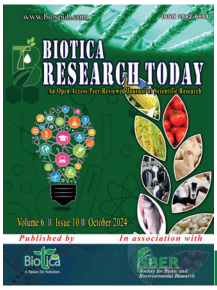

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Tree Improvement Programme for Mahua (*Madhuca longifolia*) in Eastern India

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Abstract

Mahua (*Madhuca longifolia*) serves as both a cultural cornerstone and economic lifeline for tribal communities. Its remarkable versatility spans from food and medicine to agricultural applications. Mahua is considered to be a valuable species for reforestation and agroforestry purposes due to its immense drought resistance and soil-enriching capabilities. However, the species is facing severe biotic and abiotic pressures despite its high economic importance. Destructive harvesting practices, particularly the burning of ground beneath trees to collect flowers and fruits, severely impact both mature trees and natural regeneration. Also, the natural distribution of the species is rapidly shifting due to climate change. In response, the ICFRE-Institute of Forest Productivity has initiated a comprehensive conservation program in eastern India, focusing on improved planting and breeding strategies to protect both the species and the communities dependent on it.

Keywords: Distribution shift, Forest conservation, NTFP, Tribal livelihoods

Introduction

Mahua [*Madhuca longifolia* (J. Koenig ex L.) J.F. Macbr.] is a versatile tree species of Sapotaceae family which is extensively utilized for food, fuel and fodder. The dry tropical and subtropical forests are the primary habitats for Mahua, which is widely dispersed throughout India and numerous other South Asian nations. Owing to its great ecological and economic significance, this species is highly revered in tribal cultures and is guarded by forest inhabitants. Since ancient times, several parts of Mahua have been utilized on which livelihood of local inhabitants are dependent heavily. Fermentable sugars found in Mahua flowers are used as a natural sweetener and flavouring ingredient in a variety of regional cuisines (Singh *et al.*, 2021). "Mahua Liquor" is one of the savoured drinks among the natives produced from its flowers. In rural regions, Mahua seeds are used to derive edible cooking oil and also for making soap and candles. The tree is also recognized for its diverse medicinal effects. Native people primarily employ various parts to cure a wide range of ailments, including dental problems cuts and wounds pneumonia, arthritis, ulcerations and cardiac disease (Saha and Sarankar, 2023). Mahua seed cake is also regarded a useful fertilizer for crop cultivation and the tree itself may be successfully integrated into a variety of agro-forestry systems (Srivastava *et al.*, 2020). Besides, Mahua has proved to be a great species for afforestation or reforestation purposes in drought-prone areas owing to its high drought-tolerance (Bisht *et al.*, 2018).

Indian forests generate about two trillion dollars' worth of non-timber forest products (NTFPs), with Mahua being a significant contributor. Nevertheless, local residents frequently gather these forest resources using destructive or inappropriate methods, which severely deplete the resources. Like several forest species, Mahua is facing significant ecological, environmental, socio-economic and anthropogenic pressures and as a result the suitable distribution of the species is shifting rapidly (Pradhan *et al.*, 2024). Anthropogenic pressure is the primary contributor, since rural people often ignite fires under Mahua trees to easily collect the NTFPs, such as fruits and flowers, which hinders the natural regeneration and also affects the mature trees due to intense heat and combustion. Therefore, conservation efforts must be taken immediately to prevent the species from going extinct in the future. Development

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of improved planting stocks and improvement through tree breeding activities would be extremely valuable in developing prospective conservation measures for the species and safeguarding the livelihoods of forest-dependent communities. Taking into account the threats to this species, ICFRE-Institute of Forest Productivity has taken up a comprehensive approach for conservation and improvement of Mahua.

Selection of Candidate plus Trees (CPTs)

The selection of candidate plus trees (CPTs) is regarded as a crucial and preliminary step in the tree improvement program for any species in particular. A tree's economic output is influenced by many associated characters, making it a highly complicated attribute to be used for selection. Each characteristic is essential in the multi-trait selection approach serving an important role and all individuals are scored using one scoring system. It is anticipated that the phenotypes chosen using this process would possess the necessary traits as well as have a genetically divergent base for subsequent breeding and genetic initiatives. Consequently, the selection of the best parents is the cornerstone of every breeding program aimed at tree improvement. These will constitute the genetic base for any future advancement in form and vigour. These trees are typically found in forests and exhibit superior traits relative to neighbouring individuals of the same species.

A total of 150 Mahua CPTs situated across three agro-climatic zones (ACZs), *viz*., Lower Gangetic plains zone (ACZ III), Middle Gangetic plains zone (ACZ IV) and Eastern plateau and hills region (ACZ VII) have been identified through rigorous surveys carried out in the states of West Bengal, Jharkhand and Bihar by ICFRE-Institute of Forest Productivity (IFP), Ranchi (Figure 1). The trees with superior phenotypic characters, growth and stoutness than the population mean were selected as CPTs. During the selection of CPTs, certain screenings were implemented, such as the trees having a minimum girth at breast height (GBH) of 80 cm and a minimum crown diameter of 8 m. Additional checks during the CPT selection were maintained like being free from pests and diseases and visually free from deformities such as buttresses, holes and bends. Geo-coordinate data of each CPT was recorded for future reference.

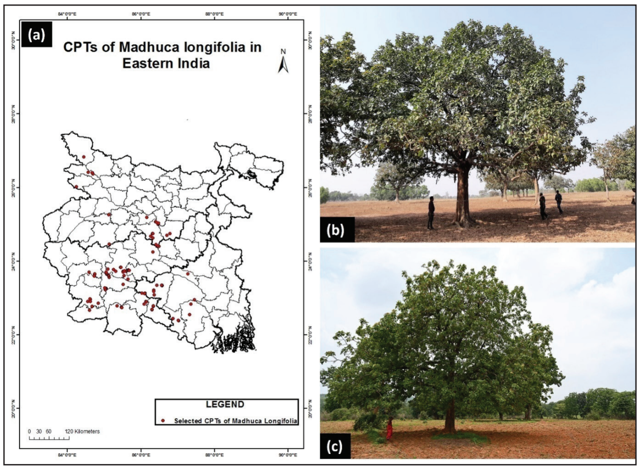

Figure 1: (a) Point-map of selected Mahua CPTs across the three states; (b & c) Sample representation of Mahua CPTs

Genetic Variability in CPTs

Several phenotypical data of the selected CPTs were recorded in field like tree height, GBH, crown diameter, clear bole height (CBH) *etc*. During the fruiting season, the selected CPTs were revisited and mature fruits were collected from them. Morphological traits of fruits like fruit length and width were recorded and then the collected fruits were depulped, washed thoroughly to extract seeds. Seed length and seed width were also recorded thereafter. Biometrical techniques were used to estimate the genetic variability present among selected CPTs. All recorded data were statistically analysed to explore maximum value, minimum value, mean, standard error, standard deviation and co-efficient of variation. High genetic variability among the phenotypic parameters of the CPTs were observed across all ACZs (Table 1). Wide variability in fruit and seed parameters of the CPTs was also noted during analysis (Figure 2).

Table 1: Variation in phenotypic characters of CPTs

Particulars	GBH (m)	CBH (m)	Tree Height (m)	Crown diameter (m)
Mean	2.04	2.80	11.60	15.26
SD	0.44	0.86	2.37	2.55
SE	0.04	0.08	0.22	0.24
Max	3.4	6.1	20	21.35
Min	1	1	7	8.85
CV%	21.31	30.88	20.42	16.73

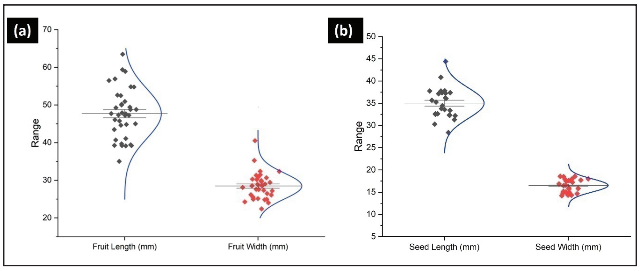

Figure 2: Variability among (a) Fruit parameters and (b) Seed parameters of Mahua CPTs

Establishment of Vegetative Multiplication Garden (VMG)

Since Mahua is a cross-pollinated species that results in heterozygosity in the plants, mass production of true-to-type planting materials is a challenge. Plants that auto-generate heterozygous nature need extensive genetic improvement research that costs a substantial sum of money. Therefore, in place of seed, vegetative material is to be used from selected CPTs and clonal evaluation is to be done to harvest higher gains in comparatively less time period.

Grafting may be a dependable, efficient and alternative method of clonal propagation for Mahua trees. To carry out grafting techniques, scions were collected from most promising 65 CPTs across ACZs. From CPTs, scion measuring ~20 cm in length and with a diameter of ~12 mm was chosen. The scion was carefully chosen to precisely match the thickness of the rootstock. Cleft grafting was carried out on approximately 1000 root stocks. The graft union was wrapped with grafting tape to reduce desiccation and provide protection from external sources. With an overall grafting success of 53.2%, grafted plants of 60 CPTs have been produced in the institute. These grafts of Mahua were used to establish one VMG at the Campus (23.35866° N; 85.24677° E). The objective of this VMG is to provide juvenile stem cuttings from selected germplasm in hedge form for production of superior clonal planting stock in future.

Employing Remote Sensing and Geographic Information System (RS-GIS)

The influence of climate change on the species was analysed using RS-GIS methodologies. The assessment was conducted by analysing the potential distribution pattern of Mahua under both current and future climatic scenarios, utilizing four Representative Concentration Pathways (RCPs) or the period of 2041-2060 in India through Maximum Entropy (MaxEnt) modelling. Following a multicollinearity test, ten bioclimatic variables selected from a total of nineteen, were utilized to model and evaluate the impacts of climate change on species distribution. In the present scenario, the mean diurnal change (Bio_2) showed the greatest gain, while the rainfall during the warmest quarter (Bio_18) and annual rainfall (Bio_12) demonstrated the most substantial gain under predicted climatic conditions. This study demonstrated Mahua is primarily found in the eastern regions of India, with the state of Jharkhand exhibiting the most suitability zones. Nonetheless, the species exhibited patterns to shift southward across all four RCP future scenarios. The projected distribution indicates a 4.5% increase in suitable habitat zone under RCP 2.6, while declines of 7.37%, 7.78% and 3.54% were observed under RCP 4.5, 6.0 and 8.5, respectively (Pradhan *et al.*, 2024). In the absence of human influence and unexpected evolutionary changes occurring within its native range, it is expected that the species will exhibit significant resilience to climate change. The eastern region of the country is found to experience a decline in suitable zones for Mahua. Hence, the promotion of the species can be encouraged in the drought-prone areas of eastern India to mitigate drought effects and enhance its distribution.

Future Implications in Tree Improvement

As forest genetic resources continue to decline globally, tree improvement programs will become increasingly vital for conserving and enhancing forest tree populations. Advances in tree breeding will enable more rapid development of improved planting stock for reforestation and restoration efforts. However, long-term genetic trials such as clonal and progeny tests will remain essential for ensuring the adaptability and sustainability of these improved forest trees over multiple generations.

Clonal tests, where genetically identical copies or ramets of selected parent trees are propagated and tested, will allow forest scientists to accurately evaluate genetically superior parent trees. This is critical for tree species like

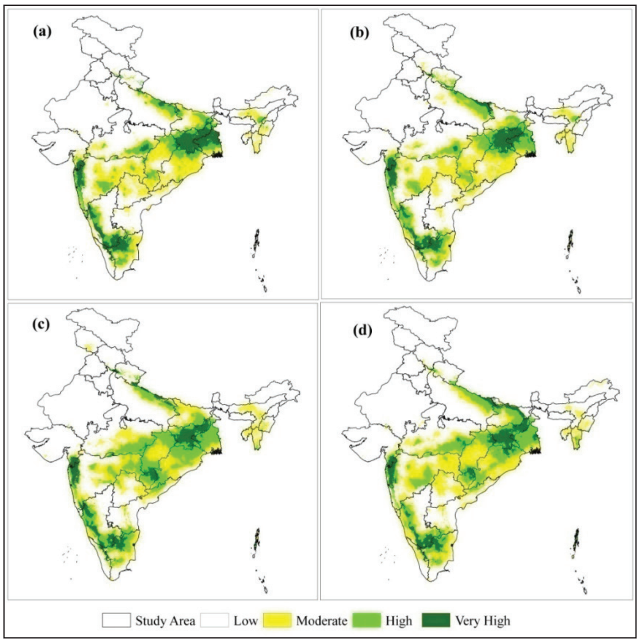

Figure 3: Prediction of suitable habitat distribution zone of M. longifolia for the year of 2041-2060: a) RCP 2.6, (b) RCP 4.5, (c) RCP 6.0, (d) RCP 8.5 (Source: Pradhan *et al.*, 2024)

Mahua which is predominantly outcrossing and highly heterozygous. The best performing clones can then be mass propagated for operational use. Meanwhile, progeny testing involves collecting open-pollinated seed from select parent trees and evaluating their offspring in field trials. This allows estimation of breeding values for traits like growth rate, wood quality and disease resistance. Through future progeny trials from selected Mahua CPTs, superior parents can subsequently be chosen for production seed orchards or breeding populations.

As tree improvement cycles continue over decades, successive generations of selected Mahua CPTs are expected to show significant genetic gains. However, their long-term adaptability and stability must be monitored through multi-location, multi-year trials. These field tests will reveal any unintended effects like reduced genetic diversity or inbreeding depression. Periodic genetic monitoring will also indicate if breeding zones need to be adjusted for anticipated climate change effects. In summary, future clonal and progeny trials will remain a cornerstone of sustainable improvement programs of Mahua focused on maintaining resilient and productive forest ecosystems.

Conclusion

The tree improvement efforts for Mahua in eastern India initiated by ICFRE-IFP tackles the critical need to protect this species, which promotes both local livelihoods and ecological health. By means of candidate plus tree (CPTs) selection and vegetative multiplication garden establishment, these initiatives ensure a varied genetical base for future breeding programs. Clonal propagation and long-term trials for this species is the key to securing sustainable livelihoods for forest-dependent communities. Promoting Mahua's farming in drought-prone regions will both increase environmental resilience and broaden its range as its distribution is rapidly shifting with changing climates. By integrating biodiversity preservation with socioeconomic advantages, these programs present a comprehensive approach to genetic improvement and conservation of Mahua, leading to a sustainable future.

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