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Morpho-Phenological Characterization and Growth of Cowpea *(Vigna unguiculata (L.) Walp.)* from Tanimbar Islands under High Humidity Conditions

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ABSTRACT

Cowpea (Vigna unguiculata (L.) Walp.) is an important legume crop with high adaptability to tropical environments. This study aimed to evaluate morpho-phenological traits, vegetative growth, and yield components of seven local cowpea accessions from the Tanimbar Islands under high-humidity conditions. The experiment was conducted from June to September 2025 at the Experimental Field of the Faculty of Agriculture, Universitas Pattimura, Ambon, using seven local accessions (KTM 9, KTM 12, KTM 13, KTM 16, KTM 17, KTM 19, and KTM 20) and one comparison variety (Arghavan IPB). Quantitative data were analysed using ANOVA followed by Tukey HSD at a 5% significance level. The results showed significant differences among genotypes in growth and yield variables. KTM 19 exhibited strong vegetative vigour; KTM 13 showed superior pod length and number of seeds per plant; and KTM 20 produced the highest number of seeds per pod. KTM 16 demonstrated the best production performance, with the highest seed weight per plant and 100-seed weight, indicating good adaptation to humid tropical conditions. In contrast, KTM 12 showed the lowest performance due to disease pressure and poor reproductive development. Based on the results, the findings indicate substantial genetic variability among Tanimbar local germplasm and highlight KTM 16 as a promising genotype for cowpea breeding programs targeting humid tropical environments.

INTRODUCTION

Indonesia, as one of the world's megabiodiversity countries, possesses extensive genetic diversity of local food crops, including cowpea (Vigna unguiculata (L.) Walp.). Cowpea originated from Africa, although its exact centre of domestication remains uncertain. West Africa is considered the primary centre of domesticated cowpea distribution, while India is regarded as a secondary centre of diversity due to its high genetic variability (Ng & Padulosi, 1988; Pant et al., 1982). Cultivated cowpeas are generally classified into five cultivar groups, namely unguiculata, sesquipedalis, textiles, melanophthalmus, and biflora (Konan et al., 2021).

Cowpea is a potential source of plant-based protein because it contains approximately 22.90% protein, low fat content, relatively high methionine levels, and no toxic antimetabolic compounds, making it suitable as a nutritious food source (Ismayanti & Harijono, 2015). Besides being consumed as food, cowpea also has potential as green manure and as a raw material for fermented products such as tempeh (Haliza, 2008).

Cowpea has relatively good adaptability to drought and high temperatures compared with many other crops (Ehlers et al., 1997). However, environmental changes, particularly high humidity conditions, may influence physiological processes, growth, and productivity. High humidity can reduce transpiration efficiency, impair gas exchange, and increase the risk of pest and disease attacks, including Bemisia tabaci, which transmits mosaic and chlorosis viruses (Taiz & Zeiger, 2015). Therefore, identifying cowpea genetic resources that are adaptive to humid environments is important. Indonesia possesses abundant cowpea germplasm resources, including local accessions from Tanimbar that are reported to have good adaptation to specific environmental conditions (Nugraha & Suwarto, 2019).

According to FAOSTAT (2022), global cowpea production reaches approximately 9.8 million tons annually, with Africa as the main production centre. In Indonesia, cowpea cultivation covers approximately 702,163 hectares, with an average yield of 1.17 t ha^{-1}. However, information on cowpea cultivation in Maluku remains limited, although several local accessions have been previously reported and evaluated (Afitu et al., 2016). Hetharie et al. (2009) also reported that local cowpea cultivation in Southwest Maluku Regency is still conducted traditionally and highly depends on environmental conditions.

Studies on cowpea phenology and growth are important for understanding plant life cycles, determining optimal planting and harvesting periods, and improving cultivation efficiency (Craufurd et al., 2009). Phenology is closely related to environmental adaptation and productivity, particularly during the reproductive stage (Ehlers et al., 1997). In addition, growth traits such as plant height, leaf number, and biomass allocation reflect interactions between genetic and environmental factors and may influence crop productivity (Poorter et al., 2012). Therefore, studies on cowpea phenology, growth, and production are important for identifying adaptive genotypes and supporting sustainable crop development under humid tropical conditions.

METHODS

Materials

This study used eight plant types, namely seven accessions of winged bean (KTM 9, KTM 12, KTM 13, KTM 16, KTM 17, KTM 19, and KTM 20) and one control variety, Arghavan IPB. The polybags measured 50 x 40 cm, and the growing medium used was natural topsoil without the addition of base fertilizer, lime, or pesticides.

Some of the tools used in this study included: a hoe, a bucket, and a small shovel for filling the polybags with the growing medium; a measuring stick or ruler for measuring plant height; and a digital scale for weighing the harvest.

Methods

The study was conducted using a polybag planting system and arranged in a Randomized Complete Block Design (RCBD) with 8 genotypes as treatments and 3 replicates, resulting in 24 experimental units. Each experimental unit consisted of one polybag planted according to the treatment, with randomization performed within each group. Four planting holes were made in each polybag, and two seeds were planted in each hole. Thinning was carried out 7 Days After Planting (DAP), leaving two healthy plants per polybag as sample plants, resulting in a total of 48 plants observed.

To determine weather conditions during the study, data were obtained from the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) via the observation station at Pattimura Airport, Laha on Ambon Island, which is the station closest to the study site. Weather data included daily relative humidity, rainfall, and sunshine duration. The climate data used covered the period from the start of planting to the end of harvest, specifically from June 27, 2025, to September 24, 2025.

The observed research parameters included phenological stages, comprising germination, cotyledon, true leaf, full vegetative stage, flowering, fruiting, and maturation. The observed morphological characteristics include pod shape, pod color, pod length, growth traits, seed shape, and seed color. Vegetative growth was analyzed to include plant height during the first seven weeks, number of branches, and number of leaves. Observed production and yield components included the day of flowering onset, number of flowers, number of pods, pod length and color, average number of seeds per pod, number of seeds per plant, weight of 100 seeds, seed weight per plant, harvest onset age, and number of pods per plant.

Qualitative data were processed descriptively and tabulated using MS Excel. Quantitative data were analyzed using ANOVA General Linear Model (GLM) and Tukey HSD post-hoc tests (α = 5%)

using the cloud-based statistical analysis platform SASoD (Statistical Analysis Software on Demand). Additionally, quantitative data were visualized in graphical form using Minitab software.

RESULTS AND DISCUSSION

Weather Conditions During the Study

Based on BMKG data from June 27 to September 24, 2025, weather conditions during the study period were dominated by stable high humidity ranging from 90.3% to 91.8%. Rainfall experienced extreme fluctuations, peaking during the period from July 27 to August 25 with an average of 1,394.5 mm, driven by exceptionally high rainfall of 853.9 mm during the sixth decadal period. Sunshine duration was very low, at only 0.47 hours in the early period, 0.8 hours in the middle period, and 0.96 hours in the late period, with a value of 0 hours in the ninth decadal period. Overall, cloudy and wet weather dominated throughout the study period.

Results

The observations in this study included qualitative and Number of Flowers at Week, as well as plant phenological stages. Qualitative traits were visually assessed on leaves, stems, flowers, pods, and seeds to examine their shape and morphological characteristics, thereby providing an initial overview of the diversity among genotypes. Number of Flowers at Week were measured using growth variables such as plant height, number of leaves, branches, flowers, and pods, which were then analyzed using ANOVA and Tukey’s post-hoc test to identify significant differences among genotypes and visualized in graphical form, also yield variables were also analyzed using ANOVA and Tukey’s post-hoc test. Additionally, phenological stages were recorded from germination to maturity, revealing variations in the timing of growth and reproductive phase attainment among genotypes. These observations provide a strong foundation for understanding morphological diversity, growth performance, and the developmental dynamics of cowpea plants under high-humidity conditions.

Qualitative characteristics of the cowpea

The results of observations on qualitative morphological characteristics—including leaf shape and color, stem cross-section and properties, flower color, and pod and seed characteristics—are presented in Table 1.

Table 1. Morphological Characteristics of Cowpea from the Tanimbar Accession and High-Yielding Varieties

No	Parts of a Plant	Genotype							
		Arghavan IPB	KTM - 9	KTM - 12	KTM - 13	KTM - 16	KTM - 17	KTM - 19	KTM - 20
1.	Leaf								
	- Leaf Type	Trifoliate	Trifoliate	Trifoliate	Trifoliate	Trifoliate	Trifoliate	Trifoliate	Trifoliate
	- Leaf Color	Green	Green	Green	Green	Green	Green	Green	Green
2.	Stem								
	- Stem cross-sectional shape	Circular	Circular	Circular	Circular	Circular	Circular	Circular	Circular
	- Stem Habit	Semi-Erect	Semi-Erect	Semi-Erect	Semi-Erect	Semi-Erect	Semi-Erect	Semi-Erect	Semi-Erect
3.	Flower								
	- Flower Color	White-Purple	White-Purple	White-Purple	White-Purple	White-Purple	White-Purple	White-Purple	White-Purple
4.	Pod								
	- Pod Color	Green	Green	Green	Green	Green	Green	Green	Green
	- Pod Shape	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical
5.	Seed								
	- Seed Color	Brown	Brown and tan	Brown	Red	Brown	Tan with brown mottled	Tan	Red with brown mottled
	- Seed Shape	Kidney	Ovoid	Rhomboid	Rhomboid	Rhomboid	Kidney	Ovoid	Kidney

Table 1 shows that most morphological characters of Tanimbar cowpea accessions and the superior variety Arghavan IPB were similar, including trifoliate leaf type (Figure 1), circular stem cross-sectional shape, semi-erect to twining stem habit, white-purple flower color, and cylindrical green pods. These similarities indicate that all genotypes shared relatively uniform basic morphological traits.

Figure 1. Leaf Type of eight genotypes at 31 days after planting; a) KTM – 20 ;b) KTM – 12; c) KTM – 16; d) Arghavan IPB; e) KTM – 13; f) KTM – 17; g) KTM – 9; h) KTM – 19.

The main differences were observed in seed characteristics, particularly seed color and shape. Arghavan IPB had brown kidney-shaped seeds, whereas the Tanimbar accessions exhibited greater variation, including ovoid, rhomboid, and kidney-shaped seeds. Seed color among the Tanimbar accessions also varied widely, ranging from brown, brown and tan, tan with brown mottled, tan, to red with brown mottled. This diversity in seed characteristics became the main morphological feature distinguishing the Tanimbar accessions from the national superior variety.

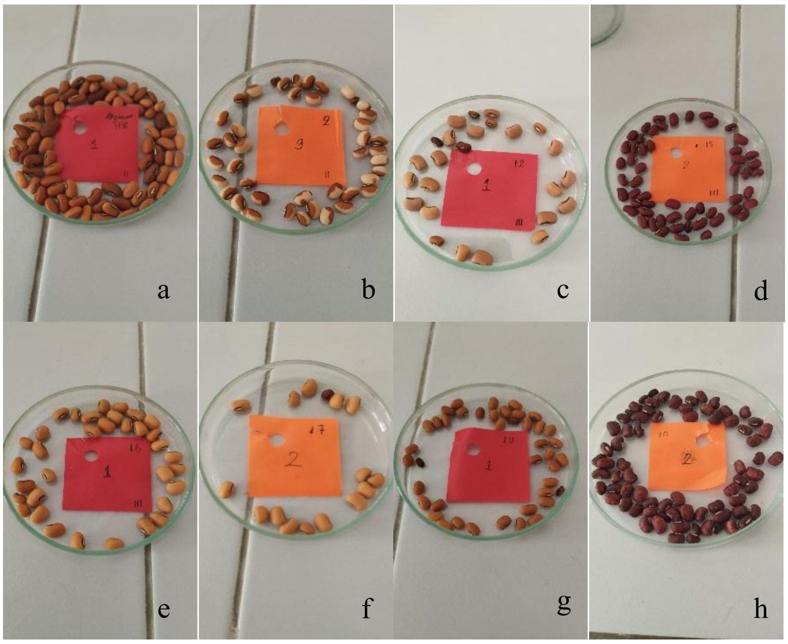

Figure 2. Seed coat color variation among eight genotypes; a) Arghavan IPB; b) KTM – 9; c) KTM – 12; d) KTM – 13; e) KTM – 16; f) KTM – 17; g) KTM – 19; h) KTM - 20

Phenology of Cowpea Accessions

Table 2 shows that the eight cowpea genotypes exhibited relatively uniform developmental patterns from the germination stage through to maturity, although there were variations in the time taken to reach each stage. The Tanimbar accessions (KTM 9, 12, 13, 16, 17, 19, and 20) generally germinated faster (2 DAP) and entered the cotyledon stage (4 DAP) earlier than the Arghavan IPB elite variety (4–6 DAP). The true leaf stage also occurred earlier in the Tanimbar accessions (11 DAP) compared to Arghavan IPB (14 DAP), while the full vegetative stage was reached simultaneously at 30 DAP. More pronounced differences emerged during the flowering (41–45 DAP) and fruiting (43–47 DAP) phases, with KTM 13 being the fastest and KTM 12 the slowest. The ripening phase showed high uniformity; the majority of genotypes matured at 67 DAP, with only KTM 13 and KTM 19 being slightly slower (68 DAP). Overall, the variation in timing among genotypes was relatively small (1–4 days), so the phenological pattern of winged beans can be considered fairly uniform despite differences in the speed of transition between phases.

Table 2. Comparison of Phenological Responses of Different Genotypes during the Vegetative and Reproductive Growth Phases

Phenological Phases	Genotype							
	Arghavan IPB	KTM 9	KTM 12	KTM 13	KTM 16	KTM 17	KTM 19	KTM 20
Germination (DAP)	4	2	2	2	2	2	2	2
Cotyledon Emergence (DAP)	6	4	4	4	4	4	4	4
True Leaf Emergence (DAP)	14	11	11	11	11	11	11	11
Full Vegetative Stage (DAP)	30	30	30	30	30	30	30	30
Flowering (DAP)	42	42	45	41	43	43	42	42
Fruiting (DAP)	44	44	47	43	45	45	44	43
Maturation (DAP)	67	67	67	68	67	67	68	67

Note: DAP = Day After Planting

Response of Cowpea Accessions on Vegetative Growth

Analysis of variance showed that not all growth variables differed significantly among genotypes. Several variables, such as plant height at weeks 3 to 7, number of leaves at weeks 3 and 5, and number of pods at week 5, were relatively uniform and therefore did not show significant differences. In contrast, variables that were significant (*) and highly significant (**) indicated clear genetic differences affecting growth and productivity.

Plant Height

Analysis of variance (Table 3) showed highly significant differences among genotypes during the early growth phase. Tukey's multiple comparison test (Table 4) identified KTM 12 as the genotype with the greatest plant height during the first and second weeks.

Table 3. Recapitulation of Analysis of Variance Results for Plant Height

Quantitative Characters	Mean Square
Plant Height at Week 1	$23{,}45^{**}$
Plant Height at Week 2	$1718{,}01^{**}$
Plant Height at Week 3	$967{,}24^{ns}$
Plant Height at Week 4	$943{,}91^{ns}$
Plant Height at Week 5	$638{,}20^{ns}$
Plant Height at Week 6	$551{,}38^{ns}$
Plant Height at Week 7	$512{,}36^{ns}$

Notes: ** = Highly significant (p < 0,01); ns = not significant

Table 4. Results of Multiple Comparison Test for Plant Height

Genotype	Quantitative Characters	
	Plant Height at Week 1 (Cm)	Plant Height at Week 2 (Cm)
Arghavan IPB	$16{,}68_{b}$	$49{,}33_{bc}$
KTM 9	$22{,}00_{a}$	$69{,}21_{abc}$
KTM 12	$23{,}65_{a}$	$98{,}26_{a}$
KTM 13	$21{,}78_{a}$	$66{,}86_{bc}$
KTM 16	$22{,}35_{a}$	$89{,}61_{ab}$
KTM 17	$21{,}31_{ab}$	$62{,}55_{bc}$
KTM 19	$22{,}93_{a}$	$90{,}13_{ab}$
KTM 20	$16{,}68_{b}$	$49{,}33_{bc}$

Note: Values within the same column followed by the same letter are not significantly different according to Tukey's HSD test at the 0.05 significance level.

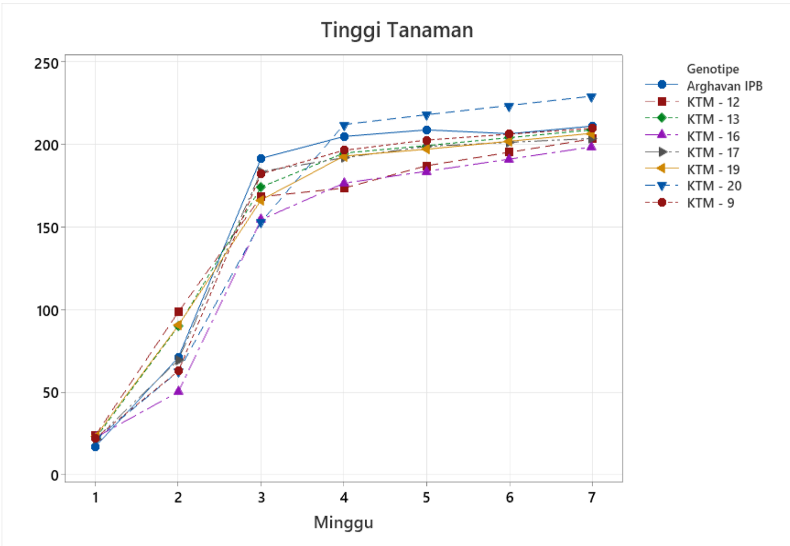

Figure 3. Visualization of Plant Height Growth of Eight Genotypes during Weeks 1–7

The growth curves showed that KTM 12 had greater plant height during the early growth stages, while KTM 20 exhibited the highest plant height at week 7. In contrast, Arghavan IPB consistently showed the lowest plant height during the observation period. Analysis of variance indicated that differences among genotypes were significant during the early stages but became mostly non-significant from weeks 3 to 7, suggesting more uniform growth among genotypes. The highest mean square value was observed at week 3, indicating greater variation during the active vegetative stage. Overall, all genotypes showed increasing plant height throughout the observation period, although growth gradually slowed during the later stages.

Number of Branches

ANOVA results showed significant differences at week 4 and highly significant differences at week 5. Tukey's test confirmed that KTM 17 had the highest number of branches among the genotypes.

Table 5. Recapitulation of Analysis of Variance Results for Number of Branches

Quantitative Characters	Mean Square
Number of Branches at Week 3	$0,31^{ns}$
Number of Branches at Week 4	$3,01^{*}$
Number of Branches at Week 5	$3,51^{**}$

Notes: ** = Highly significant (p < 0,01); * = significant (p <0,05) ns = not significant

Table 6. Results of Multiple Comparison Test for Number of Branches

Genotype	Quantitative Characters	
	Number of Branches at Week 4	Number of Branches at Week 5
Arghavan IPB	$2,60_{ab}$	$2,66_{b}$
KTM 9	$3,66_{b}$	$4,00_{ab}$
KTM 12	$1,83_{b}$	$2,66_{b}$
KTM 13	$2,66_{ab}$	$2,66_{b}$
KTM 16	$3,00_{ab}$	$3,50_{ab}$
KTM 17	$4,00_{a}$	$4,83_{a}$
KTM 19	$2,50_{ab}$	$3,66_{ab}$
KTM 20	$2,33_{ab}$	$3,33_{ab}$

Note**:** Values within the same column followed by the same letter are not significantly different according to Tukey's HSD test at the 0.05 significance level.

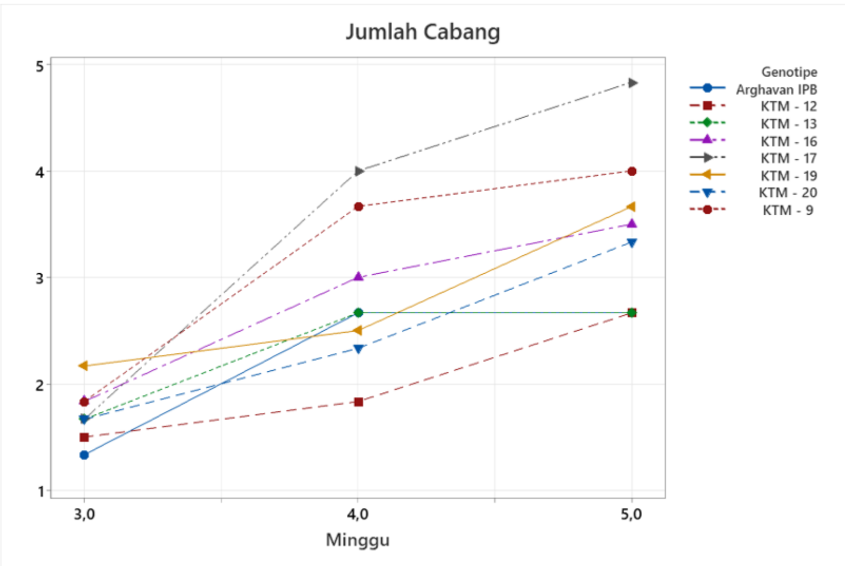

Figure 4. Visualization of Number of Branches Growth of Eight Genotypes during Weeks 3–5

Analysis of variance showed significant differences in the number of branches among genotypes, especially at weeks 4 and 5, indicating that genotypic effects became more apparent during the middle growth stage. KTM 17 consistently produced the highest number of branches, whereas Arghavan IPB and KTM 9 generally showed lower branch numbers. The growth curves also demonstrated that branch number increased throughout the observation period, with KTM 17 showing the highest growth trend among the genotypes. These results indicate that genotype influenced branch development in cowpea plants.

Number of Leaves

Table 7. Recapitulation of Analysis of Variance Results for Number of Leaves

Quantitative Characters	Mean Square
Number of Leaves at Week 1	$0,61^{**}$
Number of Leaves at Week 2	$2,91^{**}$
Number of Leaves at Week 3	$5,02^{ns}$
Number of Leaves at Week 4	$31,63^{**}$
Number of Leaves at Week 5	$58,27^{ns}$

Notes: ** = Highly significant (p < 0,01) ; ns = not significant.

Tabel 8. Table 6. Results of Multiple Comparison Test for Number of Leaves

Genotype	Quantitative Characters		
	Number of Leaves at Week 1	Number of Leaves at Week 2	Number of Leaves at Week 4
Arghavan IPB	$1,00_{b}$	$5,00_{ab}$	$17,40_{ab}$
KTM 9	$1,66_{ab}$	$4,83_{ab}$	$20,33_{ab}$
KTM 12	$2,00_{a}$	$6,33_{a}$	$18,00_{ab}$
KTM 13	$1,66_{ab}$	$5,00_{ab}$	$15,66_{b}$
KTM 16	$2,00_{a}$	$5,50_{ab}$	$19,00_{ab}$
KTM 17	$1,66_{ab}$	$5,00_{ab}$	$21,16_{ab}$
KTM 19	$2,00_{a}$	$6,00_{a}$	$22,50_{a}$
KTM 20	$1,50_{ab}$	$5,33_{ab}$	$17,00_{ab}$

Note: Values within the same column followed by the same letter are not significantly different according to Tukey's HSD test at the 0.05 significance level.

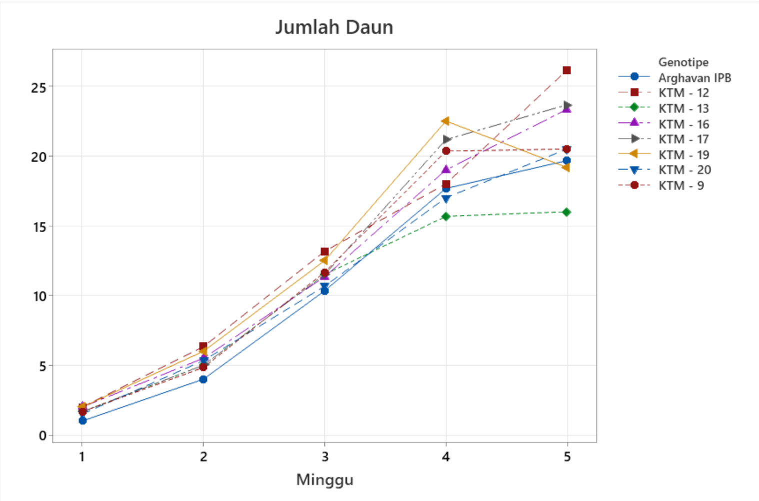

Figure 5. Visualization of Number of Leaves Growth of Eight Genotypes during Weeks 1–5

The analysis of variance in Table 7 showed that the number of leaves at weeks 1, 2, and 4 differed very significantly ($p<0.01$) among genotypes, while weeks 3 and 5 were not significantly different. The Tukey test in Table 9 indicated that KTM-12 had the highest number of leaves at week 2 (6.33 leaves), whereas KTM-19 had the highest number at week 4 (22.50 leaves). In contrast, the lowest number of leaves was recorded in Arghavan IPB and KTM-13 at week 2 (5.00 leaves), and in KTM-13 at week 4 (15.66 leaves).

Based on Figure 3, the number of leaves in all genotypes increased from week 1 to week 4 and then declined at week 5. In the first week, KTM-12, KTM-16, and KTM-19 had the highest number of leaves (2 leaves), while Arghavan IPB had the lowest (1 leaf). At week 5, KTM-12 showed the highest number of leaves, whereas Arghavan IPB and KTM-13 remained the lowest.

Number of Flowers

The ANOVA results showed significant to highly significant differences in the number of flowers.

Tabel 9. Recapitulation of Analysis of Variance Results for Number of Flowers

Quantitative Traits	Nilai Mean Square
Number of Flowers at Week 5	$26{,}76^{*}$
Number of Flowers at Week 6	$12{,}18^{tn}$
Number of Flowers at Week 7	$14{,}87^{**}$

Notes: ** = Highly significant (p < 0,01) ;* = significant (p <0,05); ns = not significant.

Tabel 10. Results of Multiple Comparison Test for Number of Flowers

Genotype	Quantitative Traits	
	Number of Flowers at Week 5	Number of Flowers at Week 7
Arghavan IPB	$6{,}60_{ab}$	$6{,}40_{a}$
KTM 9	$3{,}83_{ab}$	$4{,}16_{ab}$
KTM 12	$2{,}83_{ab}$	$2{,}00_{b}$
KTM 13	$7{,}00_{ab}$	$6{,}00_{a}$
KTM 16	$3{,}50_{ab}$	$5{,}00_{ab}$
KTM 17	$1{,}66_{b}$	$2{,}83_{ab}$
KTM 19	$7{,}50_{a}$	$6{,}16_{a}$
KTM 20	$5{,}16_{ab}$	$4{,}50_{ab}$

Note**:** Values within the same column followed by the same letter are not significantly different according to Tukey's HSD test at the 0.05 significance level.

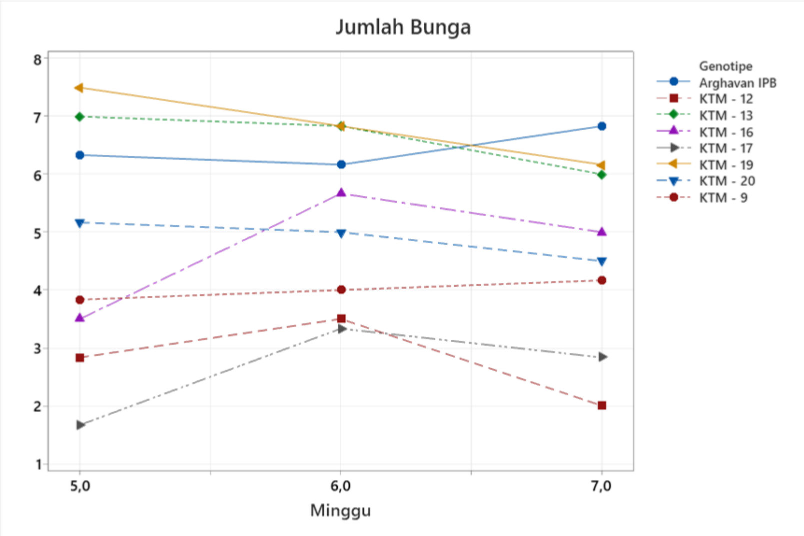

Figure 6. Visualization of Number of Flowers Growth of Eight Genotypes during Weeks 5–7

The graph showed that KTM-19 had the highest number of flowers during the early flowering stage, but its trend declined in weeks 6 and 7. In contrast, other genotypes, particularly Arghavan IPB, showed an increase in flower number until week 7. Thus, KTM-19 tended to perform better during the early flowering phase, whereas Arghavan IPB exhibited a higher number of flowers at the final observation stage.

Number of Pods

The ANOVA results showed significant to highly significant differences in the number of Pods.

Tabel 11. Recapitulation of Analysis of Variance Results for Number of Pods

Quantitative Traits	Nilai Mean Square
Number of Flowers at Week 5	$26{,}76^{*}$
Number of Flowers at Week 6	$12{,}18^{tn}$
Number of Flowers at Week 7	$14{,}87^{**}$

Notes: ** = Highly significant (p < 0,01) ;* = significant (p <0,05); ns = not significant

Table 12. Results of Multiple Comparison Test for Number of Pods

Genotype	Quantitative Traits	
	Number of Pods at Week 4	Number of Pods at Week 7
Arghavan IPB	$2{,}60_{ab}$	$6{,}60_{a}$
KTM 9	$2{,}50_{ab}$	$4{,}00_{abc}$
KTM 12	$1{,}00_{b}$	$1{,}83_{c}$
KTM 13	$3{,}33_{ab}$	$5{,}66_{ab}$
KTM 16	$1{,}16_{b}$	$5{,}00_{abc}$
KTM 17	$1{,}33_{b}$	$2{,}83_{bc}$
KTM 19	$6{,}16_{a}$	$5{,}50_{ab}$
KTM 20	$3{,}00_{ab}$	$4{,}33_{abc}$

Note**:** Values within the same column followed by the same letter are not significantly different according to Tukey's HSD test at the 0.05 significance level.

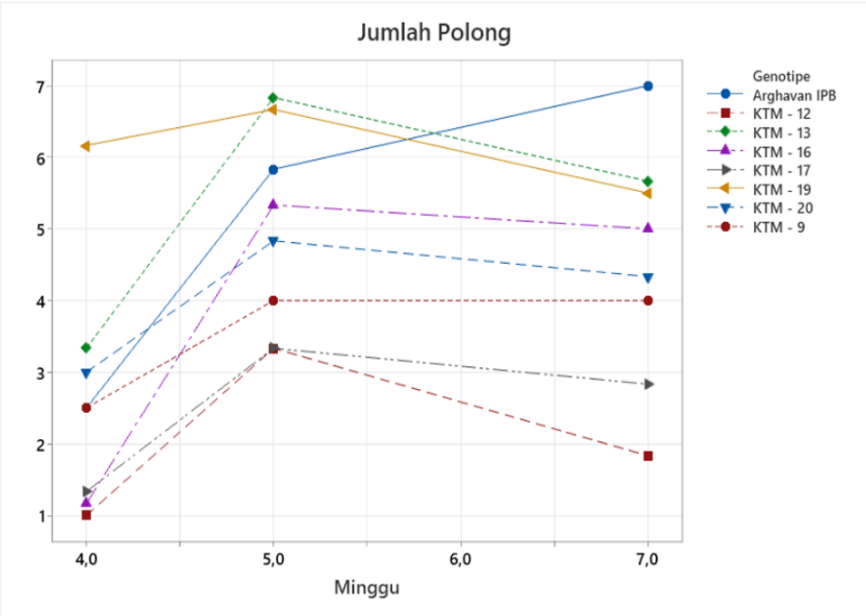

Figure 6. Visualization of Number of Flowers Growth of Eight Genotypes during Weeks 4, 5 and 7

The discussion showed that each genotype had different abilities in pod formation. KTM-19 produced the highest number of pods during the early pod formation stage, particularly at week 4, indicating a faster generative response. In contrast, Arghavan IPB had the highest number of pods at week 7, showing its ability to maintain pod formation until the end of the observation period. Meanwhile, KTM-12 consistently showed the lowest number of pods throughout the observation period. Overall, KTM-19 performed better during the early generative stage, whereas Arghavan IPB showed better performance at the final stage of observation.

Response of Cowpea Accessions on Yield Production

The results of the analysis of variance and Tukey's test describing the response of cowpea plants to the applied treatments using the SAS OnDemand platform are summarized in Table 13.

Table 13. Results of Analysis of Variance for Yield Variables in Eight Cowpea Genotypes

No	Quantitative Characters	Mean Square
1	Number of Harvested Pods	16,92**
2	Pod Length	38,08*
3	Number of Seeds per Plant	931,07**
4	Number of Seed per Pod	34,32**
5	Seed Weight per Plant	20,86**
6	100 Seed Weight	163,94**

Note: ns = not significant; * = significant ($p < 0.05$); ** = highly significant ($p < 0.01$).

The analysis of variance showed that all quantitative characters had significant effects among genotypes, indicating the presence of substantial genetic variability in cowpea yield components. The characters of number of harvested pods, pod length, number of seeds per pod, number of seeds per plant, and 100-seed weight showed highly significant differences ($p < 0.01$), while seed weight per plant showed a significant effect ($p < 0.05$). These results indicate that yield components such as pod number, pod size, and seed traits are important indicators in evaluating productivity, and the consistent differences among genotypes can serve as a basis for selection in the development of adaptive and high-yielding varieties. The analysis was further followed by Tukey's test to identify specific differences among genotypes.

Tabel 1. Tukey's Test Results for Yield Variables in Eight Genotypes

Yield Variable	Genotype							
	Arghavan IPB	KTM - 9	KTM - 12	KTM - 13	KTM - 16	KTM - 17	KTM - 19	KTM - 20
NHP	$6,60_{a}$	$3,00_{bc}$	$1,33_{c}$	$4,83_{ab}$	$4,50_{abc}$	$3,00_{bc}$	$5,83_{ab}$	$3,16_{abc}$
PL	$13,48_{ab}$	$14,57_{a}$	$7,98_{b}$	$15,75_{a}$	$15,51_{a}$	$15,39_{a}$	$14,51_{ab}$	$14,31_{ab}$
NSP	$43,80_{a}$	$30,66_{ab}$	$11,33_{b}$	$44,16_{a}$	$37,00_{ab}$	$27,66_{ab}$	$51,83_{a}$	$39,50_{ab}$
NSPo	$6,60_{ab}$	$11,71_{a}$	$5,55_{b}$	$9,40_{ab}$	$8,24_{ab}$	$11,49_{a}$	$9,04_{ab}$	$12,15_{a}$
SWP	$6,87_{a}$	$6,48_{a}$	$1,70_{b}$	$4,62_{ab}$	$7,09_{a}$	$4,07_{ab}$	$6,19_{ab}$	$6,76_{a}$
W100	$15,71_{ab}$	$23,26_{a}$	$9,80_{b}$	$10,53_{b}$	$23,28_{a}$	$15,69_{ab}$	$11,91_{ab}$	$16,65_{ab}$

Note: NHP = Number of Harvested Pods; PL = Pod Length; NSP = Number of Seeds per Plant; NSPo = Number of Seeds per Pod; SWP = Seed Weight per Plant; W100 = 100-Seed Weight. Values followed by the same letter within the same row are not significantly different according to Tukey's test (5%).

Tukey's test revealed significant genetic variation among genotypes. During the early vegetative stage, KTM 12 showed superior plant height, whereas Arghavan IPB consistently exhibited slower growth. KTM 17 excelled in branch number, while KTM 19 dominated leaf number during the late vegetative stage. Entering the generative phase, KTM 13 flowered earlier, whereas Arghavan IPB was more stable during the final stage and produced the highest number of harvested pods. Yield traits also varied among genotypes: KTM 13 showed superiority in pod length and number of seeds per plant, KTM 20 excelled in number of seeds per pod, while the highest seed weight was recorded in KTM 16 and Arghavan IPB. These patterns indicate the presence of trade-offs among genotypes, where vegetative vigor was not always directly associated with seed yield, and genotypes with slower early growth could perform better during the generative stage.

DISCUSSION

The eight cowpea genotypes showed relatively similar phenological patterns, although slight variations were observed during the early vegetative and reproductive stages. KTM genotypes generally germinated and entered the vegetative phase earlier than Arghavan IPB, while clearer differences appeared during flowering and pod formation, where KTM-13 and KTM-20 flowered earlier, whereas KTM-12 was the slowest to enter the reproductive stage. Growth curves demonstrated strong vegetative vigor during the third to fifth weeks after planting, with KTM-19 and KTM-13 exhibiting higher numbers of leaves and branches, which supported greater photosynthetic capacity. However, ANOVA and Tukey test results indicated a trade-off between vegetative growth and yield components, where genotypes with vigorous vegetative growth did not always produce the highest seed yield. KTM-13 excelled in pod length and number of seeds per plant, KTM-20 showed the highest number of seeds per pod, whereas Arghavan IPB produced the highest seed weight per plant and maintained stable performance during the late generative stage.

Based on BMKG climatic data, weather conditions during the experiment period (27 June–24 September 2025) were characterized by extremely high relative humidity averaging approximately 91%, which was unfavorable for cowpea growth. Rainfall was particularly excessive during the sixth ten-day period, reaching 853.9 mm, while total rainfall during July–August reached 1,394.5 mm, far exceeding the crop's optimal requirement and causing severe environmental stress. This stress was intensified by biotic disturbances, including powdery mildew infection on KTM-12 and KTM-17, as well as insect attacks on KTM-13, KTM-17, and KTM-9, which reduced effective leaf area. In contrast, genotypes such as KTM-13 and KTM-19 still maintained relatively high productivity, indicating possible physiological adaptation mechanisms such as stomatal regulation, antioxidant activity, and tolerance to pathogens.

Cowpea requires optimal rainfall conditions of approximately 400–700 mm per growing season with good distribution, but it is highly sensitive to excessive soil moisture, which may inhibit root aeration, reduce nutrient and oxygen uptake, and increase flower and pod abortion, particularly during the reproductive stage (Basavaraj et al., 2024). In addition, cowpea requires full sunlight exposure (>6 h day^{-1}) for optimal photosynthesis. In this study, average sunshine duration ranged only between 0.47–0.96 h day^{-1}, and even reached 0 h during the final ten-day period, combined with humidity levels exceeding 90%, severely suppressing photosynthetic activity. Consequently, branch formation, flowering, pod development, and pod retention were reduced, leading to low productivity. Abiotic stress caused by low light intensity weakened the plants, while prolonged wet conditions promoted biotic stress, particularly fungal diseases such as anthracnose (*Colletotrichum* spp.), *Cercospora* leaf spot, root rot (*Fusarium/Phytophthora*), and rust, which develop rapidly under humid tropical conditions and may potentially lead to total crop failure (Emechebe *et al,*, 1997).

The morpho-phenological responses and vegetative growth of cowpea accessions under high humidity conditions reflected distinct adaptation patterns to tropical wet environments. Several local accessions, particularly KTM-19 and KTM-17, demonstrated superior vegetative vigor compared with the national improved variety, which may be associated with adaptive physiological mechanisms under high humidity stress. High humidity and low radiation prevailing at the experimental site can influence transpiration, photosynthate distribution, and the plant's capacity to maintain water homeostasis (Taiz et al., 2015). Under such conditions, the vapor pressure gradient between the leaf surface and surrounding air decreases, thereby reducing transpiration. Reduced transpiration may subsequently limit nutrient uptake and assimilate allocation to reproductive organs, ultimately affecting canopy structure, stem elongation, and flower and pod production (Jones, 2014).

Differences among genotypes suggest that some local accessions were more efficient in regulating stomatal activity and assimilate distribution than the comparison variety. For example, genotypes with greater leaf numbers, such as KTM-19, tended to exhibit higher total photosynthetic rates, which may compensate for low radiation conditions, while may have supported assimilate allocation toward reproductive organs. This observation is consistent with reports that plants adapted to wet environments often exhibit enhanced vegetative biomass accumulation during early growth stages before transitioning into the reproductive phase (Morgan, 2005).

In addition, high humidity environments increase the risk of floral abnormalities and fruit abortion, negatively affecting final yield components. This may explain why some local accessions exhibited vigorous vegetative growth without proportional increases in reproductive yield. The present findings suggest that adaptation of local cowpea accessions to high humidity involves a combination of stomatal regulation, photosynthetic efficiency, and biomass allocation strategies. Genetic differences among local accessions therefore represent valuable resources for breeding programs targeting tolerance to high humidity stress and efficient light utilization, both of which are expected to become increasingly important under future climate change scenarios.

The discussion also demonstrated substantial variation in reproductive morphology among the eight cowpea genotypes. Morphological diversity was more pronounced in reproductive traits, especially seed shape and seed color, compared with vegetative characters that were relatively similar among genotypes. Such variation indicates the existence of important genetic diversity that may serve as a valuable germplasm source for cowpea breeding programs.

At the phenological level, all genotypes displayed relatively uniform early growth patterns, but differences became more apparent during the reproductive phase. KTM-13 and KTM-20 tended to flower and develop pods earlier, whereas KTM-12 was slower to enter the reproductive stage. These differences indicate variation in physiological responses among genotypes under conditions of high humidity and low light intensity.

Vegetative growth characteristics showed that KTM-20, KTM-13, and Arghavan IPB produced the tallest plants during observation. Nevertheless, vigorous vegetative growth was not always associated with high productivity. KTM-19 exhibited a contrasting pattern, producing relatively high numbers of branches, flowers, and pods despite not having the tallest plants. The abundant branching observed in KTM-19 likely increased the number of reproductive growth points, thereby supporting greater flower and pod formation. KTM-13 displayed a balanced combination of vegetative and generative performance through high leaf numbers, longer pods, and greater seed numbers per plant. Meanwhile, KTM-16, although not characterized by the highest vegetative growth, showed the best production performance through the highest seed weight per plant and 100-seed weight, indicating more efficient seed filling compared with the other genotypes.

Environmental conditions during the study became the primary limiting factor affecting plant growth and productivity. High humidity, excessive rainfall, and low light intensity caused mild etiolation, stem bending, and reduced photosynthetic efficiency in several genotypes. These conditions also favored the development of powdery mildew, particularly in KTM-12 and KTM-17, reducing effective leaf area and suppressing generative performance. Insect attacks on several genotypes additionally caused leaf damage and accelerated leaf senescence.

Yield analysis revealed significant differences among genotypes in number of harvested pods, pod length, number of seeds per plant, number of seeds per pod, and seed weight. Arghavan IPB produced the highest number of harvested pods, whereas KTM-19 recorded the highest number of seeds per plant, likely associated with its abundant productive branches. KTM-13 excelled in pod length and seed number per plant, while KTM-20 showed the highest number of seeds per pod. KTM-16 produced the highest 100-seed weight and demonstrated the best overall production performance under the study conditions. In contrast, KTM-12 consistently showed the lowest performance across most yield characters due to severe disease pressure and poor ability to maintain reproductive development.

Overall, the results indicate that several local cowpea genotypes originating from the Tanimbar Islands possess adaptive and productive capacities capable of competing with nationally improved varieties under humid tropical environments. In particular, KTM-16 demonstrated superior production performance through relatively high pod length, the highest seed weight per plant, and the highest 100-seed weight, highlighting its efficiency in seed filling and assimilate allocation. These characteristics indicate that KTM-16 has strong potential as a valuable germplasm source and candidate adaptive genotype for cowpea breeding programs targeting tropical wet environments.

CONCLUSION

This study demonstrated significant differences in phenological responses, vegetative growth, and yield production between local cowpea accessions and the national improved variety under high humidity conditions, indicating that the research hypothesis was accepted. KTM-16 showed the best production performance, particularly in pod length, seed weight per plant, and 100-seed weight, indicating efficient assimilate allocation and seed filling capacity. KTM-19 performed well during the vegetative and early generative stages, while KTM-13 excelled in pod length and number of seeds per plant. Arghavan IPB remained competitive through high harvested pod number and stable performance during the late generative phase. In contrast, KTM-12 consistently exhibited the lowest performance across most growth and yield characters due to its susceptibility to environmental and biotic stresses. Overall, the findings indicate that several local cowpea genotypes from the Tanimbar Islands possess adaptive and productive capacities capable of competing with nationally improved varieties under humid tropical environments, with KTM-16 showing strong potential as a valuable genetic resource for future cowpea breeding programs.

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