 m). This trait ranged between 3.05± 3.86 m and 4.56± 0.95 m at Chennai provenance trial. Volume index and total height was also found significant at 5% level of significance at these three locations. The values varied from 1849.00± 3717.98 cm^3 to 8139.00 ±3087.10 cm^3 at Thuvarankurichi, and 22950.00± 45471.86 cm^3 to 89650.00± 31664.20 cm^3 at Neyveli. At Chennai, provenance 18378 QLB ranked first with a value of 15540.00 cm^3 and 18144 KENYA registered the lowest value (2485.00 cm^3). Nine stable clones were identified based on volume index as 17577 PNG, 18122 EGYPT, 18137 KENYA, 18141 KENYA, 18297 THAILAND, 18344 MALAYSIA, 18378 QLB, 18153 PNG and 18136 KENYA.

Among all these 24 provenances, Palacherla A gave the maximum germination percentage (77.45%) with the maximum germination value of 61.36. Mixed seed lot was found to be at par with it statistically (76% and 52.62% respectively). Superior germination parameters were expressed by Provenances 17577 PNG, 18144 Kenya, 18160 Malaysia, 18134 Kenya, 18267 China and 18122 Egypt.

Suggestions/ advisory note for end-users "To-do-techniques":

The seeds would serve as the first-generation improved material which can now be used for future breeding programmes. Seeds from the select provenances may be used for operational planting programmes.

Research gaps:

Casuarina equisetifolia is generally propagated from mongrel seed sources resulting in an average productivity of 100 tonnes per ha at 4 years. However, superior planting stock yields a return of 175 to 200 tonnes per ha. An attempt was made to introduce superior international provenances of this species in India after a gap of 17 years.

Uses of research outcomes:

The productivity was found to be 170 to 180 tonnes per ha at 3 years. Eight superior international provenances have been identified for mass planting.

Publication:

- Warrier K.C.S. and Vamadevan T. 2023. Assessing the Performance and Adaptability of International Provenances of *Casuarina equisetifolia* Grown in India. *Int. J. Plant Soil Sci*. 35(18): 1999-2007.

22. Title of the project: Genetic improvement of *Thespesia populnea*.

Principal Investigator: Dr Kannan CS Warrier, Scientist F, ICFRE-IFGTB Coimbatore

Duration: 2017 - 2021

Critical analysis of the research theme and Summary of the study

Thespesia populnea (L.) Soland ex Correa is a valued multipurpose tree species. The major problem with *T. populnea* is that the stem is often crooked. The tree grows in short twists and turns with numerous limbs, therefore, lumber is generally found in short lengths. Germplasm assemblage and evaluation of different provenances or seed sources to understand the variability is fundamental to any tree improvement research. The current project envisaged to establish multilocation clonal trials of *T. populnea.*

Significant achievements/ findings of the project

Leafy cuttings from the select Plus Trees were collected and kept for rooting in the Model Nursery of IFGTB. Bud sprout could be observed in all the cuttings and the average rooting obtained was 70 per cent. Three clonal trials (Panampully Field Research Station, near Palakkad, Kerala; Gudalur Field Research Station, near Chennai, Tamil Nadu, and Thalavaipettai, near Bhavani, Tamil Nadu (Farm field)) were established with the hardened ramets of 40 select clones. Total height ranged between 73.27 cm to 106.20 cm. Clone 40 recorded the maximum value for total height whereas Clone 28 registered the minimum value with a mean and standard deviation of 90.57 and 15.84 cm, respectively. Clone 36 recorded the maximum value for collar diameter (17.95± 16.18 cm) and Clone 37 registered the minimum value (14.54±1.79 cm). Volume Index varied from 160.30± 244.31 cm^3 to 322.00 ±83.09 cm^3. The maximum value for volume index was registered by Clone 5 and Clone 37 registered the minimum value.

Suggestions/ advisory note for end-users "To-do-techniques":

The third phase of this tree improvement programme is underway at present and it is aimed at identification of superior and stable clones of *T. populnea* through multi-location field testing. Superior clones of this valuable secondary timber species shall be made available to farmers and tree growers within few years from now.

Research gaps:

The major problem with *Thespesiapopulnea* is that the tree grows in short twists and turns and lumber of good length is not generally available for public use. To address this research gap, 139 Plus Trees with straight stem and vigour were selected and a Clonal Multiplication Area was established.

Uses of research outcomes:

Clonal propagules were produces from 40 select Plus Trees of *T. populnea* and three clonal trials, first of its kind were established in Kerala and Tamil Nadu.

Publications:

- Warrier K.C.S. 2019. *Thespesia populnea* – An evergreen multipurpose tree. *Aranyam* (Kerala Forests and Wildlife Department) 40(3):46.
- Warrier K.C.S., Prabhakaran M.A. and Venkataramanan K.S. 2021. Clonal Propagation of *Thespesia populnea* (L.) Soland ex Correa. *Int. J. Agric. Environ. Biotechnol*. 14(03): 325-327.
- Warrier K.C.S. 2022. Genetic improvement and conservation of important FGR species – *Thespesia populnea* – Current status, prospects and challenges, pp 46-57. In: Forest Genetic Resource Management, Eds.: Anandalakshmi, R., Warrier, R.R., Vijayaraghavan, A., Savio, M.M.D. and Thangamani, D., Institute of Forest Genetics and Tree Breeding, Coimbatore.

23. Title of the project: Testing of New Set of Provenances of *Acaciamangium* and Estimation of Genetic Gain from First and Second Generation Seed Orchards.

Principal Investigator: 1.Dr.Maheshwar Hegde, Scientist-E(01.04.2016 to 11.07.2018) 2. Shri. A. Mayavel, Scientist – E (12.07.2018 to 31.03.2022), ICFRE-IFGTB Coimbatore

Duration: 2016 - 2022

Critical analysis of the research theme and Summary of the study:

The main objective of the project is to introduce the new set of provenances from original centre of origin and select the provenance for higher productivity in farm forest program.

Significant achievement/ findings of the project:

The CSIRO Australia has initiated the International Provenance Trial Programme of *Acaciamangium* for widening the genetic base of Acacia growing countries. New set of provenanceswere collected from original center of origin and were distributed to 6 different countries forestablishing provenance trial. Seeds of 14 new sets of provenances, two seed lots from first andsecond generation seed orchards of *Acacia mangium* have been subjected to test the variations in seed morphology, germination,seedling growth and field performance traits.Two International Provenance Trials of *Acacia mangium* at Ram Nagar, Dandeli, and Hassan, Karnataka to study the variations in field performance among the provenances. Evaluation of growth was assessed on the basis of characteristics such asheight, DBH, GBH, stem straightness, apical dominance, number of branches, branch size, boleform and survival rate. Significant variations were found in seed morphology, germination, seedling growth and field performance. The seeds of Philippines provenances recorded superiors seed morphological characteristics whereas the seeds of seed lot IFGTB-FGAM recorded thelowest values. The germination and seedling growth characteristics were higher in IFGTB-SGAM seed lot whereas PNG-FLY River provenances exhibited poor growth. The averagesurvival of the two trials was 85%, maximum plants survival rate of 96.97% wasrecorded IFGTB-SGAM seed lot followed IFGTB-FGAM. Evaluation of field performance of the provenances revealed that provenances of IFGTB-FGAM and IFGTB-SGAM seed lot recorded complete survival at both the locations and the minimum survival was recorded in PNG-Oriomo provenances at both the locations. On anoverall performance basis, the selected provenances can be ranked in the following order:IFGTB-SGAM>IFGTB-FGAM>PNG-Balimo>PNG-FlyRiver>VIE-DongHa>PNG-Lower Fly.

Suggestions/ advisory note for end users "To-do-techniques":

The superior genetics resources will be utilized forestablishing industrial pulp/timber plantation in trees outside the forest. It will also utilized for developing hybrid with *Acaciaauriculiformis* for enhanced productivity and wood quality in moderate rainfall area.

Research gaps:

Non availability of improved genetic resources of *Acacia mangium* will have the impact on wood productivity in tree outside the forest. There is an urgent need to infuse the new genetic resources to broaden the genetic base and improve the productivity.

Uses of research outcomes:

The established International Provenance Trial of *Acacia mangium* with new set of provenances from original central of origin will help to broaden the genetic base of the species and improve the productivity in trees outside the forest.

Publication:

- Mayavel A., Esakkiamal S., Sreenivasan K., Chitra P., Dharani M. and Nicodemus A. 2022.Variationinseedmorphology,germinationcharacteristicsandseedlinggrowthindifferent provenances of *Acacia mangium* Willd. *J. Pharm. Innov*. SP-11(9):522-528.

24. Title of the project: Assessment of diversity and natural regeneration status of *Sterculia urens* Roxb for development of conservation strategy in Madhya Pradesh

Principal Investigator: Dr. Naseer Mohammad, Scientist-E, ICFRE-TFRI Jabalpur

Duration: 2018 - 2022

Critical analysis of the research theme and summary of the study:

Sterculia urens Roxb. is one of the important gum-yielding species having multiple uses in pharma, health care, food, cosmetics, waste management, paper-textile, composite fiber, and leather industries. Unscientific exploitation coupled with lack of seedling recruitment resulted in large-scale eradication / reductions of populations from its natural habitat. Considering present status and economic importance of this species, the present investigation was undertaken with the aims to investigate the morphological variation, status of natural regeneration, and to propose the conservation strategy for this valuable tree species.

Significant achievements/ findings of the project:

Analysis of morphological data revealed that in the overall studied populations of *S. urens,* average tree height was recorded to be 8.68 meter. In population-wise analysis, highest average height was observed in Seoni (15.02 m), followed by Sheopur (10.9 m), Chhatarpur (9.32 m), Shivpuri (8.77 m), and Khandwa (8.83 m). Whereas, Sheopur (4.77 m) recorded highest value for clear bole height followed by Chhatarpur (4.21 m), Khandwa (3.86 m), Seoni (3.71 m) and Rewa (3.32 m) population. Highest average girth at breast height was observed in Seoni (266.22 cm) population followed by Chhatarpur (190.57 cm), Sheopur (135.9 cm) and Shivpuri (134.6 cm). Jabalpur (63.88 cm) and Tikamgarh (76.44 cm) populations recorded lower values for GBH. It is evident from assessment of morphological variability that all the morphometric traits investigated have large amount of variation. GBH recorded highest CV i.e. 63% followed by clear bole height (54%), crown diameter (50%), tree height (48%) and number of branches (46%). Natural regeneration status of *S. urens* at all the surveyed sites was observed to be very poor. On an average, 3-4 seedlings per sample plots were recorded despite profuse flowering and fruiting. Mostly, large- matured trees were found scattered on the hill tops and rocky crevices. In Gwalior, Seoni, Khandwa and Jhabua-Dhar, younger stems occupying hilltops and rocky plateau were also observed; however, their numbers were very low. Based on the estimates of final germination percentage and associated parameters i.e. mean germination time, coefficient of velocity of germination, germination rate index, germination index, peak value of mean germination, time spread of germination and energy period; it was concluded that sand was appropriate medium for germinating seed of *S. urens* in mass scale giving highest germination percentage (63.33%) with faster rate resulting in saving of time and nursery resources.

Suggestion/ advisory note for end-users "To-do-Techniques":

The study concluded that despite drastic reductions in natural populations*, S. urens* have very high range of morphological variability. Profuse flowering and fruiting were observed but natural regeneration recorded to be very poor at all the surveyed sites. Assisted natural regeneration (ANR) activities should be undertaken for this species in its natural ranges including monitoring to ensure that regeneration processes are progressing as expected, and to identify changes or conditions that may limit restoration. It is advisable that state forest departments should include this species in their plantation programmes like, Hariyali Prasar Yojna (a regional plantation programme), CAMPA, FDA sponsored afforestation programmes, *etc.* For *S. urens*, sand should be used for seed germination on commercial/mass scale due to higher germination percentage with faster rate/speed.

Research gaps:

Information about the variability and natural regeneration of *S. urens* was sparse from Madhya Pradesh.

Uses of research outcomes:

Despite reductions in natural populations, *S. urens* has very high range of morphological variability. Overall natural regeneration status was observed poor despite profuse flowering and fruiting. Based on field observations, the study recommends the inclusion of *S. urens* in plantation programs of State Forest Departments to enhance its long-term security. Additionally, we advocate for assisted natural regeneration activities within its natural ranges, emphasizing monitoring and adaptive management to ensure successful regeneration.

Publications:

- Mohammad Naseer, Dahayat A. and Pardhi Y. 2021. Effect of Growing Media on Seed Germination attributes in *Sterculia urens* Roxb. - An Endangered Gum Yielding Tree of Tropical Forest. *The Indian Forester* 147(7): 621-626. https://doi.org/10.36808/if/2021/v147i7/153636
- योगेशपारधी, मनोजपुसाम, रविकुजूर, नसीर मोहम्मद एवं फातिमा शिरीन 2020. कुल्लू (*Sterculia Urens* Roxb.): एक महत्वपूर्ण वनप्रजाति. *Vansangyan* 7(12): 27-29.

25 Title of the project:"All India Coordinated programme for genetic improvement of Teak". as four sub projects:

Sub project: - (iv) Studies on population structure, linkage disequilibrium and marker-trait association mapping of teak.

Principal Investigator: Dr. Naseer Mohammad, Scientist-E (2017 - 2022), Dr. SA Ansari, Rtd Scientist-G (2012 - 2017), ICFRE- TFRI Jabalpur

Duration: 2012 - 2022

Critical analysis of the research theme and summary of the study:

India harbours rich genetic resources of teak, with extensive natural teak-bearing forests. However, due to very high market demand, population pressure coupled with unfavourable biotic factors, teak resources have been considerably decreased in density, quality and quantity over the natural ranges. In order to adopt conservation measures and undertake genetic improvement programme, precise information of the genetic diversity and population structure are important. Although, central India is recognized as one of the major centres of genetic diversity, studies are very limited from this region compared to southern region. Therefore, present investigation was undertaken in 13 agro-climatic zones of central Indian states (Madhya Pradehs, Chhattisgarh, Odisha & Maharashtra) having natural teak populations.

Significant achievements/ findings of the project:

Coefficient of variability which is a relative measure of variability recorded higher values for tree height (24%), clear bole height (41%) and girth at breast height (27%) indicating ample scope of improvement through selection. Compared to morphological traits, wood traits have recorded considerably low coefficient of variation. This indicateed that very high selection intensity was needed for improvement in wood traits. Wood density, fibre length and fibre width recorded 13%, 9% and 11% CV, respectively. Among the studied populations, Jagdalpur population recorded highest average height, clear bole height and girth at breast height. Populations sampled from Madhya Pradesh ranked second in morphological traits. Populations from Odisha, i.e., Sambalpur (668.27 Kg/m3) and Khariar (660.42 Kg/m3) recorded higher values for wood density followed by Maharashtra and Madhya Pradesh. It was evident from correlation analysis that wood density had negative correlation with tree height, and clear bole height, whereas, wood fiber length and width recorded positive non-significant association.

Investigation using molecular markers also revealed that high level of genetic diversity existed in teak from central Indian states. STRUCTURE analysis clustered 260 genotypes sampled from 13 different agro-climatic zones into three clusters. Seoni, Khandwa, Dhamtari, Chandrapur, Sambalpur, Khariar constitutes Cluster-I; four sampled locations i.e., Mandla, Balaghat, Betul and Dewas constitutes Cluster-II; Whereas, Jagdalpur, Jabalpur and Amravati grouped in Cluster-III. However, clustering was not absolute.

Suggestion/ advisory note for end-users "To-do-Techniques":

For the selection of teak with better morphology and wood traits, areas with higher variability as revealed in the present study may be included in the tree improvement programme of this premier timber species

Research gaps:

Central India is considered as one of the major centre of genetic diversity of teak bu studies are very limited from this region. Those available were mostly based on *exsitu* raised trials or plantations with few individuals. Therefore, present investigation was undertaken in 13 agroclimatic zones of central Indian states (MP, CG, Odisha & MS) having natural teak populations.

Uses of research outcomes:

For the selection of teak trees with better morphology and wood density,areas with higher variability may be given priority in the tree selection/ improvement programme of this premier timber species.

Publications:

- Mohammad Naseer, Dahayat A, Pardhi Y. and Singh Neha 2019. Standardization of wood core maceration protocol for teak (T. grandis) and shisham (D. latifolia) – an important timber species of tropical forest. *Journal of Tropical Forestry* 35(IV): 33-41.
- Mohammad N., Rahaman S.K.M., Khatun M., Rajkumar M., Garai S., Ranjan A. and Tiwari S. 2022. Teak (Tectona grandis L.f.) demonstrates robust adaptability to climate change scenarios in central India. *Vegetos* https://doi.org/10.1007/s42535-022-00444-w.

HYDROLOGY

HYDROLOGY

1. **Title of the project:** Assessment of hydrological services imparted by forest of Kempty watershed

Principle Investigator: Dr. Parmanand Kumar, Scientist-D, ICFRE-FRI Dehradun

Duration: 2014 - 2023

Critical analysis of the research theme and summary of the study:

The project was executed to assess the hydrological services of the Kempty watershed. It was necessary to monitor the hydrological and meteorological parameters for forest impact and other changing land use on a long-term basis as part of ecological monitoring. Stream discharge was recorded hourly by H-Flume (03) equipped with an automatic water level recorder along with sediment load. Meteorological parameters of the watershed were recorded on a daily basis. Physico-chemical properties of water and soil samples were recorded periodically. The soil CO_2 emission was assessed and static and dynamic hydrologic characteristics were recorded for planning catchment area treatment. Spatial (east south and north facing) and temporal (summer winter and rainy seasons) variation of soil carbon dioxide efflux in natural forest ecosystems were essential to enhance understanding of the prevailing natural processes. As one of the most widespread engineering structures for conserving water and soil, check dams have significantly modified the local landform and hydrologic responses. The impact of the check dam was evaluated by comparing the suspended sediment concentration (SSC) of the stream before and after the construction of the check dam scenario. Results showed that check dams were able to reduce flood peaks and maintain the normal flow of water. Within the study area, four sub-watersheds were identified using ArcGIS tools, and morphometric parameters and hypsometric integral were identified. Soil quality parameters for multi-criteria analysis, with the help of compound values for the susceptibility of each watershed was defined.

Significant achievements/ findings of the project:

Hydrological services imparted by forests of the watershed were assessed along with the meteorological parameters. Evaporation from the watershed was recorded highest (85 mm/day) in the month of June and lowest (5.6 mm) in February 2020. The highest maximum temperature (28°C) was recorded in June and the lowest (10°C) during January. Wind speed and evaporation showed a slightly different trend where the maximum (3.0 km/h) wind speed during June supported evaporation.Major portion (about 88%) of total annual rainfall was received during the monsoon period which was 2800 mm and it was received on 56 rainy days whereas, a maximum 1249 mm rainfall was recorded during August in which 50% of the average total rainfall was received in 20 rainy days. Total runoff 30% generated from the watershed which was either a direct runoff of 21% or a base flow of 9%. The maximum runoff (465.59 mm) was recorded during the monsoon season which was 60% of the total runoff whereas the minimum runoff (135.31mm) was recorded during the summer season which was 18% of the total runoff. Base flow and direct runoff contributionin the stream discharge was observed 41% and 69%, respectively during monsoon. Maximum (43%) direct runoff was measured during the month of August and a maximum 27% base flow was observed in the month of September. The result revealed that there was a reduction of base flow (17%) and direct runoff (54%) during the summer season and an increment (41%) was observed in base flow and direct flow (69%) during the monsoon season, respectively. It was observed that when the rainfall exceeds the threshold limit, the proportion of rainfall contributing to runoff was found to be higher. Dissolved Oxygen in the stream water of the forested watershed has shown seasonal variation where it was highest (11 mg l^{-1}) during January and February and lowest (7 mg l^{-1}) during July. The pH varied from a high of 8.3 in the month of January to 7.0 in July. The electrical conductivity of the stream water varied from 320 to 422 μScm^{-1}.

Suggestions/ advisory note for end-users "To-do-techniques":

For better management of the watershed, several techniques viz., geological aspects, MCA, SWAT, Morphometry, and Hypsometry, were used to assess the vulnerability of all sub-watersheds to soil erosion. Different activities or observations were made under the project, to assess the role of static and dynamic hydrologic characteristics such as

geology and structural controls in spring discharge. All water quality parameters showed the ideal condition of water from the forested watershed as per BIS and WHO standards. Check dams, contour bunding, and other measures will be decided based on their channel bed slope, drainage area, the height of check dam, nature of channelization, vegetative cover, basin gradient and confluence. A combination of engineering measures such as check dams, bench terracing and stone terracing of hill slopes along with afforestation would prevent or reduce the soil erosion. A training program for the field official is proposed by the Forest Department to clarify the technical and theoretical approach.

Research gaps:

The long-term monitoring of hydrological, meteorological and environmental aspects would help in the development of appropriate and optimum strategies for sustainable supply of water. It is therefore necessary to monitor the hydrological attributes and meteorological parameters for studying the forest impact and other changing land use on a long-term basis.

Uses of research outcomes

The primary soil hydraulic properties that soil organic carbon affects are porosity, soil water retention, and hydraulic conductivity.For better management of the watershed, several techniques *viz.*, geological aspects, MCA, Morphometry, and Hypsometry, will be used to assess the vulnerability of all sub-watersheds to soil erosion. Conservation measures will be decided based on their channel bed slope, drainage area, the height of check dam, nature of channelization, vegetative cover, basin gradient and confluence.A combination of engineering measures such as check dams, bench terracing and stone terracing of hill slopes along with afforestation would prevent or reduce the soil erosion.

Publication:

- Kumar P., Singh R., Singh H, Chand T. and Bala N. 2020. Assessment of soil carbon dioxide efflux and its controlling factors in moist temperate forest of West Himalayas. *Current Science* 119 (4): 661-669.

NON-WOOD FOREST PRODUCTS

NON-WOOD FOREST PRODUCTS

1. **Title of the project:**Capacity building of VFPCs/SHGs through *v*alue addition of selected underutilized NTFPs for enhanced livelihood opportunities in arid and semiarid Rajasthan

Principal Investigator: Dr. Sangeeta Tripathi, CTO, ICFRE-AFRI Jodhpur

Duration: 2017 - 2021

Critical Analysis of the research theme and summary of the study:

This study was aimed to document harvested and used quantity of selected underutilized NTFPs in Pali and Sirohi districts of Rajasthan for exploration of possibilities for their value- added products through Village Forest Protection Committees (VFPCs)/Self Help Groups (SHGs) and their capacity building for enhanced livelihood opportunities. Most of the NTFPs are perishable and with value addition their availability during lean period in the form of a product's shelf life may be increased. Keeping this fact in view 13 value-added products were prepared and their shelf-life was studied. The acceptability of value-added products was assessed on 9-Point Hedonic Scale. Out of 13 value-added products developed in this project, the least acceptable product was *Diospyros melanoxylon* Jam which might be due to its pungent taste. Lack of trained personnel, equipment and proper storage facility for value- added products. However, due to lack of downstream processing facility, inaccessibility to the market as most of the tribals are illiterate and they are also not aware about selling of their value-added products. Therefore, no initiative is taken up by selected VFPCs /SHGs on commercial selling of value-added products. Hence, preparation of value-added products after our project period was not carried out on large scale as a group activity. Some SHG members prepared the products at their own and sold them in nearby market. The income earned by them was kept with them and not distributed in SHG bank account. As a result, SHG income as a whole did not increase.

Scientific achievements/ findings of the project:

A reconnaissance survey was conducted in Pali and Sirohi districts to document role of selected NTFPs in rural livelihoods and their possibilities of value addition to enhance tribal livelihood. Findings reveal that in 24 tribal dominated villages in Abu Road block of Sirohi district tribal population consists of Garasia, Gameti and Meena who are very poor, mostly backward living in interior forest. Livelihood systems in the study area were complex, primarily dependent on primitive mode of agriculture, followed by daily labour and NTFP (Non Timber Forest Products) collection and selling as their source of livelihood. Among these sectors, the average income from agriculture was maximum (Rs.13806/-) followed by income from NTFPs (Rs.6982) and Wage earnings (Rs. 4500/-). The income from livestock was negligible (Rs.1000/-). Contribution of total income from NTFPs was 26.56% and their collection generated 16.78% employment to the tribals. In Pali district**,** results of reconnaissance survey conducted in 70 villages revealed that maximum average income was from agriculture (Rs.22842/-) followed by income from NTFP (Rs.11796/-) and wage earnings (Rs. 5000/-). Further, average income from livestock was negligible (Rs.1000/-). The tribals/ villagers in the age of 18 to 60 years constituted main workforce in both districts. In Sirohi district, all the selected NTFPs viz. *Feronia limonia, Tamarindus indica, Butea monosperma* and *Diospyros melanoxylon*are collected in all the villages whereas in Pali district, out of 103 villages, *Momordica dioica* was collected in 96 villages followed by *Cordia gharaf* and *Leptadenia reticulata* (13 villages each). In Pali district, on the basis of collection/ annum on an average *Momordica dioica* (Kankoda) fruits were collected in maximum quantity per annum per family per kg i.e. 35.31 ± 15.68 followed by *Cordia gharaf* (Goondi) fruits (21.12 ± 2.36 kg) and *Leptadenia reticulata* (Rai Doda) pods (19.25 ± 6.04 kg). However, among these the prevailing market rate of *Leptadenia reticulata* was recorded highest i.e. @Rs. 600-800 per kg. In Sirohi district, on an average, *Tamarindus indica* (Imli) was collected in maximum quantity per annum per family per kg (51.25 ± 5.04) followed by *Feronia limonia* (Kotumbara), *Diospyros melanoxylon* (Timru) and *Butea monosperma* (Palash) flowers i.e. 30.50 ± 5.25 kg, 25 ± 5.25 kg and 18 .50 ± 2.25 kg per annum per family, respectively. Data on employment generation (per family generated mandays @ 6 hrs per day per annum) and results were in the order - *M. dioica* fruits (103.05 mandays) > *Feronia limonia* (67.5 mandays) > *Tamarindus indica* (53.5 mandays) > *Cordia gharaf* (50.0 mandays) > *Butea monosperma* (39.0) and *Diospyros melanoxylon* (37.8 mandays) > *Leptadenia reticulata* (37.5 mandays). Among NTFPs collected for subsistence use, *Momordica dioica* plays an important role in the rural livelihood in Pali district followed by *C. gharaf* fruits whereas in Sirohi district. *Tamarindus indica* was used widely in almost all the rural households followed by *Feronia limonia, Diospyros melanoxylon* fruits and *Butea monosperma* leaves and flowers.

To introduce activity of value-addition for identified key NTFPs through VFPC/SHG members and linking them with District Industries Centre for income generation, Bhurki Devi Mahila SHG, Jamboori and Mahadev Swayam Sahayata Samooh, Surpagla were selected in consultation with DFO, Sirohi. Two SHGs Desuri and Vanya Jeev Mahila Swayam Sahayata Samooh, Sangram Nadi in Desuri Range, were selected in Pali District in consultation with the DFO, Pali. Four training programmes were organized on value-addition of the selected NTFPs mentioned above. The responses of theses training programmes were recorded on 9-Point Hedonic scale through State Forest Department official, PRI functionaries and District Administration officials. A very good response of SHG members was obtained in these programmes. Out of 13 value added products, one year shelf life was recorded in *M. dioica* (Pickle), *L. reticulata* (Dehydrated pods) and *B. monosperma* (Herbal Gulal) whereas in remaining products six-month shelf life was recorded. Among these, 5 products viz. *M. dioica* (Pickle), *T. indica* (Chutney, Jam and squash), *B. monosperma*, *F. limonia* (pickle and Jam without sugar syrup) and Herbal Gulal were extremely liked by 9 respondents A very good response of SHG members was obtained in the training programmes.

Suggestions/ advisory note for end-users "To-do-techniques":

The project was field oriented and useful for generating income to the tribal people by investing minimum amount and maximum benefit. Connecting tribals to Zila Udhyog Kendra, KVIC and Small entrepreneurs for selling of value-added products in various trade fairs and *haat* bazars (local weekly markets) will definitely help them to earn within their vicinity. Identification of two facilitator for selling of value-added products will also be helpful in marketing approach and provision of revolving funds in Research Institutions for continuous preparation of value-added products even after completion of the project will be beneficial for tribals. An approach for credible product certification through Research Institutions from FSSAI, etc. will pave way for selling value-added products in national and international markets also. Establishment of Shopping Centre's by SFD and other related organizations for selling of value-added products will also be helpful. For example, in Krishi Upaj Mandi or APMC, one shop may be established in the name of "Tribal Taste" or "Wild taste" and these products should be sold on this shop.

Research gaps:

NTFPs form the secondary source of income after agriculture in Pali and Sirohi districts. Findings of reconnaissance survey conducted by AFRI, Jodhpur in 2012 revealed that most of the NTFPs collected by tribals were wasted and not utilized properly. Moreover, tribals were also not aware of value addition methods. Therefore, this project was designed to encourage optimal utilization of NTFPs and enhancing livelihood opportunities for tribals.

Uses of research outcomes:

Before our interventions, SHG members were not involved in value addition activities, but, after training programs, SHG members prepared pickle and other products for their own consumption and for selling in nearby market. The value addition practices provided to them will continue to yield benefit for years to come, while at the same time ensuring proper utilization of NTFPs.

Publication:

- Enhancing of livelihood generation through value addition of Non-Timber Forest Products: NTFPs" (Pamphlet)
- "अकाष्ठ वनोपजों के मूल्य संवर्द्धन द्वारा जीविकोपार्जन में वृद्धि" (पम्फलेट)

2. **Title of the project:** Studies on estimation of Agro-economics, market price spread and gap analysis in cultivation and processing of Senna and Isabgoal in Jodhpur division of Rajasthan

Principal Investigator: Dr. Sangeeta Tripathi, CTO, ICFRE-AFRI Jodhpur

Duration: 2017 - 2019

Critical Analysis of the research theme and summary of the study:

This study was aimed to document the cultivation practices, processing and marketing of *Plantago ovata* (Isabgol) and *Cassia aungustifolia* (Senna/Sonamukhi) in Jodhpur division of Rajasthan. Rajasthan is one of the major Isabgol producing states in India after Gujarat. Major challenges of the Isabgol value chain being a high risk crop, the entire crop getting damaged in case of bad weather and price volatility hampering the mood of farmers. Currently, the farmers share in consumer rupee is very low due to the high level of value addition done in the post-harvest value chain. Senna is an important medicinal crop grown for the extraction of Sennosides which is having laxative property and senna is drought tolerant crop thrive well in less water and require less management practices as compared to other crops and suited well to waste and low rainfall area. The challenges for Senna cultivation include market exploitation of farmers by middlemen, price fluctuations of leaves, demand-supply fluctuations of leaves, limited exports, patenting by foreign companies, low leaves yields, insect pests and diseases, labour problems (high cost, non-availability during peak season, unreasonable demands by labourers), lack of knowledge about post-harvest technology and problems associated with long term storage of leaves.

Scientific achievements/ findings of the project:

A reconnaissance survey was conducted in Jodhpur division of Rajasthan to document cultivation, harvesting and marketing of Isabgol and senna in Jodhpur division of Rajasthan. The average price of the seeds is around Rs.35 to Rs.55 per kg. RI-87, RI-89, AMB-2, GI-1, GI-2, GI 3, MIB-4, HI-34, HI-2, HI-1, HI-5, JI-4 and Niharika are the major varieties of Isabgol grown in India. Gujarat Isabgol-1, variety yields 800-900 kg of seeds per hectare. The crop suffers around 15-18% post-harvest loss due to handling at various stages in the value chain. Senna is preferred by farmers due to Good source of income, low cost of cultivation, drought tolerant crop, less maintenance, generation wise farming and can be grown on wasteland/land not being used for cultivation of crops. This crop offers an avenue and can be developed into a rural-based cottage industry starting from cultivation, grading, extraction and export. Under normal conditions an average income of Rs. 15000 - 20000 per hectare can be obtained by the farmer and value addition by way of grading and extraction results in further 25-30% net return to the rural-based small-scale industry.

Suggestions/ advisory note for end-users "To-do-techniques":

In case of Isabgol, there is currently scope of further reducing the cost of cultivation through reducing the cost of seeds and improved productivity through good agriculture practices. The post-harvest losses also need to be reduced through proper education of farmers and other handlers in the value chain. Most of the profit is being retained by high end processors. Processing is also out of reach of small companies due to large investment required in plant and machinery. Synthetic sennosides (active ingredient of Senna) are not available in the market, the demand for natural sennosides will continue to increase and provide an excellent opportunity for India to earn foreign exchange and also because of the simple cultivation practices and grading techniques, rural industries can be setup based on senna leaves and pods. In addition, there is an urgent need to develop cost-effective processes for value-added products in order to export them instead of exporting crude drugs (leaves and pods).

Research gaps:

Limited processing units exist in the State for preparing Isabgol husk for further trading and processing. Therefore, research on logistics is an area where more study is required.Lack of knowledge about post-harvest technology and problems associated with long term storage of leaves can be taken up in future for *Cassia aungestifolia*.

Uses of research outcomes:

The recommendations of the project can directly help the farmers associated with cultivation of Isabgoal and Senna by providing them a better economic picture and market conditions.

3. **Title of the project:** Socio Economic status of People in Nallamalais, Sheshachalam and North Coastal Eastern Ghats in relation with Forest Biodiversity.

Principal Investigator: Dr. Ratnaker Jauhari, ICFRE-IFB Hyderabad

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

The objective of the project was to study linkages between socio economic profile of the people and biodiversity of the region especially Non-Timber Forest Produce (NTFP) and to document relationship between biodiversity including NTFP and socio economic profile of people on macro and micro level to be useful for inputs at policy level of governance.

On a macro level the relationship between biodiversity including NTFP and socio-economic profile of the people was studied for three regions. The region of Paderu (North Coastal Eastern Ghats) was found to be the most dependent on biodiversity, followed by Achampet (Nallamala), and Tirupati (Seshachalam).

The two largest tribes of Paderu were the Bhagatas and Nookadora. For products made of bamboo, tadikelu, *etc*., they reled more on biodiversity and NTFP. The two most prevalent tribes in Achampet are Chenchus and Lambadis, who relied on diverse NTFPs found in forests. Yanadhi tribe was reliant on baskets, brooms, and other items in Sheshachalam. The Achampet division had more access to forest resources, followed by Tirupati and Paderu. Dependence is waning with time across every region.

Significant achievements/ findings of the project:

In this study, Paderu, Tirupati, and Achampet were studied for elements that affected people's socioeconomic position and how they relate to the forest's biodiversity in three different forest divisions (Nallamalais, Sheshachalam, and North Coastal Eastern Ghats).

By ensuring food and livelihood security for the tribal economy in the Achampet, Paderu, and Tirupati forest divisions in the Nallamalais, Sheshachalam, and North Coastal Eastern Ghats of India, this study aims to evaluate the impact of NTFPs on income and employment. The costs and returns of NTFP collections, as well as their impact on employment and income, were estimated. A basic random sampling technique was employed to gather data from 300 tribal families at the micro level in Andhra Pradesh and Telangana states' 3 divisions, 4 ranges, and 6 villages.

The majority of the tribes in the states of Andhra Pradesh and Telangana are dependent on forest goods. NTFPs included, dyes, fruits, resins, leaves, flowers, and seeds in addition to therapeutic plants.

The findings indicated that household dependency on forests was significantly influenced by age and education, but other socioeconomic characteristics were not significant. With age and education levels rising, a decline in reliance on the forest was seen. Therefore, it was unlikely that young people would depend on forest goods more than older people did.

Suggestions/ advisory note for end-users "To-do-techniques":

It is necessary to organize Kisan Mela, Adivasi Mela, Vana Mela, *etc*. as more and more forest villagers integrate into society. There is a need for additional NTFP usage training. Villagers ought to take an active role in preserving the wild animals and plants that have threat status.

Research gap:

Dwindling forest resources and unsustainable utilization of biodiversity affects forest dependent communities, leading to poor socio-economic conditions, migration, poor conditions of the urban areas, slums and improper utilization of the human resources. The project aimed to study linkages between biodiversity and socioeconomic aspects to address the gaps and in improving condition of people along with sustainable utilization of biodiversity.

Uses of research outcomes:

The research outcomes can be used by Andhra Pradesh Government to develop policy guidelines.

4. **Title of the project:** Processing and Value addition of Terminalias for effective livelihood improvement of forest dwellers

Principal Investigator: Dr. Rekha R Warrier, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

In addition to local consumption, non-timber forest products (NTFPs) are important traded commodities on local, regional, national, and international markets. Traded NTFPs contribute to the fulfilment of daily needs and provide employment and income. Internationally traded NTFPs, such as aromatic oils and medicinal plants, can achieve high prices compared to NTFPs traded on national markets and thus contribute to the economic development of the respective country. However, minimal statistical data on NTFPs exploitation, management, consumption and trade are available.

Significant achievements/ findings of the project:

The main objective of this project was to develop harvesting and processing methods for Terminalias (myrobalans) – a major NTFP of the country, and validate quality enhancement and commercialization. Through capacity building, the technology was disseminated to tribal folk, the main stakeholders. The details on the project, relevant research material and photo and video documentation were uploaded onto the Tribal Repository web page hosted on MoTA portal. The fruits of the myrobalans were tested for their efficacy to various diseases. It was observed that the extracts had the ability to contain different carcinogenic cell lines at minimal concentrations. This is a new finding, which is being further processed to obtain IPRs. Several meetings were arranged with pharma companies to understand their requirements of the myrobalans and the quality checks performed by their R&D labs. The details of various agencies / tribal clusters from where raw material is being procured at a common collection point were also collected.

Research gaps:

Most of the value-addition — essentially processing the raw forest produce, is done by the womenfolk and takes place outside the regions where the items are collected. As a result, tribals get very low prices for the items. Lack of value-addition also reduces the shelf-life of the produce, further reducing the bargaining power of the tribal sellers.

Uses of research outcomes:

Package of practices developed for sustainable harvest and processing for three important NTFP species.Awareness generated among the tribal communities on the need for sustainable use of NTFPs on which they have primary rights.

Suggestions/ advisory note for end-users "To-do-techniques":

To reduce poverty while maintaining or increasing forest cover, forest management needs to be coupled with infrastructure development and urbanization, which can support community benefits through the commercialization of tree products. On the other hand, built infrastructures also negatively impact forests and ecosystems through increased access contributing to overexploitation, forest conversion and fragmentation. There is a need to address trade-offs between infrastructure development and tree cover based on spatial data of forest cover, land degradation and infrastructure development.

5. Title of the project : Characterization and Utilization of Fatty Liver Curing Medicinal Plants

Principal Investigator: Dr. D. Thangamani, Scientist-D, ICFRE-IFGTB Coimbatore

Duration: 2019 - 2022

Critical analysis of the research themes & summary of the study:

The objective of the project was exploration and assemblage of fatty liver curing medicinal plants such as *Breynia retusa, Seurinega virosa, Phyllanthus reticulatus, Nigella sativa, Entada scandens,* and *Ficus glomerata* and to characterize the plants for their phytochemicals and conservation in field gene bank. Surveys were carried out in different areas of Tamil Nadu and selected nearly fifteen accessions of *P. reticulatus,* 12 accessions of *F. racemosa*, *Entada scandens* 10 accessions, 8 accessions of *S. virosa,* 8 accessions of *Breynia retusa,* 5 accessions of *Nigella sativa.* The areas were Barathapalli and Valiyakulam in Kanyakumari District; Odayakulam, Sikkarayapuram, Vijayanagar, Kovai Kutralam, Madhukkarai, Athur, Orakaliyur and Sundarapuri areas of Coimbatore District, and Thaniparai village of Virudhunagar District. The vegetative propagules and fruits were collected. Root initiation was observed after 15-20 days. The stem cuttings were collected from all 19 selected accessions and treated with different concentrations of IBA (500 ppm, 1000 ppm, 1500 ppm and 2000 ppm), The cuttings treated with 1000 ppm of IBA showed better results. Root initiation was observed after 15 – 20 days, hardened and planted. Seeds were collected from different locations and pretreated, germinated and raised seedlings were planted. Phyto-chemical analysis was carried out using dried plant material, crude extracts were prepared for qualitative phytochemical analysis under standard qualitative estimations.

Significant achievements/ findings of the project:

All plant samples (*P. reticulatus* leaf*, F. glomerata* fruit, *B. retusa* fruit, *S. virosa* root, *N. sativa* seed and *E. scandens* seed kernel, were dried and processed. The GC-MS Chromatogram showed distinct phytocompounds in leaf extracts of the selected plants The major compounds identified by the GC-MS analysis were β sitostrol, β amyrin, α amyrin, Pyridine, Maltol, Barbituric acid, Decanoic acid and n-Hexadecanoic acid. All the medicinal plants (*P. reticulatus*, *B. retusa*, *F. glomerata*) wererich with polyphenols. Germplasm assemblage has been established in Thalamalai field of KVK, Myrada and Pethykuttai, Mettupalayam, TNFD Genetics Coimbatore research station.

Suggestions/ advisory note for end-users "To-do-techniques":

The conserved germplasm will be utilized by stake holders.

Research gaps:

The gaps exist in improper management of plantation wastes for productive utilization, appropriate technology in natural dyes extraction and its applications in textile industry.

Uses of research outcomes:

Effective utilization of plantation wastes for natural dye extraction can reduce incineration of the plantation waste and provides additional income to the farmers. Small scale natural dyeing industry can be benefited using dye extractor unit developed through this project.

Publication:

- D. Thangamani, S. Poopathi Rajan, Arul Prakash T., Mohamed Nawas O. M. and Lalitha S. 2021. Conservation of *Ficus racemose* Linn. wonderful feeder of wild animals. *International Journal of Integrated Research and Development* 1(19):210-218;2021-ISSN:22788670.

6. **Title of the project:** Standardization of harvesting time and post harvesting techniques of *Helicteris isora* (*Marorphali*) and *Mucuna pruriens* (*Kaunch*)

Principal Investigator: Dr. H.O. Saxena, Scientist-E, ICFRE-TFRI Jabalpur

Duration: 2018 - 2021

Critical analysis of the research theme and summary of the study:

In present practice, the fruits of Kewanch and Marorphali are haphazardly collected from forest areas mostly by the forest dweller communities which dispose the produce to the intermediary, who control a major part of the value addition process. The collection of Kaunch seeds from wild is very tedious as the hairy structures present on the pods cause severe itching while contacting skin due to the presence of phytochemical mucunain. During collection of fruits, twigs and branches are also cut which harm the population of the species. Under the present study, the harvesting time, proper processing (effect of different types of drying on chemical constituents), and storage techniques (effect of different types of containers and storage period on chemical constituents) of these valuable medicinal produces were standardized for their sustainable management. Mature fruits of Kewanch and Marorphali were collected from forest areas in different months to standardize the harvesting time. The processing techniques were standardized by drying the plant materials in shade, sun, and artificial drying. Processed and dried seeds of Kewanch and fruits of Marorophali were stored separately in different containers i.e. HDPE bags; woven sacks; gunny bags; tin, glass, plastic containers and in open environment (control) at room temperature. The stored Kewanch seeds and Marorphali fruits were analysed for L-dopa and lupeol contents, respectively using HPTLC technique at bimonthly intervals to study the effect on bioactive chemical constituents. Themicrobial infestation during storage period of these valuable medicinal produces was also assessed at bimonthly intervals. The results indicated the January and February months, the optimum harvesting times for Kewanch and Marorphali fruits respectively in terms of their active chemical ingredients. Moreover, sun drying was observed an appropriate method of drying for obtaining maximum chemical ingredients. The study also suggested the boiling of Kewanch fruits in water for 10-15 minutes as an optimal method for their processing. The results further showed the air-tight glass, plastic and HDPE, the better containers for storing the Kewanch seeds and Marorphali fruits for a maximum period of ten and six months, respectively without significantly decrease in L-dopa and lupeol contents respectively.

Significant achievements/ findings of the project:

Harvesting time for Kewanch and Marorphali fruits was standardized. The optimum harvesting time for Kewanch and Marorphali fruits was observed as January and February months respectively in terms of their active chemical ingredients. Drying and processing techniques forKewanch and Marorphali fruits was also standardized. Sun drying was observed better in comparison to shade drying and artificial drying at 30ºC, 35ºC and 40ºC to maintain quality of Kewanch seeds and Marorphali fruits. Boiling in water for 10-15 minutes was found the optimum processing method for separating seeds from Kewanch fruits. Airtight glass containers, plastic containers, and HDPE bags were found the optimal containers to store the materials. The optimum storage period of Kewanch seeds and Marorphali fruits was found as ten and six months, respectively from the time of their storage in these containers.

Suggestions/ advisory note for end-users "To-do-techniques":

The findings of the project will be very useful for the stakeholders involved in trade of medicinal plant produces. Extension leaflets on findings of the project were prepared and communicated to the Madhya Pradesh State Minor Forest Produce Federation and Research, Extension & Social Forestry wing of Madhya Pradesh State Forest Department, Bhopal for further outreach to the NTFP collectors and other stakeholders involved in NTFP/ medicinal plants trade.

Research gaps:

Literature revealed that there were no harvesting and post harvesting techniques available for *M. pruriens* and *H. isora* species. Hence, for sustaining the quality, good processing techniques, long term storage and better economic return form these species, this study was undertaken to standardize the harvesting time and post harvesting techniques.

Uses of research outcomes:

The standardized techniques will be utilized by the NTFP collectors, forest fringe communities, SFDs, MFP federations and other stakeholders involved in NTFP/ medicinal plants trade for maintaining the quality, good processing techniques, long term storage and better economic returnform these species. Extension leaflets on findings of the project were prepared and communicated to the stakeholders.

Publications:

Extension leaflets

- Collection, Processing, and storage of *Mucuna pruriens* (L.) DC. (केवांच का संग्रहण] प्रसंस्करण एवंभंडारण)
- Collection, processing and storage of *Helicterisisora*L. Fruits (मरोड़फली के फलों का संग्रहण, प्रसंस्करण एवंभंडारण)

7. **Title of the project:** Selection of CPTs, standardization of collection practices and quality evaluation of Gum karaya (*Stercularia urens*) in Chhattisgarh state

Principal Investigator: Dr. H.O. Saxena, Scientist-E, ICFRE-TFRI Jabalpur

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

Achieving the targets of the project, several mechanical and conventional ways of tapping for gum production were assessed for their effectiveness and the safety of the plant's health. Naturally available karaya trees with girths ranging from 90 to 140 cm, 141 to 190 cm, and > 190 cm were chosen for the study at three different sites in three agroclimatic zones of Chhattisgarh state, and they were given different tapping treatments to optimize gum yield. The study revealed that the semi-arc blazing on tree trunk followed by crushing of bark, leaving fortnightly and after that refreshening of the upper crescent layer of the blaze in every 48 hrs intervals was found the most sustainable way of gum harvesting for its highest yield. Blazes made during four months (March -June) for gum tapping were observed to be recovered in 12 – 18 months. The gum yield was recorded maximum in the month of May probably due to high temperature and low relative humidity in this month. Also, the gum yield was found directly proportional to the GBH of the trees. A validated HPTLC method was developed first time for quantification of glucuronic acid content in gum karaya samples. The results showed the better quality of gum samples of Bastar agroclimatic region in terms of glucuronic acid content and viscosity. A total of 66 CPTs (28 in Bastar region; 19 in Central Plain region; 19 in Northen Hill region) were selected in different agroclimatic regions of Chhattisgarh state.

Significant achievements/ findings of the project:

The study resulted in standardization of sustainable harvesting method for optimum yield of gum Karaya. Blazes made during four months (March -June) for gum tapping recovered in 12 – 18 months. The rate of gum exudation (g) was highest in the month of May in all treatments of three experimental experiment sites. Experiments on gum tapping of *S. urens* trees revealed that gum yield is directly proportional to the GBH of the trees. The glucuronic acid content was found maximum in gum samples of Bijapur and minimum in gum samples of Manendragarh. Among all three agroclimatic regions, the quality of gum samples from Bastar agroclimatic zone was found superior in terms of viscosity and glucuronic acid content.

Suggestions/ advisory note for end-users "To-do-techniques":

Among conventional and other mechanical methods experimented in the field, the Koval's technique was found the most sustainable way of gum harvesting for its highest yield.Trainings on sustainable harvesting and processing of gum karaya were given and extension leaflets were distributed to the gum collectors and SFD officials in Sukma, Bijapur and Dantewada forest divisions of Chhattisgarh state to promote sustainable collection of gum karaya for long-term livelihood in order to prevent destructive harvesting and harm to the trees. Besides, extension leaflets were sent to the Managing Director, Chhattisgarh State Minor Forest Produce (Trading & Development) Co-operative Federation Ltd., "Van Dhan Bhawan", Naya Raipur, Chhattisgarh and the Madhya Pradesh State Minor Forest Produce Federation and Research, Extension & Social Forestry wing of Madhya Pradesh State Forest Department, Bhopalfor awareness generation and knowledge dissemination to the stakeholders involved in trades of NTFPs and medicinal plants.

Research gaps:

Abundant availability of the indigenous raw material of *Terminalia bellirica* (Baheda) if quality planting material (Candidateplustrees)/seedsource selected from the natural population with high active ingredients.

Uses of research outcomes:

The work will be of great help in managementandconservationofthisvaluablespecies. If we raise the plantationsafter taking seeds from geneticallysuperior trees, superior progeny willyieldmanifoldbenefitsaftermaturation.

Publication:

- Saxena H.O., Parihar S., Pawar G. and Sahu V.R. 2022. High performance thin layer chromatography method development and validation for quantification of glucuronic acid in gum samples of *Sterculia urens* Roxb. *JPC–Journal of Planar Chromatography–Modern TLC* 35 (2): 153-159. https://doi.org/10.1007/s00764-022-00165-5.

Extension leaflets:

- Sustainable harvesting and Processing of Gum Karaya (*Sterculia urens* Roxb.) (TFRI/BROC-01/2021/27)
- करायागोंद (*Sterculia urens* Roxb) का सतत् विदोहन एवं प्रसंस्करण (TFRI/BROC-01/2021/28)

8. **Title of the project:** Selection and Improvement of Natural Dye yielding Plants

Principal Investigator: Sh. Sindhu Veerendra**,** Scientist-C, ICFRE- IWST Bengaluru

Duration: 2016 - 2020

Critical analysis of the research theme and summary of the study:

Morinda tinctora possesses fairly good amount of natural variability in the present population as well as in selected genotypes in morphological and dye-yielding traits. The dye yielding parts are smaller diameter roots in *M. tinctoria* and are highly varied with dye content. Species distribution is discontinuous and mostly occurred in favorable geographic locations. Therefore, it is assumed that variability patters are also discontinuous. Genotypes are profuse seed bearers and exhibit good amount of variation in some geographic locations, indicating existence of alternate breeding mechanisms. Heterostyly is genotype specific and favour cross pollination by pollinators. Hence wide variability patterns are expected.

Significant achievements/ findings of the project:

Four provenances and 52 CPTs are selected based on good crown size, high dye yield and good colour intensity of dye powder. Large, thick green leaves are also source of green dye and have potential to become source of green pigments, thus the genotypes can become multipurpose species. Hence the species is a good example for domestication in terms of dye yield, fruit yield and green dye. Fruits have therapeutic values and have wide market. Laboratory protocols were developed to increase the dye yield per unit gram of root bark and improved dyeing techniques were added to enhance colour intensity and consistency in dyeing. It appeared that extracting dye in the form of powder through water was easy method which can be used for value addition to dye powder having export potential. Strong vegetative reproduction through root suckers and production of seeds in good amount make this species easy to multiply.

Suggestions/ advisory note for end-users "To-do-techniques":

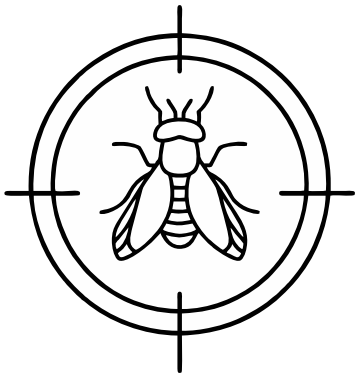
Meeting of farmers conducted to educate about *Morinda* roots extraction and quality maintenance.

Research gaps:

This is easy to fine tune the program since those dye powder characteristics are controlled by genetic factors. Hence any future characteristics of dye powders will be smoothly transmitted to their off springs. Hence there is an immediate need for progeny trials and to develop a technology to measure and compare the colouring intensity of various genotypes.

Uses of research outcomes:

Laboratory protocols developed may be utilized by end users to obtain pure dye powder. Sub-population of this species may be created through breeding for targeted traits and may be directly distributed to farmers for extraction of dye powder. These species are highly suitable for economically viable agroforestry models that will fetch additional income to farmers.



PROTECTION

(ENTOMOLOGY)

PROTECTION (ENTOMOLOGY)

1. **Title of the project**: Development of Integrated management strategy against flower gall inducers of *Prosopis cineraria* (L.) Druce

Principal Investigator: Dr. Shiwani Bhatnagar, Scientist-D, ICFRE-AFRI Jodhpur

Duration: 2017 - 2022

Critical analysis of the research theme and summary of study:

The objective of the research was to develop an integrated management strategy against flower gall inducers of *Prosopis cineraria* (*Khejri).Khejri*is the life-line of the Thar Desert as it is the most important component of the traditional farming systems of arid and semi-arid region of the north-western part of India. It plays a significant role in rural economy as a source of top feed, fuel and timber. Its pods locally known as *Sangri* are sold fresh and dehydrated at high price, and are the main constituent of *Panchkutta* and *Trikuta* vegetables preparations. In *P. cineraria* flower galls induced by *Eriophyes prosopidis,* an eriophyid mite results in severe pod reduction and gall formation. Damage by the flower galls is not only reduces the aesthetic value of the tree but also lowers down the yield of pods, thereby increasing the price. It was found that the infestation of this mite can be managed by integrated management approach viz., mechanical removal of dried galls that had fallen on surface, lopping at an interval of 1 year and using botanicals, entomopathogens and acaricides.

Significant achievements/ findings of the project:

Eriophyes prosopidis induced flower galls were found responsible for loss of pods and seed production in *P. cineraria*. The gall-infested trees appeared disorganized and deformed as green galls hanging from them. The infestation of this mite can be managed by integrating mechanical, biological and chemical measures. The mechanical removal of dried galls fallen on ground and lopping at an interval of one year can reduce the infestation considerably. Treatment with combinations of entomopathogens and botanicals viz. *Metarhizium anisopliae* + *Putranjiva roxburgii* leaf extracts and *Metarhizium anisopliae* + *Balanites aegyptiaca* leaf extracts; combination of two botanicals viz. *Putranjiva roxburgii* leaf extractand *Balanites aegyptiaca* leaf extract and chemicals abamectin 1.9% EC @1ml/l and Diafenthiuron 25% WW + Pyriproxyfen 5% WW @ 2ml/l can be utilized for effective management of flower galls of *P. cineraria.*

Suggestions/ advisory note for end-users "To-do-techniques":

Outcome of the research has application in the field. Training programmes for forest officials, NGO's and progressive farmers and other stake holders were organized. It is advised, to do only 2/3rd lopping of trees at an interval of 1 year and removal of the dried galls fallen on the ground to check fresh infestation. Integrated pest management measures should be applied at the time of flower bud initiation.

Research gaps:

Khejri, called as the lifeline of the Thar desert, is becoming infested with gall-inducing mites across Rajasthan which, in turn, is leading to massive reductions in the yield of Sangri (the fruits). No work was available which documented an effective management strategy for controlling this problem.

Uses of research outcomes:

The findings of the project can be utilized by state forest departments and farmers for managing the problem of Khejri galls**.**

Publications:

- Bhatnagar Shiwani, Khan Ameen Ullah, Sharma Neha, Tak Prem Singh, Singh Sangeeta and Nirwan Bindu 2019. *Eriophyes prosopidis* induced flower galls of *Prosopis cineraria*. *Journal of Entomology and Zoology Studies* 7(2): 01-03.
- Bhatnagar Shiwani, Khan Ameen Ullah, Vishnoi Geeta, Rathore Lokendra Singh, Kumar Bundesh and Singh Sangeeta 2018. Inflorescence gall problem of *Prosopis cineraria* in Rajasthan. *Plant Archives*18 (2): 1248-1250

2. **Title of the project:** Insect Pests of Western Himalayan Oaks and their Control.

Principal Investigator: Dr. Arun Pratap Singh, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2021

Critical analysis of research theme and summary of the study:

The Western Himalayan state of Uttarakhand in India represents five species of oaks of the genus *Quercus* - *Q. glauca* (phaliyant/harinj), *Q. leucotrichophora* (banj), Q. *floribunda* (tilonj/moru), *Q. lanuginosa* (rianj) and *Q. semecarpifolia* (kharsu)] that are important for their multiple utilization values for local communities living in the region by providing livelihood and sustenance for fodder and firewood. Besides, these temperate forests play an important role in recharging of ground water and are rich in Himalayan biodiversity. The entire western Himalaya is today witnessing an 'oak decline' throughout its distributional range. Oak forests today are under threat mainly due to anthropogenic pressures along with attack by many species of insects. Cerambycid wood borers are responsible for damaging the living trees thereby causing large scale tree mortality followed by attack by secondary borers and fungi that render the timber useless for utilization. Damage to acorns by weevils leads to poor regeneration. Hence, there was a need to understand the insect pest spectrum of oak forests and identify and study the biology of important pests which can cause significant damage and work out management options. As such field surveys across the oak forests of the state were carried out for 3 years (2017-2020) in the entire temperate oak forest zone of the state. First hand data on 114 species of insects infesting these 5 species of oaks were recorded and a database prepared on insects recorded so far in the state. It includes information on 233 species of insects. Experiments were carried out on control of stem wood borers using bio-pesticides and fumigants. Management of key important pests i.e. stem and wood borers, defoliators, shoot borers, acorn weevils and sap sucking insects by using IPM methods was suggested.

Significant achievements/ findings of the project:

Documentation of all the insects infesting oaks recorded so far in Uttarakhand state by creation of a database on 233 insects (117 Lepidoptera; 99 Coleoptera; 16 Hemiptera and1 Diptera) infesting oaks of the western Himalaya. GIS based maps were generated depicting sites undertaken for studies in Uttarakhand, for defoliator and borer infestation. Life cycle of over 50 species was studied. Biology and morphology of different life history stages of the wood borers X*ylotrechus basifuliginosus* and *Rosalia lateretia* (cerambycidae: coleoptera) was studied for the first time. Biotic and biotic factors responsible for borer outbreaks on oaks were identified as mainly extensive lopping and grazing.More severe the earlier disturbance, more was the borer infestation and vice-versa. It is recommended that prohibition on lopping of oak trees in badly borer infested oak stands to prevent them from egg laying will help in checking the further spread of the borer infestations besides burning of oak slash, removing of dead infested trees and logs from the infested sites. Chemical control measures worked out against stem wood and timber borers by using a commercially available biopesticide “TAG VERIA” an Entomo-pathogenic fungi (*Beauveria bassiana*) for secondary wood borers and also a fumigant (saturated sol of para-di-chlorobenzene in Kerosene oil) for primary borers. For defoliators are mainly surface feeders, ie Indian Gypsy Moth, *Lymantria obfuscata* Walker and Pink Gypsy Moth, *Lymantria mathura* Moore, chemical spray using synthetic pyrethriods i.e 0.1% Cypermithrin or commercially available strain of *Bacillus thuringensis* (BT), were recommended in larval stage of these insects. Mechanical control using glue bands (15 cm plastic bands coated with a sticky glue surface) applied around the full tree trunk circumference at breast height help the caterpillar population that climb down the tree trunks to overwinter besides egg mass collection and destruction. For shoot borers, acorn weevils and sap sucking insects, systemic insecticide i.e. Imidacloprid @0.5ml/litre by mixing it in soil close to the root system of the tree was recommended.

Suggestions/ advisory note for end-users “To-do-techniques”:

The current findings have improved our understanding about the spectrum of insects infesting western Himalayan oaks in a better way. These findings will help in identification, evaluation and proper management of insects harmful to oak trees in the state. The database will help in research by identification of insects, understanding their life histories, distribution range, host plant spectrum, altitudinal distribution, habits, extent and nature of damage, natural enemies, pest status, cultural, chemical and give bio control methods for harmful insects and that will help in improving the health of oak forests in Uttarakhand. Extension of this research work was done by means of presentations as scientific posters in various organization events and seminars, publication of research papers and creation of database in the form of a book made available on line free of cost to the users at the ICFRE website [link https://icfre.gov.in/books-file/book24.pdf].

Research gaps:

There is no comprehensive information available on the insects infesting western Himlayan oaks in Uttarakhand in the form of a book or database that provides identification of insect pests from their images of different stages of pest, their biology, ecology, distribution, host plant range, extent of damage, natural enemies and eco-friendly control measures for important ones.

Uses of research outcomes:

The current study improved our understanding about insects infesting the western Himalayan oaks in Uttarakhand in a better way in identification, evaluation and proper management of insects harmful to oak trees in the state. The database created will help in research by identification of insects and understanding their life histories, distribution range, host plant spectrum, altitudinal distribution, habits, extent and type of damage, natural enemies, pest status, etc. Cultural methods and IPM control options worked out and recommended will help in checking the infestation of harmful species in forest stands and timber depots.

Publications:

- Singh A.P., Bahuguna K. and Ramola G.C. 2019. New host records of polyphagous Lepidoptera on Ban Oak *Quercus leucotrichophora* A. Camus (Fabaceae) in the Garhwal Himalaya, India. *Journal of Threatened Taxa* 11(5): 13579–13591. https://doi.org/10.11609/jott.4624.11.5.13579-13591.
- Singh A.P. and Ramola G.C. 2020. *Garella ruficirra* (Hampson, 1905) [Noctuoidea: Nolidae: Chloephorinae: Sarrothripini] infesting young shoots of *Quercus lanata* Smith,1819 (Fabaceae) in Kumaon region of Uttarakhand. *Indian Forester* 146 (2): 183-184.
- Singh A.P. and Ramola G.C. 2021. New host records of lepidoptera defoliating Himalayan silver oak, *Quercus leucotrichophora* A. Camus and Ring-cupped oak, *Q.glauca* (Fagaceae) in Uttarakhand, Western Himalaya. *Entomon* 46(1):53-68.
- Singh A.P. and Lekhendra 2021. A record of *Ourapteryx dierli* Inoue, 1994 (Lepidoptera: Geometridae: Ennominae) from the Garhwal Himalaya, India. *Journal of Threatened Taxa* 13(8): 19171–19172. https://doi.org/10.11609/jott.6779.13.8.19171-19172.
- Singh A.P. 2021. *Insect Pests of Western Himalayan Oak in Uttarakhand.* Forest Research Institute (ICFRE), Dehradun, 338 p.
- Ramola G.C. and Singh A.P. 2022. Relationship between Cerambyciid borer (Insecta: Coleoptera: Cerambyciidae) infestation and human-induced biotic interferences causing mortality of kharsu (*Quercus semecarpifolia* Smith in Rees) oak trees in Garhwal, Western Himalaya, India. *Current Science* 122 (3): 327-332, https://doi.org/10.18520/cs/v122/i3/327-332
- Ramola G.C. and Singh A.P. 2022. Biology of *Xylotrechus basifulginiosus* Heller- A borer of Kharsu oak trees in the Western Himalaya. *Indian Journal of Entomology* 85(1):83-89. https://doi.org/10.55446/IJE.2022.520
- Singh A.P. and Ramola G.C. 2022. Spectrum of Insect Fauna Infesting Western Himalayan Oaks (*Quercus* spp.) and Management of Key Pests. *Indian Forester* 148(6): 555-570, DOI: 10.36808/if/2022/v148i6/165504
- Singh A. P. and Sahu Lekhendra 2022. First site record of the Burnet Moth *Milleria adalifa* (Doubleday, 1847) (Lepidoptera: Zygaenidae: Chalcosiinae) from Uttarakhand, Western Himalaya, India. *J. Bombay Nat. Hist. Soc*. 119 (2): https://doi.org/10.17087/jbnhs/2022/v119/165077
- Ramola G. C. and Singh A.P. 2023. Efficacy of bio-pesticide *Beauveria bassiana* against Kharsu oak stem and wood borer *Xylotrechus basifuliginosus* Heller, 1926 (Coleoptera: Cerambycidae) in the Garhwal region, Western Himalaya, India. *Current Science* 124,11:1-4.

3. **Title of the project :** Epidemiology and management of *Chlorophorus annularis* Fab. (Coleoptera: Cerambycidae) – A major borer of cut and dry bamboo

Principal Investigator: Dr. K.P. Singh, Scientist-F, ICFRE-FRI Dehradun
Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:
Biology, incidence and intensity of attack of *Chlorophorus annularis* Fab. (Coleoptera: Cerambycidae) was studied for the first time. *C. annularis*was reportedattacking cut and dry bamboo due to which fine dust was observed in bamboo resulting in loss of its economic value. On hatching out, larvae bore into the tissues of the bamboo beneath walls and eat out tunnels which have little definite direction, and often appear more or less to intersect or cross the one with the other. *C. annularis*was observed attacking for the first time on eight bamboo species viz:*Bambusa polymorpha,B. balcooa,B. giganteus,B multiplex, B. spinosa, B. tulda,B. vulgaris*and*Dendrocalamus strictus.* Out of these *B.polymorpha,B. balcooa*and*B. giganteus*were considered under high intensity of attack; whereas *B*, *multiplex, B. tulda*and*D. strictus* were observed under the moderate intensity of attack. *B. vulgaris*and *B. spinosa*were found under low intensity of attack. Management of cut and dry bamboo borer- *C. annularis* was done by using contact, systemic insecticides and preservatives. It was observed that contact insecticides performed better as compared to systemic insecticides and used as prophylactic treatment. Out of CCB, Borax and Ziboc preservatives; Ziboc was observed most effective preservative for the control of bamboo borer and resulted 79.49 per cent borer control in dry bamboo after 7 days dipping. It was followed by 4 days dipping (73.51), 2 days dipping (58.13) and 1hr dipping (50.44) average per cent borer control which was effective and non-polluting alternative of synthetic insecticides.

Scientific achievements/ findings of the project:
*C. annularis*has been observed attacking on eight bamboo species. Incidence and intensity of attack on different bamboo species have also been studied. Experimentation to control the damage has been undertaken using three systemic (dimethoate, monocrotophos and imidachloprid) and three contact insecticides (deltamethrin, cypermethrin, and chloropyriphos) on dry bamboo. The results revealed that contact insecticides performed better as compared to systemic insecticides. Three preservatives CCB, Borax and Ziboc 6% were also tested on green and dry bamboo against *C. annularis*. It was concluded that Ziboc was observed most effective preservative followed by CCB and Borax.

Suggestions/ advisory note for end-users "To-do-techniques":
Findings of the project would be useful in controlling the cut and dry bamboo borer. The research output needs to be extended further to the state forest departments, farmers, NGOs etc., for sustainable management aiming at economic and livelihood security to millions of people in the country.

Research gaps:
Detailed biology and ecology of cut and dry bamboo borer was not studied before. So, it was important to fill this gap in research to identify the peak period of infestation. Management strategies for the borer were not studied earlier in details therefore, insecticidal method and eco friendly method was used to fill this gap in management.

Uses of research outcomes:
Management methods can be delivered to the identified stakeholders through training programs and distribution of pamphlets explaining the management strategies to be used against the bamboo borer.

Publications:

- Singh K.P. and Sharma Manisha 2021. Management of cut and dry bamboo borer - *Chlorophorus annularis* Fab.(Coleoptera: Cerambycidae) by Using Systemic and Contact Insecticides. *Recent Advances in Biology and Medicine 1*. E-ISSN: 2378-654X. 7: 1-6.
- Singh K. P.,Sharma Manisha., Kumar Arvind. and Singh, Indu 2021.Life cycle of cut and dry bamboo borer- *Chlorophorus annularis* Fab. (Coleoptera: Cerambycidae). *Indian forester,* 147 (6): 591-595.
- Singh K. P., Faisal Mohammad, Ikram Mohsin and Pandey Sharad 2021. External morphology of immature stages of cut and dry bamboo borer, *Chlorophorus annularis* Fab. (Coleoptera: Cerambycidae). *Ann. Entomol*. 39 (2): 79-83.
- K.P. Singh, Faisal Mohammad, Sharma Manisha and Ikram Mohsin 2022. Control of bamboo borer *Chlorophorus annularis* by using eco-friendly preservatives. *Indian Journal of Forestry* 45 (3), pp.156-159.

4. Title of the project : Bio-ecology and management of Sal seed borer- *Dichocrocis leptalis* Hamp. (Lepidoptera: Pyralidae)

Principal Investigator: Dr. K.P. Singh, Scientist-F, ICFRE-FRI Dehradun

Duration: 2020 - 2023

Critical analysis of the research theme and summary of the study:

Detailed biology of Sal seed borer- *Dichocrocis leptalis* Hamp. (Lepidoptera: Pyralidae) was done for the first time. Borer completed four generations in a year. After hatching larva entered in the seed through micropylar end and feed vigorously on the endosperm by completely hollowing it and pupates there in pre-pupal stage. Incidence of attack was observed high in Timli range followed by Thano, Barkot and Kalsi ranges in Uttarakhand. Intensity of attack was observed 20-25%, 30-35 %, 55-60% and 40-45% from first to fourth generation, respectively. Managementof Sal seed borer*D. leptalis* was done under lab and field conditions. The results revealed that under laboratory conditions, the most effective fumigant against the seed borer at 24 hours, 48 hours and 72 hours was found EDB +CCl_4, followed by EDB, PDCB and CS_2. In field, maximum percentage of borer control was obtained by Imidacloprid 19.87+ Beta cyfluthrin 8.49% OD at 0.16 per cent concentration with 68.10% followed by 0.08 per cent concentration with 65.29% control, 0.04 per cent concentration with 62.07% control. Imidacloprid 17.8% SL ranked second in the per cent control at 0.16 per cent concentration with 64.84% control, followed by 0.08 per cent concentration with 62.74% control.

Scientific achievements/ findings of the project:

The current study reported *D. leptalis* as one of the major seed borers of Sal with the infestation percentage of up to 58%. The study recommended, fumigating the Sal seeds in laboratory with EDB +CCl_4 at0.02 ml/kg for 48 hours followed by EDB, PDCB and CS_2 at the same dose and duration for the maximum control of borer. The study also recommended that EDB is most suitable for germination of the seeds of Sal. In field, it was recommended to use Imidacloprid 19.87+ Beta cyfluthrin 8.49% OD at optimum concentration of 0.08% followed by Imidacloprid 17.8% SL and Cartap hydrochloride 50% SP at same concentration to obtain maximum percentage of control of the Sal seed borer.

Suggestions/ advisory note for end-users "To-do-techniques":

Findings of the project would be useful in controlling the Sal seed borer. The research output needs to be extended further to the state forest departments, farmers, NGOs etc., for sustainable management aiming at economic and livelihood security to millions of people in the country.

Research gaps:

Detailed biology and ecology of sal seed borer *D. leptalis* has not been studied earlier. Assessment of incidence in different localities and management strategies for the borer was not studied earlier.

Uses of research outcome:

Fumigated sal seeds can also be preserved for longer time. For management in field, pamphlets can be issued to the identified stakeholders explaining the suitable control methods against the seed borer.

5. Title of the project: Screening of poplar clones for tolerance against poplar leaf defoliator, *Clostera cupreata* But.

Principal Investigator: Dr. Arvind Kumar, Scientist-F, ICFRE-FRI Dehradun

Duration: 2017 - 21

Critical analysis of the research theme and summary of the findings:

The plant species has genetic ability of tolerance against herbivore. The objective of the present study was to screen the naturally tolerant clones against leaf defoliator, *Clostera cupreata* and to establish the correlation between phytochemicals and feeding preference of the *C. cupreata*. Total 88 poplar clones, developed by different organizations *viz*. FRI, Dehradun, ITC-Wimco Rudrapur, State Forest Department, Uttarakhand and clones of Australia and USA were screened against *C. copreata*. The screening of natural resistance against *C. cupreata* was done based on leaf feeding area under choice and no choice condition in the laboratory. Subsequently, phytochemicals *viz.*flavonoid, phenol and tannin content were also analyzed of these clones. Additionally, growth loss in poplar trees due to leaf defoliation was estimated.

Significant achievements/ findings of the project:

Thirteen clones viz. FRI-PD-FS-21, FRI-PD-FS-28, G-48, FRI-PD-FS-95, 1110120, WSL-18, WSL-22, FRI-PD-FS-13, FRI-PD-FS-194, FRI-PD-AM-19, FRI-PD-AM-44, FRI-PD-AM-96 and FRI-PD-AM-112 were found to be the most tolerant clones against *Clostera cupreata*. Feeding preference of *C. cupreata* was also studied under choice and no choice condition and it was found that there was significant difference in the feeding preference among the clones, in both the conditions, and was positively and significantly correlated with each other. The results also revealed that there was variation in flavonoid, phenol and tannin content among the clones. The correlation study of leaf feeding area by *C. cupreata* larvae and all three phytochemical contents were correlated with each other and results showed that flavonoid and tannin content negatively influence the feeding preference of the *C. cupreata*, but phenol content showed mixed effect. Subsequently, tree growth loss study resulted that, significant loss of tree height, diameter and total volume occurred with the defoliation of poplar tree. The height increment loss in poplar tree was maximum in the defoliation level 100% followed by 75%, 50% and 25%. It was also exhibited that maximum leaf defoliation decreased the maximum height and diameter increment. Subsequently, the diameter increment was more sensitive to the leaf defoliation as compared to height growth of the tree. The average growth loss was less influenced in the nursery condition (19.41 to 55.51%) as compared to one year old (23.64 to 66.19%) and two-year-old trees (22.12 to 65.88 %).

Suggestions/ advisory note for end-users "To-do-techniques":

These screened clones may be recommended to the farmers for field plantation. Further studies on the genetic variability of tolerant and susceptible poplar clones should be done to find out the genetics behind tolerance. These screened clones may be recommended to the farmers for filed plantation.

Research gaps:

There was no data on the loss of poplar tree growth due to defoliation during the insect defoliation period in the field. Additionally, to prevent the defoliation loss insect tolerant clones against *Closterac upreata* were needed to be identified.

Uses of research outcomes:

Thirteen clones—FRI-PD-FS-21, FRI-PD-FS-28, FRI-PD-FS-95, FRI-PD-FS-13, FRI-PD-FS-194, G-48, 1110120, WSL-18, WSL-22, FRI-PD-AM-19, FRI-PD-AM-44, FRI-PD-AM-96, and FRI-PD-AM-11 exhibiting relative superiority against the poplar defoliator, *Closteracupreata*, may be utilized in plantation by the farmers and stakeholders.

Publications:

- अरविन्द कुमार, के.पी. सिंह और रवि प्रकाश मौर्य 2019. चिनार के प्रमुख कीट एवं उनका प्रबंधन। वन अनुसंधान ई–पत्रिका।
- Two android mobile applications "पापलर के प्रमुख कीट और उनका प्रबंधन" and "Insect pests of Poplar" were developed under this project for farmers. Two technical folders for extension of information among farmerwere published.

6. Title of the project: Studies on taxonomy and host range of larval parasitoids, *Apanteles* spp. Hymenoptera: Braconidae) from Uttarakhand and Haryana.

Principal Investigator: Dr. Mohd. Yousuf, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2020

Critical analysis of the research theme and summary of the study:

The subfamily Microgastrinae belongs to family of Braconidae having 2,999 described species under 81 genera world over, and 97 valid species reported from India. All the members are endoparasitoids of lepidopteran insect pests of agriculture and forest tree species. More than hundred species of this group have been used successfully in biological control programme against various economically important pests worldwide. *Apanteles* spp. of Indian region were still unexplored thoroughly. Keeping in view the importance of *Apanteles* parasitoids, as biological control agents of forestry insect pests, work on survey, identification, taxonomy, hosts and distribution of *Apanteles* spp. in Uttarakhand and Haryana was carried out. The work on taxonomy, host range, and laboratory testing of some important species of *Apanteles* against key insect pests of forest tree species for their future field application in applied biological control of key insect pests was carried out, Uttarakhand and Haryana. Host range of different *Apanteles* spp. collected from Uttarakhand and Haryana was prepared. Laboratory testing of *Apanteles ruidus* reared from teak defoliator *Hyblaea puera* was carried out against key insect pests of different trees (Teak, Shisham, Poplar, *Lagerstromia* sp. and Litchi) but *A. ruidus* successfully parasitized, Teak skeletonizer, *E. machaeralis* and Shisham defoliator, *Plecoptera reflexa*. *A. ruidus* was also tested againt neem defoliator *Cleora cornaria*.

Significant achievements/ findings of the project:

Samples of insect fauna were collected from 515 different localities of Haryana and Uttarakhand and 348 specimens of *Apanteles* spp. were sorted out. A total of 205 samples of lepidopterous larvae were collected from Haryana and Uttarakhand for laboratory rearing and emergence of *Apanteles* spp. from different forestry trees species. Six spp. of *Apanteles* were identified: *A. neocajani* reared from the larvae of *Hyblaea puera; A. ruidus* reared from the larvae of *Hybalaea puera* and *Hyposidra successaria; A. calycinae* from *Plecopter reflexa; A. machaeralis* and *A. hyblaeae* from larvae of *Eutectona machaeralis* and *A. expulsus* from Neem defoliator *Cleora cornaria.* Twenty (including one new species) species of *Apanteles: A. antipoda, A. araeceri, A. erionotae, A. artonae, A. agilis, A. calycinae, A. caniae, A. creatonoti, A. darjeelingensis, A. expulsus, A. hyblaeae, A. javensis, A. machaeralis, A. neocajani, A. neonephoptericis sp. nov.* (reared from *E. machaeralis*), *A. phytometrae, A. prodeniae, A. ruidus, A. tachardiae* and *A. taprobanae* from insect samples collected by sweeping method and rearing have been identified up to species level. Two species *A. ruidus* and *A. expulsus* have been re-described in details. Photographs and diagnostic characters of other species have been incorporated. Host range of different *Apanteles* spp. collected from Uttarakhand and Haryana have been prepared.

Suggestions/ advisory note for end-users "To-do-techniques":

Findings included the ready record of twenty *Apanteles* species from Uttarakhand and Haryana. which can be collected easily from the given localities of Haryana and Uttarakhand for application in biological control of a key pests. This information can be utilized by academicians, Scientists and the personnels engaged in biological control of insect pests. Method of culture development of indigenous species can be utilized for taking new indigenous species from the fields for their applications in biological control of key insect pests. Larval parasitoids *Apanteles* spp. can be applied as an important component of Integrated Pest Management of key insect pests.

Research gaps:

Many species of this group have been used successfully in biological control programme against various economically important insect pests. *Apanteles* spp. of Indian region are still unexplored thoroughly. Work on survey, identification, taxonomy, hosts and distribution of *Apanteles* parasitoids as biological control agents of forestry insect pests in Uttarakhand and Haryana was required to be carried out.

Uses of research outcomes:

The known larval host range of these parasitooids will be helpful in their mass multiplication and can be used in biological control programmes against target insect pests.

Publications:

- Yousuf M. and Ikram M. 2019. First report on *Apanteles ruidus*, Wilkinson reared on *Hyblaea puera* (Lepidoptera: Hyblaeidae) teak defoliator from India. *Archive of Agriculture and Environment Science*4 (2): 219-223.
- Yousuf M., Ikram M. and Singh K. P. 2020. First record of *Apanteles expulsus*, Turner on *Cleora cornaria* (Lepidoptera: Geometridae), Neem looper from India. *Proceeding of the Zoological Society* DOI: 10.1007/s12595-020-00327-5.
- Rajwar N., Yousuf M. and Ikram M. 2020. Role of larval parasitoid *Apanteles* species in Biological Control (Larva parjeevy *Apanteles* prajatiyaon ki javik niyantaran men bhoomica). *Van Anusandhan e Patrika*, 2: 28- 29.

7. **Title of the project:** Digitization and enrichment of National Forest Insect Collection (NFIC) of Forest Research Institute Phase-II (minute insects).

Principal Investigator: Dr. Sudhir Singh, Scientist-G, ICFRE-FRI Dehradun

Duration: 2017 - 2021

Critical analysis of research theme and summary of the study:

National Forest Insect Collection (NFIC) is a renowned national treasure and houses unique collection of forestry related insects of the Indian subcontinent. Collection has pride of holding about 17,000 authentically identified species (including 1800 types) with more than 3,00,000 pinned specimens. The project was envisaged to digitize the smaller insects which could not be digitized in the I-phase due to lack of required equipments. Main objectives of the project are: i) Modification and upgradation of older NFIC Database as per present day softwares and web security protocols, ii) Hosting of Database on intra/ internet, iii) Enriching the collection by adding chalcid species not represented in NFIC and iv) Adding species into NFIC donated by various researchers from within and outside India.

Significant achievements/ findings of the project:

Digitization of 9,124 species of small insects was done with the help of Automontage digitization system mounted on stero-zoom microscope. NFIC Database has been modified and upgraded. A total of 2,223 species, donated by various researchers from within and outside India, were added into NFIC Database (including 415 chalcids). Six new species of Eulophids inducing galls or associates of galls were described as new to science.Apart from the above revisionary works on following taxa were also done in collaborations with national and foreign taxonomists: Xyleborine (Coleoptera: Scolytidae: Xyloborini) types; Bethylidae, Chrysididae, Drynididae and Formicidae (Hymenoptera) types of Kurian; Chrysomelidae and Megalopodidae (Coleoptera)types in NFIC. Following genera *Acmaeodera* (Buprestidae)*, Euphranta* Loew (Diptera: Tephritidae), *Sarju* Ghauri(Hemiptera: Pentatomidae) and *Polygraphus* (Coleoptera: Curculionidae: Scolytinae) were also revised. This project comes under the thrust area of biodiversity and efforts have been made to digitize and document national forest insect diversity. With addition of more species figures of NFIC grew to 19,331, including 2,066 types (839 holotypes and 1227 paratypes).

Suggestions/ advisory note for end-users "To-do-techniques":

Outcome of the project in form of database (http://www.nfic.icfre.gov.in) which will be extremely useful for insect diversity workers and taxonomists.

Research gaps:

NFIC is one of the richest insect depisitory in the country, with about 20,000 (including about 2000 types) authentically identified insect species mainly related to Forests of the country. It caters insect identification services to the stakeholders, biodiversity students and researchers. The collection is very old, mostly collected during 1920s to 1960s, and therefore, specimens have become prone to damage while physical handling by the users. Therefore, to protect this national heritage it was envisaged to digitize it so as to minimize physical handling on part of users. Secondly, making the collection available to large number of researchers throughout the world.

Uses of research outcomes:

Database has been hosted on the web and available to all the researchers interested in biodiversity across the globe the globe.

Publications:

- **NFIC Database**: Singh, S. (2022). National Forest Insect Collection (NFIC) Database. http://www.nfic.icfre.gov.in
- Singh S., Colombo Wasely D., Shreevihar Santosh, Mohd. Faisal, Pandey V. P. and Tribul C. M. 2021. Rediscovery of Kurian's types of Hymenoptera in Forest Research Institute, Dehradun, India, with notes on Indian bethylid fauna. *Zootaxa*, 5019(1): 1-90.
- Singh S., Kumar A. and Kaneria M. 2021. Description of five new eulophid species (Hymenoptera: Eulophidae) associated with leaf vein galls of *Madhuca longifolia* J. Koenig (Sapotaceae) in India. *Zootaxa* 5129 (1): 001- 036.
- Dubey A. and Singh S. 2021. A new whitefly of quarantine importance infesting a native and invasive plant, *Rubus ellipticus* Sm. (Rosaceae) in the Western Himalaya, India. *Journal of Asia Pacific Entomology* 24(4): 1239-1243.
- Salini S., Rabbani M. K. and Singh S. 2021.Taxonomic notes on *Sarju* Ghauri, 1977 (Hemiptera: Heteroptera: Pentatomidae) with description of a new species from India. *Zootaxa* 4951 (2): 283–303.
- Cognato A.I., Sari G., Smith S.M., Beaver R.A., Li Y., Hulcr J., Jordal B.H., Kajimura H., Lin C-S., Pham T.H., Singh S. and Sittichaya W. 2020. The essential role of taxonomic expertise in the creation of DNA Databases for the identification and delimitation of Southeast Asian ambrosia beetle species (Curculionidae: Scolytinae: Xyleborini). *Frontiers in Ecology and Evolution* 8(27):1-17. doi: 10.3389/fevo.2020.00027 (Switzerland).
- Khanday A.L., Bhuroo A.A., Kerchev I. A., Singh S. and Zubair R. M. 2020. A review of the Indian species of genus *Polygraphus* Erichson, 1836 (Coleoptera: Curculionidae: Scolytinae) with bio-ecological notes on *P. major*, a pest of *Pinus wallichiana* A. B. Jacks (Pinaceae) in Kashmir, India. *Folia Forestalia Polonica, Series A – Forestry,* 62 (3): 171–183.
- Kaneria M. and Singh S. 2020. Description of a new species of *Ericydnus* (Haliday, 1832) (Hymenoptera: Encyrtidae: Tetracneminae) from India. *Journal of the Entomological Research Society* 22(1): 75-82.
- Faisal M. and Singh S. 2018. Type specimens of Chrysomelidae and Megalopodidae (Coleoptera) in the National Forest Insect Collection (NFIC), Forest Research Institute, Dehra Dun, India. *Zootaxa* , 4420 (4): 509–529.
- Singh S. 2018. A new species of *Aprostocetus* Westwood (Hymenoptera: Eulophidae), parasitizing mango leaf gall midge (Diptera: Cecidomyiidae) from India. *Journal of Asia-Pacific Entomology* 21(2): 553–559.
- Smith, S. M., Beaver R.A., Singh S. and Cognato A. I. 2018. Taxonomic clarification and neotype designation for three Indian xyleborine species (Coleoptera: Curculionidae, Scolytinae). *Zootaxa* 4394(1): 138–140.
- Khanday A.L., Bhuroo A.A., Singh S., Ranjith A.P. and Mazur S. 2018. Survey of predators associated with bark beetles (Coleoptera: Curculionidae: Scolytinae) with redescription of *Platysoma rimarium* Erichson, 1834 from Kashmir, India. *Journal of Asia-Pacific Biodiversity* 11(3): 353-360.
- VolkovitshM. G. and Singh S. 2018.On the three enigmatic species of *Acmaeodera* Eschscholtz from India and Pakistan in the collection of Forest Research Institute in Dehradun (Coleoptera, Buprestidae: Polycestinae). *Entomological Review* 98 (7): 883–891.

8. Title of the project: Biodiversity, Habitat Association and GIS mapping of Noctuid moths (Noctuidae: Lepidoptera) of Chirpine forest of Jammu Province (Jammu & Kashmir) India.

Principal Investigator: Dr. Pawan Kumar Scientist-F (April, 2016 to May, 2018), ICFRE-HFRI Shimla

Duration: 2016 - 2019

Critical analysis of research theme and summary of the study:
Importance of the Lepidoptera especially of Noctuid moths in forest plantation was realized when the nursery and plantations of pines in different parts of the world consistently failed until suitable control measures were developed against these insect pests. During present study extensive surveys for exploration of chir pine (*Pinus roxburghii*) forest of Jammu province for collection of moths (Lepidoptera), associated flora and climatic data as well as geo-information of the visited sites was undertaken. Surveys to various chir pine forests in Jammu viz. Kathua, Sambha, Mansar, Udhampur, Reasi, Sunderbanni, Bilawar and Katra were conducted which led to collection of 236 moth samples later sorted out into various taxa. The segregation of these specimens led to identification of 65 species of Noctuid moths. Habitat association was assessed by laying quadrant method to evaluate the distribution status of the flora of the study sites.

Significant achievements/ findings of the project:
A total of 236 specimens of noctuid moths (Lepidoptera) collected from Chir pine forests of Jammu province were sorted out into 65 species of Noctuid moth. Wing venation and genitalia of identified species were studied after dissecting the adults to update the taxonomic features of the species. Data on weather parameters/geo-referencing was recorded. Diversity status of Noctuid moth in different study sites was evaluated to establish the threat status using different diversity indices. Floral diversity status of study sites was calculated to assess the preferred habitats of Noctuid moth in the Chir pine forests of Jammu province. GIS mapping of Noctuid moth distribution was conducted using ArcGIS software to develop permanent distribution database for future use in analyzing the variation in Noctuid moths diversity in the Chir pine forests of Jammu province.

Suggestions/ advisory note for end-users "To-do-techniques":
The proper identification and dispersal limit of a species will help in developing effective control measures against particular species which will help in improving environmental quality and improvement in the forest cover. Correct identification of Noctuid species is very important for the study of ecology, behaviour, abundance, true host plants and the exact dispersal limits of the for-control measures of these pest species and conservation of biodiversity. The study can be used for forecasting future distribution patterns of selected species and their food resources/plants, through evolving habitat conservation strategy and identify other insect species including insect pollinators and bio-indicators species sensitive to environment/climate change in other parts of the globe and particularly of the chir pine forests of Jammu.

Research gaps:
Because of the unique geographical location and divergent climatic conditions, North-West Himalayan region has always had a large variety of flora and fauna and the present investigation was undertaken with the objective to identify noctuid fauna (Lepidopetra) in different habitats of Chirpine forest of Jammu Kashmir and to explore the habitat preference of different noctuid species so that measures for conservation of biodiversity can be established from explored richness of noctuid fauna by establishing species association of these moths with the natural habitat.

Uses of research outcomes:
These findings can be used by SFDs and Biodiversity specialists to devise conservation plan and effective management of important biodiversity of the region. The study will also help to the Naturalist/Conservationists, researchers or Taxonomist working on the same or other groups of the area as a reference during such endeavours in this direction. The study will be a reference and baseline information for monitoring the biodiversity change due to developmental activities.

Publication:

- Kumar P**.,** Kumar M. and Kumar A. 2018. Some records of the owlet moths (Lepidoptera: Noctuidae) of Chirpine forest of Jammu province. *J. Biol. Chem. Chron.* 4**(1):** 16-18

9. **Title of the project:** Studies on Changing Forest Insect-pests Status of High-Altitude Transitional Zones and their Management in Himachal Pradesh (Phase-I)

Principal investigator : Dr. Pawan Kumar, Scientist-F, ICFRE-HFRI Shimla

Duration: 2016 - 2021

Critical analysis of the research theme and summary of the study:

The present research investigation was conducted in four sites i.e. Chanshal area (Shimla), Rohtang area (Kullu), Inderhar area (Dharmshala) and Sach area (Chamba) of High Altitudinal Transitional Zones of Himachal Pradesh. The study led to identification of 32 species belonging to the order Lepidoptera (*Ypnomeuta padella*, *Junonia iphita*, *Pieris canidia*, *Pieris brassicae*, *Pieris napi*, *Asota caricae*, *Thysanoplusia spp.*, *Agrotis ipsilon*, *Malacosoma spp., Lymantria concolor*, *Thaumetopoea processionea*, *Lasiocampa trifolii*), Coleoptera (*Melolontha furcicauda*, *Clinteria*spp., *Brahmina comata*, *Mimela amphichroma*, *Phratora vulgatissima*, *Xylotrupes*spp., *Plagiodera versicolors*, *Arthopalus rusticus*, *Calosoma beesoni, Coccinella magnifica*, *Cybister tripunctatus*, *Carabus coriaceus*, *Xylotrupes beckeri*, *Hilyotogus Holocerious*, *Scolytinae*), Hemiptera (*Halyomorpha* spp., *Podisus* spp.), Hymenoptera (*Tenthredo Cretata*, *Tenthredo* spp.), Orthoptera (*Gesonia puncliforns*), and Dermaptera (*Labidura* spp.). Diversity analysis was conducted to study the relative abundance and species richness of insects in the different sites which can be used in future studies to access any change or variation in the population of these insects.The most dominant pests *i.e.Ypnomeuta padella, Heterocrasa expansalis, Thaumetopoea processionea*, *Asota caricae*, *Phratora vulgatissima* and *Agrotis ipsilon* were recorded attacking the forest of High-Altitude Transition Zone in Himachal Pradesh. Biocontrol agents i.e. *Chrysoperla carnea* and *Trichogrammachilonis* were tested to check their efficacy in the laboratory. These methods (i.e. natural predators and parasitoids) were used along with other treatments like Biopesticides, HMOs and commercial insecticides to develop effective eco-friendly IPM to control serious pest of trees of High Altitude Transitional Zones of Himachal Pradesh.

Significant achievements/ findings of the project:

Thirty-two species of insect pests were identified which were found infesting forests of High-Altitude Transitional Zone. The biodiversity data revealed that the insects are shifting or expanding their habitat from lower altitude to higher altitude areas as the temperature, relative humidity and seasonal pattern is changing. Due to habitat destruction, many species are already extinct but with the help of this study, we can identify and conserve the threatened taxa. The majority of the insect species belonged to the orders Lepidoptera and Coleoptera. Some infestation of insect species of the order Hymenoptera, Diptera, Dermaptera and Orthoptera was also recorded damaging different parts of the trees. The main pests observed were defoliators and borers. Notably, *Ypnomeuta padella* (Ermine moth) heavily defoliated Birdcherry trees (*Prunus cornuta*) in NW Hiamalya. Aqueous Extracts of native plant species *i.e.* Pissumar, *Boenninghausenia albiflora* (2%) and Sama, *Engelhardia roxburghiana* (2%) were used to check their efficacy against larvae of *Acrea issoria* (Yellow Coster)and *Ypnomeuta padella* (Ermine moth). The selected treatment *i.e.* Cypermethrin (0.5%), Nimbicidine (2%), *B. albiflora* (2%), *Engelhardia roxburghiana* (2%) and HMO (2%) exhibited mortality of 95%, 73%, 72%, 67%, and 65%, respectively.

Suggestions/ advisory note for end-users "To-do-techniques":

The eco-friendly IPM techniques using different treatments i.e. pesticides, biopesticides, HMOs, parasites and predators of major pests standardized in the laboratory are eco-friendly in nature and suitable for field application, which can also be used against serious insect pest attacks in the natural forests in future. The study results contribute to the development of sustainable pest management approaches in high-altitude forest ecosystems, but further research and a longer-term perspective are needed for a more robust assessment of the proposed treatments' effectiveness and ecological impact.To ensure eco-friendly pest management, an integrated approach that combines techniques such as

biopesticides derived from native plants like Pissumar and Sama, Horticulture Mineral Oils and the promotion of natural enemies should be adopted.

Research gaps:

The studies on the population dynamics and diversity of insect pests of High-Altitude Transitional Zones in Himachal Pradesh was not conducted earlier. Moreover, use of native plants and biocontrol agents were required to be identified which can be effectively utilized to manage the targeted insect pests. Eco-friendly management practices were not available for containing the population of serious insect pests of HATZ, H.P. which can be disseminated tot the stakeholders.

Uses of research outcomes:

Different control treatments (Insecticides and Biopesticides) were tested in the laboratory including biocontrol agents like *C. carnea* and *T.chilonis* along with native plant formulations *B. albiflora*(Pissumar) and *E. roxburghiana*can be used in the field by H P Forest Department.

10. Title of the project: Development of integrated pest management system (IPM) for *Sapindus trifoliatus* in Andhra Pradesh and Telangana

Principal investigator : Dr. Deepa M, Scientist-E, ICFRE-IFB, Hyderabad

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

Soap nut semilooper is an important pest causing severe damage to soap nut plants. The larval incidence of soap nut semilooper varied from place to place and season to season in both the years of observations. The larval population was maximum in Kanigiri (Prakasum disttrict), Mallepally, Devarakonda (Nalgonda district) areas when compared to Markapur (Prakasum district), during 2016-19. The larval population was more on smaller plants, when compared to the grown-up plants. The incidence of Soap nut semilooper, *Tinolius eburneigutta* was observed from October first fortnight onwards in Kanigiri and Markapur and first fortnight of June in Mallepally and Devarakonda. The commercial products of *Bacillus thuringiensis* (Halt, Dipel, Biobit and Delfin) were proved to be effective on younger larvae recording 95.5 to100.0 per cent mortality from first to third instars. Low mean larval mortality of 44.0 and 22.5 per cent was recorded by fourth and fifth instar larvae and differed significantly with each other.

Significant achievements/ findings of the project:

Insect infestation study revealed that Soap nut semilooper is the most destructive pest causing 90-100% infestation followed by Blossom webbers, Flower webbers and Nut borers. The seasonal incidence study indicated that the incidence of Soap nut semilooper was maximum during June, July and August in areas of Nalagonda district and with population declining from September except Kanigiri and Markapur areas where peak was from October to December. Larval incidence was maximum in smaller plants compared to grown up plants. The maximum incidence was recorded in Kanigiri, Mallepally and Devarakonda areas during 2016-18. This differential phenology of Soap nut semiloopers has been attributed to different weather parameters. To understand the influence of weather parameters, correlation study was made on the number of adults trapped through the light trap and the larval population on soap nut. Total rainfall, minimum temperature and relative humidity (morning and evening) showed significant positive correlation with light trap catches and larval population; whereas maximum temperature had significant negative influence on both the parameters. Effectiveness of four commercial products of *Bacillus thuringiensis* viz., Biobit WP, Dipel DF, Delfin WG and Halt WP evaluated at 0.1, 0.2, 0.5, 1.0 and 1.5 g/l. were tested against first to fifth instars larvae of Soap nut semiloopers. The test insect was highly susceptible to *B. thuringiensis* irrespective of products. Among the tested products, all the products were found to be best in killing larvae at higher concentrations, i.e. 1.0 and 1.5 g/l. Egg parasitoids studies showed that, all the five *Trichogramma* species tried were found to accept the eggs of Soap nut semiloopers under laboratory conditions. Among them, *T. acheae* (55.2%), *T. chilonis* (47.0%) and *T. japonicum* (45.01 %) parasitized the maximum number of eggs. The percentage of parasitism was higher on freshly laid eggs than on a day-old egg by all the *Trichogramma* species. Laboratory experiments were conducted for assessing the knock down toxicity of new insecticidal molecules at different doses against third and fourth instar larvae of Soap nut semiloopers. It revealed that the mortality of larvae was 100 per cent in all the insecticides at recommended dose compared to botanical pesticide such as azadirachtin was found ineffective in causing the mortality. New insecticide molecules like Navaluron 10EC, Profenphos 50EC, Indoxacarb 14.5 SC and Spinosad 45 SC were found to cause 100 percent knockdown toxicity within 2 h after inoculation against third and fourth instars larvae. Field studies on the management of Soap nut semiloopers revealed that insecticides viz. Navaluran 10 EC, Profenphos 50 EC, Indoxacarb 14.5 SC and Chlorpyriphos 20 EC were effective in reducing the population of larvae of Soap nut semiloopers followed by *B. thuringiensis* and HpNPV. Whereas, the *Baeveria bassiana* and *Azadirachtin* were equally ineffective. However, the effect of B. thuringiensis and HpNPV was seen at seven days after treatment. All the treatments were effective in reducing the larvae compared to untreated check. *Clerodendrum viscosum* 1.0 percent exhibited highest antifeedant activity against loopers, while *L javanica* afforded least antifeedant activity against loopers. *S indicus* recorded the lowest LC_{50} value against Soap nut semilooper, the relative toxicity of different plant extracts against

semiloopers arranged in the descending order are *Sphaeranthus indicus, Cleistanthus collinus, Clerodendrum viscosum, Ocimum Americanum, Azima tetracantha* and *Lippia javanica.* For flower webbers with regard to number of larvae present after three days of spraying maximum 1.73 numbers of larvae per plant was noticed in Spinosad followed by Chlorpyriphos followed by NSKE (2.70), Neem oil (2.73), Imidacloprid (37.09), Profenophos (3.37), Indoxacarb (3.60), Emmamectin benzoate (3.81) and Acephate (3.97).

Suggestions/ advisory note for end-users "To-do-techniques":

Integrated Pest Management can be used to manage all kinds of pests anywhere, IPM focuses on long term prevention of pests or their damage by managing the ecosystem. Therefore, detailed work will be required to assess the impact of damage caused by insect pests of *Sapindus trifoliatus* and development of integrated management package for the control of its major insect pests and finally to disseminate the developed management package to the user groups.

Research gaps:

Sapindus trifoliatus is an important cultivated species for which integrated pest management system is lacking.

Uses of Research outcomes:

The results of the study are useful in better understanding the pest biology and their management in *Sapindus trifoliatus*. The suggested control measures can be used by growers/ farmers.

Publications:

- Deepa M. and Ramulu G. 2022. Studies on influence of weather parameters on the activity of soapnut semilooper monitored through light trap catches at Devarakonda, Nalagonda Dist. Telangana. Volume 11 Issue 5www.ijsr.net.
- Deepa M. 2022. Studies on Incidence of Soap nut Semilooper in Relation to Weather of Different Areas in Prakasum and Nalgonda District. *Res. Jr. of Agril. Sci.* 13(4): 1320–1322.
- Deepa M.,Meera D. and Venkataramana Devi C. H. 2019. Study of Relative feeding potentiality of Soap nut semilooper against *Cleistanthus collinus* plant extract. *Res. Jr. of Agril. Sci.* 10 (2):12-16.

11. Title of the project: Identification of indigenous species of *Trichogramma* (Hymenoptera: Trichogrammatidae) and their assessment against major insect pests of teak in Telangana and Andhra Pradesh.

Principal investigator : Dr. Deepa M., Scientist-E, ICFRE-IFB Hyderabad

Duration: 2017 - 2021

Critical analysis of the research theme and summary of the study:

The findings of the present study are in conformity with the view that the release of indigenous egg parasitoid, *Trichogramma chilonis,* @ 1.25 lakh/ha significantly reduced defoliation/skeletonization intensity and larval incidence of *Hyblaea puera* and *Eutectona machaeralis,* both in natural forest and plantations of teak. Further, the findings on growth data of teak trees indicate significant increase of growth at breast height (GBH) due to release of biocontrol agents. All these findings advocate the biocontrol potential of *T. chilonis* in management of key stone insect pests of teak, *H. puera* and *E. machaeralis*.

Significant achievements/ findings of the project:

Indigenous species of egg parasitoid *Trichogramma chilonis* was identified and mass multiplication of its laboratory host *Corcyra cephalonica* was undertaken and continued. Using eggs of *C cepholonica,* the egg parasitoid *Trichogramma* multiplication was done and trichocard preparation was undertaken and used for field release. The field release was also done in Medak (Akkannapet, Ramayampet) and Hyderabad (Mulugu) from July-October 2018. Release of indigenous egg parasitoid, *T chilonis*, @ 1.25 lakh/ha in natural forests and plantations of teak revealed significant variation of defoliation and skeletonization caused by teak pests, *H. puera* and *E. machaeralis*, when compared to non-released sites. The percentage defoliation assessment of *H. puera* based on the whole tree and number of leaves per tree and its percentage incidence was significantly reduced in *T. chilonis* released sites when compared to non-released sites, both in natural forests and plantations.

Suggestions/ advisory note for end-users "To-do-techniques":

Indigenous egg parasitoid, *T. chilonis* may be utilized for effective use as a biocontrol agent against *H. puera* and *E. machaeralis* and as guidelines for large scale management programme.

Research gaps:

Information about the indigenous egg parasitoid; *Trichogramma chilonis* and its role in management of major insect pests of teak forests in Telangana is lacking.

Uses of research outcomes:

Tricho cards can be used by Telangana Forest Department and private Teak farmers for pest management in Teak.

12. Title of the project: Screening for establishing bio-efficiency of ethno-insecticidal plants from the forest of Andhra Pradesh.

Principal investigator : Dr. Deepa M, Scientist-E, ICFRE-IFB, Hyderabad

Duration: 2016 - 2019

Critical analysis of the research theme and summary of the study:

The present findings point out that among all plant extracts *Ocimum americanum* (LC_{50}-0.3169 and LC_{50}-0.3115 against *Hyblaea purea* and *Eutectona macheralis*)followed by *Clerodendrum viscosum* (LC_{50}-0.4316 and LC_{50}-0.5253 against *Tinolius eburguneita* and *Atteva fabricella)*found to be effective and more toxic against selected major insect pests that tested**.** Thus it is concluded that the degree of antifeedant activity and toxicity of different plant extracts varied from insect to insect, hence depending upon the pest problem and a particular type of extract has to be applied for effective control of the pest.

Significant achievements/ findings of the project:

Botanicals act not only as insecticides but also function as antifeedants, oviposition deterrents and ovicides. The present investigation reported on the antifeedant property of leaf components of (07) seven plant extracts (*Azima tetracantha, Chloroxylon sweietenia, Clerodendrum viscosum, Cleistanthus collinus, Lippia javanica, Ocimum americanum* and*Sphearanthus indicus*) against four test insects (*Hyblea purea,Tinolius eburneigutta, Eutectona machearalis* and*Atteva fabricella*) at different concentrations. All insect cultures were maintained in a growth chamber in the laboratory at a temperature of 27 ± 2° C, 12: 12 L:D and with 70 ± 5 % RH during the experiments and the antifeedant activity observed in all the plant extracts based on the feeding behavior of the test insect species and arranged in the descending order is 1.0%>0.8%>0.6%>0.4%>0.2%>0.1% concentrations and untreated control. One per cent concentration was found to be the most effective and potent antifeedant against these leaf-feeding insect pests. Among all plant extracts *O. americanum* (LC_{50}-0.3169 and LC_{50}-0.3115 against *H. purea* and *E. macheralis*)followed by *C. viscosum* (LC_{50}-0.4316 and LC_{50}-0.5253 against *T. eburguneita* and *A. fabricella)*werefound to be effective and more toxic against selected major insect pests**.**

Suggestions/ advisory note for end-users "To-do-techniques":

Many workers recorded use of certain plant species by the native people for insect repellent, attractant, anti-feedent and insecticidal activity. Intense efforts are on to identity newer compounds of insecticidal properties with novel modes of action. Therefore, it is pertinent to validate the ethnobotanical records with respect to insecticidal properties of forest flora of this region by screening them for bioefficacy against major insect pests.

Research gaps:

There are recorded use of specific plant species by the native people of Telangana region for insect repellent, attractant, antifeedent and insecticidal activity, the efficacy of which are not scientifically validated.

Uses of research outcomes:

It will be useful in developing botanicals against certain insect pests of Telangana region.

Publications:

- Deepa. M., Meera D. and Reddy G.R.S. 2016. *Azima tetracantha* Lam. - An ethanobotanical plant with biocidal properties from the forest of Andhra Pradesh.*Van Sangyan* –A monthly open access e-magazine 3(12):24 (ISSN 2395-468X)
- Deepa. M., Meera D.and ReddyG.R.S. 2017. Extraction and Initial partition of active ingredients from *Chloroxylon sweteinia* as botanicals by Soxhlet Method. *Van Sangyan* –A monthly open access e-magazine 3(12):35 (ISSN 2395-468X).

- Deepa. M., Meera D.and Reddy G.R.S. 2017. *Sphaeranthus Indicus* Linn: An Ethanobotanical plant from the forest of Andhra Pradesh. *Van Sangyan* –A monthly open access e-magazine 3(12):46 (ISSN 2395-468X).
- Deepa M., Jacob. J.P. and Rahul K. 2022. Screening for establishing bioefficacy of ethnoinsecticidal plants for the development of formulations. *Entomon 2022: Inovations and enterprenship*: p.1-4.
- Deepa M.and Meera. D. 2022.Studies on the toxicity and relative toxicity of different plant extracts to different leaf feeding insects of Telangana Forest. *Plant archives*22 (1): 324-327.
- Deepa M. 2022. Evaluation of bioefficacy of *Lippia javanica* against *Hyblaea puera* (Lepidoptera: Hyblaeidae) from the forest of Andra Pradesh, India. *Plant archives* 22 (1):320-323.
- Deepa M.and Meera D**.** 2019.Studies on feeding behavior of different leaf feeding insect pests of forest under treatments of different ethno-insecticidal plant extracts. *International Journal of Science and Research*. Paper Id: ART20191578, ISSN: 2319:7064.

13. Title of the project: Development of volatile based lure for key insects pests of commercial tree species - teak (*Tectona garndis*) and Ailanthus (*Ailathus excelsa* and *A. tryphysa*)

Principal investigator : Dr. John Prasanth Jacob, Scientist-G, ICFRE- IFGTB Coimbatore

Duration: 2019-2022

Critical analysis of research theme and summary of the study:

Leaves of plants are also source of volatiles that can attract or deter insects feeding on them. Therefore, detailed studies on the role of volatiles in plants in eliciting the type of behavioural response in insects will further help in incorporating/ eliminating such characters in individuals. Volatile variations in species like Teak and Ailanthus are far less studied and should be exploited to develop efficient pest management strategies against key pests in nurseries and commercial plantations. Therefore, the project envisaged to identify and analyse the effect of the allelochemicals of Teakand Ailanthus on the behavioural pattern of its pests viz. *Hyblaea puera* and*Eligma narcissus a*nd and to prepare lures with potential molecules involved in the allelochemical cue for the management of the defoilatiors of Teak and Ailanthus in nurseries and plantations.

The present study identified several foliar volatiles from *T. grandis* and *A. excelsa* that have elicited strong antennal responses electro-physiologically by *H. puera* and *E. narcissus*. However, the field trials with the different blends of these identified chemicals tends to show that all the compounds that cause physiological response need not give a significant behavioural response in adult insects. The physiological status of the adult female with developed eggs may cease to play an active role in the attraction to the plant volatiles than the pheromones. Present results tend to show that this volatile identity could only be used as a cue to attract the adults towards egg laying and that this could be used in tandem with the sex pheromone to improve the efficacy of trapping. Also, the compounds that cause response by *H. puera* and *E. narcissus* identified in the present study gives a lead to utilize them for the breeding programs to identify the clones / varieties that can emit these compounds at a higher level and that they could serve as source of resistance to defoliators.

Significant achievements/ findings of the project:

GC MS analysis of hexane leaf extracts of Ailanthus showed the presence of compounds such as 3-hexanone, 2-hexanone, 2-methyl pentanal and Hexenal. No difference in the volatile composition was observed between *A. excelsa* and *A. triphysa*. From the Electroantennographic (EAG) and Gas chromatography-Mass Spectroscopic (GCMS) studies of Ailanthus compounds found to be Electrophygiologically active were synthesised and subjected for EAG studies different Blends were prepared and subjected again for EAG studies.

Compounds such as Hexanone, hexenal and hexenol were identified from the teak extracts. The peripheral antennal response of *H.purea* was more to terpen 4 ol followed by geraniol. Cis 3 hexene 1 ol, 1 Hexanol, caryophyllene oxide and linalool were at par in causing the antennal response. Based on the electrophysiological response of the *H. purea* to compounds obtained from teak seedlings various combinations of blends were made and they were assessed for the physiological response. The results showed that this volatile identity could only be used as a cue to attract the adults towards oviposition and that this could be used in tandem with the sex pheromone to improve the efficacy of trapping.

Suggestions/ advisory note for end-users "To-do-techniques":

Further identification of chemical signatures of Teak and Ailanthus will provide a lead for successful breeding of specific clones which can reduce defoliation by defoliators.Utilisation of volatile signatures of tree species for pest repellence will help in non chemical methods of pest management of economically important tree species used by the tree growers.

Research gaps:

Large-scale defoliation by pests of Teak and Ailanthus need to be managed without application of chemicals which are not feasible in terms of environment safety and cost involved in undertaking the management measures. Chemical traits in plants usually volatiles inhibiting insect pest attack are not identified and utilized for pest management strategies.

Uses of research outcomes:

Farmers, Tree growers, wood based industries and State Forest Departments can use the findings of the study.

14. Title of the project: Development of biopesticide formulation from seed oil of *Simaroubaglauca* DC for use in forestry.

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2017-2020

Critical analysis of the research theme and summary of the study:
Potential seed sources of *Simarouba glauca* were identified in Tamilnadu, Karnataka, Kerala and Andhra Pradesh through extensive surveys and seeds were collected from identified 103 potential seed sources and geographical attributes were marked for the identified trees using GPS. Seeds were processed and oil was extracted using organic solventsnamelyPetroleum ether, methanol, chloroform and n-Hexane. The oil yield of the seeds collected from 103 accessions of *S. glauca* ranged from 16.52 to 34% and maximum oil yield was observed in KD 23 seed source collected from Nallampalli, Dharmapuri. Phytochemical screening of oil was made and found the presence of Steroids and Terpenoids. The genetic source KD 23 yielded appreciably high oil and rich storehouse of bioactive constituents (secondary metabolites), with high saponifiable matters (252), free fatty acids (2 %) and unsaponifiable matters (6%) which could be tapped for use as pesticide. HPLC result revealed the presence of Stearic, Oleic, Linolenic, Linoleic acid in *S. glauca* seed oil. ^{1}H and ^{13}C NMR spectra have been recorded for oil and its FAME. FAME of *S. glauca* was characterized using GC-MS- MS and the result revealed that the FAME contained 56% of Oleic acid, 24% of Stearic acid, 13% of Palmitic acid, 5% Linoleic acid and 2% of Arachidonic acid and among 103 oil samples 94.17% of oils contained oleic acid as a major compound. Lot no. 102 (Karnataka) contains 100% of palmitic acid alone. 25% and 24% of oils contains oleic acid between the area percent of 20.01 - 30.00 and 40.01 - 50.00 respectively. *S. glauca* seed oil was tested against the 3rd instar larvae of the tobacco cutworm *Spodoptera litura*. The percentage of antifeedant activity was observed as 74.30±1.98. In vitro bioassay study was carried out for *S. glauca* seed oil against the agriculture pest *Helicopverpa armigera*. Antifeedant index was calculated as 78.88% in 24 hrs. The major active ingredient, oleic acid content in *S. glauca* seed oil was found to be as high as 51.29 % which is responsible for its antifeedant/ insecticidal activity against targeted insect pests.

Significant achievements/ findings of the project:
A biopesticide formulation named, Simca BC from seed oil of *Simarouba glauca* has been developed and released.

Suggestions/ advisory note for end-users "To-do-techniques":
Simca BC is a braod spectrum oil based biopesticide which can be used for the management of insect pests of forestry and agriculture.

Research gaps:
Studies on possibilities of using bioactive constituents of tree borne oil seeds as pesticides remained a neglected aspect hence aimed to explore the hidden insecticidal efficacy of the seed oil of *Simarouba glauca*

Uses of research outcomes:
Use of bio-insecticides in agriculture and forestry is highly warranted. Biopesticide is developed from tree borne oil seed*Simarouba glauca* for use in forestry and agriculture is an outcome of the study which will be of immense help to Biopesticide industry.

Publications:

- Santhana Bharathi N., Suresh Babu D., Sumathi R and Senthilkumar N. 2020. *Simaroubaglauca* DC: An effective biopesticide against leaf defoliators of Ailanthus and Teak plants. *Journal of Biopesticides* 13(1):34-39.
- Jayashanithini S., Rathinam K.S., Lakshmi Devi R., Sumathi R., Murugesan S. and Senthilkumar N. 2019. Physicochemical characterisation of seed oil of *Simaroubaglauca* DC from South India, *International journal of Pharmaceutical and Biological Science Archive* 7 (5):16-22.
- Oil based biopesticide Simca BC, IFGTB News Vol.1 No.3 Jan, 2020.

15. Title of the project: Development of Nano-biopesticides for application in forestry

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2019-2022

Critical analysis of the research theme and summary of the study:

Healthy leaves were collected from *Tectona grandis* (26 trees), *Ailanthus excelsa* (38 trees), *Pterocarpus santalinus* (33 trees) and *Gmelina arborea* (58 trees) processed and isolated the endophytic fungi using standard protocols and 112 entophytic fungi were isolated (39 from teak, 33 from ailanthus, 16 from gmelina and 24 from red sanders leaves). *Trichoderma harzianum, Colletotrichum* sp. *Trichoderma* sp*., Cladosporium* sp*., Curvularia* sp*., Aspergillus* sp*., Lecanicillium lecanii, Aspergillus terreus, Fusarium* sp*., Phialemonium* sp*., Acremonium borodinense* were identified morphologically. Species of *Fusarium, Aspergillus, Cladosporium, Colletotrichum, Curvilaria* and *Mucor* were commonly identified in all tree species selected for the study. The fungal endophytes were encapsulated with synthesized chitosan nanoparticles through biological method.

The formation of chitosan nanoparticles was confirmed by UV-Visible spectrophotometric analysis followed by SEM, EDX, Particle size analysis and zeta potential, FTIR and XRD. SEM analysis showed that biogenic synthesized chitosan nanoparticles using the fungal endophytes were mostly spherical in shape. Particle size/ zeta potential were proven as nano particle. This provided a platform for easy manipulation of physico-chemical properties of nanochitosan encapsulated fungal endophytes suitable for their intentional application. The Scanning electron microscopy and Particle size analysis with Zeta potential of nano chitosan encapsulated fungal endophytes confirmed that these are nanoparticle size between 100nm<to>1000nm. Molecular taxonomy using rRNA/ITS for the 15 endophytes of entomopathogenic significance and seven were identified as *Trichoderma harzianum, Aspergillus* sp., *Lecanicillium lecanii, Aspergillus terreus, Tricoderma* sp., *Phialemonium* sp*., Acremonium borodinense* based on nucleotide homology and phylogenetic analysis. Submitted sequence in NCBI – GeneBank Accession numbers between MW882241-MW882247 and OL801347 to OL801353. Preformulation of fungal spores such as *A. flavus, T. virens, T. reesi, A. oryzae, R. oryzae*, *Cladosporium* sp., *Colletotrichum* sp., *Curvilaria* sp., *Aspergillus* sp., *L. lecanii*, *A. terrus*, *Trichoderma* sp., *Fusarium* sp., *A. borodinense* and *T. harzianum* made in different concentrations revealed that at concentrations of 1000 to 2500 ppm, significant larvicidal activity was observed with 20-35 percent in 1000 ppm, 19-45percent in 1500 ppm, 27-66.7 percent in 2000 ppm and 35-80.7 percent in 2500 ppm ,respectively against *E. narcissus* and *S. litura*. Fungal spores of *A. terrus*, *L. lecanii* and *T. harzianum* were prominently responsible for the larvicidal activity. The nanobioinsecticide formulated with chitosan nanoparticles (F1) in 0.15% and 0.25% concentration established 50.6 per cent (48hrs) and 84.6 per cent larval mortality against *E. narcissus* in 48-72 hrs with zero phytotoxicity effects. Moreover, it did not have any negative effects on non-target beneficial organisms. Similarly, formulation (F1) was tested against *S. litura,* initially larvae develop resistance and exhibited 47.6 per cent larval mortality at 1000 ppm in 24 hrs. In 72 hrs larvae becomes sensitive to formulation and which exhibited 67.8% larval mortality at 2500 ppm concentration when compared to the control.

Significant achievements/ findings of the project:

A nano bioinsecticide formulated with chitosan nanoparticles (F1) in 0.15% and 0.25% concentration established 50.6 per cent 48hrs) and 84.6 per cent larval mortality against *E. narcissus* in 48-72 hrs with zero phytotoxicity effects.

Suggestions/ advisory note for end-users "To-do-techniques":

The preformulation was safe against beneficial insect honey bee and no phytotoxicity on host plants. It was found effective on target insect defoliators. It may be considered as a potential bioinsecticide with high efficacy, effective delivery, broad-spectrum, highly persistent, non-toxic, biodegradable and alternate to chemical insecticides.

Research gaps:

Biological control of insect pests and diseases affecting cultivated plants has gained considerable attention since it helps in reducing the use of chemical pesticides in agriculture. Use of microorganisms for the management of insect pests and diseases is risk free. Endophytic fungi are microorganisms that offer great-untapped potential effective for insect pest management. Long shelf life, persistent in environment, high efficacy, and effective delivery are major criteria for biopesticides industry and nanotechnology wil provide the solution.

Uses of research outcomes:

Chitosan (biopolymer) nanoparticle encapsulated endophytic fungal spores of entomopathogenic significance as nano-bioinsecticide was developed with significant efficacy for the management of insect pests of agriculture and forestry as an output of the project. The development of nano-based biopesticides, is a new approach and has strong commercial potential in today's economic context.

Publication:

Sequence deposited in NCBI

- Thirteen species of endophytic fungi of entomopathogenic significance were deposited in NCBI GenBank MW882241 to MW882247 and OL801347 to Ol801353.

16. **Title of the project:** Registration and commercialization of the most effective biopesticide formulation using the seed extract of *Hydnocarpus pentandra* for the management of isect pests of agriculture and forestry importance

Principal Investigator: Dr. N. Senthilkumar, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016-2019

Critical analysis of the research theme and summary of the study:

Natural distribution of *Hydnocarpus pentandra* in Southern Western Ghats of Tamil Nadu, Karnataka and Kerala was studied, collected seeds, processed and extracted oil. Saponifiable free fatty acids separated from the seed oil were further separated into saturated and unsaturated free fatty acids. It was found that seed oil contained 93% triglycerides. The triglycerides were converted into fatty acid methyl esters (FAME) and identified 14 bioactive compounds through GC MS analysis, of which hydnocarpic and Gorlic acids were found to be more. Seed oil showed antagonistic activity against human fungal and bacterial pathogens.

Significant achievements/ findings of the project:

A commercial bio-pesticide formulation from *H. pentandra* under Indian regulatory regime for the effective management of insect pests in Agriculture and Forestry importance has been developed.

Suggestions/ advisory note for end-users "To-do-techniques":

Varsha Bioscience and Technology India Pvt Ltd and Institute of Forest Genetics and Plant Breeding jointly carried out a series of studies *viz.,* identifying the sources of raw material, maximization of extraction process, identifying and isolating the principal active ingredients, derivation of formulation and down streaming process, physico-chemical parameters, stability and bio-efficacy of the formulation. Exclusive licence was awarded to Varsha Bioscience and Technology India Pvt Ltd, Hyderabad for commercialization with due royalty.

Research gaps:

Plants contain a virtually untapped reservoir of pesticides which are used as templates for synthetic pesticides. Hence, recent research has been focused for the development of pesticides from the natural products as bio pesticides. Non-edible tree borne seed oil is one such source to develop biopesticides.

Uses of research outcomes:

Hydnocarpic acid as an active ingredient with insecticidal potential has been identified and developed as a biopestcide from seed oil of *Hydnocarpus pentandra* for use in agriculture and forestry will be of immense help to Biopesticide industry.

Publication:

- Murugesan, S., Senthilkumar N., Krishnkumar N., Suresh Babu D., Rajeshkannan C., Manivachakam P. and Sumathi R. 2012. Hy-Act (HyPSO 25 EC)- Seed oil based biopesticide from *Hydnocarpuspentandra*: An IPM for some of the defoliators of forest trees. *Pestology*, XXXVI (3): 12-14

17. **Title of the project:** Study of sal regeneration in borer affected areas

Principal Investigator: Dr. P.B. Meshram, Scientist-G & Shalini Bhowate, Scientist-C, ICFRE-TFRI Jabalpur

Duration: 2017-2019

Critical analysis of the research theme and summary of the study:

No detail specific information is available in borer affected unprotected areas of Mandla and Dindori forest divisions.Hence the project was undertaken to study the impact assessment of sal (*Shorea robusta*) heartwood borer epidemic on the regeneration status of sal forests in Dindori and Mandla Forest Divisions, Madhya Pradesh

Significant achievements/ findings of the project:

Surveys were conducted in heartwood borer affected in unprotected sal forest areas. The study was undertaken in the areas where remedial felling carried out after sal-borer infestation in year 1998-99. The compartments were sampled by laying out nested quadrates (10x10m) for trees, 3x3m for saplings/ shrubs and 1x1m for seedlings/ herbs). During the study period, regeneration was recorded into three categories-(a) saplings (established regeneration) plants below 20 cm girth at breast height with a height of 2 m and above (b) seedlings (un-established regeneration) plants below 2 m of height excluding the recruits (c) recruits (plants having two leaves stage).

Suggestions/ advisory note for end-users "To-do-techniques":

Sal forest should be properly protected by biotic interference as well as ground fire. Attacked trees by sal borer, *Hoplocerambyx spinicornis* belonging to categories 1 and 2, i.e., dead trees and trees with dead crown having heaps of wood dust more than 7 cm high above the ground should be felled, debarked and converted in to the logs. Lops and tops of felled trees should be removed from the forest to maintain the forest hygiene. Thinning of weak, diseased sal trees and transplanting its associate species should be done to reduce the density of sal in pure sal forests. Sal seed collection should be suspended in the borer affected areas till the area gets fully regenerated. Badly affected areas, where sal regeneration was poor or absent, the open area created should be filled by introduction of suitable miscellaneous species either through seed sowing or transplanting.

Research gaps:

No proper study on the status of regeneration in heartwood borer affected forests is available and also the study on impact of canopy gaps on regeneration of affected forests is also not available hence this project was taken up.

Uses of research outcomes:

This study will help in developing a regeneration strategy to ensure considerable plant diversity and vegetation cover at the forest floor even under continual pressure of fuel wood extraction and other severe perturbations.

18. Title of the project: Studies on the diversity of beneficial insects in forest ecosystem in Madhya Pradesh

Principal Investigator: Dr. Pawan Kumar, Scientist- E as PI w.e.f. 1.7.2019, ICFRE-TFRI Jabalpur

Duration: 2017-2020

Critical analysis of the research theme and summary of the study:

Insects play a major role in forest ecosystem, and are integral part of the functioning of ecosystem. The role of insect pests in forest ecosystem is well documented however, the ecosystem services provided by the insects as parasites, predators, productive insects, insects as human food and pollinators in forest ecosystem have been ignored. Some of the insects are directly related to the livelihood and sustenance of the tribal communities. A comprehensive list of beneficial insects in forest ecosystem, and status of their population in different agro-climatic zones of Madhya Pradesh is required to devise effective conservation and management strategies.

Significant achievements/ findings of the project:

During the study total 5,543 number of individuals of ten beneficial insect species were collected from 11 agroclimatic zones of Madhya Pradesh. Among these, density of honeybees (*Apis dorsata*) was found to be maximum followed by red ants, whereas predatory bug *Canthecona furcellata*, egg parasitoid *Trichogramma raoi* were found to be minimum. Analysis of beneficial insect species diversity revealed that in 2017 Shannon-Weiner diversity index of *Apis dorsata* (0.36) was the highest followed by *Oecophylla smaragdina* (0.25) and lowest in *Xanthopimpla cera* (0.09). Evenness was highest in *Xanthopimpla cera* (0.54) which means that population of this insect was less diverse in Madhya Pradesh.

Suggestions/ advisory note for end-users "To-do-techniques":

Information on diversity of beneficial insects in forest ecosystem of Madhya Pradesh will be disseminated to different target groups through various training programmes organized by institute time to time and also through publication of pamphlets/ brochures/ leaflets, etc.

Research gaps:

Diversity of some beneficial insects in forest ecosystem in Madhya Pradesh is not properly documented hence the project was taken up.

Uses of research outcomes:

The data will help in correlating the abundance and diversity status in relation to the abiological parameters after subjecting the data to various analysis indexing which in turn will help to establish the impact of climatic factors on population and diversity of beneficial insects in various agroclimatic zones of the state of Madhaya Pradesh.

19. Title of the project: Taxonomic study of Tettigoniidae (Orthoptera) of India" (under All India Co-ordinated project on Taxonomy (AICOPTAX)

Principal Investigator: Dr. Pawan Kumar, Scientist- E as PI w.e.f. 29.5.18, ICFRE-TFRI Jabalpur

Duration: 2016-2022

Critical analysis of the research theme and summary of the study:

The purpose of present study was to provide species diversity assessment of long horned grasshoppers in the study area. As very scanty work on these aspects has been carried out, the study had added new biodiversity data and species status so as to develop the conservation strategy in forests of Madhya Pradesh, Maharashtra and Chattisgarh.

Significant achievements/ findings of the project:

The Present study provided an array of Tettigonids diversity from different Agroclimatic zones of Madhya Pradesh, Maharashtra and Chhattisgarh. For which detailed surveys were carried out in various sites during the year 2016-2019. A total of 452 insect specimens of family Tettigoniidae from more than 235 sites in five different habitats (agriculture land, grasslands, barren land, forest and plantations) in different agroclimatic zones were collected. Sixteen species specimens were identified and preserved in TFRI Insectary. Out of these Sixteen species ten species are known from Madhya Pradesh and six species viz. *Himertula* sp., *Isopsera pedunculata*, *Mecopoda elongate, Phaneroptera nana, Phaneroptera falcate, Sathrophyllia fuliginosa* are new locality records from Madhya Pradesh.

Suggestions/ advisory note for end-users "To-do-techniques":

The study will add new biodiversity data and species status so as develop the conservation strategy for the long-horned grasshopper species and lead to know the taxonomic status of these species. The study will definitely help in evolving Habitat Conservation Strategy and identify Tettigonid species sensitive to environment/climate change in the selected area. Diversity of Orthoptera in this region will be helpful for further ecological balancing as well as role of their interactions with the biodiversity.

Research gaps:

As no work on the biodiversity of thetettigonids of the selected regions has been carried out by any worker so the study will add new biodiversity data and species status so as to develop the conservation strategy for the long horned grasshopper species and lead to know the taxonomic status of these species.

Uses of research outcomes:

The study had added new biodiversity data and species status so as to develop the conservation strategy in the fForests of Madhya Pradesh, Maharashtra and Chhattisgarh.The study will definitely help in evolving Habitat Conservation Strategy and identifytetigoniid species sensitive to environment/ climate change in the selected area.

20. Title of the project: Monitoring and dissemination of knowledge to manage sal heartwood borer, *Hoplocerambyx spinicornis* in Chhattisgarh

Principal Investigator: Dr. Mohan C., Scientist-B, ICFRE-TFRI Jabalpur

Duration: 2019 - 2022

Critical analysis of the research theme and summary of the study:

Study aims to monitor the status of sal (*Shorea robusta*) heart wood borer in sal forest ecosystem and disseminate the strategy for management of sal heart wood borer to front line staff of Chhattisgarh state forest department.

Significant achievements/ findings of the project:

Surveyed different ranges of Sal forest areas of Ambikapur, Korba, Kanker, Narayanpur, Keiskal, East Bhanupratapur, Ghariyaband and Kawardha Forest Divisions for monitoring of Sal heart wood borer. The status of Sal borer in Chhattisgarh has been found to be alarming during the project period. Data on number of Sal borer infested trees revealed that 674 Sal trees were affected during the year 2019, 930 Sal trees during the year 2020 and 1070 Sal trees during the year 2021. Twelve trainings on Sal heartwood borer and its management were conducted to manage Sal heart wood borer *H. spinicornis* through Tree Trap Operation to frontline staffs of state forest department (SFDs) of Chhattisgarh, each training having at least 25 participants as beneficiaries. Feedback was also taken from the participants of the training programme to compile valuable and important suggestions for improving the efficiency of future training programs.

Suggestions/ advisory note for end-users "To-do-techniques":

This study will help for effective dissemination of management strategies for management of Sal heart wood borer in Sal forest through field demonstration to the frontline staff of State Forest Department. Theoretical and practical knowledge will also be helpful to user groups and to the local people as source of livelihood. The results were disseminated to user groups like progressive farmers, NGOs, SHGs and State Forest Departments, Forest Corporations and Federations through regular training programmes organized by the Institute, demonstration, scientific publications and extension materials

Research gaps:

There is no sufficient information on monitoring and dissemination of knowledge to manage Sal heartwood borer, *Hoplocerambyx spinicornis* in Chhattisgarh with special reference to last epidemic, collection and identification of Sal borer and trap tree operation for management of sal borer in the state.

Research outcomes:

Training and exposure for sensitization of front line staff was done about basic information on bio ecology and current field practices for management of sal borer.

Publication:

- Mohan C., Rajeswar Rao G. and Malviya R.K. 2022. Monitoring of Sal heart wood borer *Hoplocerambyx spinicornis* in Chhattisgarh. *The Pharma Innovation Journal* 11 (2) 438-442.

PROTECTION

(PATHOLOGY)

PROTECTION (PATHOLOGY)

1. **Title of the project:** Isolation and characterization of *Rhizobium* strains from leguminous trees and their evaluation in biological nitrogen fixation

Principal Investigator: Dr. Vipin Parkash, Scientist- F, ICFRE-FRI Dehradun

Duration: 3 years

Critical analysis of the research theme and summary of the study:
The main aim of present investigation is to prepare a database of wild *Rhizobium* strains/isolates and to conserve the important isolates/strains and their biodiversity. *Rhizobium* strains are in endophytic symbiotic association and have been associated with improved plant growth through biological nitrogen fixation. The biodiversity of these endosymbiotic bacteria especially in wild legumes of Uttarakhand state was analyzed and the isolates/strains of *Rhizobium* isolated from *Acacia catechu*, *Bauhinia vareigata, Erythrina blakei* and*E. variegata*, were utilized in establishing the seedlings of target plant species through bioinoculation and trans-bioinoculation. The bacterial consortium (*Rhizobium* strains) in the rhizosphere helped in absorbing the macronutrients which are essential for the seedlings/plantlets because these macronutrients are not absorbed by plantlets. The study of microbial occurrence, status and diversity is important from conservation and efficient utilization point of view also.

Significant achievements/ findings of the project:
The plant species with the highest number of nodules was *Acacia catechu.* No bacterial strains were isolated from nodules of *B. variegata.* In *Erythrina blakei,* the shape of root nodules was semi-globus but some nodules were caudiciform in shape. The others mostly showed globus nodules. The maximum available Nitrogen and Phosphorus content was found in soil sample collected from Dakpathar (FRI/DB) and minimum available nitrogen content in Nainital (FRI/NT). Hence, less nitrogen and phosphorus content in soil improved the capability of plants to nodulate with Rhizobial bacteria. More nodules were found in foot hills/mid hills soil sample/s. Root nodules of *Acacia catechu* which were isolated from Assan barrage, Raipur region of Dehradun, Nainital area and Tons river area, had a higher concentration of the leg-haemoglobin. *Rhizobium* strain *e.g.* FRI/RAI/AC-4 had fixed the maximum nitrogen in the form of precipitation (nitrogenase enzyme).FRI/ASR/AC-4 took less time to reach exponential phase (15hrs.). The other consortium of *Rhizobium* isolates/strains (FRI/ASR/AC-1, FRI/DB/AC-2, FRI/DB/AC-3, FRI/RAI/AC-4, FRI/UKS/AC-5 and FRI/TR/AC-6) reached exponential phase after 16 hours. Pulse-soaked water of *Phaseolus vulgaris* (*Rajmah*) was better substrate for mass multiplication of Rhizobial isolates/strains. The trans-bioinoculation was successful in case of *Dalbergia sissoo.* It was observed that all the isolates/strains isolated from *Acacia catechu* were effective and has ability to cross inoculate *Dalbergia sissoo* seedlings. Inoculated seedlings of *Peltophorum pterocarpum* had more shoot length than *Dalbergia sissoo* and *Bauhinia variegata* seedlings after 90 days of inoculation.

Suggestions/ advisory note for end-users "To-do-techniques":
The medium /mode of dissemination/diffusion to these end users are either through trainings/ workshops or either awareness programmes. The material for dissemination of results is in the form of research papers, posters, pamphlets, brochures and leaflets in English or in Hindi and radio /TV talks in local language/dialect for better understanding of the stakeholders.

Research gaps:
The leguminous plants/trees with less nitrogen efficiency are to be trans-bioinoculated with more efficient isolated rhizobial strain/s. Trans bio-inoculation of Rhizobia may also effectively improve the yield and productivity, reducing the use of chemical fertilizers and hence, preventing the environment with its harmful effects. In tree species trans-bioinoculation studies are scanty.

Uses of research outcomes:
Mass multiplication of best rhizobial bio-inoculants on bio-prospected substrate/s were used as a carrier medium for *Rhizobium* bacterial growth. This technique(along with other Mycorrhizal bioinoculants) was also extended to the farmers/villagers/stakeholders. Native Rhizobium strains isolated from wild leguminous tree species can be used as introduced strains as a good biofertilizer in forest nurseries and plantations in order to boost up quality planting stock production and overall biomass yield of leguminous forest plant/tree species.

Publication:

- Kaundal R., Parkash V., Paul S., Thapa M. 2023. Synergism of plant microbe interactions for remediation of potentially toxic elements. *J. For. Sci.*, 69: 127–143. (https://doi.org/10.17221/1/2023-JFS)

2. **Title of the project:** Mortality of *Pinus wallichiana* in Nanda Devi Biosphere Reserve

Principal Investigator: Dr. Shailesh Pandey, Scientist-E, ICFRE-FRI Dehradun

Duration: 2018-2021

Critical analysis of the research theme & summary of the study:

Understanding of tree mortality is central to any prediction of forest dynamics. *Pinus wallichiana* (blue pine), a keystone species, is functionally important in Nanda Devi Biosphere Reserve (NDBR) and, therefore, mortality issues make its conservation important. Understanding factors influencing species distribution is essential for mitigating mortality. The locations of *P. wallichiana* mortality in NDBR to generate mortality distribution map. Maximum entropy modeling (MaxEnt) was typically applied at a regional spatial scale, and here we assessed its usefulness when predicting the distribution of blue pine at a local scale. The SENTINEL and MaxEnt-based eco-distribution maps of blue pine are of immense importance for monitoring future mortality spread to support decision making, future planning, *in situ* and *ex situ* conservation and management. Severe infestation of blue pine by Himalayan dwarf mistletoe (*Arceuthobium minutissimum*) was observed affecting growth and physiological parameters, leading to mortality. Importantly, *Fusarium solani* and *F. oxysporum* isolated from the decayed roots of *P. wallichina* were found pathogenic on healthy blue pine seedlings. Four species of bark beetles *viz.*, *Ips stebbingi*, *Polygraphus major*, *Pityogenes scitus* and *Pityogenes spessivtsevi* (Coleoptera: Scolytidae) were found to be associated with the symptomatic trees.

Significant achievements/ findings of the project:

Using the MaxEnt programme and supervised classification algorithm over the Sentinel dataset, mortality prediction mapping of blue pine was carried out in NDBR. Model showed an AUC value range 0.889±0.141 (current)–0.988±0.008 (mortality), where the Jackknife test elaborated that the environmental variables Precipitation (Percentage Contribution (PC)=34.30% and Permutation Importance (PI)=1.1%) contributed most, followed by temperature seasonality (Bio 4; PC=25.90% and PI=31.20%) and maximum temperature of warmest month (Bio 5; PC=22.40% and PI=40.30%). The response curves also showed that the precipitation ranged from 138–154 mm with maximum at 145 mm (p=0.88); slope at 2.5° (p=0.97) and 9° (p=0.91); and wind ranged from 1.76–2.00 ms^{-1} with amaximum (p=0.92) at 1.85 ms^{-1}.Along the altitudinal gradient, the mortality maps showed majorly (~4 km^2) lying between 3001–3250 m amsl, i.e., subarctic climate (Dwc) in accordance with the KGCC. Hazard maps generated through an ensemble approach are of high utility for surveillance and monitoring of blue pine mortality by inferring the spread direction in due course.

Suggestions/ advisory note for end-users "To-do-techniques":

Removals of heavy mistletoe-infested trees, identification of resistant or moderately resistant and mechanical control through pruning tree branches are the effective method for mistletoe removal. Moreover, use of plant growth promoting microbes for raising healthy planting stock of blue pine and other tree species is a possibility. The SENTINEL and the MaxEnt-based model-based distribution maps of blue pinemortality supported decision-making, *in situ* and *ex situ* conservation, and future planning of the health status of *P. wallichiana* and other forest trees in NDBR.

Research gaps:

Research gaps identified were the preparation of MaxEnt model-based mortality distribution map of blue pine and the identification of factors responsible for its mortality in NDBR.

Uses of research outcome:

The research findings support conservation and future planning for better health of blue pine and other forest trees in NDBR.

3. Title of the project: Standardization of bio control mechanism to control diseases in Forest Nurseries

Principal Investigator: Dr. A. Karthikeyan, Scientist G, ICFRE-IFGTB Coimbatore

Duration: 2018-2020

Critical analysis of the research theme and summary of the study:

Kerala Forest Department is maintaining five central nurseries located at Nilambur Kulathupuzha, Chalakudi, Munnar and Kannur. The major seedlings propagated in these nurseries are *Tectona grandis, Switenea mahogany,* and *S.macrophylla,* etc. The seedlings/planting stocks are often infected by various root pathogens and other climatic factors. To identify and control the diseases by bio control mechanism the disease incidence was assessed and recorded. In the Central nursery Nilambur, 22.8 % of *T. grandis* seedlings were affected by leaf rust disease caused by *Olivia tectonae,* 21.3 % seedlings were affected by leaf blight disease caused by *Colletotrichum gleosporoides.* This pathogen also caused 22.6% of leaf blight disease in *S. macrophylla* seedlings. In the Shola forest nursery at Devikulam, Munnar only leaf spot diseases were observed and pathogen was identified as *Fusarium oxysporum.* Whereas in Kannur central nursery the seedlings of *T. grandis* were very healthy and observed less than 4.5 % caused by diseases. In Chettikulam, Chalakudy nursery, mostly *Saraca asoka* seedlings were observed with blight disease caused by *F. oxysporum* with 2.2% disease. Similarly, in the central nursery at Kulathupuzha, 1.8 % leaf rust disease was noticed in *T. grandis s*eedlings. To control these diseases the bio control agent *Trichoderma viride* was used under laboratory conditions and found to have an antagonistic effect against the pathogens such as *Colletotrichum gleosporoides, Olvia tectonae* and *Fusarium oxysporum*. The biocontrol agent *T. viride* was multiplied and distributed to all the central nurseries. The forest staffs were also trained to apply the *T. viride* to the diseased seedlings.

Scientific achievements/ findings of the project:

It is found that the pre inoculation of biocontrol agent *Trichoderma viride* in the seedlings of *T. grandis* prevent the root rot disease in nursery. The blight and root rot diseases *of Swietenia macrophylla* was controlled by application of *T. viride.*

Suggestions/ advisory note for end-users "To-do-techniques":

Based on the outcome of the study the *T. viride* cultures formulated in liquid form and supplied to each central nursery of Kerala for application in the seedlings as pre inoculation. A demonstration of application was conducted to the officials of Kerala Forest Department.

Research gaps:

Information how to identify and control the diseases by bio control mechanism is fragmentary. Hence, this project was formulated with funding support of Kerala Forest Department to identify and control the diseases in central nurseries with biocontral agents.

Uses of research outcome:

The biocontrol agent *T. viride* was multiplied and distributed to all the central nurseries. The forest staffs were also trained to apply the *T. viride* to the diseased seedlings.

4. **Title of the project:** Bio formulations of Micromonospora for bio control and bio fertilization activity in Casuarinas

Principal Investigator: Dr. A. Karthikeyan. Scientist G, ICFRE-IFGTB Coimbatore

Duration: 2018-2022

Critical analysis of the research theme and summary of the study:

A rapid spread of wilt disease in Casuarina clones was reported by Casuarina growers from Tindivanam, Cuddalore and Villupuram regions of Tamil Nadu. The disease showed the symptom of chlorotic and sudden wilt of foliage particularly in young Casuarina clonal plantations. The disease was identified as bacterial wilt caused by *Ralstonia solanacearum* and to control this disease an actinomycete *Micromonospora* which was reported as biocontrol agentwas applied in nursery and field conditions against *R. solanacearum* and other soil pathogens. *Micromonospora* is an actinomycetous bacteria and recognized as a source of secondary metabolites for controlling pathogens. *Micromonospora* was isolated from the root nodules of *Casuarina equisetifolia* and cultured in ISP -2 medium. The isolated strain was identified as *M. maritima* by 16s rRNA sequence and maintained in the refrigerated condition for mass multiplication. Besides, the pathogenicity test of *R. solanacearum* in *C. equisetifolia* seedlings and antibiosis test with *M. maritima* were conducted at laboratory conditions. In the pathogenicity test the infected *C. equisertiolia* showed chlorotic and wilting of cladophylls due to application of *R. solanacearum.* The antibiosis test results suppression of *R. solanacearum* by *M. maritima*. Based on these findings the *M. maritama* broth was applied in the root zone of infected Casuarina clones @ 10 ml/plant. After 30 days of application the infected clones developed new foliage and new sprouts. The entire infected plantation was recovered up to 95% and showed improvement of growth too. Similarly in the nursery and field trials *M. maritima* + *Frankia* not onlyimprove the growth of *C. equisetifolia* and *C. junghuhniana* but also suppressed the inoculated pathogens of *Fusarium oxysporum*, *Trichosporium vesiculosum* and *R. solancearum*.

Significant achievements/ findings of the project:

The actinomycetous *Micromonopsoramaritima* was applied to control the wilt disease of *Casuarina equisetifolia* in Tindivanam and Vilupuram (Tamilnadu) which were recovered 100% after 30 days of application. The farmers gave a feed-back that the *Micromonopsora* is very effective in controlling the wilt disease of *C. equiseifolia.* Tamil Nadu News print and papers Ltd., also tested in three locations to control the bacterial wilt diseases and found effective. Further, *Micromonospora* and *Trichoderma viride* were appliedfor controlling collar rot of CH2 clones of *Casuarina equisetifolia* plantations at Rajamundhry which belongs to A.P. Paper mills. Application of *Micromonospora* also controlling wilt disease of CH5 clones of *Casuarina* hybridat Farmers field in Tamil Nadu showed 100% recovery from the bacterial wilt disease. Based on these feedbacks a product called 'Mona 20' was developed and released. Similarly, more root nodule producing *Rhizobium aegytpiacum* was identified and mass multiplied. Further it was found that *Frankia* + *Micromonospora* inoculated *Casuarina* clones showed improved growth and health in field conditions.

Suggestions/ advisory note for end-users "To-do-techniques":

It was deduced from this study that *Micromonospora* is an effective biocontrol agent for controlling the bacterial wilt disease in Casuarinas.Based on the feedbacks and results a product called 'Mona 20' was developed and released. Further it was found that the combined actinomycetes (*Frankia* + *M. maritma*) improved the plant growth and health. Mass cultures of *Frankia* are being distributed to farmers and paper mills for growth improvement of Casuarinas.

Research gaps:

Application of *Micromonospora*to this bacterial wilt disease in Casuarina hybrids was not reported or studied earlier.

Uses of research out comes:

The effective *Micromonospora*was made as a product and named 'Mona 20'. This product is being supplied to Casuarina growers and paper companies at a price of Rs. 300 / 500 ml. The Institute has now advised Casuarina growers and paper companies to inoculate this product as pre-inoculation in Casuarina clones or rooted stem cuttings. This product has reached among Casuarina growers for the biocontrol of bacterial wilt.

Publications:

- Karthikeyan A**.,** Kanchanadevi K. and NicodemusA. 2020. Micromonospora: A promising bio control agent for bacterial wilt disease of Casuarina pp.246-251. In: Proceedings of 6th International Casuarina workshop held at Krabi, Thailand from 21 to 25 October 2019 (Eds) M. Haruthaithanasan, K. Pinyopusarek, A. Nicodemus, D. Bush, and L. Thomson, Kasetsart University, Bangkok, Thailand .
- Karthikeyan A., Kanchanadevi K. and Nicodemus A. 2022 Effect of Frankia and Micromonospora on growth and health improvement in Casuarina clones. *Journal of Forest Research* 27 (2) 129- 132 : Doi.org/1080/13416979.2022.2035902

5. **Title of the project:** Development of microbial inoculants consortia for quality seedling production and imparting Training-cum-Demonstration on Bio-fertilizer production and application in nursery and field

Principal Investigator: Dr. V. Mohan, Scientist-G and Dr. A. Karthikeyan, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2019-2022

Critical analysis of the research theme and summary of the study:

Plant Growth Promoting Rhizosphere (PGPR) microorganisms are known for promoting growth and biomass in plants through nitrogen fixation and soil nutrient mobilization. Rhizosphere soil samples collected from the root zone of 28 different commercially important tree species fromthe Kerala Forest Department Central nurseries atChettikulam, Nilambur and Kulathupuzha. Soil samples were analyzed for their physico-chemical parameters showed acidic pH (4.51 to 6.9) in the nurseries. The electrical conductivity ranged from 0.1 to 1.51. The available nitrogen was observed high in Kulathupuzha and phosophorus content was more in Chettikulam. The biochemical assay was performed to identify the biochemical characteristics of PGPR strains and positive results in producing indole acetic acid (IAA) both qualitatively and quantitatively. High amount of IAA production was observed in C12 (*Actinomycetes*) followed by C6 (Phosphate Solubilizing Bacteria) in Chettikulam. High amount of IAA production was observed in N11 (Actinomycetes)N10 (*Azospirillum*) and N 7 (*Peusomonas*) in Nilambur and high amount of IAA production was observed in K8 (*Acinomycetes) and* K7 (*Acinomycetes*) in Kulathupuzha. Population density of different Arbuscular Mycorrhizal (AM) fungal spores in 28 different commercially important tree species from chettikulam were estimated and the study showed that maximum number of AM fungal spores was observed in *Tectona grandis* (7196 /100 g of soil). Minimum number of AM fungal spores were recorded in the rhizosphere soil samples of *Aegle marmelos* (61/100 g soil), *Swietenia macrophylla* (1885/100 g of soil) in Chettikulam nursery. Further, minimum numbers of AM fungal spores were recorded in the rhizosphere soil samples of *Syzygium cumini* compost (39/100 g soil) in Nilambur and *Dendrocalamus strictus* (3202/100 g of soil). Under the training component Institute of Forest Genetics and Tree Breeding (IFGTB) and Kerala Forest Department organized training program on "Training on Biofertilizers' to the Front line of Staff of Kerala Forest Department on 09.03.2022 and 11.03.2022 at Kulathupuzha, Central Nursery and Chettikulam, Central Nursery attended by total of 79 participants.

Significant achievements/ findings of the project:

Antagonistic potential of the 36 isolates were studied against the selected six different plant pathogens namely *Fusarium oxysporum, Rhizoctonia solani, Collectotrichum* sp*., Sclerotium rolfsii, Phytopthora* sp., and *Diplodia natalensis* under *in vitro* conditions. It was observed that, the Actinomycetes isolates C8 and C12 showed antagonistic activity against most of the fungal pathogens in Chettikulam whereas the isolates N8 (*Actinomycetes)* and N 9 showed antagonistic activity against the fungal pathogens in Nilambur.

Research gaps:

Diversity and use of plant growth promoting bacteria (PGPRs) in Kerala are not well known. Hence, to know the diversity status of PGPRs associated with the different commercially important tree species grown in Kerala this project was formulated.

Uses of research outcomes:

The potential strains of PGPRs have improved the growth and biomass in nurseries. Training on the basics and application method of the PGPRs were imparted to the frontline staff of Kerala Forest Department. The native PGPRs isolated from Kerala are very promising biofertilizers for the improvement of native tree species of Kerala.

6. **Title of the project:** Development of salt tolerant beneficial microbial consortia from Mangroves for bio-remediation

Principal Investigator: Sh. Anish V. Pachu, CTO, ICFRE-IFGTB Coimbatore

Duration: 2019-2022

Critical analysis of the research theme and summary of the study:

The objective of the project was to study the abundance of beneficial rhizosphere microbes and AM fungi from mangroves and to investigate the effect of salt tolerant beneficial microbes in growth enhancement of forestry tree species under saline soil condition. Results of the study proved that beneficial plant growth promoting microbial strains and AM fungi are abundantly available in mangrove rhizosphere soil and that their population density varied spatially and temporally. The study has identified seven microbial strains from mangrove soil *viz*., *Bacillus haynesii*, *Pseudomonas stutzeri* (Strain-1), *Pseudomonas stutzeri* (Strain-2), *Pseudomonas* sp., *Lysinibacillus mangiferihum*, *Bacillus cereus* and *Bacillus velezensis*. Out of the total, four strains *viz*., *Bacillus haynesii*, *Pseudomonas stutzeri* (Strain-1), *Pseudomonas stutzeri* (Strain-2) and *Pseudomonas* sp., together with AMF consortia were employed for bio-inoculation studies with common forestry species *viz*., *Albizia lebbeck, Azadira chtaindica, Casuarina equisetifolia, Dalbergia sissoo, Eucalyptus camaldulensis, Leucaena leucocephala, Pongamia pinnata, Swietenia mahogany* and *Thespesia populnea* and evaluated the efficacy of beneficial microbes on growth enhancement in nursery seedlings maintained in nursery condition at 2.0 to 5.0% of salt range. Results of the study proved significant growth enhancement in the tree seedlings bio-inoculated with combination of all the four microbial strains plus AM fungi than that of single strain bio-inoculation in nursery condition.

Significant achievement/ findings of the project:

The rhizosphere soil/ sediment of mangrove species studied in different space and time had shown significantly abundant beneficial plant growth promoting microbial (PGPR) and AM fungi population. The salt tolerant microbial consortia of both PGPR and AMF employed for bio-inoculation studies in nursery under saline soil condition had shown significant growth enhancement of the forestry tree species.

Suggestions/ advisory note for end-users "To-do-techniques":

The effectiveness of the microbial strains in tree growth improvement are further required to be validated based on the field studies. A "Training on Biofertilizers' to the Front line of Staff of Kerala Forest Department was conducted.

Research gaps:

Land degradation due to extreme salt content in cultivable agriculture soil in majority of the semi-arid and arid regions of the world is one of the increasing global environmental problems affecting soil physical properties and fertility, which seriously deter crop productivity. The study was planned for developing adaptive measures to plant growth stress under saline conditions by inoculating salt-tolerant beneficial plant growth promoting microbes from mangroves.

Uses of research outcomes:

The findings of the study in nursery level will be promising to various end-users like tree growers forutilization of these potential beneficial microbes as bio-inoculants for good quality and healthy seedling production as well as bioremediation in the salt affected/problematic soils.

Publications:

- Pachu Anish V. and Mohan V. 2023. Diversity Status of Arbuscular Mycorrhizal (AM) Fungi in Association with Selected Mangrove Plants in Tamil Nadu, *Kavaka* 59(1): 75-82.
- Mohan V., Karthikeyan A**.** and Pachu Anish V. 2022 Biofertilizers and Biomanures (in Malayalam), Indian council of Forestry Research and Education, 58p.

7. **Title of the project:** Incidence, forecast, and control of emerging and re-emerging disease problems in nurseries and plantations of sandalwood.

Principal Investigator: Dr. A. Muthu Kumar, Scientist – E, ICFRE-IWST Bengaluru

Duration: 2016 - 2021

Critical analysis of the research theme and summary of the study:

The observation and documentation of diseases associated with Sandalwood nurseries and plantations (young) were carried out at Karnataka (Government and private), Tamil Nadu (Government and private), Andhra Pradesh (Private), Telangana (Private) and Kerala (Government). It was observed that the nurseries at Srineevasapura and Dindigul were the major larger ones supplying sandalwood seedlings to many parts of the country, therefore the observation was restricted to the selected locations, in addition to the one at IWST. Following were some of the diseases/deficiencies observed and studied during the project period viz., Powdery Mildew, Leaf Blight, Fusarium Wilt, Collar Rot, Damping Off, Downy Mildew, Sooty mold, Leaf Spot, Phosphorous and Magnesium nutrition deficiency. Based on the incidence and severity index, the disease Powdery Mildew, Leaf Blight, and Fusarium Wilt were found to be significant in nurseries and young plantations of sandalwood, while the incidence of other diseases was minor and was found emerging and less well-understood. The disease Powdery Mildew was the major one and prevalent across Sandalwood cultivation areas in the Southern part of the country, where local microclimatic/epidemiological factors influence the disease prevalence. The critical surveillance along with analysis of agglomerated data revealed incidence and severity of powdery mildew disease was periodic and predisposed by seasonal factors confirming the re-emergence of this disease across different Agro-Climatic Zones (ACZ). The indorsed chemical control of the application of copper and sulphur fungicides for Powdery Mildew disease was not effective against the causative agent, signifying the impact of climate change on host-pathogen interaction (re-emergence of the pathogen). Machine learning techniques predicted cloud factor, temperature, and humidity were the epidemiological factors responsible for Powdery Mildew disease.

Significant achievements/ findings of the project:

Incidence and prevalence of Powdery Mildew disease were inevitable in Sandalwood plants, where the disease was frequently observed in nurseries of similar ACZ's and different AESR's substantiating the influence of micro climatic factors. Prediction model analysis based on Machine Learning technique revealed cloud factor (broken / closed) and its affiliation with temperature (moderate) and humidity (high) where the conducive factors in incidence and perpetuation of the disease. Phosphorous deficit leaves/plants are highly prone to Powdery Mildew disease in nurseries.The identification of *Pseudoidium santalacearum* (U. Braun and Hosag) as a causal organism for Powdery Mildew disease in Sandalwood plants is the first kind of report from the Southern part of India. *Pestalotiopsis guepinii* (Desm.) Steyaert was identified as the causal organism of leaf blight of Sandalwood plants, based on symptomatology and characterization study. Morphological and molecular characterization of the pathogen of Sandalwood wilt disease showed *Fusarium equiseti* (Corda) Sacc., as the causal organism.

Suggestions/ advisory note for end-users "To-do-techniques":

Leaf blight caused by *Pestalotiopsis guepinii* (Desm.) Steyaert and wilt caused by *Fusarium equiseti* (Corda) Sacc., were found to be newly emerging diseases in Sandalwood plants. Sandalwood plants were diagnosed with downy mildew symptoms in young plantations, a new problem but the least incidence perceived. Phosphorous and Magnesium nutrition deficiencies were common in nurseries and young plantations investigated and predicted to be an emerging abiotic problem in Sandalwood plants. Sandalwood growers in Southern India are advised to approach nearby plant protection centres for the management of diseases.

Research gaps:
There is a lack of knowledge on incidence of emerging diseases and re-merging diseases in Sandalwood.

Uses of research outcomes to the identified stakeholders:
Awareness / knowledge was shared with the stakeholders on the incidence and prevalence of diseases like Powdery Mildew, Leaf Blight, Fusarium Wilt, Collar Rot, Damping Off, Downy Mildew, Shooty Mold and Leaf Spot associated with Sandalwood plants in nurseries and plantations of Southern India.Knowledge on re-emergence of Powdery Mildew as one of the major disease in the nurseries of Sandalwood was shared with the stakeholders.

Publications:

- Muthu Kumar A., Soundararajan V., Rekha J., Divya Bharathi M. and Mamatha N. 2021. Foliar blight disease of Indian Sandalwood (Santalum album l.) trees caused by the pathogen *Pestalotiopsis guepinii* (Desm.) Steyaert. *Asian Journal of Microbiology, Biotechnology & Environmental Sciences* 23(3) 96-100.
- Muthu Kumar A, Soundararajan V., Manoj Kumar P.E., Abhilash A., Rekha J., Vijayalakshmi, G. and Mamatha N. 2021. Impact of change in micro climatic factors for incidence and prevalence of powdery mildew disease in Indian sandalwood (*Santalum album* L.). *Ecology, Environment and Conservation* 28(1) 271- 273
- Application of Machine Learning Techniques in Prediction of Powdery Mildew Disease in Sandalwood (*Santalum album* Linn.) (Pamphlet)

SILVICULTURE
AND
TREE IMPROVEMENT

SILVICULTURE AND TREE IMPROVEMENT

1. **Title of the project**: Evaluation of existing Sandalwood (*Santalum album*) plantation and development of agroforestry trials with capacity building to promote cultivation

Principal Investigator: Dr. N. K. Bohra, Scientist-C, ICFRE-AFRI Jodhpur

Duration: 2017 – 2021

Critical analysis of the research themes and summary of the study:

There is a high demand of quality seeds and seedlings from the sandalwood growers. Currently the seedling production suffers because seeds are collected by the traders from the undefined/ unimproved seed source, poor quality of seeds, low rate of germination and uncertainty of quality of plants used for the planting programmes, still the number of sandalwood growers are increasing to develop bio-resource of sandalwood in the country to meet indigenous and export demand. A scientific model for sandalwood cultivation was made in which along with primary and intermediate hosts, agriculture operation was also included so that during 15-20 years of sandalwood plantation maturation period, farmers can get some income for their livelihood. Three agroforestry trials were established with different host combinations and design at Anand Agriculture university, Gujarat, Jaipur National University. Jaipur, Rajasthan and Research and Demonstration Centre, Rajkot, Gujarat. Seedlings were raised from the seeds procured from Mayur, Kerala and after pre-treatment sandal seedlings were raised and plantations were done in August 2017. Periodic growth data with respect to height, collar diameter and average crown (left to right and south to north) were recorded. Trainings were given for capacity building of local farmers, NGOs, foresters, and others at various forums and places. For mass awareness, lectures and conference presentations were given and articles in electronic and print media were issued.

Significant achievements/ findings of the project:

On the basis of growth data, the best treatment was found for Sandalwood plants with pigeon pea, casuarina and guava with turmeric as agriculture crop in between the plantation. At the age of 4 ½ year of sandalwood plantation best treatment was found with sandal having pigeon pea and casuarina. It attained height of 4.09 m with collar diameter 10.1 cm and mean average crown 3.03 m at Jaipur National University, Jaipur, Rajasthan. Sandalwood plants were placed at 5 x 5 m distance along with primary host different horticulture plants viz., lemon, guava, custard apple, Indian gooseberry (Amala) were planted. At 4 years of age in April 2021 sandalwood trees have average crown 107.53 cm under control. The best treatment was found in sandalwood with custard apple having average height 234.5 cm, average collar diameter 5.15 cm and average crown 178.88 cm. At Rajkot forest department land sandalwood plantation was done with different horticultural hosts like lemon, guava, custard apple and Casuarina. The distance between sandal to sandal was 5x5 meter whereas intermediate hosts were planted at a distance of 1 and 2 meter. Initially primary host red mehndi (*Alternenther* sp.*)* and then pigeon pea (*Cajanus cajan*) seedlings were used with sandalwood. At the age of 4 ½ years sandalwood data with all treatment shows mean height 222.71 cm, collar diameter 119.75 cm and mean crown 116.12 cm. The best treatment was found in sandalwood with lemon and custard apple at 1 and 2 meter apart, respectively with mean height 315.91 cm, collar diameter 7.18 cm and mean crown 165.23 cm.

Survey of existing plantation shows that less than 5x5 meter distancing of sandal plantation without 1 and 2 meter distance good horticulture plants as intermediate host will not give better results and less spacing or fast growing plants cam hemper sandal growth. Casuraina, Babul and other plants can be used as longterm but regular pruning is needed so that sandal get good sunlight and shade both for better growing. New initiative of dragon fruit and growing cash crop between may be useful. At Anand sandalwood Agroforestry trial combination of sandal of sandal; pigeon pea; cauraina; Guava with Turmeric shows best for the area having good soil condition with better management. Here and later on horticulture plants provide additional income till sandal mature fully. At Jaipur National university field where land and soil condition was not better horticulture crops like Anola and Sitafal proved better results. Only rainfed crop between sandal is possible. At Rajkot sandal with sitafal and Nimbu found better with chana crop in beteen sandal. VAM initiated study shows future potential and further studies in long term is suggested. Haustorial study clearly shows haustoria and interaction of sandal with host confirm earlier studies.

Suggestions/ advisory note for end-users "To-do-techniques":

Different model established in Rajasthan and Gujarat clearly indicates that sandal to sandal distance should be 5x5 meter bare minimum. This also shows that adding pigeon pea as host with horticulture plants as intermediate host not only provide income but support better sandal plantation growth. Cash crop like turmeric in semi-arid area with better water and soil management and cash crop in reified area is also suggested.

Research gaps:

Sandalwood is a highly valuable species and fetches great revenue. Its cultivation has gained more popularity over recent years, however, due to the species being a non-native of Rajasthan and Gujarat, the local sandalwood growers often face a multitude of problems. Studies are required to underline the problems and their causes, to create awareness among farmers how best to address the issues, and to develop and recommend the best sandalwood cultivation model for the concerned regions.

Uses of research outcomes:

The recommended model can be used by sandalwood cultivators to gain better financial returns.

2. **Title of the project:** Identification of Juvenility Markers to improve rooting potential of some important tree species

Principal Investigator: Dr. S. K. Rajput, CTO, ICFRE-AFRI Jodhpur

Duration: 2016-2020

Critical analysis of the research theme & summary of the study:

Realizing the importance of clonal propagation in forestry, it has been the subject of continuous research for more than a century to develop the propagation methods by vegetative means for commercially important tree species. It is important to select a good and vigorous stock plant as juvenile as possible to serve as a source for further multiplication. In plants, juvenility is referred to the period during which a plant cannot be induced to flowers whereas maturity is occurred if a plant gives flowers. The changes from juvenile to mature characteristics are well known as phase changes phenomenon. In most of the tree species, propagation is successful at juvenile stage and with increase in age there is a gradual loss of rooting capacity. Cloning of mature trees is more desirable because superior trees can be selected at mature stage only. Therefore, rejuvenation is essential to get best rooting response. With the discovery of rejuvenation methods, vegetative propagation of tree species through various means like using cuttings from juvenile mother tree, grafting, rooting of sprouts and coppice shoots have been initiated by foresters and scientists. Understanding the degree of juvenility is the key in any successful clonal forestry programme. The selection of juvenile explain increases the success of any protocol and make it very reliable and robust as well. The juvenility in the three important species of semi-arid region namely *Ailanthus excelsa* (*Ardu*), *Azadirachta indica* (*Neem*) and *Tecomella undulata* (*Rohida*) was not studied before and there was need to study the juvenility in these species including identifying and selection of juvenile material. It was found that in *neem* and *ardu* the appearance of three-leaflet stage was an indicator of juvenility and the correct indication of juvenile nature of coppice shoots in these species. In neem apart from the three-leaflet stage the internodal distances were also recorded as marker for the identification of juvenility. It was further observed that the growth potential in these juvenile shoots was also more as compared to seedlings. Total chlorophyll, photosynthetic rate and stomatal conductance were found higher in coppice shoots than the mature. Whereas the secondary metabolites like total protein content and phenol content were maximum in the mature plants. The rooting experiment clearly indicated that juvenile coppice shoot cuttings showed better rooting as compared to mature plants which failed to root at all.

Significant achievements/ findings of the project:

Leaflet number per leaf was identified as juvenility markers in *ardu* and *neem.* The appearance of three leaflets in coppice shoots indicated their juvenile nature in both the species. The treatment of irrigation, compost 5kg per plant and 2 percent NPK was best for coppice shoot number and shoot length. Highest photosynthetic rate was observed in coppice shoots in *ardu.* The result of chlorophyll estimation revealed that *neem* was having highest chlorophyll content from seedling stage. The rooting in coppiced shoot cuttings was obtained in *ardu* and *neem*. Highest rooting was observed in the month of July. The middle portion of shoot with collar diameter 1.52 cm in *ardu* and 0.7 cm in *neem* showed minimum rooting.

Suggestions/ advisory note for end-users "To-do-techniques":

The findings are useful to locate or develop the juvenile shoots on mature trees. The techniques were robust, reliable and cost effective. Most of the tree species have difficulty in rooting during propagation, especially from material collected from mature trees. The research findings improved the rejuvenation techniques by coppicing of the tree coupled with irrigation and application of NPK and compost. The use of middle portion of coppice shoots produced maximum rooting and helped in developing reliable clonal techniques for difficult to root tree species. This study will help the researchers for the improvement of existing propagation protocol of these three species including micro- and macro-propagation by selecting the juvenile material for their future studies.

Research gaps:

Identification of juvenile material is essential to develop reliable clonal propagation protocol and increase its success. The juvenility in the three important species of semi-arid region namely *Ailanthus excelsa* (Ardu), *Azadirachta indica* (Neem) and *Tecomella undulata* (Rohida) were not studied before.

Uses of research outcomes:

The project led to identification of juvenile markers that can be used by researchers to identify the right material for more efficient vegetative propagation of these species. The research findings will help to recommend taking up measures to apply rejuvenation techniques whenever necessary, for example, by coppicing of the tree coupled with irrigation, NPK and compost doses.

Publication:

- Saini L.S., Rathore T. R., Rajput S. K. and Tomar U. K. 2020. Factors affecting rooting potential in stem cuttings of *Ailanthus excelsa* Roxb. *Indian Forester* 146:1078-1080.

3. **Title of the project:** Studies on phenology, molecular analysis and wood properties of *Tecomella undulata* with respect to three flower colour morphotypes

Principal Investigator: Dr. Desha Meena, Scientist-D, ICFRE-AFRI Jodhpur

Duration: 2017-2021

Critical analysis of the research themes and summary of the study:

Tecomella undulata (Rohida) is an important timber yielding tree species of arid and semi- arid regions. This tree is recognised as state flower because of variability in the colour of the flower (yellow, orange and red). This project aims to study the density and distribution pattern, wood properties and molecular analysis of *Tecomella undulata* with respect to different flower colour morphotypes. An intensive survey was carried out in Sikar, Churu, Nagaur, Bikaner, Jodhpur, Jaisalmer, Barmer and Jalore districts of Rajasthan and 14 sites were identified to study population distribution and density pattern among different flower colour morphotypes. Further, to study the phenological parameters (pod and seed size, flowering and fruiting pattern and percentage), ninety trees were marked at Bhadrajune in Jalore district and data were recorded for two consecutive years. Physical and mechanical properties of wood of different morphotypes were also studied for the first time by taking nine logs (three logs of each flower-coloured tree) from Mohangarh, Jaisalmer. Ten sections were cut from 1 log, hence 30 wood sections for each colour were converted, seasoned and properties like specific gravity, modulus of elasticity, modulus of rupture, Hardness (N), Shear Strength Parallel to grain, Tension Parallel to grain, Compression parallel to grain and Compression perpendicular to grain were investigated. Molecular analysis among these morphotypes was also studied using Start Codon targeted (SCoT) marker system in which genomic DNA was extracted from young leaves using the modified CTAB method. In all 63 SCoT markers were tested for the present study, out of which 14 primers were shortlisted based on the amplification and PIC content.

Significant achievements/ findings of the project:

Based on the survey, it was found that density of orange morphotypes was high and low for red morphotypes in Rajasthan. In the survey, it was observed that orange morphotype was distributed uniformly and found to be more, followed by the yellow and red flowered morphotypes in Rajasthan. Phenological parameters like pod length, seed length of orange morphotype, pod width for yellow morphotypes and seed weight for red morphotypes were found to be more in comparison to other morphotypes. Variations in the onset of the flowering seasons among the three morphotypes were also observed during the survey. Orange and red morphotypes showed flowering about two-three weeks earlier than the yellow morphotype. Peak flowering for all morphotypes was observed in the month of February with a decline towards the end of March. Further, the transition phase from flowering to fruiting was observed from April to the July end. Strength properties among different flower colour morphotypes were also compared for the first time. It was found that red- flowered trees strength data was significantly higher from other yellow and orange-flowered trees due to the changes in specific gravity (Sp. gravity – red - 0.67, yellow - 0.63, orange -0.60). Clustering pattern of dendrogram using UPGMA analysis clearly bifurcated into two distinct groups. The first group consisted of yellow morphotypes and second group containing red and orange morphotypes.

Suggestions/ advisory note for end-users "To-do-techniques":

Based on density, distribution pattern and wood property studies, it was found that the population of red morphotypes was low but the wood strength of red morphotypes was high compared to other two morphotypes. The wood property studies showed that variation existed between these three morphotypes in terms of strength, so it is recommended to grow red morphotypes followed by yellow trees for the conservation of such an important tree species of arid region. Knowledge generated from the study will be passed on to the farmers to make them aware in growing this important tree species of arid region and get economic benefits.

Research gaps:

Variation exists among different flower colour morphotypes of the speciesat phenological, wood properties and molecular level.There was no previous systematic study correlating the flower colour morphotypes of *Tecomella undulata* with the wood characteristics.

Uses of research outcomes: The findings of the project will be beneficial for the tree growers and the wood-based industries for ensuring long-term economic benefits by growing the best morphotype.

Publications:

- देशा मीणा, अनिल सिंह चौहान,आस्था शर्मा,२०२२,राजस्थान में फूलों के रंग के आधार पर रोहिड़ा के संख्या धानत्व और वितरण पैटर्न का आंकलन. आफ़रीदर्पण, वर्ष १६, अंक ०१ से ०४.
- "रोहिड़ाः मारवाड़ का सांगवान (एक कदम आनुवंशिक सुधार की ओर)"
- *Tecomella undulata* (Rohida): Marwar Teak of Rajasthan (A Step Towards Genetic Improvement) (Pamphlet)

4. Title of the project: Studies on Seed Germination and Nursery Technology of *Anogeissus pendula*

Principal Investigator: Dr. N. K. Bohra, Scientist-C, ICFRE-AFRI Jodhpur

Duration: 2016 - 2019

Critical analysis of the research themes and summary of the study:

Anogeissus pendula is a very important tree in arid and semi-arid regions of western India and plays an important role in greening the wide areas of the region. For refinement of nursery techniques aiming to produce quality seedlings of this species parameters viz. seed germination, collar diameter, seedling length, etc. to determine the quality of seedlings and overall production, were studied. The project results will be helpful in developing a total protocol from seed collection to production of quality seedlings. Seeds collected from various locations showed great variation in their length (4.5 to 8.3 mm) and width (3.42 to 5.67 mm), however no direct relation of germination percentage with seed size was observed. Best result for germination with 24 hours cold water treatment was observed in seeds collected from Sawai Madhopur (Tree No. 2) and Bundi, Rampura (Tree No. 3). Even trees located in same localities showed variation in germination percentage which may be due to genetic variability and, therefore, reproductive biology of species is to be studied. Seeds collected from diverse locations showed variation in germination index ranging from 0.0 to highest 0.44 in T. No. 2 of Kota. Again, germination index in trees from same locality varied. Overall mean germination index was 0.09. Gibberellic acid treatment affected the germination in several seed lots, however, in many seed lots it had no effect even from 500 ppm to 1500 ppm concentration of GA3. In Bundi T(b) control (no treatment) germination was 0.66% which increase 0.99% with 500 ppm and then with 1000 ppm and 1500 ppm it remained same as 1.32% whereas in Kota T(a) control showed 0.97% germination which reached to 1.94% with 1500 ppm GA3. Kota T(d) control showed 4.37% germination which decreased with increase in GA_3 concentration. Sawai Madhopur T(a) showed increase in germination with 500 ppm but higher concentration showed no effect. In Sawai Madhopur different seed lots showed variation even in neighboring trees. In Desuri and Kumbhalgarh area not much change in germination of GA_3 treatment was observed. In Desuri Ki Naal (Plot 4) control showed 4.49% germination while 500 ppm showed 5.06% germination. On increasing GA_3 concentration germination percentage decreased. In Kali Ghati (Jojawar) no effect of GA_3 was observed. In Parsuram Mahadev seed lot control performed better with 2.6% germination but with 1500 ppm it reached to 5.73%. Variation indicated effect of GA_3 treatment on seed dormancy but its effect was not uniform to all seed lots. In one-month old seedlings of *Anogeissus pendula* different biofertilizers viz. Azospirillum, Azotobactor, P.S.B. and *Trichoderma* were applied and in control no biofertizer was added. Ten ml of each biofertilizers having 108 to 1010 cfu/ml count were added in 1000 cc polybag and 300 cc root trainers. Results indicated that in polybags best results were obtained in Azotobactor treated 1000 cc polybags having mean height 76.6 cm and mean collar diameter 2.15 mm. PSB treated polybags showed nearly same results with mean height 75.6 cm and mean collar diameter 2.22 mm. In 300 cc root trainer also Azotobactor performed better with mean height 90.3 cm and mean collar diameter 9.3 mm while Azospirillum treated seedlings had mean height 89 cm and mean collar diameter 5.9 mm. Use of Agromin, Neutron, Neem ki khad as growth promoting substance were found good but there was no significant difference between them.

Significant achievements/ findings of the project:

Seed size varied in length from 4.5 to 8.3 mm and in width also varies from 3.42 mm to 5.67 mm. however no direct relation of germination percentage with seed size was observed. Soaking of seeds in Cold water for 24 hours can give up to 3 percent germination in laboratory conditions while hot water treatment up to 2 percent germination was achieved in different seed lots. However, with Gibberlic acid treatment up to 5 percent germination was observed in some seed lots. In four-month old seedling, best results were obtained in 1500 cc Polybags having 1:1:2 potting mixture ratio of soil: Sand: Vermicompost. In 1000 cc polybags and 300 cc root trainer having potting mixture ratio 1:1:1 with biofertilizer treatment, the best result was obtained in 300 cc root trainer with Azotobacter.

Suggestions/ advisory note for end-users "To-do-techniques":

As species has germination problem a detailed study on its reproductive biology with reference to habitats, long-term seed storage and seed viability is needed. Therefore, the availability and use of quality seeds is one of the most essential factors for successful plantations.

Research gaps:

Anogeissus pendula is very important in arid and semi arid regions of western India and plays an important role in greening the wide areas of the region. However, reliable nursery practices for the species were not available.

Uses of Research outcomes:

The project led to the identification of best practices for growing seedlings, in terms of potting mixture ratio, container type and additional treatment with biofertilizers which may be utilized by nurseries to achieve good seed germination and improve seedling growth.

5. Title of the project: High-density plantation management for wood production and assessment of wood properties of coppiced material

Principal Investigator: Dr. Dinesh Kumar, Scientist-G, ICFRE-FRI Dehradun

Name of Co-PI: Dr Anita Tomar

Duration: 2018-23

Critical analysis of research theme and summary of the study:

Planting of trees on a high density is key to producing large volumes of wood at a shorter rotation. This is important for end-uses which do not require large diameter woods such as for particle board, fibre board, paper, fuel, etc. With use of suitable species, the high-density plantations can be coppiced and managed to produce wood for several rotations without need for replanting. It is, therefore, important to determine the species and spacing for high density plantation and study properties of the coppiced wood material.

Significant achievements/ findings of the study:

Fast-growing tree species were planted under high-density plantations at four sites in district Nainital (Uttarakhand), Saharanpur, Raebareli and Prayagraj (Uttar Pradesh) namely *Salix alba, Toona ciliata, Celtis australis* in Nainital district; *Melia dubia, Eucalyptus* hybrid*, Dalbergia sissoo* in Saharanpur district; *Eucalyptus* hybrid, *Casuarina junghuhniana* and *Gmelina arborea* in Raebareli, and *Eucalyptus* hybrid, *Melia dubia, Casuarina junghuhniana, Gmelina arborea* in Prayagraj. Spacing tested were 1 × 1 m, 1.2 × 1.2 m and 1.5 ×1.5 m. *Eucalyptus* hybrid at 1 × 1m spacing (3374.43 t ha^{-1}) followed by *Melia dubia at* 1 x 1m spacing (1594.96 t ha^{-1}) produced the greatest total biomass at the age of 3½ years in Prayagraj. In Raebareli, Eucalyptus planted at 1.5 × 1.5 m spacing (1040.32 t ha^{-1}) and 1.2 × 1.2 m spacing (941.07 t ha^{-1}) gave highest total biomass. Comparison of coppiced and non-coppiced wood for calorific value, cellulose content and hemi-cellulose content revealed non-significant differences in plantations at Saharanpur, however, lignin content was higher in non-coppiced wood than coppiced wood. Interaction with industries revealed that smallwood produced in high density plantation has commercial utility for pulping, cardboard, particle board, fibre board, firewood, briquette, etc.

Suggestions/ advisory note for end-users "To-do-techniques":

In areas where industries such as cardboard, particle board, fibre board, firewood, briquette, etc. are willing to buy small wood, planting of tree species such as *Eucalyptus* hybrid and *Melia dubia* may be carried out at close spacing of 1x1 m to 1.5 x 1.5 m and the plantations may be coppiced after two years for supply of wood to such industries.

Research gaps:

Information is not available about comparative performance of tree species in different spacings to establish high-density plantation for production of smallwood/firewood. Information about cellulose, hemicellulose and lignin content and specific gravity of coppiced wood and non-coppiced wood is lacking. Information is also required about possible utility of smallwood from coppiced plantation.

Uses of research outcome:

Market survey showed that shoots from coppicing are saleable and are used for firewood, briquette, pulping, cardboard, particle board, etc. and is useful for stakeholders. Plantations may be undertaken to get early production from high density plantations.

Publication:

- Singh B.K., Tomar A., Khan F.A. and Beauty K. 2022. Growth, Biomass and Carbon sequestration of fast-growing tree species under high-density plantation, Prayagraj. *Current Science* 122(5): 618-622.

6. **Title of the project:** Evaluation of genetic resources of *Melia dubia* in Tamil Nadu and Kerala for productivity enhancement in tree farming

Principal Investigator: Dr. Rekha R Warrier, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2012-2022

Critical analysis of the research theme and summary of the study:

Large-scale plantations of *M. dubia* have been raised by the state forest departments, private entrepreneurs and farmers since 2009. There is an urgent need to initiate a tree improvement programme by identifying superior genotypes and having a broader genetic base for developing breeding strategies. The crucial steps in tree improvement are documenting variability, selection, propagation, progeny testing.

Significant achievements/ findings of the project:

Plus tree selections revealed significant variation in the natural growing regions of the species, which was not region-specific. High variability in fruit and stone characters contributed to the genetic divergence. Germination was also highly variable, with 11 per cent of the trees recording less than 10 per cent germination. A clonal trial established at Mondipatti revealed significant variation between clones. Wood properties assessed revealed variations in wood density, with some clones recording high density. *Melia dubia* is an excellent agroforestry species with scope for intercropping throughout its growth. The leaf litter does not show any allelopathic effect. Hence the mulch would improve the soil fertility. The returns are better in an agroforestry model than as sole crop. However, wide spacing is recommended to facilitate better light penetration leading to an enhanced yield of the intercrops. DNA barcodes have been developed for species delimitation to enable early identification of the species or screening during its vegetative phase.

Suggestions/ advisory note for end-users "To-do-techniques":

A basic understanding of the species in terms of its growth, silviculture and performance across different locations is essential prior to recommending superior material for large scale plantations. The agroforestry models should enable better economic returns for tree growers. The generation of DNA barcodes can be used for species delineation during non-flowering phases.

Research gaps:

Being a species popular among farmers, there is an urgent need to characterize and select different genotypes available in the country for breeding, improvement and selection of superior biotypes.

Uses of research outcomes:

Basic information of the species in terms of its growth, silviculture and performance across different locations is available for stakeholders. Identification of superior germplasm in terms of growth and passport data on morphological and genetic diversity was generated for future tree improvement programmes. Agroforestry models with different crops are available for field.DNA barcodes for species delineation during non-flowering phases are essential tools for early diagnosis.

Publications:

- Warrier Rekha R., Priyadharshini P. and Krishnakumar N. 2012. *Melia dubia* – a potential indigenous fast-growing species for farmlands. *Indian Forester* 138:567-568.
- Mohanraj M., Kalpana B., Warrier Rekha R. and Bragadeeswaran S. 2015. Physiological and Biochemical Variability Studies of *Melia dubia*. *Research Journal of Forestry* 9: *22-26.*

- Janani S., Priyadharshini P., Jayaraj R.S.C., Buvaneswaran C., Warrier R.R. 2016. Growth, physiological and biochemical responses of Meliaceae species – *Azadirachta indica* and *Melia dubia* to elevated CO_2 concentrations. *J. App. Biol. Biotech.* 4(3): 52-60.
- WarrierRekha R. 2015. Comparative Morphology and Wood Characteristics of *Melia dubia* and *Melia azedarach* for Easy Identification. *My Forest* 51 (2): 69-76
- Arun R., Silambarasan S., Senthil K. and Jacob John Prasanth 2016. Sap feeders and their management in multiplication garden of *Melia dubia*. *My Forest* 52(1-4): 57-62.
- Warrier Kannan C.S., Raja Jaya Livingston and Warrier Rekha R. 2018. Genetic Divergence in Fruit and Stone traits of *Melia dubia* Cav. in India. *International Journal of Genetics* 10(10): 530-533.
- Geetha S., Venkataramanan K.S., Warrier Kannan C.S. and Warrier Rekha R. 2018. Propagation protocols for enhancing conservation and utilization of *Melia dubia* Cav. *Journal of Tree Sciences* 37(2): 22-35.
- Warrier Rekha R., Samidurai P., Jeevith S., Raja Jaya Livingston, Warrier Kannan C.S. 2018. Variation in coppice-shoot growth among clones of *Melia dubia* Cav. *My Forest* 54(4): 29-37.
- Annapurna D., Warrier R.R., Arunkumar A.N., Aparna R., Sreedevi C.N. and Joshi G. 2021. Development, characterization, functional annotation and validation of genomic and genic-SSR markers using de novo next generation sequencing in *Melia dubia* Cav. *3 Biotech* 11(7):1-15.
- Warrier R. R. 2021. DUS Descriptors for *Melia dubia*. pp.15-21. In book: Recent Advances in *Melia dubia* Cav. Indian Council of Forestry Research and Education, M/s Bishen Singh Mahendra Pal Singh.
- Warrier R. R., Geetha S., Raja Jaya Livingston and Warrier Kannan C.S. 2021. Clonal Forestry in *Melia dubia*. pp.51-62. In book: Recent Advances in *Melia dubia* Cav. Indian Council of Forestry Research and Education, M/s Bishen Singh Mahendra Pal Singh.
- Kumar Aditya, Kumar Ashok, Joshi Geeta and Warrier R. R. 2021. Molecular Techniques to Analyze Genetic Diversity in *Melia dubia*. pp.75-86. In book: Recent Advances in *Melia dubia* Cav. Indian Council of Forestry Research and Education, M/s Bishen Singh Mahendra Pal Singh.
- Warrier Rekha R. 2015. *Melia dubia* as an agroforestry crop. In: Training manual on 'Agroforestry Models Establishment and Management'. pp 10 -12.
- Warrier R.R. 2013. *Melia dubia*. In: Nursery and Clonal Technology – A Training Manual. Eds.:Modhumita Dasgupta and Rekha R. Warrier, Institute of Forest Genetics and Tree Breeding, Coimbatore, p 73-81.
- Warrier, R.R. 2011. Planting Stock Production in *Melia dubia*. In: Planting Stock Improvement, Training Manual. Eds.: Warrier, K.C.S., Sivakumar, V., Gurudev Singh B. and Kumar, N.K. 2011, Institute of Forest Genetics and Tree Breeding, Coimbatore, p 73-81.
- Warrier Rekha R. 2011. *Melia dubia* - Money Spinning Trees Series 2. Institute of Forest Genetics and Tree Breeding, Coimbatore. 24 p.

7. **Title of the project:** Germplasm assemblage of Dalbergias, Its characterization and evaluation

Principal Investigator: Dr. K. R. Sasidharan, Scientist-F and Dr. D. Thangamani, Scientist-D, ICFRE-IFGTB Coimbatore

Duration: 2017 – 2021

Critical analysis of the research theme and summary of the study:

The objective of this project was exploration and conservation of the valuable Indian Rosewood (*Dalbergia latifolia* Roxb.) germplasms. Altogether, 173 phenotypically superior trees of *D. latifolia* and *D. sissoides* were selected from Kerala and Tamil Nadu, covering 14 forest divisions of the former and seven forest divisions of the latter. A total number 137 trees of *D. latifolia* were selected out of which 94 from Kerala and 43 from Tamil Nadu. The genetic resources assembled will serve as Field Gene Bank (FGB) for conservation and utilization of these species, particularly for the genetic improvement. Morphometric characteristics of the selected trees like GBH, total height and bole length and geo co-ordinates were collected from the selected trees. The root cuttings of the selected superior trees were collected and vegetative propagation carried out. Clonal plants raised from 69 superior trees of Dalbergia were planted in 2019 at Varavoor area of Wadakkancherry Forest Range, Thrissur Forest Division, Kerala to establish the Germplasm Assemblage. A set of 60 clones were assembled in the campus of Vanavarayar Institute of Agriculture, Manakkadavu, Pollachi, Coimbatore district, in 2020. The clones of Dalbergias were studied for morphological characters of the leaf-lets. It was also noticed that the leaf-let morphometric parameters of Kerala clones were significantly lower than that of Tamil Nadu clones. The results of UPGMA analysis revealed that both *D. latifolia* and *D. sissoides* are placed in the same clusters, indicating that these species are closely related. When the Principal Co-ordinate Analysis (PCoA) was carried out, the 56 clones were also divided into two major groups - one group containing 40 clones of *D. latifolia* and *D. sissoides,* ranging from values 0.000 to -0.14 of the co-ordinate-1 and the other group with only 16 *D. latifolia* clones with values ranging from 0.13 to 0.27 of the co-ordinate-1. Both the groups accommodated a mixture of Kerala and Tamil Nadu clones. The Analysis of Molecular Variance (AMOVA) showed significant genetic variation among the superior trees selected in both *D. latifolia* and *D. sissoides* clones were considered together, the variance noticed was 71 percent within the populations, 21 percent among the populations and 8 percent within the regions The outcome of the biochemical characterization of the leaves of Dalbergia species indicated the presences of tannins, saponins, glycosides, triterpenoids, phenols, flavonoids, carbohydrates, proteins and fats.

Significant achievements/ findings of the project:

A set of 60 clones were assembled in the campus of Vanavarayar Institute of Agriculture, Manakkadavu, Pollachi, Coimbatore district, in 2020.

Suggestions/ advisory note for end-users "To-do-techniques":

The research works carried out on establishing the assemblage of the genetic resources of *D. latifolia* and *D. sissoides* and their characterization have generated basic information which will enable us to proceed with advanced research in the field of conservation and utilization of these species.

Research gaps:

Gaps have been recognized for identification of superior trees, propagation, characterization and evaluation of genetic resources for conservation.

Uses of research outcomes:

The identified superior genetic resources were assembled as Field Gene Bank (FGB) for conservation and utilization of these species, particularly for the genetic improvement.

Publications:

- Vasudevan R., Sasidharan K.R., Venkataramanan K.S., Thangamani D. and Sivanantham S. 2020. Standardization of macropropagation technique for *Dalbergia latifolia* Roxb. through root cuttings, its application in production of quality planting stock and conservation of genetic resources. *International Journal of Advanced Research and Review* 5 (11): 09-19.
- Thangamani D., Sasidharan K.R., Girija S., Vimaladevi S., Vasudevan R., Lalitha S. and Anandalakshmi R. 2020. Characterization and cytotoxic activity of *Dalbergia latifolia* wood extract. *American Journal of Agriculture and Forestry* 8 (5): 208-213.
- Vasudevan R., Thangamani D., Lalitha S. and Sasidharan K.R. 2023. Population structure and genetic diversity analysis of *Dalbergia latifolia* and *Dalbergia sissoides* using RAPD markers. *Journal of Applied Biology and Biotechnology* 11(5): 59-69.

8. Title of the project: Exploration, Collection and Evaluation of Forest Genetic Resources and Development of National Gene bank

Principal Investigator: Dr. K. Palanisamy, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2012-2019

Critical analysis of the research theme and summary of the study:

The project was proposed for conservation and management of genetic resources of 2 economically important species *Tectona grandis* and *Eucalypytus camaldulensis*. The objective of the project was to explore and collect the germplasm of *Tectona grandis* and *Eucalyptus camaldulensis* from different geographical zones and to identify active germplasm sites for effective utilization. Research Institutes, State Forest Departments and Industries have established plantations, seed orchards, seed production areas, provenances and clonal assemblage for *T. grandis* and *E. camaldulensis* in different states. However these resources are scattered, not systematically documented and there is no mechanism to access these germplasm. Therefore, the natural populations and plantations and selection of desirable and distinct populations for conservation is essential and evaluated.

Significant achievements/ findings of the project:

In Tamil Nadu and Kerala, a total of 252 teak plantations and 40 natural teak populations were explored, evaluated and documented. The geographical data like locations, latitude, longitude, altitude, soil type topography, and morphological characteristics of the plantations and natural populations like tree height, GBH, clear bole height, tree form etc have been documented. In Tamil Nadu 108 teak plantations and 38 natural populations in different locations were evaluated at Coimbatore, Erode, Salem, Nilgiris, Tirunelveli and Kanyakumari, out of which 23 plantations showed better growth characteristics and tree form have been selected for conservation.Outstanding teak trees have also been noticed in the natural populations and plantations in different locations in Tamil Nadu and marked for conservation. Seeds were collected from selected germplasm and conserved in seed bank.

In Kerala, a total of 144 teak plantations and 2 natural populations at Trichur, Chalakudy, Nilanmbur, Vazhikadavu, Ranni and Konni area have been evaluated and documented. Significant variation on growth characteristics, tree form and bark texture has been noticed in different locations. The teak trees in Trichur and Chalakudy showed significant growth characteristics (17-30 m ht > 100 cm GBH) with straight trees, while majority of the trees in the plantation at Nilambur showed 17-25 m height with straight tree form. In the present investigation 52 teak plantations and 40 natural populations have been selected for conservation in Tamil Nadu and Kerala. Twenty-three genetic resources of Teak which showed good growth characteristics, maintenance and seed collection have been identified as active germplasm sites for further maintenance and effective utilization. The SPAs of Teak at Topslip Tamil Nadu were found to be the potential source of Teak seeds.

Suggestions/ advisory note for end-users "To-do-techniques":

The selected natural populations, plantations, superior trees, seed orchards, SPAs and clone bank will be useful for tree improvement programme. Best germplasm of teak in Tamil Nadu and Kerala have been identified. The selected 52 plantations, superior teak trees, and 23 SPAs and seed orchards of Teak will be useful for raising clonal plantation and thereby will improve productivity.

Research gaps:

The genetic resources of Teak and eucalyptus are scattered, not systematically documented and there is no mechanism to access the germplasm.

Uses of research outcomes:

The selected natural populations, plantations, superior trees, seed orchards, SPAs and clone bank will be useful for tree improvement programme.

Publication:

- Palanisamy K. 2013. Conservation and Management of Genetic Resources of Teak in India. In: Forest Genetic Resource Management, pp124-139, Eds.: K. Palanisamy, M. Maria Dominic Savio and N. Krishnakumar, Institute of Forest Genetics and Tree Breeding, Coimbatore, , 2013.

9. **Title of the project:** Selection, Evaluation, Conservation and Documentation of Genetic Resources of Teak and other important species for Enhancement of Productivity

Principal Investigator: Dr. K. Palanisamy, Scientist-G and Dr. D. Thangamani, Scientist-D, ICFRE-IFGTB Coimbatore

Duration: 2017 - 2018

Critical analysis of the research theme and summary of the study:
Plantations have been established in large scale for Teak in the country, but the genetic resources have not been evaluated and documented systematically. Though quality seeds and high yielding clones have been developed, but have not been utilized effectively due to lack of information on availability and source. The objective of the project focused on the evaluation of the genetic diversity, flowering and fruit setting in seed production areas of teak and to identify the potential SPAs; to evaluate and document the established genetic resources of Teak and other important species and to develop teak clones for the clonal plantation programme and finally *ex situ* conservation of valuable germplasm of teak in field gene bank and seed bank.

Significant achievements/ findings of the project:
Extensive field surveys were made in Kerala and 34 teak SPAs (Ranni, Konni, Thenmala, Nilambur, Nemmara and Wayanad forest divisions) were evaluated for growth characteristics, tree form, pest attack, flowering and seed production. A total of 116 teak trees from 21 SPAs (Ranni, Konni, Achenkovil, Nilambur and Wayanad forest divisions) were used to study the genetic diversity through ISSR markers. The established genetic resources like teak plantations, natural populations and permanent preservation plots were evaluated. The data for growth, tree form, yield, seed production, seed collection, utilization of the orchard/SPA, present status, year of establishment, area, maintenance, No. of clones, GPS data were recorded. The superior trees were selected in the plantations and marked for final felling. The superior trees were multiplied through coppice shoots and the clones were developed for the clonal plantation programme. The vegetative propagules were collected from the selected germplasms for *ex situ* conservation.

Suggestions/ advisory note for end-users "To-do-techniques":
Since the natural populations are limited in Kerala, both natural populations and plantations have been evaluated, documented and selected for conservation. In addition, the established genetic resources of teak and other important species like seed production areas (SPA), Clonal seed orchards (CSO), Seedling seed orchards (SSO), clone bank, provenance stands, germplasm bank, progeny trial, clonal trial etc. have been identified, evaluated and documented for the effective utilization.

Research gaps:
There exist gaps how to evaluate the status of SPA and seed orchards for tree form, flowering pattern, seed production to identify the potential genetic resources for seed collection and utilize it for planting programme and thereby improve teak productivity.

Uses of research outcomes:
Thebest populations and plantations were identified and selected for conservation. In addition, the established genetic resources of teak and other important species like seed production areas (SPA), Clonal seed orchards (CSO), Seedlingseed orchards (SSO), clone bank, provenance stands, germplasm bank, progeny trial, clonal trial etc.have been identified, evaluated anddocumented for the effective utilization.

Publication:
- Thangamani D., Mohamed Nawas O.M., Lalitha S., Subramani S.P. and Palanisamy K. 2020. Genetic diversity and genetic variation assessment among Tectonagrandis seed production area populations. *International Journal of Creative Research Thoughts*, ISSN:2320-2882; 8 (4):3842-3846.

10. Title of the project: Germplasm assemblage of medicinal plants *Caesalpinia bonduc* and *Annona muricata* their characterization and utilization

Principal Investigator: Dr. D. Thangamani, Scientist-D, ICFRE-IFGTB Coimbatore

Duration: 2019-2023

Critical analysis of research theme and summary of the study:

The objective of the project was to assemble genetic resources of *Annona muricata* and *Caesalpinia bonduc* from different parts of Tamil Nadu and Kerala and conserve the genetic resources in field gene bank and seed bank. Surveys were conducted in different zones of Tamil Nadu and Kerala and 25 accessions were collected from 20 locations of home gardens and agro climatic locations. The propagated plants were assembled in germplasm bank for conservation and characterized for its phytochemicals.

Significant achievements/ findings of the projects:

Annona muricata and *Caesalpinia bonduc* seeds, leaves and stem cuttings were collected from 20 different locations of Tamil Nadu. In *Annona muricata* the propagation with soft stem with apical bud (20-25mm) showed good response with IBA 1500 ppm, the shoot proliferation starts after 2 weeks and root proliferation approximately within 60 days with increase in rooting percentage. In *Caesalpinia bonduc,* the cuttings treated with 1500 ppm IAA showed better shoot proliferation in 2 weeks and also root initiation have been noticed after 4 weeks. As the survival percentage was very low, seeds were collected, pretreated by mechanical scarification followed by seeds soaked in water for 48 hours and 50% H_2SO_4 for one hour showed better result of 70% and 80% germination, respectively. Qualitative and quantitative analysis of ACGs (acetogenins) in *A. muricata* fruits revealed a range of 2.49 to 16.47 mg per kg while bonducin content in *Caesalpinia bonduc* seedsranged between 0.155 to 0.788 %.

Suggestions/ advisory note for end-users "To-do-techniques":

The germplasm has been assembled at KVK, MYRADA, Thalamalai and Pethykuttai, Mettupalayam, Coimbatore which can be utilized further for stakeholders.

Research gaps:

The study is to be made to fill in the gaps existing in identification and characterization of selected medicinal plants.

Uses of research outcomes:

Medicinal plants rich in active molecules has been assembled as germplasm bank.

Publication:

- Thangamani D., Mohamed Nawas O. M., Lalitha S., Arul Prakash T. and Poopathi Rajan S. 2020. Biochemical Characterization, Antioxidant and Cytotoxic Activity of *Annona muricata* L. Accessions Fruit. *International Journal for Research in Applied Science & Engineering Technology ISSN: 2321-9653.*

11. Title of the project: Assessment of *Calophyllum inophyllum* clones for oil yield and site specificity

Principal Investigator: Dr. R. Anandalakshmi, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2016-2021

Critical analysis of the research theme and summary of the study:

Calophyllum inophyllum, a potential Tree Borne Oilseed (TBO) and its kernel oil has good market demand as medicinal oil. A wide germplasm assemblage from Tamil Nadu, Kerala, Andamans and Puducherry has been made by IFGTB and multilocation trials have been established. Assessing the performance of the clones across locations to identify high yielding clones was the aim of the project. The study will help to utilize the under-utilized TBO on a sustainable basis for its oil, promote livelihood of the farming community and support social and urban forestry programs.

Significant achievements/ findings of the project:

Six high yielding clones of *Calophyllum inophyllum* were approved and recommended to the Variety Releasing Committee of ICFRE and same were released as clonal varieties. Training was imparted on cultivation of *Calophyllum inophyllum* to farmers and foresters. Webinar training on income generation through *Calophyllum innophyllum* was organized in collaboration with magazine – Pasumai Vikatan. Another farmers training in collaboration with NGO, Vanathukkul Tiruppur Organization, Tiruppur was also conducted to create awareness among the farmers about the underutilized TBO.

Suggestions/ advisory note for end-users "To-do-techniques":

Breeding program for *Calophyllum inophyllum* was carried out collecting germplasm from Tamil Nadu, Kerala, Puducherry and Andamans. Clonal MLTs were established and evaluated for fruiting and oil yield for 3 consecutive years and released 6 high yielding clones. The clones need to be popularized among tree growers for economic benefits.

Research gaps:

Elite *Calophyllum inophyllum* clones, a promising TBO, can be made available to meet the medicinal oil and biofuel demand.

Uses of research outcomes:

The extension activities carried out under the project helped to create awareness among the farmers about the underutilized TBO in a big way.

Publications:

- Anandalakshmi R. 2020. Physiological and biochemical traits of adaptability in *Calophyllum inophyllum* (L.). *International Journal of Chemical Studies* 8(1): 1894-1902
- Anandalakshmi R. 2021. Effect of clonal variation on oil content and oil properties of *Calophyllum inophyllum* L.: A Multipurpose tree. *Asian Journal of Research in Agriculture and Forestry* 7(1): 48-57
- Anandalakshmi R. 2019. Punnai Marathil Palavidhamana Nanmaigal (in Tamil). *Pasumai Vikatan* dated 10.5.2019., pp.35-37
- Anandalakshmi R. 2020. எண்ணெய்வருமானம்கொடுக்கும்புன்னை. *Pasumai Vikatan,* October, 2020
- Anandalakshmi R. 2018.*Calophyllum inophyllum* – A potential Tree Borne Oilseed of South India. IFGTB Publication.
- Anandalakshmi, R. 2018. Punnaivalarppomnanmaiadaivom (Tamil), IFGTB publication.

12. Title of the project: Development of seed pelleting techniques for commercially important tree species

Principal Investigator: Dr. R. Anandalakshmi, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2016-2019

Critical analysis of the research theme and summary of the study:

The purpose of any seed pelleting is to improve seed performance such as to eradicate seed borne pathogens or protect from soil borne pathogens, optimize ease of handling and accuracy of planting (reduce gaps in stand or the need for thinning of seedlings, particularly when mechanical planters are used), and to improve germination. In conventional production, seed is often treated with chemical fungicides which reduce seed and seedling losses due to seed borne and soil borne diseases. Ideally, the pelleting materials are somewhat permeable to oxygen and absorb water quickly so that the pellet splits immediately upon hydration. This ensures quick, uniform and healthy seedling stock production in a user friendly manner even at the grass-root level. As production and supply of ready to use tree seeds is "need of the hour" in order to promote and encourage tree cultivation, nursery entrepreneurs and quality seedling stock production for afforestation and agroforestry purposes, this study is of importance.

Significant achievements/ findings of the project:

Seed pelleting was standardized for 7 tree seeds namely *Aegle marmelos, Acacia nilotica, Albizia lebbeck, Albizia amara, Acacia leucophloea, Sapindus emarginatus* and *Gmelina arborea*. Standardized species-specific grading method, pretreatment, and identified suitable binder, filler and beneficial microbe for pelleting were used. Improvised seed cakes were made for direct dibbling to support eco-restoration and afforestation programs. The ready to use "seed cakes" were supplied to farmers and obtained good feedback. A product 'IFGTB seed cake mix' was developed for preparing seed balls or seed cakes and supplied to SFDs and NGOs.

Suggestion/ advisory note for the end-users "To-do-techniques":

Seed cake technology was improvised for afforestation of tree crops in dry tracts. The technique includes selection of suitable species, grading method, pretreatment and identified suitable binder, filler and beneficial microbes. A product "IFGTB seed cake mix" was released as a ready to use mixture to preparing seed balls/ cakes. The technology was transferred to SFDs and the seed cake mix was sold to farmers and NGOs.

Research gaps:

To improve seed germination and seedling quality through pelletization and to develop "ready to use" pelleted seeds of important tree species this study was undertaken

Uses of research outcomes:

The seed pellets were supplied to farmers and obtained good feedback. The ready to use "seed pellets" and "seed balls" or "seed cakes" are suitable for commercial supply.

Publication:

- Anandalakshmi R., Rajesh C., Geetha S., Murugan E., Suresh Kumar K. and Sathish A. 2021. IFGTB Seed Cake Mix – An Innovative Seed Ball Technology. IFGTB News, January 2021.

13. **Title of the project:** Research to assess performance of pelletized Sandal seeds in nursery and field on comparative performance assessment of pelletized, non-pelletized and planted seedlings in the field

Principal Investigator: Dr. R. Anandalakshmi, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2017-2020

Critical analysis of the research theme and summary of the study:

In sandalwood, though the seeds are slightly larger, inherent problems of dormancy and need for host plant for nursery establishment renders seedling raising a cumbersome process. Besides, at nursery stage damping-off disease of juvenile planting stock is a serious problem that needs to be overcome. As a solution for these practical difficulties, seed pelleting with appropriate enhancers/ protectors and beneficial microbes was envisaged along appropriate host plant. This study envisaged suitable pretreatments, seed pelleting, seedling production of sandal and to study the success of seed pelleting on nursery raising and field establishment on direct dibbling. It was found that *Pithecellobium dulce* can be used as both primary and secondary host for sandalwood in field. Seed pelleting was successful for Sandalwood forest afforestation with proper size grading, GA3 pretreatments, polybag size of 25 cm x 30 cm helped production of quality planting stock of sandal.

Significant achievements/ findings of the project:

Marayoor and Coimbatore sandalwood seed sources were found to be superior. Size grading - diameter class 6.7 mm and above possessed very high vigour. Sandalwood seed pellet could be stored up to one year between 10 to15°C. Soaking in 500 ppm GA3 for 6 hours followed by coating with binder Polyvinyl pyrrolindine and filler Charcoal was recommended for sandalwood seeds. Sand pellet trials were laid in 5 forest areas of Dharmapuri district. Sandalwood seedlings grown in polybags of size 25 cm x 30 cm were found to establish well. *Pithecellobium dulce, Casuarina junghuhniana* and *Duranta repens* at nursery stage and *Pithecellobium dulce* at field were found to be suitable hosts for Sandalwood.

Suggestion/ advisory note for the end-users "To-do-techniques":

Pithecellobium dulce is a good perennial host for sandalwood and it serves as both a primary or secondary host. Sandalwood cultivation with proper host and quality planting stock would give promising results to the farmers and SFDs. Pelleted sandal seeds can be used for afforestation purposes.

Research gaps:

This study envisages suitable pre-treatments, seed pelleting, seedling production of sandal and to study the success of seed pelleting on nursery raising and field establishment on direct dibbling.

Uses of research outcomes:

Suitable seed source, pre-treatment, pelleting of Sandal seeds, suitable polybags, suitable beneficial microbes, appropriate host for sandal were identified and the information was disseminated to Tamil Nadu Forest Department and farmers. Sandal seed pellets are being prepared and supplied to farmers and NGOs.

Publications:

- Anandalakshmi R., Murugan E., Rajesh C., Suresh Kumar K. and Geetha S. 2022. Efficacy of seed grading and priming on germination and seedling vigour of Sandal. *Indian Forester* 148(2):142-147.
- Anandalakshmi R., Karthikeyan A., Suresh Kumar K., Rajesh C., Geetha S., Murugan E. and Ananthakumar M. 2023. Identification of suitable perennial host for Sandal in nursery and field. *Indian Forester* 149(4):379-386

14. Title of the project: Evaluation and Popularization of *Neolamarckia cadamba* (Roxb.) Miq in Tamil Nadu and Kerala.

Principal Investigator: Dr. A. Vijayaraghavan, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016-2022

Critical analysis of the research theme and summary of the study:

Neolamarckia cadamba being a promising and valuable raw material for wood-based pencil/ match wood/ plywood industries, there is always a high demand for its wood in the market. The project aims to popularize the species among farmers by means of agroforestry trial, to identify the best performing progenies and to shortlist the stable and site-specific clones for improving the productivity of plantations. With the identification of best progeny and clone the demand of the raw material will be met.

Significant achievements/ findings of the project:

Performance of the progenies from the progeny trials established at three locations viz., Neyveli, Nagercoil (Tamil Nadu) and Panampally (Kerala) were observed and the best performing individuals/ progenies from the progeny trials and from the plantations were selected and marked as clones. Clones were mass multiplied and raised the multilocation clonal trials and evaluated. Based on the performance of the clones recorded at frequent interval on its height and girth at breast height (gbh) from one to three-year old clonal trials, clones viz., 116,105, 111, 112, 140, 144, 127, 119, 115, 138, 60 and 80 were short listed for further confirmation by on farm trials. In order to popularize the species established 8 demo trials at farmers field and in KVK centres viz., at Kodur, Villupuram district Namakkal, Kenipet, KVK-TNAU, Tindivanam, Tirupur, Andiyur, Erode district, ICAR-KVK-MYRADA Centre at Gobichettipalayam and ICAR-KVK-MYRADA Centre at Thalamalai, Erode district.

Book on cultivation of *N. cadamba* were prepared in vernacular language (Tamil and Malayalam) and released during the tree growers mela conducted at Tindivanam (2017-18) and in Coimbatore (2020). During the COVID-19 pandemic period webinar was organized by IFGTB in collaboration with Pasumai Vikatan (famous press in Tamil) and delivered a talk on *Kaimel Kasu Tharum cadamba maram* and it has reached more viewers. Training on Cultivation of *N. cadamba* was conducted in collaboration with an NGO called Vanathukkul Tiruppur-VETRY Organisation, Tirupur district for farmers and tree growers.

Suggestion/ advisory note for the end-users "To-do-techniques":

Breeding program for *N. cadamba* was carried out by collecting germplasm from Tamil Nadu, Kerala and Andamans. Clonal MLTs were established and evaluated for high productivity for 3 consecutive years and the best performing clones were short listed. The clones need to be released and it has to be popularized among tree growers for economic benefits.

Research gaps:

Very few research work was carried out on improvement of *Neolamarckia cadamba* in India and improving its productivity of plantations. The current project aims to popularize the species among farmers by means of agroforestry trial and to identify the best performing progenies and to shortlist the stable and site specific clones for the release.

Uses of research outcomes:

The extension activities carried out under the project helped to create awareness among the farmers about the underutilized species in a big way.

Publications:

- Mohan V., Chowndariya J., Krishnamoorthi S., Vijayaraghavan A., Pachu Anish V. and Sushamani K. 2019. Diversity of Beneficial Rhizosphere Microbes Associated with *Neolamarckia cadamba* Clones in Nursery". *Journal of Academia and Industrial Research* 8 (4): 73-80.
- Vijayaraghavan A., Sureshand G. and Anees A. 2019. Know your trees on *Neolamarckia cadamba. Vanvigyan ENVIS newsletter on (FGR) and Tree Improvement*, IFGTB (*Jan -Mar* 2019), 5.
- Vijayaraghavan A., Sureshand G. and Rukesh A.G.2021. Demo-cum-Clonal trials for Popularisation of *Neolamarckia cadamba.* A networking initiative with KrishiVigyan Kendra (KVK). IFGTB News Letter Vol 3 (2) July.
- Mayavel A., Soosai Raj J., Hegde Maheshwar, Palanisamy K., Anandalakshmi R., Vijayaraghavan A. and Rajasugunasekar D. 2017. Exploration, Collection and Conservation of Genetic Resources of FGRMN Prioritized Species pp., 89-106. In: Forest Genetic Resource Management Eds: K. Palanisamy, D. Thangamani, S. P. Subramani, R. S. Prashanth.
- Vijayaraghavan A. 2020.Vellai Kadambu Sagupadi. In: Magathana Vilaichal Tharum Marachagupadi Muraigal (in Tamil), Eds.: Pala Chandrasekaran, Rajesh Gopalan and S. Murugesan, IFGTB, Coimbatore, pp.35-44 IFGTB publications.
- Vijayaraghavan A. Productivity Enhancement in Forestry Plantations- A hand Book Published by National Subject Matter Specialist (NSMC). "New varieties and cultivation practices for *Neolamarckia cadamba* to enhance Productivity" pp 81-82
- Vijayaraghavan A. 2020. Cultivation and its management practices of *Neolamarckia cadamba* in Vernacular language (Malayalam) released during tree growers Mela 2020 at IFGTB, Coimbatore.

15. Title of the project: Evaluation of Second-Generation *Eucalyptus camaldulensis* Clones for Higher Productivity

Principal Investigator: Dr. A. Vijayaraghavan, Scientist-F, ICFRE-IFGTB Coimbatore

Duration: 2016-2022

Critical analysis of the research theme and summary of the study:

Eucalypts are among the most widely cultivated forest trees in the world. IFGTB has initiated tree breeding programme on Eucalyptus during the year 1996 and released around 11 best performing and high productive Eucalyptus clones during 2010 (4 clones: IFGTB-EC-1, 2, 3 & 4) and 2014 (seven clones: IFGTB-EC-5, 6, 7, 8, 9, 10 & 11). Clone selection from the first and second generation seed orchards, (FG-SSOs and SG-SSOs), Clone Selection Blocks (CSBs) has been undertaken and also aimed at establishing VMG with the new clones. This project aims at establishment of clonal trials at different locations to screen the best performing clones and the short-listed clones will be raised in multi-location clonal trials (MLT's).

Significant achievements/ findings of the project:

Assessment of clones established in multilocation trials was carried out to identify high productive clones. The best planting material for a particular location has been identified from the already selected clones, which was the final output of the tree improvement. These clones viz., 192, 215, 22, 122, 126, 333, 186, 358 had been identified as stable clones across the location and few clones each for specific location and the same can be recommended for planting programmes to the end users.

Suggestion/ advisory note for the end-users "To-do-techniques":

Breeding program for *Eucalyptus camaldulensis* was carried out by selection of clones from the first and second-generation seed orchards, (FG-SSOs and SG-SSOs), Clone Selection Blocks (CSBs). The clones need to be tested further through MLT's to identify the stable clones for the purpose of clonal release.

Research gaps:

The present project envisages establishment of clonal trials to select and short list the best performing new clones to improve the productivity by 10 %. The short listed clones (25- 40 clones) can be mass multiplied to raise multi location clonal trial (Clonal selection trial). Finally, about 5-10 new clones which are stable across the location and site specific clones will be identified for release.

Uses of research outcomes:

The best planting material for a particular location has been identified from the already selected clones, which is the final output of the tree improvement. These clones will be recommended for planting programmes to the end users.

Publications:

- Nair Smitha G., Veerasamy Sivakumar, Vijayaraghavan A., Suresh G., Anees A., Vinoth Kumar A. and Yuvaraj T. 2021. Stability of stem form Quotient in clones of *Eucalyptus camaldulensis* Dehnh across Southern India. *Indian Forester* 147 (2) pp: 183 – 190.
- Nair Smitha G., Veerasamy Sivakumar, Vijayaraghavan A., Chitra P., Anees A. and Suresh G. 2021. Biplot Analysis of Genotype-by-Environment Interactions for Single Tree Volume of *Eucalyptus camaldulensis Dehnh* clones. *Frontiers in crop improvement* 9(1):419-422.
- Nair Smitha G., Veerasamy Sivakumar, Vijayaraghavan A., Suresh G., Anees A.,Vinoth Kumar A. and Yuvaraj T. 2021. Selection of clones of *Eucalyptus camaldulensis* Dehnh based on stability for tree volume. *Electronic journal of Plant Breeding* 2: 183 – 190.

16. Title of the project: *Industrees* for Industries: Deployment, Demonstration & Release of *Eucalyptus tereticornis* X *E. grandis* selections to Farmers as A veneer and pulp tree crop

Principal Investigator: Dr. B. Nagarajan, Scientist-G, ICFRE-IFGTB Coimbatore

Duration: 2017-2022

Critical analysis of the research theme and summary of the study:

The eucalypt farmers in the States of Tamil Nadu, Andhra Pradesh and Telengana are aware of pedigreed plant resources. Most have adapted to short-pedigreed clones *in lieu* to the traditional untested seeds and clones. A concept called "*INDUSTREES*" (Eucalypt Trees Bred for Single purpose Industrial use) aiming a single purpose selection for the veneer industry was attempted in this project. An inter-specific hybrid of *E. tereticornis x E. grandis* (TEREGRANDIS) developed through controlled pollination was tested for its industrial use in participation with R&D of ply industries. Six ortets of *E. tereticornis x E. grandis* crosses (TG-1, TG-2, TG-3, TG-4, TG-5 and TG-6 were selected from an eight-year-old full sib progeny trial (Panampally, Palakkad District Kerala). The selections were tested for wood properties and their industrial suitability in participation with R&D of Ply industries. These plantations are being monitored and the initial results at 24 months are indicative that the selections TG1, TG3 and TG5 are well adapted across sites. The shortlisted prospective selections are envisaged to be deployed as a Veneer Tree Crop (VTC). The trials await their 36 months of evaluation after planting.

Significant achievements/ findings of the project:

Control pollinated *E. tereticornis x E. grandis* full sib family progeny was evaluated. Characteristics such as self-pruning, stem straightness and cylindrical nature were primary selection criteria. Wood characteristics suiting plywood industry was also an important parameter. The combinations had the optimal productivity and accomplished the industrial requirements of producing face and core veneer. Based on 24-month growth data (height, girth and stem straightness) out of the six selections tested, three *E. tereticornis x E. grandis* full sib clones TG1, TG3 and TG5 were found to adapt and perform well across three different agro-climatic conditions in the state of Tamil Nadu.

Suggestions/ advisory note for end-users "To-do-techniques":

Clonal trials in the above said locations could be evaluated after their full rotation of 60 months (2026) and subjected to testing for their veneering ability. Meanwhile, based on the ensuing 36 month evaluation large scale block plantations in participation with farmers the release of selections could be achieved by 2028.

Research gaps:

Specific end use selection is an aspect that goads genetic improvement programs. Phenotypes or ideotypes of Eucalypts with cylindrical straight clear bole (12-14 meters) would aid in higher level of veneer extraction. Also, lowered radial shrinkage and homogenous wood without growth stress knots was looked forward by the industries.

Uses of research outcomes:

Three demonstration trials have been showing promising performance at Neyveli at 30 months and will be shown to the stakeholders under extension activities.

Publication:

- Nagarajan B. Mayavel A., Palanisamy M. and Rajasugunsekar D. 2017. Full Sib Breeding in Red Gums: An effective tool to develop interspecific hybrids, pp. 149-167. In: Plantation and Agroforestry – Pulpwood Value Chain Approach (Eds: K.T.Parthiban and R.Seenivasan) Scientific Publishers, New Delhi, India ISBN. (978-93-86347-98-5).

17. Title of the project: Genetic improvement of *Swietenia macrophylla* for higher productivity

Principal Investigator: Dr. M.V. Durai, Scientist-D (upto 31st March 2017)

Dr. S.P. Subramani, CTO (from April 2017 onwards), ICFRE-IFGTB Coimbatore

Duration: 2016 - 2020

Critical analysis of the research theme and summary of the study:

Intensive surveys were carried out in Tamil Nadu and Kerala and selected 40 Nos of phenotypically superior trees from 25 populations of *Swietenia macrophylla*. Various morphometric characters of these trees were recorded in the field. Significant variation was observed in moisture content, wood density, fiber length, lumen diameter, wall thickness etc. Vegetative propagation method was standardized using terminal juvenile shoots collected from selected CPTs in different concentrations of IBA using different potting media i.e. sand, sand+coir-pith, sand+coir-pith +vermiculite. The cuttings treated with IBA @ 2000 ppm in the sand with coir pith medium showed maximum rooting and survival percentage. The morphological characteristics and variations of fruits and seed were studied using image analyzer and also standardized seed germination methods. A progeny trial of *S. macrophylla* was established at Gudalur RF, Maraimalainagar, Chennai in 0.67 ha land area and the seedlings of 40 families were planted by randomized block design (RBD) method in the spacing of 3m x 3m in four replications. Another trial was established in at Udumalaipet, Tiruppur district, Tamil Nadu. Growth performance was recorded and the seed source from Burliar, Tamil Nadu showed significant variations in height, GBH and performance. Application of 5% neem oil spray was used against the attack of leaf web worm and jewel beetle in the trials.

Significant achievements/ findings of the project:

It was recorded that the seed sources from Nilambur and Kannur shown highest growth performance than other seed sources. Similarly, a demo trial plot has been established in farmer's land at Nallagoundan Pudhur, Udumalaipet, Tirupur Dist., Tamil Nadu.

Suggestions/ advisory note for end-users "To-do-techniques":

The baseline data generated in the field will be beneficial for farmers, tree growers, SFDs, highway authorities to promote cultivation in Tree outside Forests (ToFs). Brochures and pamphlets with technical knowledge will be prepared and published for popularization of the species and extension activities for future improvement of the tree species.

Research gaps:

The project was undertaken for popularization of a fast growing timber yielding species *Swietenia macrophylla*in trees outside areas and also to establish a germplasm bank with wide genetic base for further improvement of the species.

Uses of research outcomes:

The best seed sources from Kerala and Tamil Nadu have been identified based on growth superiority. The tree growers of Tamil Nadu and State Forest Department were benefited by understanding tree cultivation techniques.

Publications:

- Durai M.V., Balamuniappan G. and Geetha S. 2016. Qualitative and quantitative analysis of phytochemicals in crude extract of big – leaf mahogany (*Swietenia macrophylla* King.) *International Journal of Herbal Medicine* 4(6): 88-91.
- Durai M.V. and Balamuniappan G. 2016. Phytochemical screening and antimicrobial activity of leaf, seed and central-fruit-axis crude extract *of Swietenia macrophylla* King. *Journal of Pharmacognosy and Phytochemistry* 5(3): 181-186.
- Durai M.V., Balu A., Raja Rishi R. and Karthikeyan A. 2017. First Report of *Apate monachus* (Coleoptera: Bostrychidae) in Big-leaf Mahogany (*Swietenia macrophylla* King) Plantations in India. *Journal of Entomology and Zoology Studies* 5(6): 1900-1902
- Subramani S.P. and Kuralarasan R. 2019. Adventitious root induction in branch cuttings of *Swietenia macrophylla* and grafting with allied species. In.: Proceedings on National Workshop on 'Securing wood demand through enhancing productivity of planted forests' held in IFGTB, Coimbatore during 29-30, January, 2019, Eds.: Mayavel, A, Nicodemus, A., Murugesan, S. and Mohit Gera, 131 p.

18. Title of the project: Selection and screening of germplasm of *Acacia nilotica* L. (Babul) to improve Productivity in Tamil Nadu

Principal Investigator: Dr. K. Panneer Selvam, Scientist-D, ICFRE-IFGTB Coimbatore

Duration: 2016 - 2022

Critical analysis of the research theme and summary of the study:

This project was undertaken to identify superior seed source and understanding the variability of *Acacia nilotica* with reference to growth and tree form in different agroclimatic zones of Tamil Nadu. Field surveys were undertaken in various districts of Tamil Nadu for selection of CPTs of *A. nilotica*. A total of 50 CPTs were selected and the morphometric data and GPS reading were recorded. Seed accession of 50 CPTs of different agroclimatic zones were raised in the nursery and recorded all germination data. Significant differences were found among 50 progenies for growth characters like germination percentage, collar diameter, shoot length, root length, fresh weight and dry weight at nursery stage during 180 Days After Sowing (DAS) of evaluation. The study revealed that CPT 33 was found best which was followed by CPT 41 and CPT 26 for growth characteristics particularly in germination percentage, collar diameter, shoot length, root length, fresh weight and dry weight. Progeny trials were established in different agro-climatic zones and morphological data was recorded. Significant differences were observed in 50 half sib progenies of *Acacia nilotica* at 06 MAP. Among the progenies, CPT 40 showed superiority for growth characteristics particularly in collar diameter and height which was followed by CPT 42 and CPT 10.

Significant achievements/ findings of the project:

Established three progeny trials in Thuvarankuruchi, Manakudi and Ariyalur, Tamil Nadu.

Suggestions/ advisory note for end-users "To-do-techniques":

Seedlings from the selected 50 CPTs may be used for establishing the further trials.

Research gaps:

Acacia nilotica is one of the short rotation tree species but, the germplasm which occur in different parts of Tamil Nadu was not screened and superior trees were not shortlisted for tree improvement.

Uses of research outcomes:

A total of 50 Candidate Plus Trees were shortlisted for further tree improvement and three progeny trials established.

Publication:

- Panneer Selvam K., Ezhumalai, Vikayaraghavan A., Sivaprakash M. and Sathyabama B. 2018. *Acacia nilotica* tree improvement through tank bed plantations of Tamil Nadu to increase the green cover, enhance the rural livelihood and mitigate global warming. *Devagiri Journal of Science* 4(1): 08-15.

Indian Council of Forestry Research and Education

(An autonomous body of Ministry of Environment, Forest and Climate Change, Government of India)

P.O. New Forest, Dehradun-248 006