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Morphology characteristic and biomass production of jack bean (*Canavalia ensiformis*) at different growth stages in Blora, Central Java, Indonesia

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Abstract: In Indonesia, various types of indigenous bean plants are distributed across different regions. However, crops like the jack bean (*Canavalia ensiformis*) are still considered neglected and underutilized. This study evaluated the morphological characteristics and biomass production of jack bean at different growth stages cultivated in alluvial type of soil at teak tree forest area in Blora, Central Java, Indonesia. A field experiment was conducted using a completely randomized block design with four replications. Sixteen jack bean seeds were sown in 1 × 1 m² plots. Morphological parameters (plant height, plant length, stem diameter, node length, number of nodes, rachis length, number of leaves, leaf length, leaf width, number of flowers, and number of pods) were measured at three distinct growth stages: the vegetative, flowering, and pod development stages prior to harvesting. Forage yield was assessed after harvesting at each growth stage. The highest fresh forage yield (43.23 tons/ha) was observed at the pod development stage, compared to the vegetative (19.39 tons/ha) and flowering (34.35 tons/ha) stages. Fresh leaf and stem production at the pod development stage also showed significantly higher values (22.51 tons/ha and 20.85 tons/ha, respectively). Based on its favorable morphological traits and substantial biomass yield, jack bean at the pod development stage demonstrates strong potential as a forage resource for ruminants, particularly in the context of Indonesia's arid and remote regions.

Keywords: *Canavalia*; Growth stage; Jack bean; Sustainability; Tropical legume.

Introduction

In Indonesia, various types of indigenous bean plants are distributed across different regions. However, crops such as jack bean (*Canavalia ensiformis*) are still considered neglected and have not been widely cultivated for food or feed purposes. To date, comprehensive data on the morphological characteristics, forage production, and potential of jack bean as a functional feed for ruminants have not been compiled by researchers in Indonesia. Nevertheless, studying local legume plants is increasingly important in light of global food crises and the growing need for local legumes as sustainable sources of food and feed. Local legumes play a vital role in nitrogen fixation, reducing the need for synthetic fertilizers, improving soil fertility, and promoting sustainable agriculture. Additionally, they enhance soil health, prevent erosion, and contribute to lower greenhouse gas emissions, making them an essential crop for sustainable farming and climate resilience. The multifunctionality of local legumes makes them a valuable resource in integrated agricultural systems that support both human and environmental well-being (Schmidt and De Oliveira, 2023; Prasojo et al., 2023a; Indriani et al., 2024)

The study was conducted in India about in the mineral content across different jack bean genotypes showed that selecting genotypes with higher calcium content could effectively improve protein levels in jack bean. These findings emphasize the potential of jack bean as a valuable source of nutrients, particularly protein, in regions where malnutrition is a concern (Lenkala et al, 2014). The study from Indriani et al. (2019) supports the idea of increasing mineral content in *Canavalia* species through proper management and cultivation techniques. Mineral nutrient uptake (such as calcium, magnesium, sodium, iron, and copper) was also enhanced with nitrogen fertilization, but no significant effects were observed on phosphorus, manganese, or zinc concentrations (Britz et al, 2023). In the study by Hocking and Pate (1977), indicate that minerals like nitrogen (N), phosphorus (P), and potassium (K) are mobilized efficiently from the vegetative parts of the plant, while other elements such as calcium (Ca) and sodium (Na) are less mobile. This mobilization process is critical for seed development, as the nutrients stored in senescing (aging) leaves and pods are redirected to support the growth of the seed.

The study by Wijaya and Suarna (2020) focuses on the morphological characteristics of *Canavalia gladiata* (sword bean) and its potential as livestock fodder. The research reveals that *Canavalia gladiata* is a leguminous plant with distinct morphological traits, including large leaves, fragrant white flowers, and bright red seeds. The vegetative phase lasts for 4-5 months, followed by a generative phase where pod maturation can take 5-6 months or longer. The Swathi and Karpagam (2023) study provides detailed anatomical insights into *Canavalia virosa* (wild sword bean). The research examines various plant structures, including the leaf, petiole, petiolule, stem, and stomata. Key anatomical features identified include the presence of sclerenchyma bundle sheaths, calcium oxalate crystals, and parasitic stomata. The study also reveals that the leaves have a dorsi-ventral structure with a well-developed palisade layer, and spongy mesophyll cells containing abundant chloroplasts.

The stems of *C. ensiformis* are woody, cylindrical, and long, with a soft outer layer. When subjected to lateral pressure, the stem becomes oval-cylindrical in shape (Rajput, 2003). The leaflets are elliptical to oval, with a rounded base and a conical tip. While jack beans are primarily self-pollinating, their flowers are frequently visited by bees, resulting in a cross-pollination rate of 20% or higher (Morris, 2007). In addition to the potential of jack bean seeds, the plant's biomass can also serve as valuable animal feed, particularly for ruminants. Under tropical conditions in Brazil, *C. ensiformis* has been shown to produce a biomass yield of 21.81 tons/ha of fresh matter and 11.29 tons/ha of dry matter (Teodoro et al., 2014). The nitrogen-fixing capability of legume nodules such as jack bean makes them suitable for intercropping with non-nodulating plants, improving environmental conditions and enhancing crop productivity (Prasojo et al., 2019; Prasojo et al., 2022). The root type of jack bean is a white taproot (USDA, 2013), but this plant has few root branches (Christina et al., 2023).

The interaction of plants with their environment is often reflected in their phenotype. Morphological traits are fundamental in the natural sciences, and studying the phenotypic diversity of organisms is crucial for understanding plant patterns and processes (Prasojo et al., 2021b). In leguminous plants, the morphological characteristics and biomass production are highly influenced by the timing of cutting, which corresponds to different growth phases. Determining the optimal cutting time can significantly impact both the quality and quantity of biomass produced (Prasojo et al., 2021b; Shortnacy et al., 2023). Studies on the use of jack bean plants as ruminant feed are limited, particularly regarding morphological characteristics and biomass production across different growth phases. Understanding these characteristics can provide insights into the optimal cutting time for maximizing biomass yield, as the cutting time is directly related to the plant growth stages. Harvesting jack bean plants at specific growth stages could offer a significant breakthrough for livestock production in Indonesia, utilizing jack bean as a protein-rich forage source beneficial for ruminants. The objective of this study was to evaluate the morphological characteristics and biomass production of jack bean (*Canavalia ensiformis*) at the vegetative, flowering, and pod development stages prior to harvesting.

Result and Discussion

Morphological characteristics

The morphological characteristics of jack bean at different growth stages are summarized in Table 1. There were significant differences in plant height, plant length, and number of leaves across growth stages. Plant height at the pod development stage was significantly higher ($P \leq 0.05$) at 69.85 cm, compared to the vegetative and flowering stages (53.23 cm and 56.67 cm, respectively). Similarly, plant length at the pod development stage was significantly higher ($P \leq 0.05$) at 75.58 cm, compared to the vegetative and flowering stages (59.95 cm and 63.57 cm, respectively). The pod development stage also produced a significantly higher number of leaves ($P \leq 0.05$) with 35.00 leaves, compared to the vegetative stage (19.00 leaves). However, there was no significant difference in the number of leaves between the pod development and flowering stages (29.00 leaves). Stem diameter increased progressively with growth stages. On the other hand, node length, rachis length, leaf length, and leaf width showed no significant differences between growth stages. Notably, at the pod development stage, jack bean produced approximately four pods, which could have valuable implications for livestock feed and nutrition.

The findings of this study indicate that the morphological characteristics and biomass production of *Canavalia ensiformis* (jack bean) are highly dependent on the plant's growth stage. The significant differences in plant height, length, and number of leaves across different growth stages suggest that the timing of harvest is crucial for optimizing biomass yield, particularly for use as forage in livestock systems. Specifically, the pod development stage demonstrated the highest plant height and leaf production, both of which are critical components of biomass yield. These results align with previous studies on other legumes, such as cowpea (*Vigna unguiculata*) and soybean (*Glycine max*), which also showed increased biomass production during later growth stages when compared to earlier vegetative stages (Prasojo et al., 2021b).

The observed increase in plant height and leaf number at the pod development stage could be linked to the plant physiological adaptation to maximize reproductive success. As legumes enter reproductive phases, they often increase their leaf area to support pod formation and nutrient allocation to seeds. This phenomenon is consistent with the findings of Teodoro et al. (2014), who reported that *C. ensiformis* plants grown under tropical conditions in Brazil exhibited higher biomass and leaf area during reproductive stages. The increase in biomass, particularly leaf biomass, is critical for forage quality, as leaves are the most digestible and nutrient-rich part of the plant, contributing significantly to the protein content of the forage. Jack beans tend to grow like a creeper once they reach the pod development phase. This is seen in the significant changes in plant length among growth stages. *Canavalia ensiformis* is the most common *Canavalia* genus growth in Indonesia. Another study with other species, *C. rosea* has a creeping habit with thick and fleshy stem can grow to 10 meter or more in length, and about 2,5 cm in diameter (Gonzalez et al, 2014). Interestingly, stem diameter increased progressively with growth stages, indicating continuous structural development of the plant. This is consistent with studies on other leguminous plants, such as Sunn Hemp *(Clotalaria juncea)*, which show that stem thickness is correlated with the plant's ability to store and transport nutrients efficiently (Dewanti et al, 2024a). Thicker stems may support the increased biomass production observed during the pod development stage, as the plant requires stronger vascular structures to distribute water and nutrients to its growing leaves and pods.

In other hand, other morphological traits, such as node length, rachis length, leaf length, and leaf width, showed no significant differences between growth stages. This suggests that these traits may be more stable and not as responsive to the plant developmental phase compared to traits such as plant height and leaf number. Similar findings have been reported in research on other legumes, such as pigeon pea (*Cajanus cajan*), where certain morphological traits remained stable across growth stages while others, like leaf production, varied significantly (Borges et al., 2022). These stable traits may represent inherent characteristics of the species that are less influenced by environmental factors or growth stages. The presence of pods at the pod development stage is of particular interest from a nutritional perspective. Pods and seeds represent a significant source of protein, which is essential for ruminant nutrition. This aligns with the findings of Silva et al. (2021), who emphasized the importance of legume pods in providing high-quality protein in agroforestry systems. The four pods produced per plant in this study may seem low compared to other legumes, but jack bean has been known to produce higher seed yields under optimal conditions, suggesting that environmental factors, such as soil fertility and water availability, may influence pod production in this context (Akib et al., 2018).

Forage production

The evaluation of forage production in jack bean across various growth stages revealed significant differences in total fresh weight, fresh leaf weight, and fresh stem weight (Table 2). The results demonstrate that forage production increases progressively with the growth stages of jack bean, with the pod development stage yielding the highest biomass. Specifically, the pod development stage produced the greatest fresh weight of leaves, stems, and total biomass (both leaf and stem combined). Although the pod development stage showed a higher biomass yield, the total fresh weight between the flowering and pod development stages did not differ significantly (34.35 tons/ha and 43.23 tons/ha, respectively). Similarly, no significant difference was observed in fresh leaf weight between the flowering and pod development stages (22.51 tons/ha and 21.76 tons/ha, respectively). However, fresh stem weight was significantly higher ($P \leq 0.01$) at the pod development stage.

The results of this study demonstrate significant differences in forage production of *Canavalia ensiformis* (jack bean) across various growth stages, with the pod development stage yielding the highest biomass, particularly in stem weight. This trend aligns with the general patterns observed in leguminous crops, where later reproductive stages are associated with greater

Tabel 1. Morphological characteristics of jack bean (*Canavalia ensiformis*) at each growth stage (mean±SD).

Parameters	Growth Stage		
	Vegetative	Flowering	Pod developing
Plant Height	53.23±5.00[a]	56.67±4.24[a]	69.85±13.14[b]
Plant Length	59.95±5.07[a]	63.57±5.06[a]	75.58±14.12[b]
Stem Diameter	5.77±0.65[a]	6.13±0.58 [ab]	6.83±0.47[b]
Node Length[ns]	3.58±0.59	3.90±0.62	3.80±0.64
Number of Node	11.00±1.33[a]	13.00±1.64[ab]	14.00±2.48[b]
Rachis Length[ns]	10.83±0.83	12.07±1.58	11.25±1.24
Number of Leaves*	19.00±3.73[a]	29.00±9.15[b]	35.00±7.40[b]
Leaf Length[ns]	14.67±1.23	15.12±1.14	15.07±0.99
Leaf Width[ns]	8.60±0.62	9.28±0.69	9.38±0.35
Number of Flower*	-	4.00±2.26[a]	10.00±5.49[b]
Number of Pod*	-	-	4.00±2.14[b]

[ns] :non significant; [ab]: Different superscripts on the same line indicate significant differences ($P<0.05$); *: Different superscripts on the same line indicate highly significant differences ($P<0.01$).

Tabel 2. Biomass production of jack bean (*Canavalia ensiformis*) at each growth stage (mean±SD).

Parameters	Growth Stage (ton/Ha)		
	Vegetative	Flowering	Pod developing
Total Fresh Weight*	19.39±5.74[a]	34.35±7.21[b]	43.23±14.44[b]
Fresh Leaf Weight*	13.01±4.04[a]	21.76±4.78[b]	22.51±6.49[b]
Fresh Stem Weight*	6.11±1.66[a]	12.59±2.51[b]	20.85±8.31[c]

[ns] :non significant; [ab]: Different superscripts on the same line indicate significant differences ($P<0.05$); *: Different superscripts on the same line indicate highly significant differences ($P<0.01$).

biomass accumulation. In a similar vein, studies on soybean (*Glycine max*) have shown that biomass accumulation is significantly higher during later stages due to increased resource allocation towards reproductive structures (Prasojo et al., 2021b). This reinforces the idea that harvesting jack bean at the pod development stage could yield the most biomass, particularly when both leaf and stem components are considered.

While the results show a significant increase in total biomass and stem weight, the relatively stable fresh leaf weight between the flowering and pod development stages suggests a potential plateau in leaf growth. This finding indicates that while leaves contribute substantially to forage quality, the stems play a more dynamic role in biomass production as the plant progresses to later stages of growth. The creeping growth habit of jack bean plants results in a large number of stems produced and allowing meristem lateral to develop. This is in accordance with Rivera *et al.* (2019) which states that leguminous plants with creeping growth types such as *Pueraria phaseoloides* and *A. pintoi* have long stems so that they will produce higher stems. In addition, stem production in leguminous plants will be directly proportional to plant growth. In other words, the higher the growth stage of a plant, the higher the stem produced. This is in accordance with the results of research by Hashiguchi et al. (2011) which states that plant size and stem thickness are correlated with the growth of leguminous plants such as *L. japonicus* with the creeping habit growth, so that it will increase the production of total fresh weight and stem fresh weight.

Total fresh leaf weight production showed an increase with the increasing growth stage of jack bean. This is because the higher the growth stage (cutting age) of jack bean will produce more nodes and branching that will produce more leaves as well. Morris (2007) stated that the number of leaves of jack bean will increase in line with the age of the plant. Fehr et al. (1971) stated that nodes are part of the stem where leaves are formed. The growth stage of pod formation in leguminous plants has a greater number of nodes when compared to the vegetative and flowering growth stages, so that the number of leaves produced will be even greater. Research conducted by Prasojo et al. (2021b) showed that soybeans with reproductive growth stage 5 (R5) had more branches and leaves than reproductive growth stage 1 (R1) and 2 (R2) in all cultivars. Another study by Dewanti et al. (2024a) showed that the cutting age of 12 weeks after plantingin *Crotalaria juncea* L. plants had the highest number of branches and leaves when compared to the cutting age of 8 and 10 weeks after planting. Its cutting age also affect the biomass production, nutrient content, and prussic acid (Dewanti et al, 2024b).

In conclusion, this study reinforces the importance of selecting the appropriate growth stage for harvesting *Canavalia ensiformis* to optimize forage production, making it a promising legume for sustainable livestock feed systems. Further research should explore the nutritional and in vitro digestibility of jack bean in every developmental stages, the environmental factors influencing pod and seed production, as well as the potential of jack bean to enhance soil fertility through nitrogen fixation, positioning it as a valuable crop in tropical and subtropical agricultural systems.

Material and Methods

Plant material and experimental site

Jack bean (*Canavalia ensiformis*) Setren accession seeds were used as plant material for this study. The study was carried out at an elevation of 100 meters above sea level in Megeri Village, Kradenan District, Blora Regency, Central Java (7°21'40''S 111°26'36''E) (Figure 1). Most of the land in Blora Regency is dry land. The soil type characterized as alluvial. The climate of Blora Regency is tropical climate, relatively high temperatures in the dry season and sufficient rainfall in the rainy season (Prasojo, *et al*., 2023a). Precipitation and air temperature data for the location in 2023 (Figure 2) were obtained from the Ministry of Public Works and People's Housing (PUPR) Bengawan Solo Data for Ngawi Regency, East Java (URL: Sistem Informasi Hidrologi & Kualitas Air (bbws-bsolo.net)).

Climatic conditions

The precipitation and average air temperature during the research in 2023 can be seen in Table 1. The lowest rainfall during the crop maintenance period occurred in September and the highest in November, while the lowest and highest air temperatures occurred in September and October, respectively.

Experimental design and cultivation

The research area employed a randomized block design with three treatments and four replications. Each replication consisted of plots measuring 1 m^2 (1x1 m) with a total of 12 plots and a spacing of 0.5 m between plots, comprising three growth stages: vegetative (VG), flowering (F), and pod development (P). Planting was done by making holes in the soil approximately 2-3 cm deep (Prasojo et al., 2023b), with one jack bean seed planted per hole at a spacing of 25x25 cm, in 4 rows, resulting in a plot density of 16 seeds/m^2. Plant maintenance included watering and weeding, with watering conducted once a day at 05:00 AM if there was no rainfall, and weeding done weekly.

Figure 1. Experimental site of *Canavalia ensiformis* research in Blora, Central Java, Indonesia.

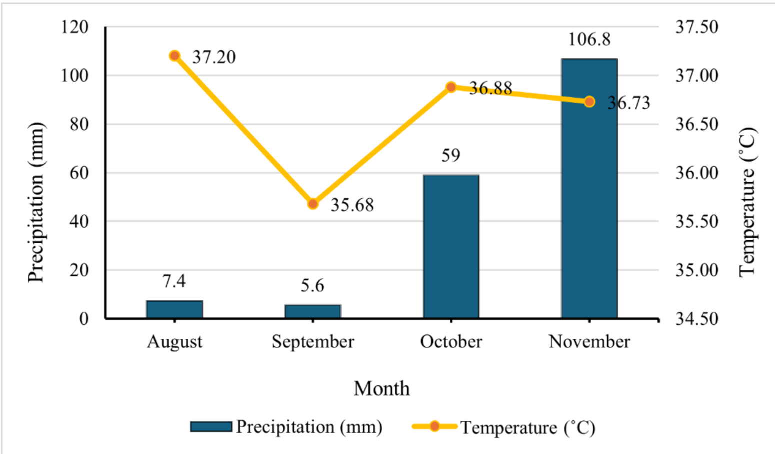

Figure 2. Monthly precipitation and average temperatures during experimental cultivation of 2023.

Measurements of morphology

The germination of jack bean seeds occurred 7 days after planting. Morphological characteristics of the plants including plant height, plant length, stem diameter, node length, number of nodes, rachis length, number of leaves, leaf length, leaf width, number of flowers, and number of pods from five randomly selected plants in each plot were measured before harvesting. Plant height and length were measured using roll meter from the soil surface to the highest point of the plant (Dewanti et al., 2024a), while plant length was measured by straightening the plant vertically and measuring from the soil surface to the longest point of the plant. Stem diameter was measured using a digital calliper, and node length was measured using a measuring tape at the third node from the bottom. The number of nodes was manually counted from the main stem nodes. Rachis length was measured using a measuring tape on the main stem rachis. The number of leaves was manually counted for each plant using hand counter. Leaf length and width were measured using a measuring tape. The number of pods and flowers was manually counted for each growth stages (number of flowers for the flowering stage and number of pods for the pod development stage).

Measurement of cutting and yield

The plant sample cutting was performed 14 cm from the soil surface in different plant growth stages. The cut plants were then weighed using a hanging scale to obtain fresh weight. After weighing the total fresh weight (leaves and stems), separation between leaves and stems was conducted to weigh the fresh weight of each part separately (Prasojo *et al*., 2021a). Total fresh, fresh leaf, and fresh stem weight is converted into tons/ha.

Statistical analysis

Statistical analysis was used to compare the results of morphological characteristics and biomass production among different growth stages. The data were statistically analysed using analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) if significant differences were found (at a significance level of 95%) using SPSS 23.0 (SPSS Inc., USA).

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