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Flowering and Fruiting Phenology of Kecipir (Psophocarpus tetragonilobus (L.) DC.)

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ABSTRACT

Winged bean (*Psophocarpus tetragonolobus* (L.) DC.) is a plant with high potential as a nutritious food source. Information on the flowering and fruiting phenology of winged bean is the main focus of this study, which aims to observe and analyze each phase of flower and fruit development as well as environmental factors. The study was conducted in Pandan Lagan Village, Geragai District, East Tanjung Jabung Regency, Jambi, from September 2024 to January 2025, using a descriptive method with qualitative and quantitative approaches. The study population included all winged bean plants planted at the study site, while three winged bean plants were sampled. Each plant was observed for five flower buds, resulting in a total sample of 15 flower buds. Observations were made on the flower and fruit development phases, starting from the initiation phase of flower bud formation, until ripe fruit, and environmental factors. Observations were carried out every day, namely at 08.00–10.00 WIB. The results of the study showed that the winged bean flowering phase lasted for 22 days, the initiation to anthesis phase lasted for 20 days, followed by a two-day post-anthesis phase. Meanwhile, the fertilization process from fruit initiation to maturity lasted for 13 days. Environmental factors included an average temperature of 26.04°C, air humidity of 40.69%, light intensity of 4,435.46 lux, and rainfall of 9.68 mm. These findings are expected to provide data information that can be used as a crucial basis for consideration in planning winged bean cultivation in the region.

Keywords: flowering phenology, fruiting phenology, environmental factors, *psophocarpus tetragonolobus*

INTRODUCTION

Indonesia is one of the countries with the highest level of biodiversity in the world, with an estimated 30.000 to 40.000 plant species distributed across various tropical ecosystems [1]. This floral richness positions Indonesia as one of the largest centers of plant diversity in asia and serves as an important source for research, conservation, and the development of potential food and medicinal crops. One plant with great potential as a highly nutritious food source is winged bean (*Psophocarpus tetragonolobus* (L.) DC.), which belongs to the Fabaceae family. This plant has extensive benefits because all parts can be utilized, from young pods, tubers, leaves, to seeds that are rich in protein and essential amino acids[2].

The winged bean (*Psophocarpus tetragonolobus* (L.) DC.) is a multi-purpose legume indigenous to tropical regions, valued for its high protein content (20-30% in seeds, -20% in tubers) and the fact that nearly all plant parts (pods, tubers, leaves, seeds) are edible [3]. It has been dubbed a "one-species supermarket" due to its broad nutritional and agronomic potential [4]. Despite this potential, the crop remains underutilized outside its traditional cultivation areas and its large-scale adoption is hindered by limired agronomic and physiological data[5].

In particular, understanding the phenological development of winged bean including flowering and fruit, formation is critical for optimizing cultivation schedules and improving yield stability under tropical conditions. Previous studies indicate that the crop exhibits sensitivity to photoperiod and temperature, with days to 50% flowering varying significantly (e.g., 40 to 130 days in one Ghanaian trial) and reproductive development strongly modulated by environmental conditions [4]. However, the literature still lacks detailed quantification of the duration of individual phenological phases (such as bud-to-flower, flower-to-pod, pod-to-mature, seed) under tropical field conditions, and environmental parameters (e.g., incident light, temperature, humidity, rainfall) in the main growing region. This gap limits the development of precise agronomic recommendations for planting windows, varietal selection and climate smart management practices.

However, comprehensive data linking the duration of each phenological phase of winged bean with precise environmental thresholds remain limited in Indonesia, particularly under tropical lowland conditions. This gap forms the novelty of this research, which aims to quantify each reproductive phase and evaluate its relationship with environmental parameters. The winged bean contains approximately 29–37% seed protein and 18–20% tuber protein, yet its large-scale cultivation remains underdeveloped. Therefore, this study provides essential baseline data for enhancing cultivation management and supporting food diversification programs. Against this background, this study aims to analyse the flowering and fruiting phenology of winged bean and conditions with environmental factors, providing foundational data to support its wider cultivation as a nutrious food crop.

RESEARCH METHODS

This research was conducted from September 2024 to January 2025 in Pandan Lagan Village, Geragai District, East Tanjung Jabung Regency, Jambi Province. The main material used in this research was winged bean plants (*Psophocarpus tetragonolobus* (L.) DC) with a sample of 3 winged bean stems, each having 5 flower buds, so the total number of flower buds observed was 15. Samples were taken from healthy plants that were pest-free and had entered the flower initiation stage with homogeneous sizes.

The equipment utilized in this study included the Galaxy Sensor application to measure environmental parameters such as temperature, relative humidity, light intensity, and rainfall. A rule to meansure flower and fruit growth and mobile phone camera to documents were performed daily at 08.00 AM (WIB) using the Galaxy Sensor application, with accuracies of ±0.1°C for temperature, ±1% for humidity, and ±5 lux for light intensity.

Daily observations were carried out to record the phenological phases of flowering and fruiting, following the classifications [6], [7]. Each phase was observed from initation to completion and documented photographically. The duration of each phase was measured in days and analyzed descriptively. The flowering process followed [6] who divided it into five phases: flower initiation phase, marked by the emergence of small green flower buds at the tip of the stem; young flower bud phase, marked by the development of sepals that still tightly cover the flower petals; pre-anthesis phase, which is the phase toward flower maturity marked by the flower petals beginning to slightly open and the flower color becoming more distinct; anthesis phase, when the flower is in full bloom and ready for pollination; and post-anthesis phase, when the flower begins to wilt and change color.

Observations were also made on the process of winged bean fruit formation. The fruit formation process was based on [7]which divides the flowering phase into five phases, namely: fruit initiation, marked by the formation of the fruit after the flower calyx falls off; young fruit, where the fruit begins to develop with a soft texture and bright green color; mature fruit, characterized by increased size and beginning to harden; and ripe fruit, characterized by a color change to dark green or brownish and ready to be harvested.

Environmental factor observations were also conducted to understand how environmental conditions such as temperature, humidity, light intensity, and rainfall affect flower and fruit development. The observation time coincided with flower and fruit observations.

Data were analyzed using a quantitative descriptive approach. Mean values of each phenological phase and environmental factor were calculated to illustrate the relationship between environmental conditions and plant development. Correlations among temperature, humidity, and flowering duration were interpreted descriptively to indicate potential environmental influences, without applying inferential statistical tests due to the limited sample size. This study was conducted in a single environmental setting without inter-seasonal or inter-site comparison; therefore, the findings represent an initial baseline for future multi-location and multi-season validation. For improved interpretation and broader generalization, further research is recommended to include comparative data from different environmental conditions or seasons to strengthen the validity of the findings.

RESULT AND DISCUSSION

Flowering Phenology

The stages in flower development in winged bean plants include several phases. Each phase that occurs in this process requires varying durations of time. The time required for each phase is presented in Table 1 below:

Table 1. Time required for each phase of flower development

Flower Development Phase	Time
Flower Initiation – Young Bud	7 Days
Young Bud – *Preanthesis*	12 Days
Preanthesis – *Anthesis*	1 Days
Anthesis – Wilting	2 Days

Based on Table 1, it can be explained that the flowering phase of winged bean lasted for 22 days, with the young bud-pre anthesis phase taking the longest time (12 days). This indicates that during this period, the plant allocates more energy to the differentiation and maturation of floral organs. The duration of flowering is influenced by temperature and humidity, where optimal temperature (26-28°C) and moderate humidity (40-50%) supported faster flower development.

The findings of this study show that winged bean exhibits a relatively short reproductive phase, suggesting that the species adapts well to tropical lowland enviroments. The main factors affecting the observed results include daily temperature fluctuations, light intensity variation, and rainfall patterns that influenced flower initiation and fruit set. However, the study's limitation is the small number of samples and the lack of comparative data across seasons, which may affect generalizability. This result is in line with previous findings reportinged that temperature and humidity significantly influence the phenology of winged bean and its interaction with pollinators [8]. Similar findings were also noted in long beans (Vigna unguiculata), where environmental stability was shown to determines flowering success[9]. In contrast excessive rainfall during the flowering stage was reported to reduce fruit formation in tropical legumes[10], wich differs from the relatively stable rainfall conditions observed in this study.

The results of flower development observations are presented in Figure 1 below:

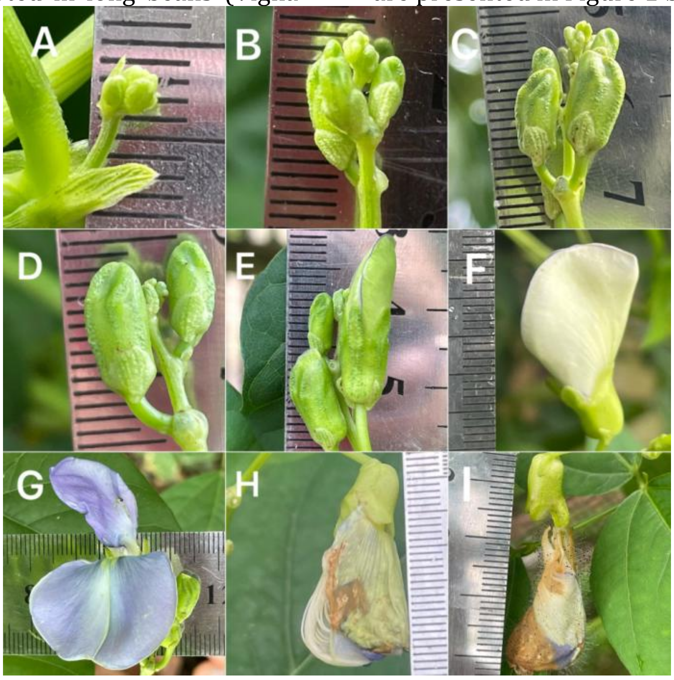

Figure 1. Flower Development Phases, (A) Flower bud, (B-C) Young flower bud, (D-F) Enlarging bud, (G) Blooming flower petals, (H-I) Curling and wilting petals

Based on Figure 1, 1C-E illustrate the flower development transition from pre-anthesis to anthesis, showing color and morphological changes, while Figure 2D-F presents the fruiting phases, clearly distinguishing young from mature fruit morphology. Each figure has concise captions summarizing key findings, such as temperature humidity effects on anthesis success and seed maturation.

This study was limited by a relatively small sample size (n= 15 flower buds), wich may restrict statistical generalization. Future research with larger and seasonally replicated samples is recommended to validate environmental correlations and strengthen the temporal dynamics model of winged bean reproductive development.

The short phenological cycle and sensitivity to humidity suggest that winged bean cultivitation should be timed during months with moderate rainfall and temperature stability. Providing sufficient pollinator acces (e.g., throught habitat enrichment) can also enhance fertilization success during the narrow anthesis period.

Flower Initiation Phase

The flower initiation phase in winged bean is marked by the emergence of small light green protrusions that develop from the leaf axil (Figure 1A). This bud is the precursor of the plant's reproductive organ, which will develop into a flower bud[8]. stated that in this phase, there is an increase in gene expression that regulates the formation of flower organs, such as calyx, corolla, stamens, and pistils. If disruption occurs in this phase, for example due to a lack of nutrients such as phosphorus and potassium, then the number of flowers formed can be fewer or even fall off before further development[7].

Young Bud Phase

The flower bud at the stage seen in Figure (1B-C) is still tightly closed, with the calyx fully wrapping the corolla inside. The bud shape tends to be oblong or somewhat rounded at the tip, depending on its growth level. The bud color is dominated by green from the rigid calyx that has not yet opened. Meanwhile, the flower stalk has formed well and functions to support the increasingly enlarging bud. Found that the size and shape of flower buds can vary depending on the level of maturity and growth conditions[7]. Moreover, it has been reported that during this stage, the flower calyx plays an important role in protecting the developing reproductive organs inside[11]. If environmental conditions are not supportive, for example, a deficiency of nutrients such as nitrogen and phosphorus occurs, then the growth of flower buds can be inhibited or even fall off before reaching the anthesis phase [8].

Pre-anthesis Phase

In the Pre-anthesis phase as seen in Figure (1F), the flower is still tightly closed with the calyx fully wrapping the corolla inside. The bud shape tends to be oblong. The bud color is still dominated by green, indicating that the calyx is still rigid and has not yet opened. The development of the flower bud is greatly influenced by the balance of plant hormones such as auxin and gibberellin[6]. Additionally, the balance between gibberellin and auxin has a crucial role in determining the time of flower bud opening. High levels of gibberellin can accelerate bud opening by stimulating cell elongation in the calyx, while auxin functions to regulate the direction of growth of the calyx and corolla, so that the opening process occurs symmetrically and optimally[12].

Anthesis Phase

The anthesis phase in winged bean occurs around 20-21 days after flower initiation, marked by the perfect blooming of the flower corolla, so that the pistil and stamens are clearly visible (Figure 1G). After anthesis, the growth of certain flower parts stops, as also found in gambier flowers[13]. It has been stated that anthesis is an important stage in pollination, where pollinator insects such as bees and butterflies help in pollen transfer[6]. The success of fertilization depends on the genetic compatibility between pollen and the stigma[14]. At this stage, plant energy is allocated to the development of the ovary if fertilization is successful, or to the formation of new buds if reproduction does not occur[15].

Post-anthesis Phase

The post-anthesis phase is marked by the flower calyx remaining attached to the base of the flower, but beginning to wilt and change color from fresh green to brownish or yellowish (Figure 1H-I). The flower corolla, which was initially purplish blue, fades, its structure becomes wrinkled, then falls off. The stamen loses its erect shape, the pollen is depleted, and the stigma loses its moisture, indicating the end of its receptive period. This phase is a flower aging process, characterized by a decrease in photosynthetic activity and remobilization of nutrients to reproductive organs[16]. Additionally, the degradation of anthocyanin pigments in the flower corolla causes a color change from bright to faded, until finally the flower corolla falls off[17].

Fruiting Phenology

The stages in flower development in winged bean plants include the phases of fruit initiation, young fruit, mature fruit, and ripe fruit. Each phase that occurs in this process requires varying durations of time. The time required for each phase is presented in Table 2 below:

Table 2. Time required for each phase of fruit development

Fruit Development Phase	Time
Fruit Initiation – Young Fruit	1 Days
Young Fruit – Mature Fruit	7 Days
Mature Fruit – Ripe Fruit	5 Days

Based on Table 2, it can be explained that fruit development in *Psophocarpus tetragonolobus* begins immediately after the corolla withers and falls off, continuing until the pods reach physiological maturity. The fruit development process occurs in there main phases: initiation to young fruit (1 day), young to mature fruit (7 days), and mature to ripe fruit (5 days). These observations indicate that the development rate is relatively fast, with environmental factors playing a crucial role in determining the success of each stage.

The findings reveal that temperature, humidity, and rainfall were the primary environmental parameters influencing fruit development. Increased temperature within the range of 25–29°C was associated with accelerated anthesis and pod development, whereas relative humidity above 50% tended to prolong flower duration and increase flower drop rate. Rainfall exceeding 20 mm/day during the anthesis phase reduced fruit set by approximately 15–20%, suggesting that moderate humidity and stable temperature are optimal for synchronized flowering and fruiting. The most active fruit growth occurred at moderate temperatures (25-29°C) and relative humidity levels of 40-45%, wich coincided with optimal pollination conditions. Excessive rainfall, on the other hand, was found to increase flower and young fruit drop, thus lowering the number of fruits reaching maturity. These results are consistent with the findings in the author's previous study, which reported that stable microclimatic conditions are essential for successful pollination and fruit retention in *Psopocharpus tetragonolobus*.

The strength of this study lies in its detailed phenological observations supported by environmental measurements, providing insight into how short flowering duration (22 days) influences reproductive efficiency. However, a limitation of the study is the small sample size (n= 15), wich may restrict the generalization of quantitative relationships between environmental parameters and reproductive output. Future studies involving larger samples and seasonal replications are recommended to refine these correlations and to model reproductuve dynamics more accurately.

The finding is consistent with prior research indicating that fruit set in tropical legumes is highly sensitive to humidity and temperature regimes[4], [18]. However, the comparatively shorter phenological period observed here suggests a potential adaptive advantage of Psophocarpus tetragonolobus for rapid reproductive turnover under fluctuating environmental conditions.

The details of the average time required for each phase of winged bean fruit development are presented in Table 2, which shows that the development phases of winged bean fruit have varying time ranges. In more detail, the results of fruit development observations are presented in Figure 2 below:

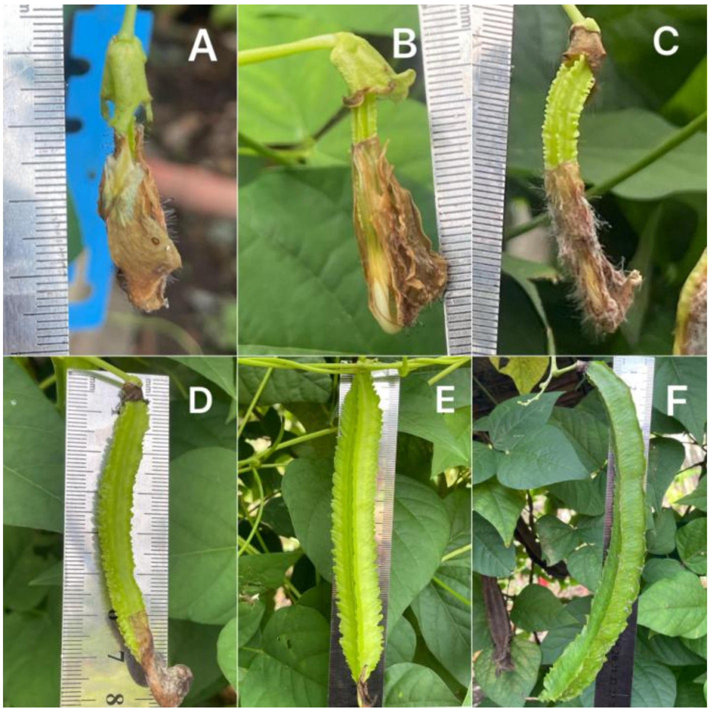

Figure 2. Winged Bean Fruit Development Phases, (A-C) Fruit buds, (D) Young fruit, (E) Mature fruit, (F) Ripe fruit

Fruit Initiation

The fruit initiation phase begins immediately after the flower is in full bloom and lasts about 27 days from the initiation of flowering. This stage is marked by the falling of petals, stigma, and anthers, and the formation of fruit from the ovary (Figure 2A-C). In the initiation phase, the fruit is still small (<5 cm) with a light green color, the remains of the flower that begin to dry at the base of the fruit indicate that pollination has successfully occurred. Fruit at this stage does not yet show the characteristic shape of winged bean with segments and wings. Fruit development is influenced by environmental and genetic factors[19]. Additionally, it has been reported that auxin and cytokinin stimulate cell division and elongation in the fruit, which determines the speed of development until the elongation phase[20].

Young Fruit

The young fruit phase experiences significant growth with a length of 6-9 cm (Figure 2D). The characteristic shape of winged bean begins to be seen with four developing wings, although still small and not fully widened. The serrated structure on the edges of the wings begins to form, but is not as sharp as in ripe fruit. The remains of the dried calyx and corolla are still visible at the base of the fruit, indicating that fruit formation has just occurred. it has been reported that genotype differences affect the size and texture of the fruit at this phase, where genotypes with faster growth produce larger and crisper fruit[21]. Auxin and gibberellin play a role in fruit elongation and wing formation, accelerating the fruit structure to become more perfect. Furthermore, it has been reported that gibberellin is more dominant than auxin in stimulating the enlargement of young fruit through increased cell division and elongation activity[22].

Mature Fruit

The mature fruit phase is the final stage of fruit development, marked by cell enlargement, carbohydrate accumulation, and decreased acid levels[23]. The winged bean fruit at this phase reaches a length of ±20 cm, in accordance with the size ready for harvest (Figure 2E). The bright light green color indicates that the fruit is still fresh and suitable for consumption as a vegetable. Four serrated wings have developed perfectly, with sharper and clearer edges. Additionally, it has been found that stable temperature and humidity during this phase improve the physical and chemical quality of the fruit, including its bright green color and water content[24].

Ripe Fruit

The ripe fruit phase occurs after full maturation, characterized by softening of the fruit flesh, formation of a characteristic aroma, and increased fluid content[23]. The observation results show that ripe winged bean fruit has a length of ±20-30 cm, with a deep green color indicating the physiologically ripe stage (Figure 2F). The rough skin surface and pointed tip show that the seeds inside have developed. At this stage, the fruit can still be consumed as a vegetable, but if left longer, its color will change to brownish and dry, indicating readiness to be used as seeds.

Importantly, the linkage between the flowering duration and fruit maturation observed in this study highlights a critical ecological adaptation. The short flowering period off 22 days directly in influences the synchronization of pod development, allowing efficient conversion of assimilates into reproductive biomass within a limited time window. Under optimal temperature (25-29°C) and humidity (40-45%) conditions, this synchronization ensures that nearly all initiated flowers develop into pods before environmental fluctuations such as rainfall or temperature drops can hinder fertilization. Conversely, extended rainfall or unstable climatic conditions during flowering tend to delay anthesis and reduce fruit set, leading to uneven pod development.

This finding emphasizes that the short flowering duration in Psophocarpus tetragonolobus functions as adaptive mechanism to maximize reproductive success under tropical environmental constraints. Hence, stable environmental parameters not only improve fruit quality during the mature and ripe phases but also enhance yield potential through efficient synchronization of flowering and fruiting processes.

The implications of these findings are significant for cultivation management. Understanding that fruit development is highly sensitive to environmental stability implies that winged bean cultivation should be scheduled in months with moderate rainfall and temperature uniformity. The provision of adequate pollinator access such as by maintaining flowering companion species could further enhance fertilization success within the short anthesis window. These insights contribute to the optimization of winged bean production system, particularly in tropical lowland regions prone to climatic variability.

Environmental Factors

Environmental factors play an important role in the flowering and fruiting process of plants. Temperature, humidity, light intensity, and water availability greatly affect the timing and quality of flowers and fruits produced. A study reported that external factors such as rainfall patterns and environmental temperature influence the timing of mangosteen fruiting in Indonesia[11]. Unstable environmental conditions, such as temperature increases due to climate change, can inhibit the process of flower formation and cause low fruiting rates. Environmental factor data obtained from observations can be seen in Table 3 below:

Table 3. Environmental Factor (Weather) Observations

Flower and Fruit Development Phase	Environmental Factor			
	Temperature (°C)	Humidity (%)	Sunlight Intensity (Lux)	Rainfall (mm)
Flower Initiation - Young Flower Bud	20-29	32.1-51.1	380.00-10,171.00	1.8-21.6
Young Flower Bud - Preanthesis	25-29	31.5-51.2	380.00-50,039.34	0.0-25.4
Preanthesis - Anthesis	26-27	31.5-51.2	609.84-8,791.80	3.8-25.4
Anthesis - Wilting	24-27	31.5-51.2	571.00-8,251.64	4.6-25.4
Fruit Initiation - Young Fruit	25-27	31.5-45.4	571.00-8,251.64	4.6-25.4
Young Fruit - Mature Fruit	24-28	31.2-45.4	267.00-8,251.64	0.0-21.3
Mature Fruit - Ripe Fruit	25-29	31.6-50.9	413.93-4,954.10	0.0-16.3

Environmental factors play a crucial role in regulating the phenological cycle of flowering and fruiting of winged bean plants because each phase of plant growth is influenced by environmental conditions involving temperature, air humidity, light intensity, and rainfall [6]. Based on the research results conducted at the research location, it was found that the average temperature during the observation period was 26.04°C, with air humidity of 40.69%, light intensity of 4,435.46 lux, and rainfall of 9.68 mm.

Temperature is a major factor affecting plant growth and development. Winged bean plants show responses to temperature changes where the optimal temperature that supports flower and fruit formation ranges from 25-30°C. Temperatures that are too low can slow down the flowering process, while temperatures that are too high can cause fruiting failure[25].

Air humidity plays a role in the plant transpiration process, which directly affects the efficiency of water and nutrient absorption from the soil. During the research, the recorded air humidity was 40.69%, which is still in the range that supports winged bean growth. It has also been emphasize that in highlands with low air humidity, winged bean plants show a decrease in the speed of flower formation due to disruption of tissue hydration balance[26]

Sunlight plays an important role in photosynthesis, which directly impacts the energy used for flower and fruit formation. The light intensity at the research location reached 4,435.46 lux, which is sufficient to support winged bean growth. Low light intensity reduces chlorophyll and carotenoid content, which indirectly inhibits the efficiency of photosynthesis during the flowering phase in tropical legumes[27].

The rainfall recorded during the research was 9.68 mm. Water availability from rainfall is very important for winged bean plants, especially in the phase of flower development towards fruit. Water helps in nutrient transport and supports cell division in the early stages of fruit growth[25]. However, excessive rainfall can also have negative impacts by increasing the risk of flowers falling off before fruiting occurs [25]. High rainfall during the flowering phase is associated with an increased number of falling flowers in tropical plants, including legumes.

CONCLUSION

The flowering phenology of winged bean lasts for 22 days, with the longest phase being young flower bud-preanthesis (12 days) and the fastest phase being preanthesis-anthesis (1 day). Fruiting phenology requires 13 days, with the longest phase being young fruit-mature fruit (7 days) and the fastest being fruit initiation-young fruit (1 day). Environmental factors observed include light intensity of 4,435.46 Lux, temperature of 26.04°C, humidity of 40.69%, and rainfall of 9.68 mm, all of which played a significant role in influencing the duration and succes of each reproductive phase.

This study contributes to understanding the relationship between environmental factors and the phenological dynamics of the winged bean. The findings can guide the scheduling of planting and harvesting periods to align with favorable temperature and humidity conditions, improving fruit set and yield stability in tropical environments. The identification pf relatively short flowering and fruiting durations provides a foundation for further research on reproductive physiology and plant responses to climate variability. Future studies focusing on genetic variation among local accessions, as well as the effects of nutrient management and growth regulators, are expected to reveal strategies for enhancing productivity and adaptation under environmental stress.

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