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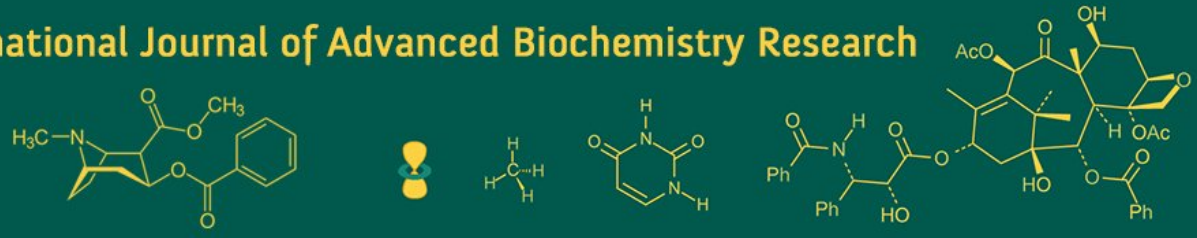

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Evaluating morphological and reproductive trait interrelationships in selected *Butea monosperma* trees for genetic improvement

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Abstract
This study aimed to evaluate the associations between morphological and reproductive traits in *Butea monosperma* across three districts in Madhya Pradesh: Chhindwara, Mandla, and Balaghat. A total of 30 phenotypically superior trees (10 from each district) were assessed for five key traits: tree height, girth at breast height (GBH), crown spread, flowering intensity, and fruit yield. Correlation analysis revealed significant positive relationships between all the morphological and reproductive traits, indicating that trees with larger sizes (height and girth) also tended to have wider crowns, higher flowering intensity, and increased fruit yield. These correlations highlight the potential for using these traits as selection criteria for breeding and conservation efforts. This study provides valuable insights into the phenotypic characteristics of *Butea monosperma*, which can inform strategies for the conservation of superior trees for future breeding programs.

Keywords: *Butea monosperma*, morphological traits, reproductive traits, genetic improvement, correlation analysis, phenotypic variation, selection criteria, conservation and breeding

Introduction
Butea monosperma (Lam.) Taub. commonly known as Flame of the Forest or Palash, is a multipurpose deciduous tree native to the Indian subcontinent. It is ecologically and economically significant due to its use in traditional medicine, agroforestry, dye production, and as a host for lac insects. Its vibrant flowers and adaptability across a range of climatic and edaphic conditions have made it an integral component of tropical dry deciduous forests (Tandon *et.al.* 2003) [9].

The reproductive biology of *Butea monosperma* has been well-documented and indicates a mixed breeding system, with both self- and cross-pollination mechanisms facilitated primarily by birds and insects (Tandon *et al.* 2003) [9]. Understanding its flowering and fruiting behavior is vital for effective conservation and breeding programs. Flowering intensity and fruit yield, in particular, are closely linked to environmental cues and intrinsic morphological traits such as tree height and crown spread (Muthuswamy and Senthamarai, 2014) [54].

Despite its widespread distribution and importance, *Butea monosperma* has not been widely improved through scientific breeding programs. Given the current pressures from habitat degradation and overharvesting, identifying superior phenotypes with high reproductive potential is essential for sustainable management. Studies of phenotypic variation and correlation among traits offer a cost-effective method for identifying elite trees in natural populations (Singh *et.al.* 2017) [3].

Morphological traits such as tree height, girth at breast height (GBH), and crown spread are often considered proxies for tree vigor and reproductive fitness. These traits influence photosynthetic capacity, resource acquisition, and structural stability, which in turn impact flowering intensity and fruit yield. Significant positive correlations among these traits have been documented in several tropical tree species, suggesting their utility in selection and breeding (Shivanna, 2020) [7].

Evaluating the relationships between morphological and reproductive traits can also provide insight into the allocation of resources within trees. The trees with wider crowns may intercept more light, enhancing energy availability for reproductive structures. Such

correlations help clarify whether large vegetative size leads to increased reproductive success or whether both are expressions of overall tree health (Khan and Sharma,2008) [4].

In *Butea monosperma*, variation in flowering and fruiting traits has been observed across regions due to differences in altitude, soil type, rainfall, and temperature. However, the extent to which morphological traits influence reproductive performance in this species has not been thoroughly quantified. Understanding these trait relationships is crucial for in situ conservation as well as for selecting plus trees for future clonal or seed-based propagation (Tandon *et al.* 2003) [6].

Madhya Pradesh, a biodiversity-rich state in central India, harbors extensive natural populations of *Butea monosperma*. The districts of Chhindwara, Mandla, and Balaghat in particular exhibit ecological variation and offer a unique opportunity to study phenotypic diversity. Characterizing the trait correlations in these zones could guide regional conservation strategies and serve as a basis for large-scale tree improvement programs (Singh *et.al.* 2017) [3].

This study was therefore undertaken to assess the correlation among morphological and reproductive traits of phenotypically superior *Butea monosperma* trees in the districts of Chhindwara, Mandla, and Balaghat. Specifically, we evaluated tree height, GBH, crown spread, flowering intensity, and fruit yield. The findings aim to identify trait combinations that can be used for selecting elite trees for conservation and genetic enhancement initiatives.

Methodology

Study Area

The study was conducted in the natural forests of Madhya Pradesh, focusing on three key districts: Chhindwara, Mandla, and Balaghat. These regions are located in the central part of Madhya Pradesh and are known for their rich forest biodiversity, including significant populations of *Butea monosperma* (Flame of the Forest). The forests in these areas provide an ideal environment for the growth of this species, characterized by a tropical and subtropical climate that supports robust tree growth and reproductive potential.

Sampling and Tree Selection

In total, 30 *Butea monosperma* trees were randomly selected from the natural forests of Chhindwara, Mandla, and Balaghat, with 10 trees selected from each district. The trees were chosen using the Individual Tree Selection (ITS) method, which is a common practice in forest tree improvement. This method involves selecting individual trees based on superior phenotypic traits that reflect the genetic potential of the species. The selected trees were mature, aged over 20 years, and displayed phenotypic traits that indicated high productivity and vitality.

Selection Criteria

The selection of superior trees was based on the following phenotypic traits, which are critical for evaluating the overall fitness and potential of the trees:

1. **Tree Height:** The height of each tree was measured to assess its growth potential. Taller trees are typically indicative of better overall health and vigor.
2. **Girth at Breast Height (GBH):** The circumference at 1.3 meters above ground level was recorded for each tree to measure its stem diameter. Larger girth values are associated with better growth and reproductive capacity.
3. **Crown Spread:** The horizontal spread of the tree's crown was measured along both the north-south and east-west axes. A broader crown spread suggests a higher level of canopy development, which is important for photosynthesis and overall tree productivity.
4. **Flowering Intensity:** The flowering intensity was visually assessed on a scale of 1 to 5, with 1 representing minimal flowering and 5 representing abundant flowering. Strong flowering intensity is crucial for seed production and reproductive success.
5. **Fruit Yield:** The quantity and weight of fruit produced by each tree were recorded. Higher fruit yield is indicative of the tree's reproductive fitness and potential for seed collection.

Data Collection

Data was collected during the flowering and fruiting seasons to capture the full spectrum of phenotypic traits. The following methods were employed to measure the traits (Chaturvedi and Khanna, 1994) [1].

1. **Tree Height Measurement:** The height of each selected tree was measured using a Ravi multimeter to ensure accurate measurements
2. **GBH Measurement:** The girth at breast height was measured using a standard measuring tape at 1.37 meters from the ground.
3. **Crown Spread Measurement:** The crown spread was measured by calculating the distance between the furthest branches along the north-south and east-west axe
4. **Flowering Intensity Rating:** Flowering intensity was rated on a scale of 1 to 5 based on visual observation, with higher scores assigned to trees with more abundant and vibrant flowers Olubode *et al.* (2015) [6].
5. **Fruit Yield Estimation:** The number of pods and the total weight of fruits from each tree were recorded during the peak fruiting season to estimate the overall fruit yield (Shukla *et.al.* 2014) [8]

Statistical Analysis

The collected data were subjected to descriptive statistical analysis to identify trees exhibiting superior phenotypic characteristics. Individuals with greater height, larger girth at breast height (GBH), wider crown spread, enhanced flowering intensity, and higher fruit yield were recognized as potential candidates for future breeding programs. Pearson’s correlation coefficient was employed to examine the relationships between morphological and reproductive traits. The superior trees identified through this process will serve as valuable sources for seed collection and will be utilized in genetic improvement initiatives to enhance the productivity and adaptability of *Butea monosperma* in the region.

Results

Correlation analysis revealed strong, significant positive relationships among all morphological and reproductive traits of Butea monosperma across Chhindwara, Mandla, and Balaghat (Table 1).

Table 1: Pearson correlation coefficients (above diagonal) and p-values (below diagonal) among morphological and reproductive traits of *Butea monosperma* across Chhindwara, Mandla, and Balaghat (N = 30).

Trait	Tree Height (m)	GBH (cm)	Crown Spread (m)	Flowering Intensity (1-5)	Fruit Yield (kg/tree)
Tree Height (m)	—	0.95474	0.90331	0.78720	0.90195
GBH (cm)	2.80E-16	—	0.96182	0.85229	0.93858
Crown Spread (m)	8.39E-12	2.71E-17	—	0.88175	0.93344
Flowering Intensity (1-5)	2.47E-07	2.28E-09	1.22E-10	—	0.89302
Fruit Yield (kg/tree)	1.01E-11	1.82E-14	5.44E-14	3.24E-11	—

Note: All correlations are significant at $p<0.001$.

Tree height showed strong positive correlations with GBH (r=0.95), crown spread (r=0.90), flowering intensity (r=0.79), and fruit yield (r=0.90), indicating that taller trees generally have larger crowns, higher flowering intensity, and greater reproductive output. Similar patterns have been reported for *Tectona grandis* and Eucalyptus, where height is a strong predictor of biomass and reproductive success (Kaur *et al.* 2022; Tandon *et al.* 2003) [2, 9]. GBH was also strongly correlated with crown spread (r = 0.96) and fruit yield (r = 0.94), supporting its use as a reliable indicator of maturity and productivity. Larger girth may facilitate better mechanical support for wider crowns and higher fruit loads (Singh *et.al.* 2017) [3]. Crown spread was positively associated with flowering intensity (r = 0.88) and fruit yield (r = 0.93). Broader crowns increase light interception and flower production, thereby enhancing pollination and fruit set (Shivanna, 2020; Muthuswamy and Senthamarai, 2014) [7, 5]. Flowering intensity exhibited a strong correlation with fruit yield (r = 0.89), underscoring its importance for reproductive success. Increased floral abundance likely enhances pollinator attraction, improving fertilization and seed set (Tandon *et al.* 2003) [9]. Fruit yield was positively associated with all morphological traits, confirming that larger, healthier trees are generally more productive (Khan and Sharma, 2008) [4]. Overall, the strong interrelationships among tree height, GBH, crown spread, flowering intensity, and fruit yield suggest that selecting for one or more key morphological traits could indirectly improve reproductive performance; a cost-effective strategy for large-scale selection in natural populations.

Conclusion

This study demonstrates that morphological and reproductive traits in *Butea monosperma* are closely linked, with larger and more vigorous trees tending to produce higher yields. The strong positive correlations among height, GBH, crown spread, flowering intensity, and fruit yield indicate that these traits can serve as reliable selection criteria in breeding and conservation programs. By prioritizing these traits, it is possible to enhance both productivity and genetic sustainability of *B. monosperma* populations in Madhya Pradesh and other similar agro-ecological zones.

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