RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
58 (4) 1749-1760, 2026
http://doi.org/10.54910/sabrao2026.58.4.26
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

MORPHOLOGICAL TRAITS ASSOCIATED WITH CANOPY IDEOTYPE AFTER PRUNING IN TEA (*CAMELLIA SINENSIS* L.) HYBRID PROGENIES

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SUMMARY

Hybridization between high-yielding *assamica* and high-quality *sinensis* tea types results in wide genetic variation that provides opportunities for early selection of elite tea genotypes. This study evaluated 24 F_1 hybrid progenies derived from eight cross combinations (*sinensis* × *assamica*) to assess shoot regeneration, branching, canopy development, and plant architecture under heavy and medium pruning during six months of observation. Several progenies derived from the Suka Ati-40 parental line showed more vigorous vegetative growth than the other hybrid combinations. According to the Union for the Protection of New Varieties of Plants (UPOV) descriptors, most hybrid progenies displayed upward or outward leaf orientation, together with shrub growth habit and spreading canopy architecture. Shoot number had a positive correlation with canopy diameter and the number of primary branches, whereas shoot length showed a positive correlation with canopy diameter. These results provide useful morphological criteria for identifying tea genotypes associated with a desirable canopy ideotype and support early clonal selection in tea breeding programs.

Keywords: Tea (*C. sinensis* L.), hybrid progenies, pruning, canopy ideotype, morphological traits, early clonal selection

Key findings: Tea (*C. sinensis* L.) hybrid progenies derived from crosses between *sinensis* and *assamica* showed wide variation in shoot regeneration and canopy development after pruning, providing useful morphological traits for early clonal selection.

Communicating Editor: Prof. Naqib Ullah Khan

Manuscript received: January 15, 2026; Accepted: July 25, 2026.

Citation: Setyorini T, Taryono, Murti RH, Wulandari RA (2026). Morphological traits associated with canopy ideotype after pruning in tea (*Camellia sinensis* L.) hybrid progenies. *SABRAO J. Breed. Genet. 58 (4) 1749-1760. http://doi.org/10.54910/sabrao2026.58.4.26*.

INTRODUCTION

Tea (*Camellia sinensis* [L.] O. Kuntze) is a widely cultivated perennial crop, a globally consumed non-alcoholic beverage, known for its numerous health benefits (Kan *et al.*, 2024). The classification of commercially cultivated tea plants comprised three main types based on leaf morphology, namely, *sinensis*, *assamica*, and *cambod*. The *sinensis* type is a small-leaved shrub with compact branching and erect leaves, generally recognized for its high tea quality. In contrast, the *assamica* type is a tall, large-leaved plant with wide branch spread and horizontal leaves, commonly characterized by higher yield potential. The *cambod* type shows intermediate morphological characteristics between the two tea types (Ponmurugan *et al*., 2019). Among these tea types, *sinensis* and *assamica* are the principal parents used in hybrid breeding programs to combine superior yield and quality traits.

Tea breeding seeks to develop genotypes with high yield and quality. Hybridization has, therefore, taken place to combine these desirable traits, although genetic and physiological barriers limit cross-compatibility and hybrid survival (Kumarihami *et al*., 2016). Nevertheless, successful breeding programs have demonstrated that crosses between selected *sinensis* and *assamica* clones can produce promising hybrids with improved agronomic performance and tea quality (Kumarihami *et al*., 2016; Widhianata *et al.*, 2022). Each surviving F_1 hybrid represents a unique genotype resulting from genetic recombination, making individual evaluation essential for identifying promising breeding materials.

Previous studies on progenies derived from crosses between *sinensis* and *assamica* tea types have reported wide variations in morphological traits, yield, and quality, with several hybrids showing promising agronomic performance (Widhianata *et al*., 2022). In advancing the development of elite hybrids, vegetative propagation through cuttings is a widely practiced technique and requires prior pruning of mother plants to stimulate shoot production. Post-pruning assessment provides important information on regenerative growth, canopy development, and shoot regeneration, which are in close association with long-term tea productivity.

Pruning at defined intervals and plant heights suppresses apical dominance, stimulates bud sprouting, improves branching patterns, and maintains plants in the vegetative and harvestable stages (Hossen *et al.*, 2021). Additionally, several studies have shown pruning to improve canopy structure, photosynthetic efficiency, and nutrient allocation, which may contribute to higher leaf productivity and bush longevity (Hossen *et al.*, 2021; Kan *et al.*, 2024). Pruning intensities range from light to heavy pruning and have specific physiological effects, with heavier methods generally showing robust regenerative outcomes through enhanced shoot renewal (Lu *et al.*, 2022).

The morphological responses to pruning are also important from a breeding perspective because they contribute to canopy architecture, which is a key component of plant ideotypes. The concept of crop ideotype, first proposed by Donald (1968), emphasizes the identification of plant architectures associated with improved crop performance through the selection of desirable morphological characteristics. Plant architecture, particularly canopy architecture, influences light interception, resource-use efficiency, and vegetative development (Wei *et al*., 2026). In tea, earlier studies have primarily focused on individual aspects of post-pruning vegetative growth, including shoot regeneration, canopy recovery, and physiological responses (Lu *et al*., 2022; Zhang *et al*., 2023; Kan *et al*., 2024). However, few studies have integrated these morphological traits within the framework of a canopy ideotype to support early selection in tea breeding.

Previous studies comparing *sinensis* and *assamica* tea types under different pruning treatments revealed varied growth responses. The *sinensis* type showed greater plant height and bud production, whereas the *assamica* type exhibited higher productivity (Akbar *et al.*, 2014). However, information on the post-pruning growth performance of individual F_1 hybrid progenies derived from crosses between *sinensis* and *assamica* remains limited. Furthermore, the canopy ideotype for improved hybrid performance has not reached a clear identity, despite its potential importance for early clonal selection in tea breeding. Therefore, this study aimed to (i) evaluate post-pruning growth of F_1 tea hybrid progenies, (ii) identify superior canopy traits associated with canopy ideotypes, and (iii) determine the relationships among morphological and growth traits to support early clonal selection in tea breeding.

MATERIALS AND METHODS

Plant materials and procedure

The present study was conducted in the field of PT. Pagilaran tea estate, Batang, Central Java, Indonesia, where new hybrid progenies of *C. sinensis* var. sinensis (Tambi-1 and Tambi-2) and *C. sinensis* var. assamica (TRI-2025, Kiara-8, Suka Ati-40, and Cinyiruan-143) clones served as research material. The selection of *sinensis* parental clones (Tambi-1 and Tambi-2) relied on their high quality, whereas the *assamica* parental clones (TRI-2025, Kiara-8, Suka Ati-40, and Cinyiruan-143) were options for their vigorous vegetative growth and high-yield potential. These complementary characteristics formed the basis for developing F_1 hybrid progenies with improved agronomic performance and quality.

The study evaluated a total of 24 F_1 hybrid progenies derived from eight cross combinations. These were two progenies from Tambi-1 × TRI-2025, four from Tambi-1 × Kiara-8, six from Tambi-1 × Suka Ati-40, two from Tambi-1 × Cinyiruan-143, three from Tambi-2 × TRI-2025, three from Tambi-2 × Kiara-8, three from Tambi-2 × Suka Ati-40, and one from Tambi-2 × Cinyiruan-143. The five-year-old hybrid progeny trees entailed cultivation under uniform soil and agronomic management conditions.

Monitoring of environmental conditions continued throughout both observation periods. Following heavy pruning (January–July 2023), the experimental site comprised various characteristics. These included average daily rainfall ranging from 3.25 to 11.30 mm, relative humidity from 78.26% to 87.20%, mean air temperature from 24.90 °C to 26.23 °C, and surface soil wetness ranging from 0.81 to 0.95. During the observation period following medium pruning (May–August 2024), the corresponding values ranged from 1.00 to 5.70 mm day^{-1}, 72.11% to 81.74%, 25.64 °C to 26.95 °C, and 0.69 to 0.89, respectively. Meteorological data came from the NASA Langley Research Center Prediction of Worldwide Energy Resources (NASA POWER) project.

Each hybrid plant represented a unique F_1 genotype derived from a cross between *sinensis* and *assamica*. Although several progenies resulted from each cross combination, every F_1 individual possessed a distinct genetic constitution resulting from meiotic recombination and segregation. Therefore, each hybrid plant sustained treatment as an independent genotype rather than as a biological replicate, incurring evaluation as a single experimental unit. This approach is consistent with the early-stage evaluation of perennial breeding populations, where the selection of individual F_1 plants was dependent on their own phenotypic performance.

Two different types of pruning were conducted, namely, heavy pruning in January 2023 and medium pruning in May 2024. Heavy pruning proceeded by cutting the main stems to a height of 30–40 cm above the ground to stimulate vigorous basal shoot development and rejuvenate plant structure. Medium pruning, conducted 16 months later, involved trimming the main stems 10–20 cm from the apical shoots (Lu *et al*., 2022).

Data collection

Observations on morphological traits continued monthly from one to six months after heavy pruning for each F_1 hybrid plant. The provision of a more detailed assessment of early shoot regeneration had the number of new shoots also recorded weekly during the first and second months after pruning. The observation included (a) the number of new shoots, where considering a shoot has emerged when it reached a minimum length of 1–2 cm; (b) the length of new shoots, determined by measuring the first 10 newly emerged shoots on each plant; (c) canopy diameter, measured in two perpendicular directions (north-south and east-west), and expressed as the mean of the two measurements (Prastiwi and Lontoh, 2019); and (d) the number and diameter of the primary branches, recorded one month after pruning.

Visual documentation of canopy development, as performed, used standardized photographs taken after four months of heavy pruning and three months after medium pruning. This enabled us to qualitatively illustrate differences in canopy development and growth habit among the evaluated F_1 hybrid plants. Qualitative morphological characteristics' classification utilized the International Union for the Protection of New Varieties of Plants (UPOV) descriptor standards for tea, including leaf blade orientation, plant type, and plant growth habit. These qualitative traits received recording for each individual F_1 genotype and helped in the characterization of canopy ideotypes.

During the sixth month after heavy pruning, several F_1 hybrid plants exhibited symptoms of *Helopeltis* infestation and *Exobasidium* infection. The study retained the affected plants in the observations because the symptoms developed under natural field conditions; however, considering their occurrence ensued when interpreting changes in shoot growth during the observation period.

Statistical analysis

Each F_1 hybrid represented an independent genotype rather than a biological replicate; therefore, quantitative data summarization was descriptive for each hybrid progeny. Calculating Pearson's correlation coefficients sought to determine the relationships among quantitative morphological traits at $P < 0.05$. Principal component analysis (PCA) proceeded to visualize the multivariate relationships among hybrid progenies and morphological traits. Descriptive statistics calculation used Microsoft Excel 2021. Pearson's correlation analysis and PCA used Python version 3.13.3.

RESULTS

The results revealed variation in the number of new shoots among tea (*C. sinensis* L.) hybrid progenies after heavy pruning. Differences in the rate of bud emergence were also evident among the tea genotypes. In general, the majority of progenies initiated bud development within the first month (four weeks) after pruning (Figure 1). The initial number of emerging shoots widely varied, ranging from one to 12, and the progenies Tambi-2 × Suka Ati-40 (G2 and G3) exhibited

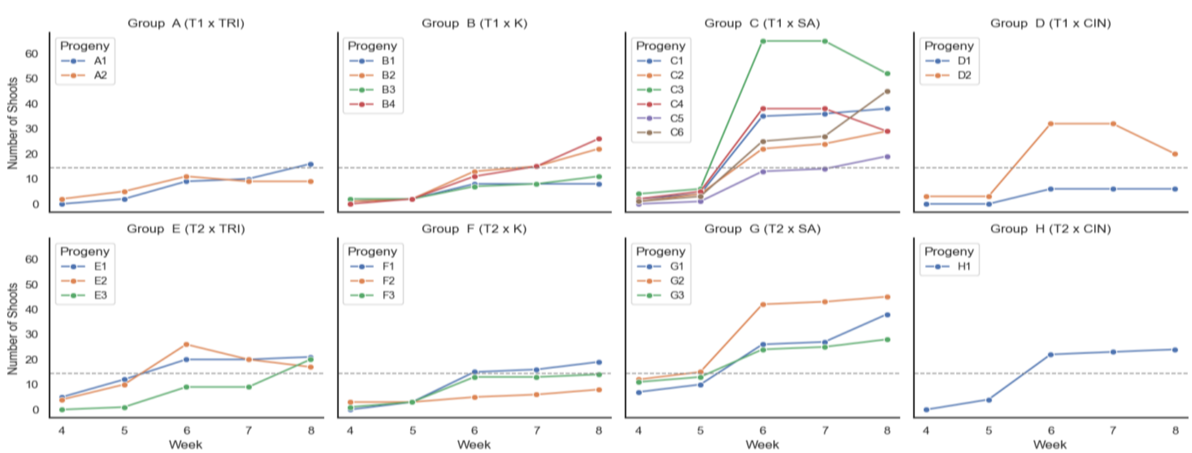

Figure 1. Shoot emergence rate based on the number of shoots from 4 to 8 weeks after pruning in tea.

the highest shoot number during early observation. In several progenies, a marked increase in shoot number emerged by the sixth week after pruning. For instance, the tea progeny Tambi-1 × Suka Ati-40 (C3) initially produced a limited number of shoots; however, it experienced a substantial increase at this stage and remained relatively consistent in subsequent observations.

After pruning, the dynamics of shoot regeneration considerably varied among the 24 evaluated tea progenies. In general, the number of emerging shoots sharply increased within the first month after pruning, and most progenies reached their peak shoot number between the second and third months. However, the rapid early response was particularly notable in the tea progenies Tambi-1 × Suka Ati-40 (C1, C3, and C6) and Tambi-2 × Suka Ati-40 (G2), with the highest shoot number relative to the overall mean. Following the initial flush recovery, the majority of progenies showed a gradual decline, and shoot number stabilized from the fourth month onward. Progenies derived from the parental genotype Suka Ati-40 consistently maintained shoot number above the overall mean, whereas progenies derived from TRI-2025, Kiara-8, and Cinyiruan-143 generally remained below the mean throughout the observation period.

Shoot elongation following pruning showed a steady increase across all progenies under observations recorded during the six-month period. Most tea progenies exhibited rapid elongation within the first three months, after which shoot growth continued at a slower but relatively consistent rate. Progenies Tambi-1 × TRI-2025 (A1), Tambi-1 × Suka Ati-40 (C4), Tambi-1 × Cinyiruan-143 (D2), Tambi-2 × TRI-2025 (E1 and E3), and Tambi-2 × Suka Ati-40 (G2) recorded the maximum shoot length by the end of the evaluation period, exceeding the overall mean by a wide margin (> 40 cm). In the final month of observation, a decrease in shoot length resulted in progenies Tambi-2 × Suka Ati-40 (G3) and Tambi-2 × Cinyiruan-143 (H1). During the sixth month, some plants exhibited symptoms of *Helopeltis spp*. infestation and leaf spot disease caused by *Exobasidium vexans*, which affected young shoots and leaves.

After pruning, new shoots emerged from the primary branches and became distinguishable one month after pruning in all hybrid progenies. Most hybrid progenies displayed two to three primary branches (Table 1), whereas a few showed more than three primary branches. The average diameter of the primary branches varied among the hybrid progenies, with Tambi-2 × Cinyiruan-143 (H1) exhibiting the largest average branch diameter (2.8 cm).

The new shoots formed after pruning exhibited varied leaf blade orientations among hybrid progenies (Table 2). These leaf blade orientations' classification was according to the tea descriptor standards established by UPOV. Most genotypes expressed upward (1) and outward (2) leaf blade orientations, whereas only one progeny, Tambi-1 × TRI-2025 (A2), displayed a horizontal (3) orientation.

The growth and development of new shoots, including leaf expansion at each branching point, contributed to canopy development. Canopy diameter progressively increased in all the 24 hybrid progenies throughout the observation period (Figure 2). Several progenies, particularly Tambi-1 × Kiara-8 (B4), Tambi-1 × Suka Ati-40 (C5 and C6), and Tambi-2 × TRI-2025 (E3), exhibited rapid canopy expansion and excelled the overall mean by more than 60 cm at the end of the evaluation period. Tambi-1 × Suka Ati-40 (C1) maintained a canopy diameter above the overall mean throughout the observation period.

Across the hybrid progenies, considerable variation was apparent in plant architectural types under the two pruning regimes (Table 3). Following heavy pruning, Tambi-1 × Kiara-8 (B1), Tambi-1 × Suka Ati-40 (C4), T1 × CIN (D1), and T2 × K (F2) demonstrated semi-arbor characteristics, whereas most progenies remained in the shrub category. Under medium pruning, all progenies displayed shrub-like growth.

Most progenies exhibited spreading growth habits four months after heavy pruning, whereas a few progenies, including Tambi-1 ×

Table 1. Primary branches' number and diameter in hybrid progenies of tea.

Hybrids (female × male)	Hybrid progenies code	Number of primary branches	Diameter of primary branches (cm)
Tambi-1 × TRI-2025	A1	2	2.0
	A2	2	1.8
Tambi-1 × Kiara-8	B1	4	0.5
	B2	3	0.8
	B3	3	0.7
	B4	3	1.5
Tambi-1 × Suka Ati-40	C1	5	1.4
	C2	3	1.7
	C3	7	0.6
	C4	3	1.0
	C5	2	0.8
	C6	2	1.5
Tambi-1 × Cinyiruan-143	D1	2	2.3
	D2	3	1.7
Tambi-2 × TRI-2025	E1	3	1.5
	E2	3	1.7
	E3	3	1.8
Tambi-2 × Kiara-8	F1	2	1.0
	F2	2	1.0
	F3	3	1.3
Tambi-2 × Suka Ati-40	G1	3	1.7
	G2	4	1.8
	G3	3	1.0
Tambi-2 × Cinyiruan-143	H1	3	2.8

Table 2. Leaf blade orientation of the tea hybrid progeny according to UPOV descriptors (UPOV, 2021).

Hybrids (female × male)	Hybrid progenies code	Leaf blade attitude
Tambi-1 × TRI-2025	A1	2
	A2	3
Tambi-1 × Kiara-8	B1	2
	B2	2
	B3	1
	B4	1
Tambi-1 × Suka Ati-40	C1	1
	C2	2
	C3	2
	C4	1
	C5	1
	C6	2
Tambi-1 × Cinyiruan-143	D1	1
	D2	1
Tambi-2 × TRI-2025	E1	2
	E2	2
	E3	1
Tambi-2 × Kiara-8	F1	2
	F2	1
	F3	2
Tambi-2 × Suka Ati-40	G1	1
	G2	2
	G3	1
Tambi-2 × Cinyiruan-143	H1	2

Note: (1) upwards, (2) outwards, (3) horizontal.

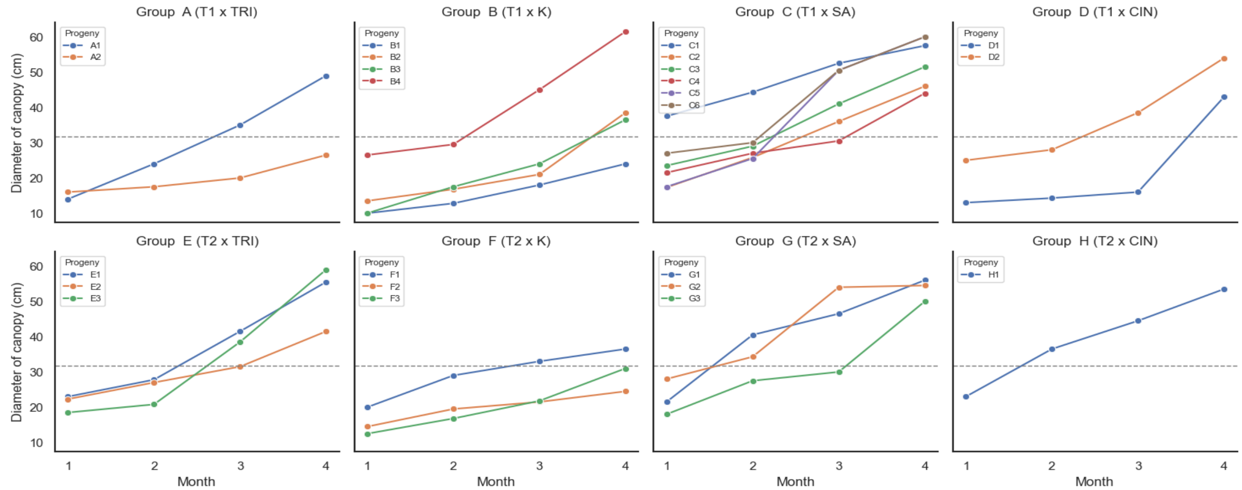

Figure 2. Canopy diameter expansion from 1 to 4 months after pruning. Horizontal dashed lines represent global means across all crosses.

Table 3. Plant type and plant growth habit after four months of heavy pruning and after three months of medium pruning in tea.

Hybrids (female × male)	Progenies code	Four months after heavy pruning		Three months after medium pruning	
		Plant type	Plant growth habit	Plant type	Plant growth habit
Tambi-1 × TRI-2025	A1	1	5	1	5
	A2	1	3	1	3
Tambi-1 × Kiara-8	B1	2	3	1	5
	B2	1	3	1	5
	B3	1	5	1	5
	B4	1	5	1	5
Tambi-1 × Suka Ati-40	C1	1	5	1	5
	C2	1	5	1	5
	C3	1	5	1	5
	C4	2	3	1	5
	C5	1	5	1	5
	C6	1	5	1	5
Tambi-1 × Cinyiruan-143	D1	2	3	1	5
	D2	1	5	1	5
Tambi-2 × TRI-2025	E1	1	5	1	5
	E2	1	5	1	5
	E3	1	5	1	5
Tambi-2 × Kiara-8	F1	1	3	1	3
	F2	2	3	1	5
	F3	1	5	1	5
Tambi-2 × Suka Ati-40	G1	1	5	1	5
	G2	1	5	1	5
	G3	1	5	1	5
Tambi-2 × Cinyiruan-143	H1	1	5	1	5

Note: Plant types: (1) shrub, (2) semi-arbor; Plant growth habits: (3) semi-upright, (5) spreading.

TRI 2025 (A2), Tambi-1 × Kiara-8 (B1, B2), Tambi-1 × Suka Ati-40 (C4), Tambi-1 × Cinyiruan-143 (D1), and Tambi-2 × Kiara-8 (F1, F2), showed semi-upright growth habits. Under medium pruning, nearly all progenies expressed spreading growth habits with a more lateral regrowth pattern.

Among the observed morphological traits, Pearson's correlation analysis sought to examine the relationships among quantitative traits. A positive correlation was noteworthy between the number of shoots and the diameter of the canopy (r = 0.60**), as well as between the number of shoots and the number of primary branches (r = 0.55**). Additionally, shoot length was in a positive correlation with canopy diameter (r = 0.54**). Conversely, the number of primary branches showed a weak negative correlation with branch diameter (r = -0.30).

In comprehensively evaluating the relationships among measured morphological traits, principal component analysis (PCA) proceeded. The first two principal components explained 74.6% of the total variation, with PC1 and PC2 accounting for 43.2% and 31.4%, respectively. PC1 has characteristics mainly of canopy diameter, shoot length, and the number of shoots, with PC2 primarily characterized by the number of primary branches. The biplot showed a clear separation among the tea hybrid progenies. Tambi-1 × Suka Ati-40 (C1 and C3) and Tambi-2 × Suka Ati-40 (G2) displayed a position on the positive side of PC1 and were in association with higher observed values for shoot number and canopy diameter. In contrast, Tambi-1 × TRI-2025 (A1 and A2) and Tambi-1 × CIN (D1) were in a location on the negative side of PC1, showing an association with relatively lower values for most measured growth traits.

DISCUSSION

Pruning initiates a series of physiological processes that stimulate bud break and shoot regeneration in tea (*C. sinensis* L.) by altering hormonal balance, promoting the release of dormant axillary buds, and promoting the remobilization of carbohydrate reserves to support new vegetative growth (Kan *et al*., 2024). Although all hybrid progenies responded to pruning, their regrowth patterns differed considerably, indicating variation in their genetic capacity for post-pruning recovery. Hybrid progenies derived from the parental clone Suka Ati-40 consistently maintained relatively higher shoot numbers throughout the observation period, suggesting this parent contributed favorable alleles associated with vegetative regeneration. Differences in post-pruning performance among progenies are likely in relation to genotype-dependent regulation of meristem activity and hormonal responsiveness, particularly involving auxin-cytokinin interactions that control bud outgrowth (Lardon *et al*., 2020; Liu *et al*., 2024). Shoot number increased rapidly during the first two months after pruning, corresponding to the typical flush recovery phase in tea, before gradually stabilizing as plant resources underwent redistribution to sustain subsequent shoot growth (Lardon *et al*., 2020).

In addition to genetic factors, seasonal environmental conditions also appeared to influence the post-pruning shoot regeneration of the tea hybrid progenies. The rapid increase in shoot production during the first two months after pruning corresponded to the typical flush recovery phase in tea, characterized by active bud break and vigorous shoot initiation. In contrast, the subsequent decline in shoot production during the latter part of the observation period may have gained influence from seasonal environmental conditions. The transition to the dry season in the study area revealed complements of reduced soil moisture, where reports stated to suppress bud initiation, restrict shoot elongation, and reduce the survival of developing shoots in tea (Wulansari *et al*., 2022).

Hybrid progenies exhibiting greater shoot elongation after pruning showed more vigorous vegetative growth, an important characteristic for sustaining canopy renewal in tea. Shoot elongation influences came from both genetic background and internode development. Previous studies have shown that *assamica* generally produces longer internodes than *sinensis,* while hybrid tea plants have released reports of exhibiting internode characteristics more similar to *assamica* (Ponmurugan *et al*., 2019). Similar responses have also appeared in reports following pruning, where vigorous shoot elongation expressed an association with enhanced vegetative recovery and renewed canopy development (Lu *et al*., 2022). The increased shoot elongation observed in some hybrid progenies probably reflects genetic differences inherited from their parental combinations that regulate stem growth and internode expansion. Such variation provides a useful basis for identifying promising genotypes for subsequent clonal evaluation in tea breeding programs.

Variations in primary branch diameter among the hybrid progenies further indicate differences in post-pruning structural development. The formation of two to three primary branches in most hybrid progenies was consistent with the typical branching response reported in tea following pruning (Lu *et al*., 2022). Branch thickening showed a close relation to cambial activity, regulated by hormonal signaling and carbohydrate availability during vegetative regrowth (Zhang *et al*., 2023). The variation observed among the hybrid progenies suggested differences in their capacity to allocate assimilates for structural growth after pruning. Such differences could help identify genotypes with desirable structural characteristics for subsequent clonal evaluation.

Canopy development following pruning reflected the integrated responses of shoot regeneration and branch growth, making it an important indicator of vegetative recovery in tea. Genotypic differences in canopy expansion observed in the presented study agree with previous reports showing that canopy architecture received strong impact from genetic background and post-pruning physiological responses (Wang *et al*., 2018; Zhang *et al*., 2023). Canopy expansion after pruning has shown an association with increased phytohormone activity and more efficient allocation of assimilates to developing shoots (Lu *et al*., 2022; Zhang *et al*., 2023). The consistently enhanced canopy development observed in progenies derived from Suka Ati-40 suggests that this parental clone contributed favorable characteristics associated with canopy recovery after pruning. Such variation provides valuable information for identifying genotypes with favorable canopy architecture for early clonal selection.

Qualitative morphological traits, such as leaf blade orientations and plant growth habit, complement quantitative measurements of vegetative growth and canopy development, thereby supporting tea breeding. These traits are included indicators in the UPOV guidelines for varietal characterization and remained relatively stable following pruning, with most hybrid progenies maintaining upward or outward leaf orientation and a spreading growth habit. Reports of similar variation have emerged among tea types, where *sinensis* generally exhibits upward leaf orientation, while *assamica* tends to display a more horizontal orientation (Ponmurugan *et al*., 2019). Beyond varietal characterization, these morphological traits revealed a close relation to canopy architecture, which influences light interception, air circulation, canopy management, and harvesting efficiency. Therefore, integrating qualitative descriptors with quantitative growth traits may improve the identification of tea genotypes with superior canopy architecture for subsequent breeding and clonal evaluation.

Understanding the relationships among morphological traits is important for identifying growth characteristics that develop simultaneously during post-pruning recovery. The positive correlation observed between shoot number, canopy diameter, and the number of primary branches indicates that these traits tended to increase together during vegetative regrowth. Likewise, the positive association between shoot length and canopy diameter suggests that longer shoot elongation complements a larger canopy expansion. In contrast, the weak negative correlation between branch number and branch diameter indicates a potential trade-off between branch proliferation and stem thickening (Table 4). Similar relationships among canopy components have also been outcomes in tea, where shoot architecture has the regulation of coordinated vegetative growth and post-

Table 4. The correlation between various parameters of tea.

Traits	Number of shoots	Shoot length	Diameter of canopy	Number of primary branches
Shoot length	0.29			
Diameter of canopy	0.60**	0.54**		
Number of primary branches	0.55**	-0.07	0.18	
Diameter of primary branches	-0.02	0.31	0.32	-0.30

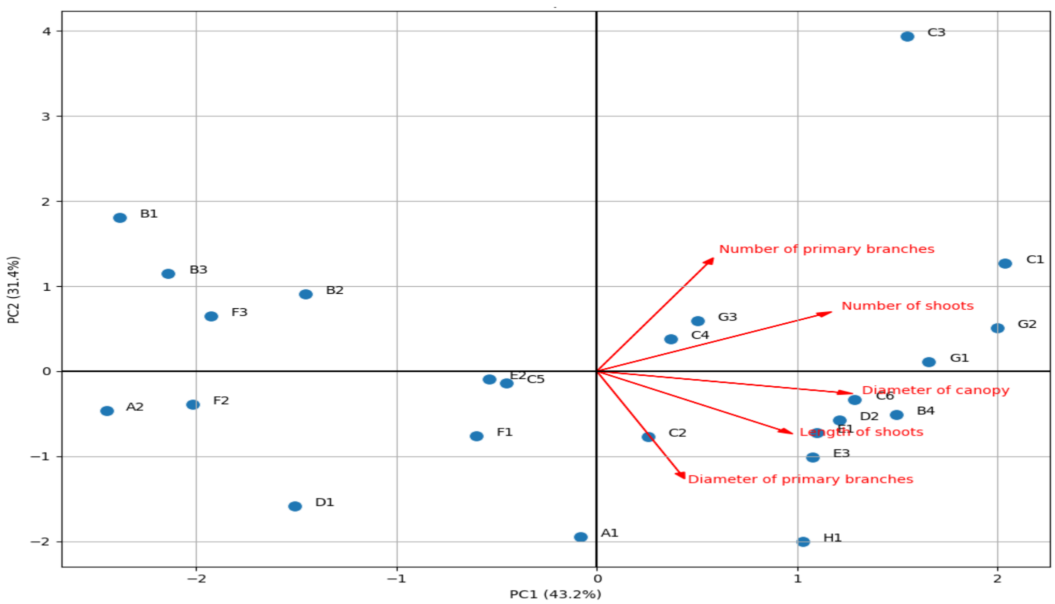

Figure 3. PCA biplot of 24 tea progenies based on shoot number, shoot length, canopy diameter, and branch characteristics.

pruning responses (Wang *et al*., 2018; Zhang *et al*., 2023). Comparable relationships have also occurred in reports on other perennial crops, where canopy traits are in positive association with morphological development (Kumar *et al*., 2023). These relationships provide useful information for identifying complementary morphological traits during early phenotypic evaluation of tea breeding materials.

Principal component analysis (PCA) provided a comprehensive overview of the relationships among evaluated morphological traits and facilitated the characterization of phenotypic variation among hybrid progenies. Reports stated similar applications of PCA in tea, where multivariate analysis effectively summarized phenotypic variation and identified the major traits contributing to genotype differentiation and germplasm characterization (Arefin *et al*., 2024) (Figure 3). In the latest study, PCA complemented the correlation analysis by simultaneously evaluating multiple growth traits, allowing a clearer characterization of post-pruning growth patterns among the hybrid progenies.

The promising study demonstrates that post-pruning shoot regeneration, canopy development, and qualitative morphological characteristics provide complementary information for the early evaluation of tea hybrid progenies. Together, these traits represent key morphological components associated with a desirable canopy ideotype after pruning. This integrative approach is consistent with the ideotype concept proposed by Donald (1968), in which combining multiple complementary traits could improve selection efficiency. Hybrid plants exhibiting rapid shoot regeneration, stable canopy development, and desirable plant architecture can be priorities for subsequent clonal evaluation before resource-intensive field testing. Similar approaches have had successful recommendations in tea breeding, where morphological characterization has become an essential component of germplasm evaluation and parent selection (Bandara *et al*., 2024). Given the commercial propagation of tea through cuttings, early identification of superior hybrid plants based on post-pruning performance may improve breeding efficiency by reducing the number of genotypes advanced to clonal propagation and long-term field evaluation. This strategy is consistent with previous studies showing that pruning response provides valuable information for selecting breeding materials with favorable vegetative characteristics (Akbar *et al*., 2014). Integrating quantitative growth traits with qualitative morphological descriptors could further improve the efficiency of early clonal selection and facilitate the identification of superior tea genotypes for subsequent field evaluation.

CONCLUSIONS

The tea hybrid progenies (*sinensis* × *assamica*) exhibited wide variation in shoot regeneration and canopy development after pruning. Among the evaluated progenies, Tambi-1 × Suka Ati-40 and Tambi-2 × Suka Ati-40 showed greater shoot regeneration and canopy development than the other hybrid combinations. The identified morphological traits represent key components of a desirable canopy ideotype and can be beneficial for early clonal selection of tea hybrid progenies before clonal propagation and field evaluation.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support provided by PT Pagilaran in facilitating access to plant materials. Funding support for this research came from the Indonesian Education Scholarship, the Center for Higher Education Funding and Assessment, the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, and the Indonesia Endowment Fund for Education.

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