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GENETIC IMPROVEMENT OF TROPICAL TIMBER TREE SPECIES THROUGH PLUS TREE SELECTION : *Artocarpus hirsutus* LAMK.

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ABSTRACT

Genetic improvement of tree species plays an essential role in agroforestry to ensure wood availability. *Artocarpus hirsutus* is an important timber species, endemic to the Western Ghats. A multistage plus tree selection was conducted throughout Kerala, emphasizing different agro-ecological zones. 105 candidates plus trees were identified using the comparison tree method, and 21 plus were identified from the selected candidate plus trees using baseline-regression analysis from different agro-ecological zones. Correlation analysis was performed to highlight relationships among key tree characteristics used to identify plus trees. This study provides valuable insights for the future genetic improvement of important timber tree species, which play a key role in maintaining the quality of natural resources such as wood and the conservation of species.
***Keywords* :** Agro-ecological zones, Base population, Candidate plus tree, multi-stage selection, Tree breeding.

Introduction

Forest tree breeding is a fascinating application of genetics, reproductive biology and economic principles to the genetic improvement and management of forest trees. Our natural forests and trees have great value to society by providing clean water, fresh air, carbon storage, timber, and non-timber forest products. Timber is the most important product among these because, in addition to well-known products such as lumber, furniture, and plywood, it is the raw material for wood-based panels, pulp and paper, and many chemical products. Wood is also used as fuel in many parts of the world. Forest tree breeding is an integral component of modern silviculture, used to increase economic profitability through enhanced wood production (White *et al.*, 2007). Tree breeding modifies the genetic composition of tree populations to better fulfil human needs, as natural selection has not produced the best material for human purposes. The biotic and abiotic components of the environment are continually changing, so historical adaptations may be outdated (Pâques, 2013). The enormous achievements in breeding crop plants and domesticated animals have encouraged forest tree breeders in their work. In fact, the economically important forest trees are now at the beginning of a corresponding domestication process. Poplars (Populus spp.) are at the head of this development (Bradshaw & Strauss, 2001). The historical roots of forest tree breeding lie in experimental work with populations of different origins, that is, provenance experiments, which began in the eighteenth century (White *et al.*, 2007).

Artocarpus hirsutus is an endemic timber tree species, occurring in the West Coast semi-evergreen, Southern moist mixed deciduous, and Southern dry mixed deciduous forests of Kerala, part of peninsular India (Shailendra *et al.,* 2020). The wild jack tree, *Artocarpus hirsutus* (Moraceae), is one of the endemic timber species of the southern Western Ghats. It is especially popular along the Malabar Coast. The tree is reported in the early scientific literature in the Hortus Indicus Malabaricus (Rheede, 1682). It is one of the best commercial timber species. Under British colonial governments, the Royal Forest Department classified the timber of *Artocarpus hirsutus* alongside the royal timber teak, rosewood, sandalwood, and ebony (Sam *et al.,* 2006). However, from a local utilisation perspective, *A. hirsutus* is the most popular timber species along the Malabar Coast. Better timber quality and lower cost may be the reasons for this. According to current information, 18 species of Artocarpus have been reported from India, but *A. hirsutus* is the only endemic species (Ahmedulla & Nair, 1977).

Materials and Methods

The research was conducted within the geographical boundaries of Kerala, India. Kerala is situated between the Arabian Sea to the West and the Western Ghats to the East, encompassing a land area of 38,863 square kilometres. Geographically, Kerala can be categorised into three distinct regions: the Highland, the Mid Plains, and the Coastal Areas, with the Mid-Lands positioned between the Highland and the Coastal Plains. Approximately 29.65% of the overall land area was characterised by forested lands and plantations.

Selection of the base population

To locate existing populations of *A. hirsutus,* we conducted a comprehensive review of the relevant literature, including research articles, reports, and working plans. This aimed to pinpoint viable populations of the target species. Subsequently, an initial survey was conducted to assess the suitability of these populations as potential baseline samples. In the field, we examined factors including stand size, frequency and density of the target species, growth conditions, the presence of qualified candidate trees, and environmental factors. These observations were pivotal in both selecting appropriate base populations and establishing the criteria and methodology for selection.

In prioritising base population selection, we focused on ensuring a sufficiently large sample size to enable effective selection procedures. Additionally, we emphasised that candidate trees met the selection criteria. The initial phase of the plus tree selection initiative focused on identifying natural stands of trees. This encompassed extensive surveys across the study area spanning May 2021 to December 2024.

Across various forested areas, we conducted on-site surveys, meticulously recording population data and precise geolocations.

Selection criteria and methods: We evaluated designed populations using the screening guidelines outlined by Clark and Wilson (2005) and Kim *et al.* (2020) to identify potential candidate trees. The tree selection process employed specific criteria, including robust, thriving growth; a minimum height of 20 meters; a straight stem; well-dispersed, sunlit branches; inherent pruning; lush, dense foliage; and impressive flowering and fruiting attributes. Larger trees with greater height and circumference were sorted as a result of the population survey. In the first stage, tree scoring was used to select trees from the identified ones. Trees that have the highest scores for qualitative characteristics among the trees selected as candidate-plus trees. The trees selected for the breeding program were marked with serial numbers at breast height. These trees were subjected to the comparison-tree method, and at least 5 candidate trees were selected from each population. These selection attributes are directly linked to timber quality, physiological efficiency, and the individual's health. The comparison tree method helps identify candidate trees from each population, which are then subjected to plus tree selection programs.

From the identified populations, plus trees were selected using the baseline regression method (Rudolf, 1956). For this, the regression of trunk volume vs crown volume of each candidate tree was determined. Trunk volume was calculated using the quarter girth formula, and crown volume was calculated as the product of the squared crown diameter and the crown length.

$$\frac{\text{Girth squared} \times \text{Height } (G^2 \times H)}{\text{Crown diameter squared} \times \text{Crown length } (D^2 \times L)}$$

Trees above the regression lines were selected as plus trees. To measure the total tree height (HT) and crown diameter (CD), Haga altimeter and electronic TruPulse 200 Laser Rangefinder were used. The flexible tape was used for measuring crown length (CL) and girth at breast height (GH). The number of primary (PB) and secondary (SB) branches was determined using the standard counting method, and a Garmin GPS eTex 10 was used to record geolocation.

Data analysis: ANOVA was performed in IBM SPSS to assess significant differences; linear regression was performed to identify the plus tree; and correlation analysis was performed in PAST.

Results

Selection of the base population and trees of *A. hirsutus*

Based on the literature, an extensive field survey was conducted in natural forests, including protected areas, plantations and home gardens. The major viable populations of the target species were located in southern Kerala due to agroecological conditions.

Plantations of the target species were found in Trivandrum district, home gardens with populations of *A. hirsutus* were found in Alappuzha and Kottayam districts, and natural populations were found in the remaining regions of the state. Generally, plantations are preferable to natural stands in selection efforts if plantations of a suitable seed source are available. A total of 21 base populations were identified from different locations of the study area.

From the identified base populations, 105 candidates plus trees were selected using the criteria proposed by Clark and Wilson (2005) and Kim et al. (2020). The total height of the selected candidate plus trees of *A. hirsutus* ranged from 18.4 m (AHT61) to 45.2 m (AHT11), with a mean of 31.35 ± 4.65 m. Girth at breast height was observed to be minimum in AHT61 from Krishnapuram (1.1 m) and maximum in AHT93 from Sultan Bathery (4.19 m). Crown diameter of the identified candidate plus trees ranged from 6.2 (AHT104) to 14.8 (AHT86), with a mean of 10.08 ± 1.5 m. Crown length ranges from 6.2 m to 25.3 m with a mean of 11.81 ±3.53. The number of primary branches varied from 2 to 13, with a mean value of 6.52 ± 3.53. The number of secondary branches ranges from 6 to 19, with a mean value of 13.68 ± 2.6.

Using regression analysis, 21 plus trees were selected from the identified candidate plus trees. The total tree height selected, plus trees, varied from 24.9 (AHT62) to 45.20 (AHT11), with the mean value 35.12 ± 4.2 m. The maximum tree height was observed in the plus tree selected from Karimangod. Girth at breast height of the plus trees varied from 1.29 (AHT62) to 4.19 (AHT93), with a mean of 2.94 ±0.74 m. A large, healthy crown is essential for maximising photosynthetic potential. The crown should be evenly distributed. The mean crown diameter observed from the plus trees was 11.4 ±1.28 m with a maximum value of 14.8 m (AHT86). Crown length is also an important characteristic that determines the tree's architecture, which in turn affects the production. Crown length varied from 8.2 m to 25.1 m, with a mean of 13.83 ±4.15 m. The number of primary and secondary branches, as well as branch angle, also play an important role in timber quantity and quality. Hence, these characters were also included in the selection criteria for plus tree selection. The mean number of primary branches and secondary branches was 6.85 ±2.32 and 14 ±2.91 respectively.

The correlation analysis indicated that productivity-related traits and the primary and secondary branches are strongly and significantly associated at 1% level, while height also showed a significant positive influence on productivity, suggesting their importance as selection criteria for superior trees.

Discussion

Selected candidate trees in the present study had fairly good straightness, a compact crown, and a clear bole. Several trees, based on apparent growth, clear bole, stem straightness, and priority traits, were selected across different tree species, viz. *Azadirachta indica* (Dhillon *et al.,* 2003), Dalbergia sissoo (Bangarwa, 1993; Yadav *et al.,* 2005), Melia composita (Binu & Santoshkumar, 2019), Ailanthus triphysa (Lalnunpuia *et al.,* 2021), Azadirachta indica (Neethu, 2023) and *Swietenia macrophylla (*Moor *et al.,* 2021). Acacia catechu, *Albizia procera* and *Eucalyptus* spp. (Chauhan & Gera, 2012). Candidate plus trees are outstanding individuals that occur in natural stands or in even-aged stands. They exhibit one or more desirable characteristics or traits. Such trees occur infrequently; therefore, special efforts were undertaken to locate them. To enhance the efficiency of selection, Hazel and Lush (1942) underscored the importance of taking into account the following factors: 1) the level of genetic diversity within the population (in relation to the economic significance of the trait), 2) the heritability of the traits, and 3) the genetic and environmental relationships between each trait. The selection of traits can vary significantly based on the intended purpose or utilisation of the species in question. Selection of a good phenotype based on desired traits is the preliminary step for a mass-scale multiplication programme and genetic improvement of any tree species (Clark & Wilson, 2005). The selection of the best techniques depends on several factors, including species characteristics, stand characteristics, historical data, variability, and inheritance patterns of the selection programme (R. S. Chauhan *et al.,* 2018). The individual tree selection approach prescribed by Ledig (1974) is the most widely used and generally the most satisfactory for achieving rapid, cost-effective genetic gain in an initial tree improvement programme (Zobel & Talbert, 1984). The second important consideration when determining the criteria, as suggested by Hazel and Lush (1942), is the heritability of the selection traits. Stem straightness and roundness are directly related to wood quality and ease of processing; even the simple selection of tree form can improve the quality and quantity of the product (Shelbourne, 1969; Zobel & Talbert, 1984). Hence, CPTs were preliminarily selected based on the stem form. Numerous studies have examined the estimation of heritability and additive genetic coefficients of variation for parental growth and stem form characteristics in forest trees. In a comprehensive review conducted by Cornelius in 1994, it was observed that the heritability of form traits, particularly straightness and roundness, exceeded that of growth traits. Moreover, when analysing additive genetic coefficients of variation, it was evident that height and diameter exhibited lower values, with medians of 8.5% and 8.6%, respectively, whereas straightness showed a median of 11.65%. High heritability accompanied by high genetic advance for several growth characteristics has also been demonstrated in growth characteristics like tree height, diameter (Ferguson *et al*., 1977; Naraynan *et al*., 2009; Dlamini *et al*., 2017), clear bole height (Jha, 2013) and bole straightness (Vargas-Reeve *et al*., 2013), and including these traits as selection criteria increased the reliability of selecting the superior phenotype in the study. Scientists used stem straightness, clear bole height, pruning ability and disease resistance for the selection of candidate plus trees of *Melia composita* (Johar *et al.,* 2016); basal diameter, plant height and volume index for the selection of 20 plus trees of *M. dubia* (Kumar *et al.,* 2013); height and diameter growth, stem straightness, self-pruning ability and crown diameter for the selection of 11 CPTs of *M. composita* in Punjab (Gera, 2012). In addition, Johar et al. (2016) and Chauhan and Gera (2012) considered the natural pruning ability trait when selecting candidate plus trees (CPTs) in *M. composita*.

Numerous scientists have successfully selected plus trees for hardwood using the baseline method. For instance, Binu (2019) employed the baseline method to select Plus trees of *Melia dubiai* from various regions in Kerala. Additionally, Dhillon *et al*. (2009) used the baseline method to choose candidate plus trees of *M. azaderach* from diverse agro-climatic areas in Punjab. Nevertheless, effective selections grounded in qualitative traits have been accomplished in various species, including *Ailanthus excelsa* (Daneva *et al.,* 2018), *Azadirachta indica* (Dhillon *et al*., 2003), *Dalbergia sissoo* (as evidenced by Bangarwa in 1993 and Yadav *et al*. in 2005), and *Salix alba* (highlighted by Paray *et al*. in 2017). Plus, tree selection is crucial for achieving immediate improvements in seed stands or seed production areas. It is essential to exercise careful judgment when selecting these plus trees to optimise the use of genetic diversity. In this current study, considerable emphasis was placed on assessing the qualitative and quantitative attributes of *Artocarpus hirsutus* trees within the natural population. Specifically, characteristics such as clear bole height, bole shape and branching pattern were given significant consideration during the selection process. Previous findings have also shown that several growth traits, including tree height, diameter (Dlamini *et al.,* 2017), clear bole height (Jha, 2012), and bole straightness (Vargas-Reeve *et al.,* 2013), exhibit high heritability and substantial potential for genetic improvement.

In any tree improvement program, the first crucial step is to identify all potential variations within a species. This entails a thorough examination of genetic variation across tree species, focusing on both morphological and biochemical characteristics. This practice is a fundamental aspect of tree development programs. The extensive diversity observed in commercially valuable traits underscores the significant potential for utilising phenotypic selection to enhance productivity. This approach aims to effectively harness the genetic resources available in natural populations. This is particularly important because forest trees typically exhibit genetic variability that enables them to thrive, grow, and reproduce successfully in diverse environmental conditions (Antonovicks, 1971).

Tree characteristics such as tree height, girth at breast height (GBH), and crown diameter typically exhibit natural variability. Among these, height and GBH hold particular commercial significance for timber species. However, it is worth noting that growth-related traits, like height, are predominantly influenced by environmental factors, resulting in relatively low heritability. Consequently, selecting trees primarily based on height may not be the most effective approach. These findings align with observations by Abijith (2018) and Das (2018) in their studies of Ailanthus triphysa, which examined height, GBH, and crown width. Their research demonstrated that the observed variation in the population was largely attributable to environmental factors, suggesting that selection based solely on these criteria may not be advisable. Similar variations have been noted in other tree species, such as *Melia dubia* (Binu, 2019) and *Lagerstroemia speciosa* (Jamaludheen *et al.,* 1995), further underscoring the importance of considering environmental factors when making selections in tree breeding programs.

The correlation among the selected characters was also analysed in the study. Significant positive correlation was observed between the total height of the tree and the number of primary branches at the 0.05 level in *A. hirsutus*. The number of primary and secondary branches also showed a significant positive correlation at the 0.01 level. Additionally, tree selection studies conducted on naturally occurring Melia composite reported a highly significant and positive correlation between age and other morphological characters, namely height, clear bole height, and GBH (Johar *et al*., 2016). Similar studies were conducted by Niveditha *et al*. (2025), who conducted candidate plus tree selection and diversity analysis of *Artocarpus hirsutus* in central Kerala and identified 30 candidate plus trees. Hierarchical cluster analysis was performed using Squared Euclidean distances to categorise the candidate plus trees into distinct groups, highlighting genetic relationships among the trees and facilitating targeted selection for breeding programs.

Conclusion

The present study is a model tree-breeding program for the genetic improvement of tropical timber species through plus-tree selection. This study identified 21 plus trees of A. hirsutus using the comparison tree method (to select candidate plus trees) and regression analysis (to select plus trees). Regression analysis is the most suitable and effective method for selecting plus trees in an age-unknown base population. Hence, regression analysis is recommended for selecting plus trees in programmes for age-unknown tropical timber species. The correlation studies also emphasised the importance of selection criteria in the selection programmes.

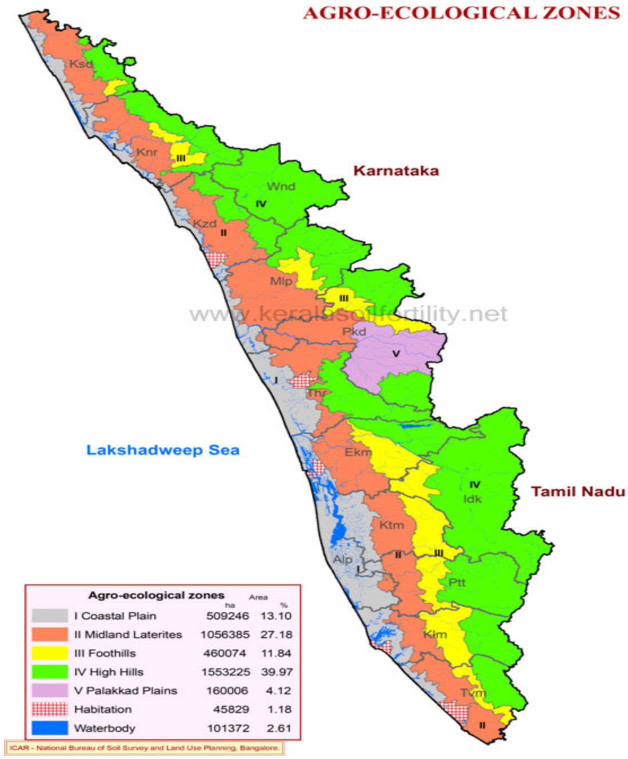


Fig. 1 : Agro-ecological zonation of the study area (Kerala State Planning Board, 2012).

Table 1 : Identified populations of *A. hirsutus* from different locations of Kerala.

Sl No	Population	Location	Range	Agro-ecological Zone	Latitude	Longitude
1.	AHP1	Trivandrum	Palode, Pacha	Midland Laterites	08.72504	77.0214
2.	AHP2	Trivandrum	Palode, Pacha	Midland Laterites	08.72178	77.01419
3.	AHP3	Trivandrum	Palode, Karimangode	Midland Laterites	08.73796	77.02358
4.	AHP4	Trivandrum WL	Neyyar WLS, Kaithode	High hills	08.59108	77.16967
5.	AHP5	Trivandrum WL	Neyyar WLS, Kaithode	High hills	08.58934	77.16915
6.	AHP6	Trivandrum WL	Neyyar WLS, Kaithode	High hills	08.58987	77.16982
7.	AHP7	Trivandrum WL	Palode, Ponmudi	High hills	08.73929	77.124
8.	AHP8	Kottayam	Erumeli, Nedumkavu Vayal	Foothills	09.4548	76.84632
9.	AHP9	Kottayam	Erumeli, Nedumkavu Vayal	Foothills	09.45299	76.84636
10.	AHP10	Kottayam	Erumeli, Oottupara	Foothills	09.44771	76.76667
11.	AHP11	Kottayam	Erumeli, Kaalaketti	Foothills	09.4448	76.93515
12.	AHP12	Thenmala	Thenmala, Thenmala	High Hills	08.969953	77.766831
13.	AHP13	Ranni	Ranni, Krishnapuram	Coastal Plain	09.14819	76.05109
14.	AHP14	Ranni	Ranni, Kaavaalam	Coastal Plain	09.18763	76.52469
15.	AHP15	Ranni	Ranni, Thathampilli	Coastal Plain	09.50648	76.34909
16.	AHP16	Malayatoor	Kodanad, Mahagony Thottam	Foothills	10.19756	76.55973
17.	AHP17	Palakkad	Olavakkod, Dhoni	Palakkad Plain	10.87049	76.6223
18.	AHP18	Wayanad South	Chedleth, Chethalayam	High Hills	11.6752	76.30329
19.	AHP19	Wayanad WL	Sulthan Bathery, Naiketty	High Hills	11.76187	76.14982
20.	AHP20	Wayanad North	Begur, Kattikulam	High Hills	11.86042	76.083958
21.	AHP21	Kannur	Kottiyur, Kommeri	High Hills	11.85048	75.740017

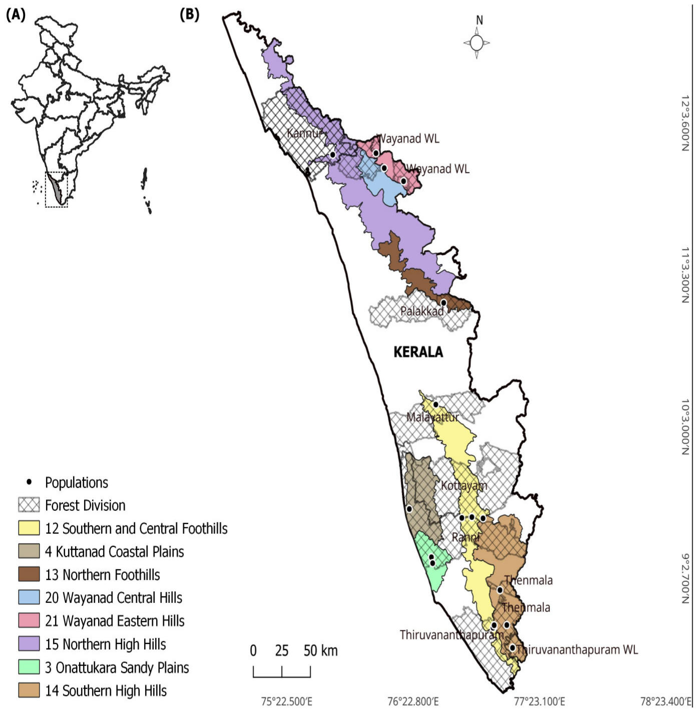
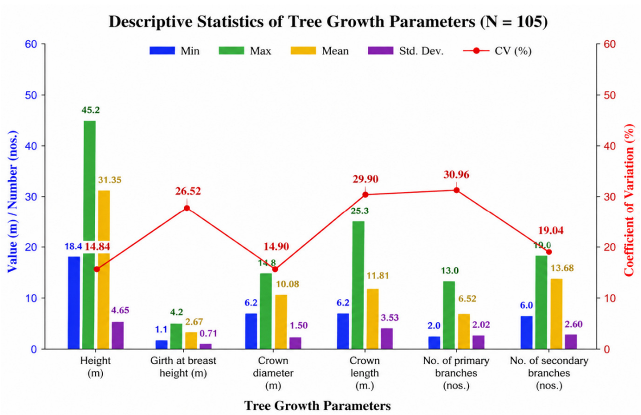
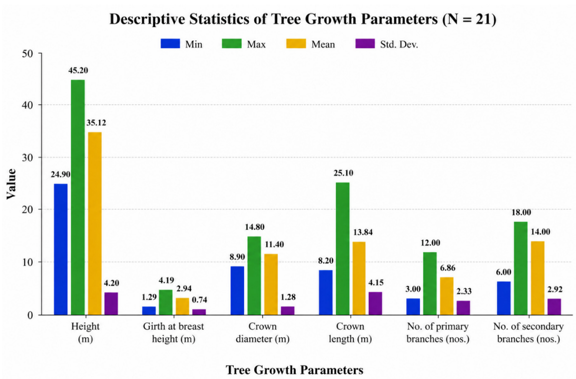


Fig. 2 : Geo-locations of identified populations of *Artocarpus hirsutus* in Kerala



Graph 1 : Descriptive Statistics of tree growth of selected candidate plus trees.

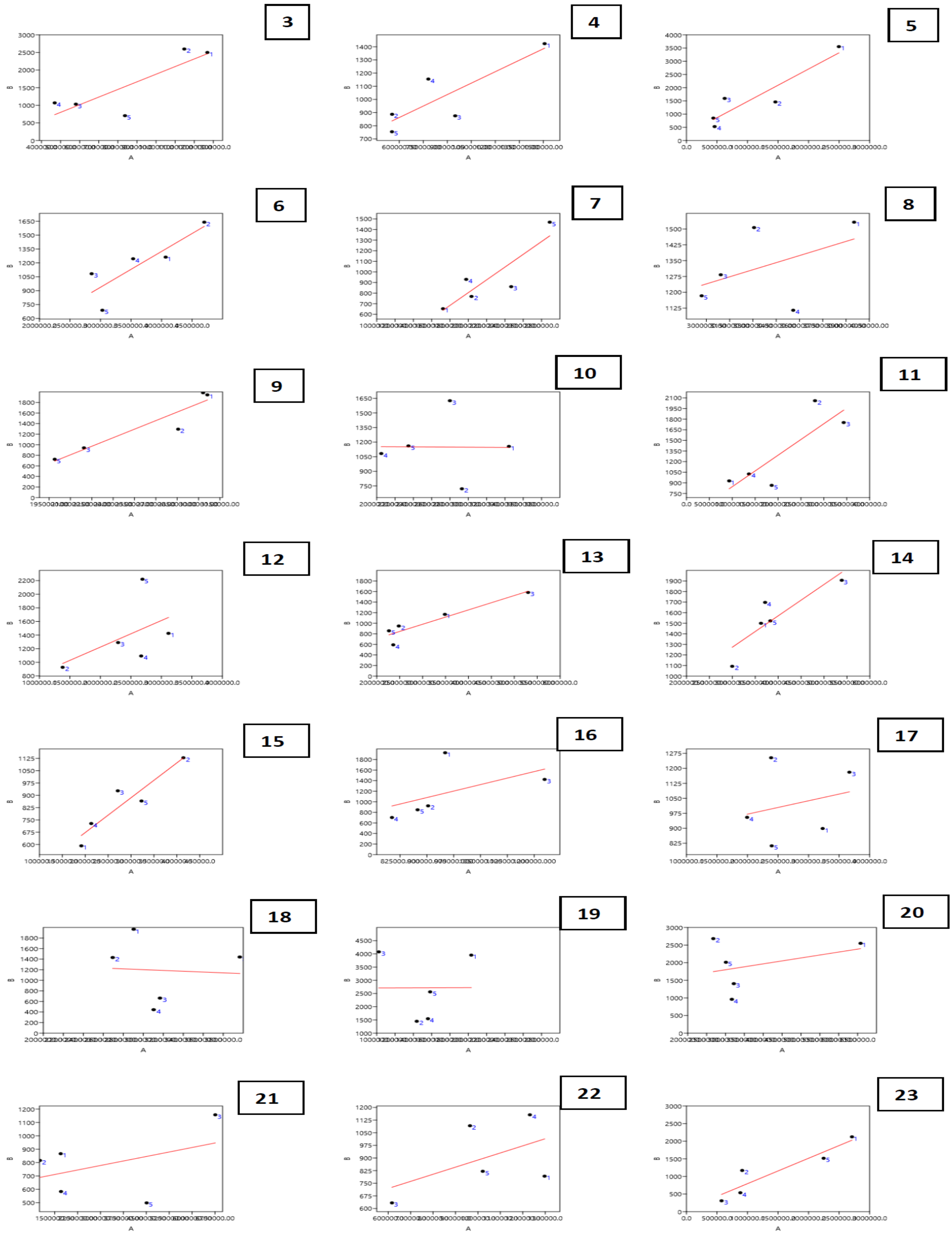


Graph 2 : Descriptive Statistics of Tree Growth Performance of the selected plus trees

Table 2 : Correlation analysis of the morphological characters

	H	D	L	P	S
G	0.420	0.191	-0.194	0.205	0.133
H		0.268	0.389	0.546*	0.215
D			0.005	0.254	0.058
L				0.174	0.041
P					0.633**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).



A- Crown volume (m^3), **B-** Trunk volume (m^3)

Graph 3-23: Regression analysis used for the selection of plus trees from each population

Fig. 3-23 : Photographs of the selected plus trees of *Artocarpus hirsutus* from different agroclimatic zones of Kerala

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Conflict of interest

We declare that we have no known financial or personal relationships that could have appeared to influence the work reported in this paper.

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