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LINKING VEGETATIVE GROWTH, STOMATAL TRAITS, AND YIELD PERFORMANCE OF COWPEA (*Vigna Unguiculata* L.) VARIETIES UNDER DRY-ZONE CONDITIONS OF SRI LANKA

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ABSTRACT

Cowpea (Vigna unguiculata L.) is a vital legume crop in the Low Country Dry Zone of Sri Lanka, contributing to protein security and sustainable farming under moisture-limited conditions. This study evaluated vegetative growth, leaf anatomical traits, and yield performance of three cowpea varieties (MI 35, Dawala, and Waruni) in Batticaloa district, Sri Lanka. The experiment was laid out in a randomized complete block design with three replicates of 25 plants each, cultivated on 30 m² plots with 50 cm row spacing and 30 cm plant spacing. Growth parameters: plant height, number of branches, number of leaves, and leaf area index (LAI) were measured at 2, 4, and 6 weeks after planting (WAP). Grain yield was recorded at two harvests, and stomatal traits; density, guard cell dimensions, pore size, and stomatal ratio were assessed to evaluate varietal differences in adaptation. Data were subjected to analysis of variance (ANOVA), with mean comparisons performed at the 5% significance level using Minitab 17 version. Significant differences were observed among the cowpea varieties for vegetative growth, stomatal traits, and yield ($P<0.05$). MI 35 exhibited the greatest early vegetative vigor, reaching plant heights of 16.88 ± 0.43 cm at 2 WAP, 31.01 ± 0.85 cm at 4 WAP, and 17.72 ± 1.92 cm at 6 WAP, with corresponding leaf numbers of 8.90 ± 0.93, 27.12 ± 1.85, and 36.92 ± 1.99, and LAI values of 12.62 ± 1.59, 12.75 ± 1.62, and 33.00 ± 1.33. Despite this early vigor, Dawala produced the highest grain yield, ranging from 1,255–1,525 g/plot in the first harvest and 1,175–1,300 g/plot in the second harvest, likely due to its balanced canopy development, moderate stomatal density (2.440 ± 0.021 stomata/mm²), and conservative water-use traits. The variety Waruni reported the highest stomatal density (2.738 ± 0.123 stomata/mm²) and largest guard cell length (25.96 ± 1.25 µm), indicating potential for rapid gas exchange, but achieved intermediate grain yields of 830–870 g/plot and 915–950 g/plot in the first and second harvests, respectively. These findings highlight the importance of integrating vegetative vigor, stomatal functionality, and reproductive allocation when selecting cowpea varieties for dry-zone conditions

Key words: Cowpea, Varietal differences, Vegetative growth, Stomatal anatomy, Reproduction efficiency

INTRODUCTION

Cowpea (*Vigna unguiculata (L.) Walp*), commonly known as black-eyed pea, is an important legume crop with significant nutritional, agronomic, and ecological value in tropical and subtropical agroecosystems (Walp et al., 2024).Cowpea seeds and leaves are excellent sources of plant-based protein (20-30%), carbohydrates, vitamins, and essential minerals, making them crucial in addressing protein-energy malnutrition and micronutrient deficiencies in low-income populations, including rural communities in Sri Lanka (Abebe & Alemayehu, 2022).

Furthermore, the balanced amino-acid profile of cowpea complements cereal proteins, improving overall dietary quality when consumed with staples like rice or maize (Elhardallou et al., 2015).In Sri Lanka, cowpea is widely cultivated in dry and intermediate zones and is incorporated into traditional cropping systems both as a grain and a vegetable (Lanka et al., 2013).The crop ability to thrive under water-limited conditions and on low-fertility soils enhances its suitability for semi-arid regions like Batticaloa, characterized by erratic rainfall and frequent drought spells (Soujanya & Gurjar, 2024).

Drought tolerance stems from its adaptive physiology, enabling sustained growth and reproduction even under soil moisture deficits attributes that are increasingly valuable under climate change scenarios (Nunes et al., 2022).Beyond nutritional security, cowpea plays a critical role in sustainable agricultural systems through biological nitrogen fixation (Shevkani et al., 2025).With symbiotic rhizobia in root nodules, cowpea can fix atmospheric nitrogen, improving soil fertility and reducing reliance on external nitrogen fertilizers (Hui et al., 2025).Enhancing soil nitrogen not only improves the productivity of subsequent crops but also contributes to soil health and ecosystem functioning, particularly in the degraded and nutrient-poor soils common in Eastern Sri Lanka (Hui et al., 2025).These features make cowpea an essential component of crop rotation, intercropping, and sustainable intensification strategies designed to support smallholder livelihoods (Kim et al., 2025).Despite its importance, yield stability and performance of cowpea varieties vary spatially due to genotype × environment interactions, making region-specific evaluation essential to identify varieties that match local agroecological conditions (Ndenkyanti et al., 2022).

Vegetative traits like plant height, branch number, leaf number, and leaf area index are key indicators of early growth vigor and canopy development that influence light interception, biomass accumulation, and ultimately grain yield (Abebe & Alemayehu, 2022) However, variability in these traits among cowpea genotypes has been documented, underscoring the need for targeted evaluation for specific regions like Batticaloa.

In Sri Lanka, limited research has investigated the variability of cowpea genotypes across diverse climatic zones, particularly in the Eastern Province. Most studies have focused on drought responses at critical growth stages (e.g., flowering) or general cultivation patterns rather than comparative performance of widely grown varieties such as Dawala, Waruni, and MI 35 under local conditions (Camarero et al., 2025).

Moreover, existing literature often lacks comprehensive integration of vegetative growth parameters with yield outcomes, creating a research gap in understanding how early growth dynamics predict final yield performance in drought-prone landscapes of Sri Lanka (Unguiculata, 2019).Given these gaps, our study aimed to evaluate growth and yield performance of three cowpea varieties in Batticaloa, focusing on vegetative growth variables alongside yield data to determine the best-adapted variety for sustainable production in this region. This research not only provides empirical insights for local variety recommendation but also contributes to climate smart legume production strategies critical for food security, soil fertility management, and farmer livelihoods in Eastern Sri Lanka.

MATERIALS AND METHODS

Experimental Location

The experiment was conducted in the Batticaloa District of the Eastern Province, Sri Lanka, which falls within the Low Country Dry Zone agro-ecological region. The experimental site is characterized by a tropical dry climate with distinct wet and dry seasons. Rainfall is predominantly received during the Northeast monsoon, while the remaining months experience relatively dry conditions. The region experiences comparatively high temperatures throughout the year, with warm daytime conditions favorable for legume cultivation. Soils in the area are generally sandy to sandy loam in texture and are considered low in inherent fertility, which is typical of agricultural lands in the Eastern Province. These agro-climatic conditions make the region well suited for cowpea *(Vigna unguiculata* L.*)* cultivation and provide an appropriate environment for evaluating varietal performance and treatment effects under dry-zone conditions.

Planting Materials

Three cowpea (*Vigna unguiculata* L.) varieties*, MI 35, Dawala,* and *Waruni,* were obtained from the Legumes and Oil Crops Research Centre, Angunakolapelessa, Sri Lanka.

Experimental Design

The experiment was conducted in treatment plots of 30 m² arranged in a randomized complete block design (RCBD) with three replicates. Each replicate consisted of twenty-five plants, with spacing maintained at 45 cm between rows and 30 cm between plants within rows,and all experimental units were maintained under uniform agronomic and environmental conditions throughout the study period (Yala Season).

Crop Management and Establishment

Cowpea (*Vigna unguiculata* L.) seeds were directly sown in the field at the recommended spacing during the Yala season. Irrigation was applied every four days during the first three weeks after sowing and subsequently every seven days, with special attention given to the flowering and pod-filling stages. All land preparation, irrigation, weed, pest, and disease management practices were carried out according to the recommendations of the Department of Agriculture (DOA), Sri Lanka, and were maintained uniformly across treatments throughout the experimental period.

Data Collection

Growth parameters were recorded at 2, 4, and 6 weeks after planting (WAP). Plant height (PH), number of branches per plant (NB), number of leaves (NL), and leaf area index (LAI) were measured, while yield performance was assessed through first and second grain harvests. Stomatal characteristics were determined using the clear nail polish impression technique. Fully expanded leaves were collected from the abaxial (lower) surface of randomly selected plants within each variety during morning hours. A thin layer of transparent nail polish was applied and allowed to dry, after which the impression was carefully removed and mounted on glass slides. Stomatal observations were conducted under a compound light microscope at 40× magnification, and the number of stomata per microscopic field was recorded (Wu & Zhao, 2017;Idris et al., 2019).

Statistical Analysis

Data was tested for normality to satisfy the assumptions of ANOVA. Subsequently, analysis of variance (ANOVA) was performed to determine significant differences among cowpea varieties. Mean separation was performed using Tukey's honestly significant difference (HSD) test. Results are presented as mean ± standard error (SE), and differences among means were considered significant at the 5% probability level ($p \leq 0.05$).

RESULTS

Evaluation of Morphological traits

Plant height

Plant height differed significantly among the three cowpea varieties at 2, 4, and 6 weeks after planting (WAP) ($p < 0.001$; Figure 1). At 2 WAP, *MI 35* recorded the greatest plant height (16.88 ± 0.43 cm), followed by *Waruni* (4.84 ± 1.33 cm) and *Dawala* (3.68 ± 0.94 cm). This varietal trend persisted at 4 WAP, with MI 35 remaining markedly taller (31.01 ± 0.85 cm), while comparatively lower heights were observed in *Waruni* (16.48 ± 2.25 cm) and *Dawala* (11.20 ± 1.04 cm). At 6 WAP, MI 35 continued to exhibit the highest plant height (17.72 ± 1.92 cm), whereas *Waruni* (13.28 ± 0.98 cm) and *Dawala* (14.40 ± 1.15 cm) showed reduced growth relative to *MI 35*. The consistently superior early and mid-stage growth of *MI 35* suggests greater vegetative vigor and better adaptation to the low soil fertility and moisture-limited conditions characteristic of the Batticaloa Low Country Dry Zone, indicating its suitability for cultivation under dry-zone agro-ecological conditions.

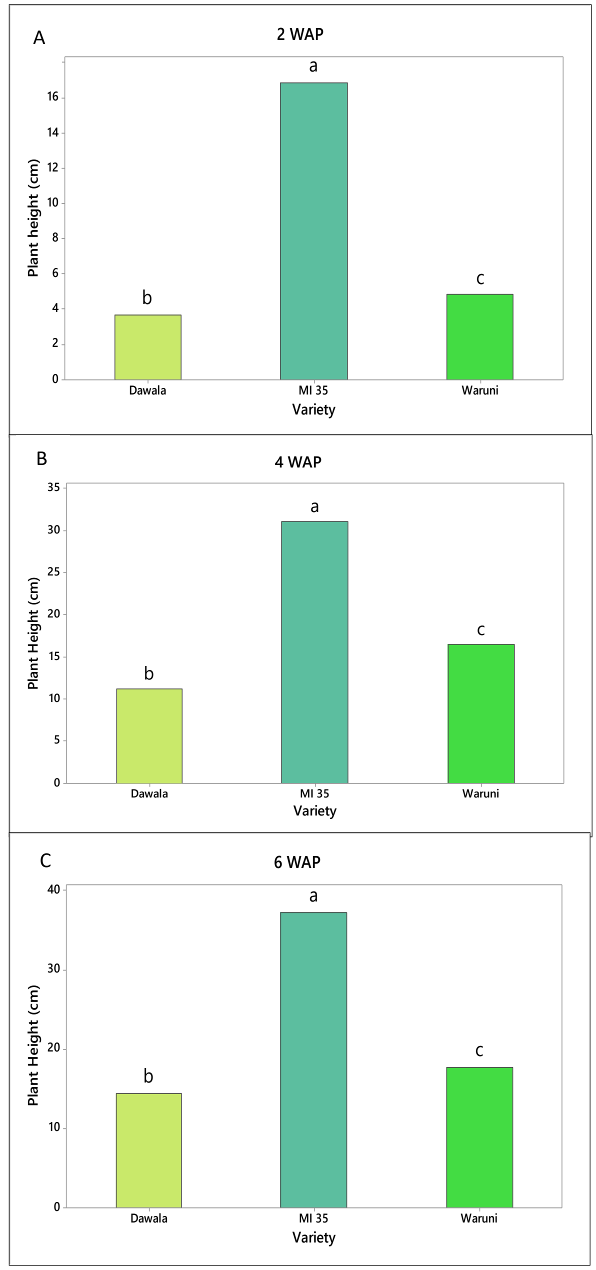

Figure 1. Variation in plant height of selected cowpea (*Vigna unguiculata* L.) varieties measured at 2(A), 4 (B) ,and 6 weeks (C) after planting (WAP)

Number of Leaves

There was significant variation in the number of leaves among the tested cowpea varieties. Across all growth stages (2, 4, and 6 WAP) (Figure 2), *MI 35* consistently exhibited the highest leaf number, recording 8.90 ± 0.93 at 2 WAP, 27.12 ± 1.85 at 4 WAP, and 36.92 ± 1.99 at 6 WAP, all significantly higher than *Dawala* (2.52 ± 0.51, 12.40 ± 1.12, 21.28 ± 1.45) and *Waruni* (2.32 ± 0.47, 11.68 ± 1.20, 20.84 ± 1.32) ($p < 0.001$).

Dawala and *Waruni* did not differ significantly from each other at any stage. The consistently greater leaf production of *MI 35* suggests superior vegetative vigor, potentially enhancing photosynthetic capacity and supporting better adaptation under the low fertility and moisture-limited conditions of the Batticaloa Low Country Dry Zone.

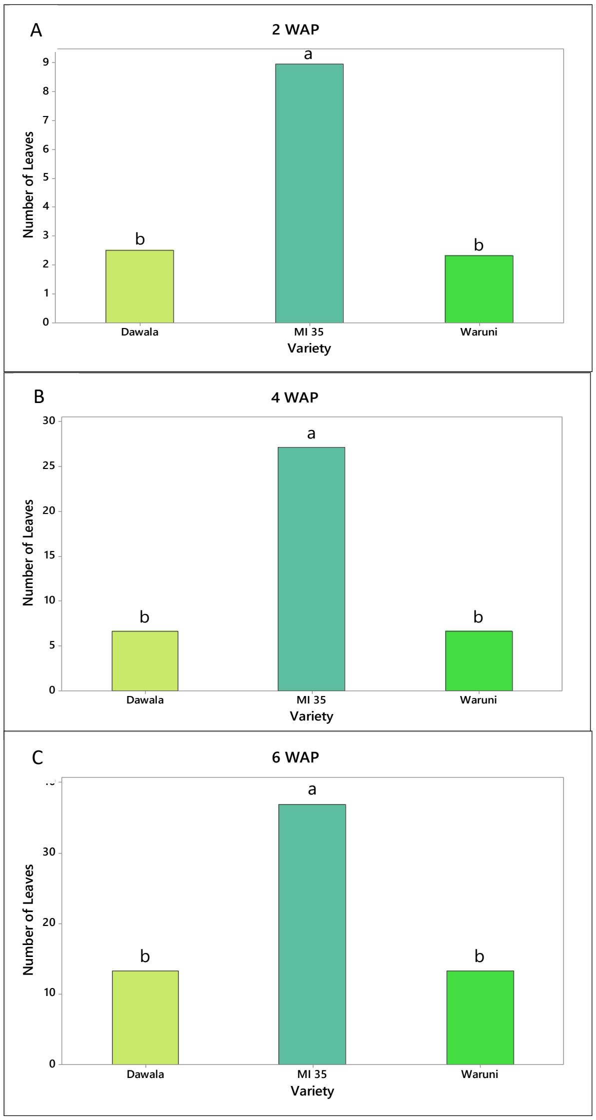

Figure 2. Variation in the number of leaves of selected cowpea (*Vigna unguiculata* L.) varieties measured at 2(A), 4 (B), and 6 weeks (C) after planting (WAP)

Number of branches

Branch development was not observed at 2 weeks after planting (WAP), indicating that the plants were still in the early vegetative growth stage. Significant differences among varieties were observed at 4 WAP ($p = 0.006$) (Figure 3), with *MI 35* producing a significantly higher number of branches (2.84 ± 0.37) compared to *Dawala* and *Waruni*. By 6 WAP, MI 35 maintained a higher mean number of branches (4.28 ± 0.67), although the differences among the varieties were no longer statistically significant ($p = 0.122$). These results suggest that *MI 35* exhibits earlier branching, which may contribute to enhanced vegetative vigor and potential yield advantages under the low fertility and moisture-limited conditions of the Batticaloa Low Country Dry Zone.

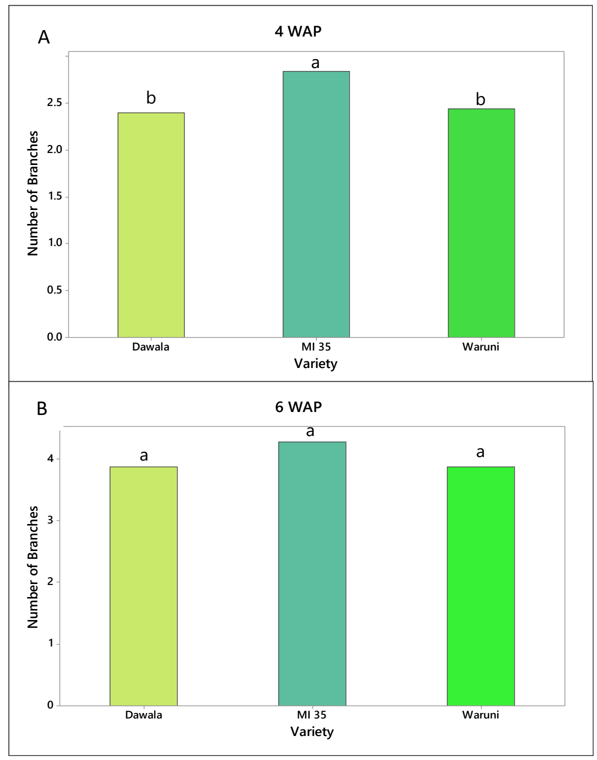

Figure 3. Variation in the number of branches of selected cowpea (*Vigna unguiculata*) L.) varieties at 4 (A), and 6 weeks (B) after planting (WAP)

Leaf area index

Leaf area index (LAI) exhibited significant varietal differences at 2 and 6 weeks after planting (WAP), while no significant variation was observed at 4 WAP. At 2 WAP, Waruni recorded the highest LAI (14.86 ± 2.42), which was significantly greater ($p < 0.001$) than *MI 35* (12.62 ± 1.59) and *Dawala* (12.62 ± 1.59). At 4 WAP, LAI values were comparable among all varieties ($p = 0.901$).

By 6 WAP, *MI 35* achieved the highest LAI (33.00 ± 1.33), followed closely by *Waruni* (32.26 ± 1.39), whereas *Dawala* recorded the lowest value (32.00 ± 1.42), with differences among varieties being statistically significant ($p = 0.036$) (Figure 4). Higher

MI 35 values were observed at later growth stages, which may be associated with better plant growth performance, which may enhance light interception and photosynthetic efficiency, supporting improved adaptation to the low fertility and moisture-limited conditions of the Batticaloa Low Country Dry Zone.

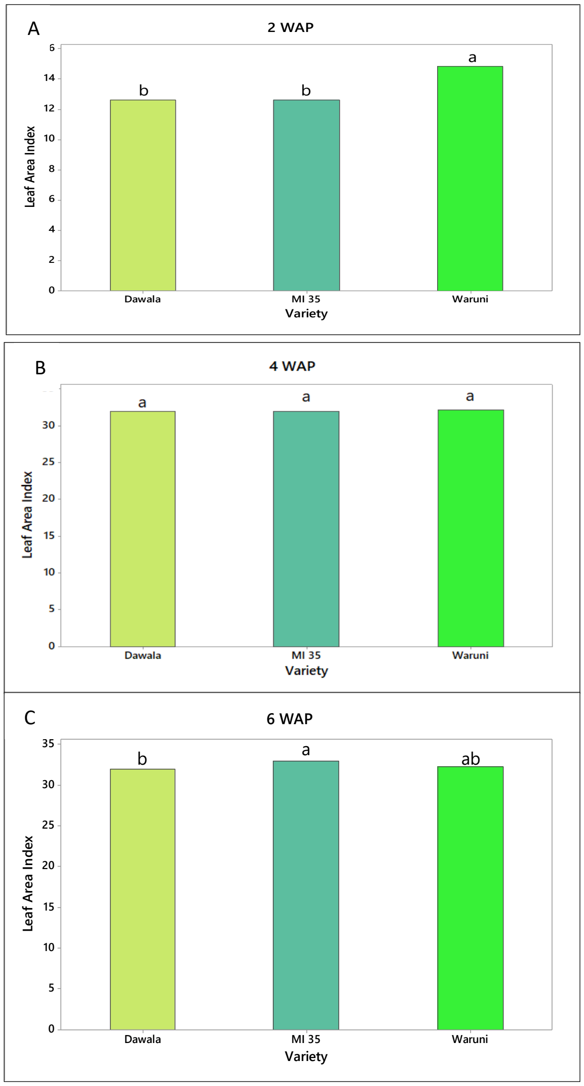

Figure 4. Variation in leaf area index of selected cowpea (*Vigna unguiculata* L.) varieties measured at 2(A), 4 (B), and 6 weeks (C) after planting (WAP)

Stomatal Traits

Stomatal traits, which regulate gas exchange and water loss, showed significant variation among the tested cowpea varieties, reflecting differences in potential photosynthetic efficiency and adaptation strategies (Figure 5).

Stomatal density, expressed as the number of stomata per mm², was highest in *Waruni* (2.738 ± 0.123), followed closely by *MI 35* (2.710 ± 0.054) and *Bombe* (2.652 ± 0.113), indicating a higher potential for CO_2 assimilation. In contrast, *ANKCP1* (2.275 ± 0.215) and *Dawala* (2.440 ± 0.021) recorded lower stomatal densities, suggesting a more conservative water-use strategy, while *MICP1* (2.616 ± 0.095) showed intermediate density.

Guard cell dimensions, a key determinant of stomatal opening capacity, also varied significantly among varieties. *Waruni* exhibited the longest guard cells (25.96 ± 1.25), whereas *Bombay* (19.23 ± 0.29) and *MICP1* (18.79 ± 0.38) had shorter cells. Guard cell width varied only slightly (8.558 ± 0.48 µm in *Bombay* to 9.03 ± 0.21 µm in *ANKCP1)*, indicating that length was the main contributor to functional differences. Larger guard cells in *Waruni* may facilitate faster stomatal opening and increased transpiration under favorable conditions, while shorter guard cells in *MICP1* and *Bombay* may reduce water loss, representing an adaptive response to dry conditions.

Pore dimensions, reflecting the functional aperture of the stomatal complex, showed notable varietal differences. *ANKCP1* and *Waruni* had the widest pores (4.017 ± 0.25 and 3.960 ± 0.27, respectively), whereas *MICP1* had narrower pores (3.474 ± 0.27). Pore length followed a slightly different pattern, with *MICP1* having the longest pores (13.248 ± 0.57) despite lower width, suggesting an elongated, narrow aperture that may influence transpiration differently from broader, shorter pores. *Dawala* and *Bombay* exhibited intermediate pore lengths, indicating moderate stomatal functionality. These differences highlight varietal strategies for balancing CO_2 uptake with water conservation, a key consideration in the low-fertility, moisture-limited conditions of Eastern Sri Lanka.

Stomatal ratio further emphasized varietal adaptation. The variety *Waruni* had the highest ratio (2.920 ± 0.17), suggesting stomata are concentrated on the abaxial surface to reduce direct evaporative water loss while maintaining photosynthetic efficiency.

The variety *MICP1* had the lowest ratio (2.102 ± 0.11 C), indicating a more uniform stomatal distribution, which may favor balanced gas exchange under moderate conditions.

The *Waruni* and *ANKCP1* exhibited stomatal traits conducive to high gas exchange, with large guard cells, wide pores, and high stomatal ratios, potentially supporting enhanced growth and stress tolerance. Conversely, *Dawala* displayed traits favoring water conservation, consistent with its superior yield performance under the Batticaloa Low Country Dry Zone. *MI 35*, while having high vegetative vigor and moderate stomatal density, demonstrated a trade-off between early growth potential and final grain yield under low-input, dry-zone conditions.

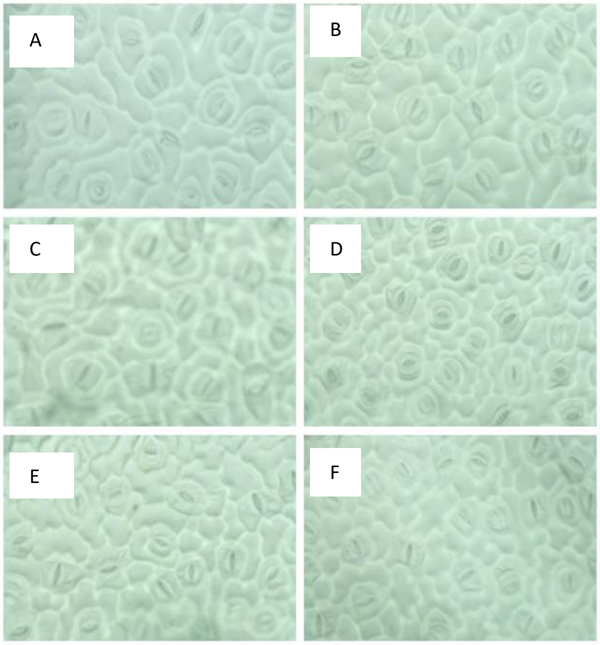

Figure 5. Stomatal characteristics of selected cowpea (*Vigna unguiculata* L.) varieties, A-*ANKCP1* B-*WARUNI* C-*BOMBAY* D-*MI35* E-*DAWALA* F-*MICP1*

Yield and Productivity

Yield performance differed significantly among the three cowpea (*Vigna unguiculata* L.) varieties cultivated in 30 m² plots arranged in a randomized complete block design (RCBD) with three replicates ($p < 0.001$; Figure 5). *MI 35* produced the lowest average yield per plot, with 400 ± 12 g in the first harvest and 750 ± 15 g in the second harvest. *Waruni* exhibited intermediate yields, averaging 850 ± 20 g in the first harvest and 933 ± 18 g in the second harvest, whereas *Dawala* recorded the highest yields, with 1,390 ± 35 g in the first harvest and 1,238 ± 28 g in the second harvest, (Figure 6) indicating statistically significant superiority over the other two varieties.

The yield trends are closely linked to vegetative growth characteristics. *MI 35* displayed superior early vegetative vigor, with higher plant height, leaf number, and leaf area index. However, its relatively low branching and compact canopy likely limited pod formation and grain accumulation. In contrast, *Dawala*, which showed moderate early vegetative growth, developed a more balanced canopy structure and greater branching at later stages, supporting higher pod set and grain production. *Waruni* exhibited intermediate vegetative growth and yield performance. Similar results were reported by (Muhaijeer et al. et al., 2008), who observed significant differences in growth and yield among cowpea cultivars grown in sandy regosols of Batticaloa, emphasizing the importance of selecting suitable cultivars for dry-zone conditions. While early vegetative vigor can aid establishment under challenging conditions, canopy architecture, branching pattern, and pod formation capacity are critical determinants of final grain yield. For local farmers, *Dawala* represents a high-yielding variety suited to the dry-zone environment, offering both improved productivity and resilience under low-input conditions, which can contribute to enhanced food security and farm income in the region.

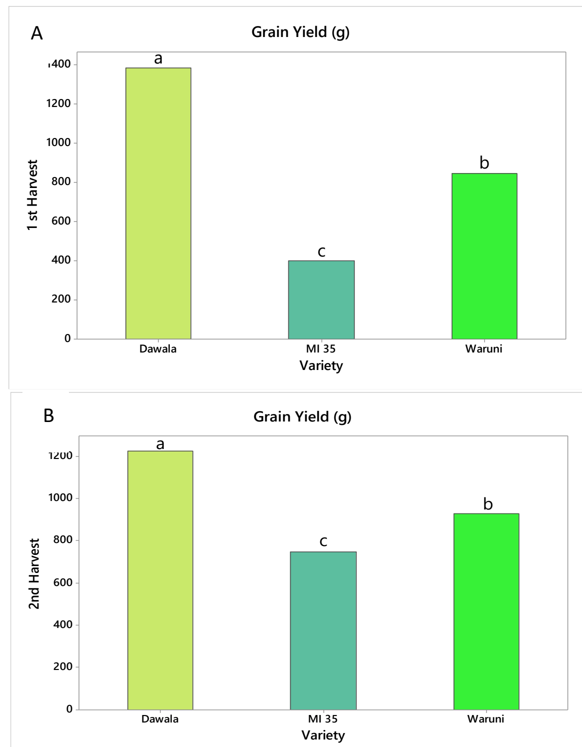

Figure 6. Average grain yield per 30 m² plot of selected cowpea (*Vigna unguiculata* L.) varieties in first (A) and second harvests (B)

DISCUSSION

This study demonstrated significant varietal differences in vegetative growth, stomatal traits, and grain yield among selected cowpea (*Vigna unguiculata L.*) varieties grown under Batticaloa Low Country Dry Zone conditions. The observed variations align with previous Sri Lankan research indicating that cowpea performance is highly dependent on varietal characteristics and management conditions.

The present findings are consistent with the results reported by (Muhaijeer et al. et al., 2008), who observed significant differences in growth and yield among cowpea (*Vigna unguiculata*) cultivars cultivated in the sandy regosols of the Batticaloa district. Their study highlighted the importance of varietal adaptability to low-fertility sandy soils in improving productivity under dry-zone conditions. Similarly, in the present study, significant variation was observed among the tested cultivars in vegetative growth, stomatal traits, and grain yield, confirming that varietal selection plays a crucial role in enhancing cowpea performance in the Low Country Dry Zone of Sri Lanka.

Consistent with earlier findings on root and morphological traits, cowpea varieties exhibit substantial differences in early growth and yield component traits under stress conditions.(Santos et al., 2020) reported that root morphology was closely associated with yield potential, particularly under moisture stress, suggesting inherent varietal differences in water and nutrient acquisition strategies that influence above-ground growth and productivity. In our study, *MI 35* exhibited strong early vegetative vigor (height, leaf number, and LAI), a trait that may be linked to resource acquisition strategies highlighted in root trait research. However, *MI 35*'s vigor did not translate into the highest yield, indicating that early vegetative investment alone may not guarantee reproductive success under dry-zone stress.

Regarding plant growth performance and yield, intercropping arrangement research showed that spatial patterns significantly influence cowpea growth and yield, underlining the importance of plant growth performance and light interception in yield formation (Banjara et al., 2022). In our results, *Dawala* developed a more balanced canopy and branching pattern, which likely enhanced pod set and grain yield, consistent with these earlier observations.

Stomatal traits play a critical role in balancing carbon assimilation and water loss, particularly under dry-zone conditions. (Wijayaraja et al., 2023) found that water stress during the flowering stage significantly affected leaf gas exchange and hydraulic traits, leading to reduced yields in cowpea varieties, with some varieties like *Waruni* being more resilient due to maintenance of functional leaf traits under stress. Our observation that *Waruni* and *ANKCP1* had high stomatal density and functional pore characteristics suggests enhanced potential for gas exchange, which may support growth under moderate stress but could also increase water loss under severe dry conditions. In contrast, *Dawala* exhibited comparatively lower stomatal density and intermediate leaf anatomical characteristics. This conservative stomatal behavior may have reduced excessive water loss, thereby improving water-use efficiency under moisture-limited conditions of the Batticaloa Low Country Dry Zone. Such a strategy likely enabled *Dawala* to maintain better physiological stability during the reproductive stage, ultimately contributing to superior grain yield. These findings are consistent with previous reports indicating that varieties with moderated stomatal density and improved water-use efficiency perform better under dry-zone stress conditions (Wijayaraja et al., 2023).

Soil fertility and nutrient management have been shown to significantly influence cowpea growth and yield in Sri Lanka. For instance, (Priyadharshini & Seran, 2010) demonstrated that paddy husk ash application improved yield components, emphasizing the role of potassium in supporting reproductive growth. Similarly, (Lanka et al., 2023) found that organic amendments such as cow dung and jeewamirtha enhanced vegetative growth and yield, illustrating the importance of balanced nutrient supplies for optimal performance. These findings suggest that varietal differences in nutrient responsiveness may also contribute to observed yield variation in our experiment.

Moisture stress research in Sri Lanka has repeatedly underscored the need for varieties that maintain gas exchange and leaf function under limited water availability. (Wijayaraja et al., 2023) emphasized that reductions in leaf functional traits directly influenced yield parameters under mild stress, reinforcing the importance of stomatal and hydraulic traits for resilience. The stomatal data support this concept: stomatal traits of *Waruni* variety may support sustained photosynthesis in intermittent dry periods, whereas *Dawala* conservative stomatal configuration likely contributed to better water retention and higher grain yield under prolonged dry conditions.

Breed improvement and varietal selection studies have highlighted the genetic variability present in Sri Lankan cowpea germplasm and the potential for enhancing adaptation and productivity through targeted breeding (Fiscus et al., 2024; Lanka, 2016). The significant differences observed in stomatal, vegetative, and yield traits in our study underscore the importance of germplasm diversity in addressing Dry Zone challenges. Genetic variability studies also emphasize the value of selecting varieties with specific morpho-physiological traits to improve yield stability in marginal environments (Begna & Teressa, 2024).

The practical implications for farmers in the Dry Zone are clear. Varietal selection should not only emphasize early vigor and fast growth but also focus on traits that enhance water-use efficiency and reproductive success under moisture stress. Grain yield of *Dawala* variety under Batticaloa conditions suggests that conservative stomatal behavior, balanced canopy architecture, and efficient resource allocation are key determinants of productivity. This supports the recommendation of cowpea varieties that maintain functional traits under stress for inter-season cultivation and residual moisture utilization, as suggested by earlier Sri Lankan studies on moisture stress tolerance in cowpea (Wijayaraja et al., 2023). There has been increasing interest in sustainable agricultural practices in modern agriculture, with many studies exploring the use of organic inputs as environmentally friendly alternatives (Kasthurirathna et al., 2025; Kumarasena et al., 2025; Pushpakumari et al., 2023; Wijesundara et al., 2025; Wijesundara et al., 2026).

Future research should integrate stomatal and root trait analysis with physiological assessments of water-use efficiency and nutrient uptake dynamics, building on existing Sri Lankan findings that link morphological traits to yield outcomes. Multi-locational trials across dry-zone microclimates would further validate varietal adaptability and support the development of region-specific agronomic recommendations.

CONCLUSIONS

The present study revealed significant varietal differences in growth, yield, and stomatal anatomical traits among the evaluated cowpea varieties cultivated under the water limited conditions of Eastern province, Sri Lanka. These differences highlight the strong influence of genotypic variability on physiological performance, assimilate partitioning, and yield formation.

The variety *MI 35* exhibited vigorous vegetative growth characterized by greater plant height, leaf number, and higher stomatal density, indicating high photosynthetic potential. However, this did not translate into higher yield, suggesting inefficient assimilate allocation toward reproductive organs. In contrast, *Dawala* recorded the highest yield, which can be attributed to superior reproductive efficiency, balanced vegetative growth, and moderate stomatal characteristics that favor effective water-use regulation and sustained pod development under field conditions.

The variety *Waruni* showed anatomical traits associated with high gas exchange capacity, including larger guard cells, wider stomatal pores, and a higher stomatal ratio, suggesting strong physiological activity.

The integration of growth, yield, and stomatal traits indicates that optimal cowpea productivity depends not only on enhanced photosynthetic capacity but also on efficient assimilate partitioning and balanced stomatal regulation. The variety *Dawala* emerges as a promising variety for higher yield under the tested planting density and environmental conditions.

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