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Research Article
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Phenology of flower and fruit formation progression in *Musa acuminata* cv. Cavendish

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Abstract: Phenology is the study of plant life cycle stages and seasonal activities observed throughout the year. *Musa acuminata* cv. Cavendish bananas are valued for their resistance to pests and diseases, as well as their health benefits. This study was conducted at the Faculty of Sustainable Agriculture to determine the stages of flower and fruit development in Cavendish bananas, aiming to enhance yield through improved agricultural practices. Five main parameters were measured, including daily observations of each phase of banana fruit development. The number of days each bract takes to open and naturally fall off was recorded, starting from when each bract fully opens until it drops. The time required for each phase to form was recorded, the number of hands (banana clusters) was counted for each bunch, and finally, the harvested bananas were weighed to determine the average weight of each finger. The results indicate that Cavendish bananas grown in Sabah take approximately 89 days to complete the flower and fruit development cycle, producing 103–105 bracts and passing through 12 distinct growth stages. This development period aligns with findings from South Africa, where Cavendish bananas mature in 85–100 days after flowering. Variation in banana fruit maturity is influenced by environmental factors, such as climate, which affect the growth cycle.

Keywords: bracts, Cavendish banana, fruit development, phases, phenology

1. Introduction

Banana (*Musa* spp.) belongs to the Musaceae family. Musa acuminata is widely distributed, and Malaysia is considered the main origin of *Musa acuminata* (Mathew & Nagi, 2017). Bananas are tropical plants originating from Southeast Asia and play an important role in the global agricultural sector. This plant thrives in tropical areas, making it easy to cultivate in various locations with suitable climates. Today, bananas are extensively grown worldwide, especially in tropical regions, with major producers and exporters including countries in Latin America, the Caribbean Islands, and Asia. In Asia, major banana-producing countries include the Philippines, India, Thailand, Indonesia, and Malaysia. In Malaysia, banana cultivation is widespread due to its adaptability to various soil types and tropical climates.

Bananas are available year-round because this crop does not depend on a specific season. This makes it a continuous and easily accessible food source. Bananas are also a very versatile fruit. They can be eaten fresh as table fruit, cooked in various dishes, or processed to produce products such as banana chips, smoked bananas, banana flour, and more. However, their uses

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depend on the cultivar grown, as different banana varieties have distinct textures, flavours, and sweetness levels that are suitable for different purposes.

Popular cultivars in Malaysia include Cavendish, Pisang Emas, Pisang Raja, and Pisang Rastali (Mohamad & Aman, 2009). Globally, bananas are typically triploid (containing three sets of haploid chromosomes and usually sterile), resulting from the crossing of two types of bananas, *Musa acuminata* (genome AA) and *Musa balbisiana* (genome BB), producing various genome variations such as AAA (Cavendish banana), AAB (Pisang Raja), and ABB (Pisang Awak). Traditionally, Musaceae species have been classified based on combinations of morphological, phenological, and floral characteristics (Wikantika et al., 2021). In 2017, banana cultivation in Malaysia covered 34,894.06 hectares, yielding 350,492.59 metric tonnes. For the export market, the total export value of bananas in 2016 was RM34 million, with a production yield of 25,101.46 metric tonnes. This amount increased to RM40 million in 2017, with 27,450 metric tonnes exported (Mulia, 2019).

In Malaysia, bananas such as Cavendish, Mas, and Rastali can be eaten directly. Bananas such as Raja, Tanduk, Nipah, and Pisang Awak are often made into banana chips or fried bananas. Cavendish, Mas, and Berangan bananas are usually exported and commercialized overseas. Bananas are categorized as climacteric fruits, meaning they ripen or mature after being harvested, or continue the ripening process even after being picked (Febri, 2023). In Malaysia, most farmers prefer banana cultivation due to high market demand, and the more stable prices it offers compared to other crops. However, many farmers consider banana cultivation high-risk, as bananas are said to require a long period, about 10 months, to reach harvest. This directly leads to various issues, such as disease outbreaks and animal disturbances, which can affect crop yield (Mahmud, 2022).

Banana phenology is the study of changes and developmental phases from the early stages to maturity (Weinert & Simpson, 2016). It involves monitoring key growth stages, including bud emergence, leaf formation, flowering, fruit development, and fruit ripening. Understanding the banana phenology cycle enables producers to optimize management and plan planting and harvesting dates within the studied period. Moreover, phenology is important for understanding how environmental factors such as temperature, sunlight, and humidity affect the banana life cycle. By knowing the correct timing for each growth phase, farmers can plan agronomic activities such as pruning, fertilizing, and pest control more effectively. This can increase both the yield and quality of bananas. Banana phenology also helps determine the optimal harvest time. Harvesting at the right time ensures bananas reach the desired maturity level. For example, bananas harvested too early may lack the desired sweetness and texture, while those harvested too late may be easily damaged and have a shorter shelf life. Leaf emergence rates are important in subtropical areas as they inform growers when management practices such as fertilisation and leaf removal should be carried out (Weinert & Simpson, 2016). However, detailed phenological information on banana cv. Cavendish flower and fruit development under Sabah climatic conditions remains limited. Therefore, this study was conducted to determine the developmental and maturity stages of Cavendish banana flowers and fruits.

2. Materials and Methods

2.1 Location and duration of the study

The study was conducted at the Banana Plot at Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan, Sabah located at latitude 5°55'50.3"N and longitude 118°00'31.1"E. The region experiences an average temperature range of 24°C to 35°C. The study began in June and continues until November 2024, lasting six months. Observations were conducted on twelve different banana plants.

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2.2 Banana fruit development phase

The development of the banana fruit follows a series of stages, starting from flower formation to maturity. Banana cv. Cavemdish trees were marked, and each tree's flower was tagged and observed for changes until the fruit was matured. After fruit set, observations were carried out every day. During these observations, visual changes in morphology and colour were recorded. Digital images of the transitional phase were captured with a smartphone. These stages include flower formation, pollination, fruit enlargement, and fruit ripening, which eventually lead to harvest readiness. Each of these phases is crucial in determining the yield and quality of the banana fruit (Fabro-Realin et al., 2022).

2.3 Observation of banana flower bract opening and shedding

Observation began with the emergence of the banana flower from the centre of the banana stem, designated as day one, and continued until the banana heart shed its final bract. Each bract was recorded at different stages of development. To ensure accuracy, smartphone images were used to track and document the bract-opening process (Waniale et al., 2021).

2.4 Duration of each growth phase

The duration of each phase was observed from flower formation as a day one until the fruit matured. Observations were carried out every day. The transitional phase was counted manually (Fabro-Realin et al., 2022). Four-year-old trees were marked, and each tree's inflorescence was randomly tagged and observed for changes until the fruit was set and matured. After fruit set, observations were carried out every seven days. During these observations, visual changes in morphology and colour were recorded. Digital images of the transitional phase were captured with a camera (DSLR-A200, Sony, Japan).

2.5 Calculation of the total number of banana hands

The total number of banana hands was calculated after a bunch of bananas was harvested. The bunch was cut, and each hand was counted and labelled. Each hand was recorded through photos taken with a smartphone. The total number of hands for each bunch was then manually counted and recorded as data (Pinang, 2020).

2.6 Calculation of the weight of cavendish bananas

The ripe bananas were weighed using a scale. The weight of the bananas was recorded, and this data was used for comparison with the weight from other plants (Suwito & Daud, 2024). Each fruit weight was recorded, and the average weight was calculated using a formula:

$$\text{Average weight} = \frac{\text{Total weight of the bananas}}{\text{Total number of hands obtained per bunch}}$$

3. Results and Discussion

3.1 Banana fruit development phase

Throughout the study, the development of the Cavendish banana flower and fruit showed distinct changes across 12 phases, from phase 1 to phase 12. The process began with the emergence of the flower at the centre of the pseudostem, which then developed into a bunch of fruit. Figure 1 illustrated the progression in the development of the Cavendish banana flower and fruit throughout the study.

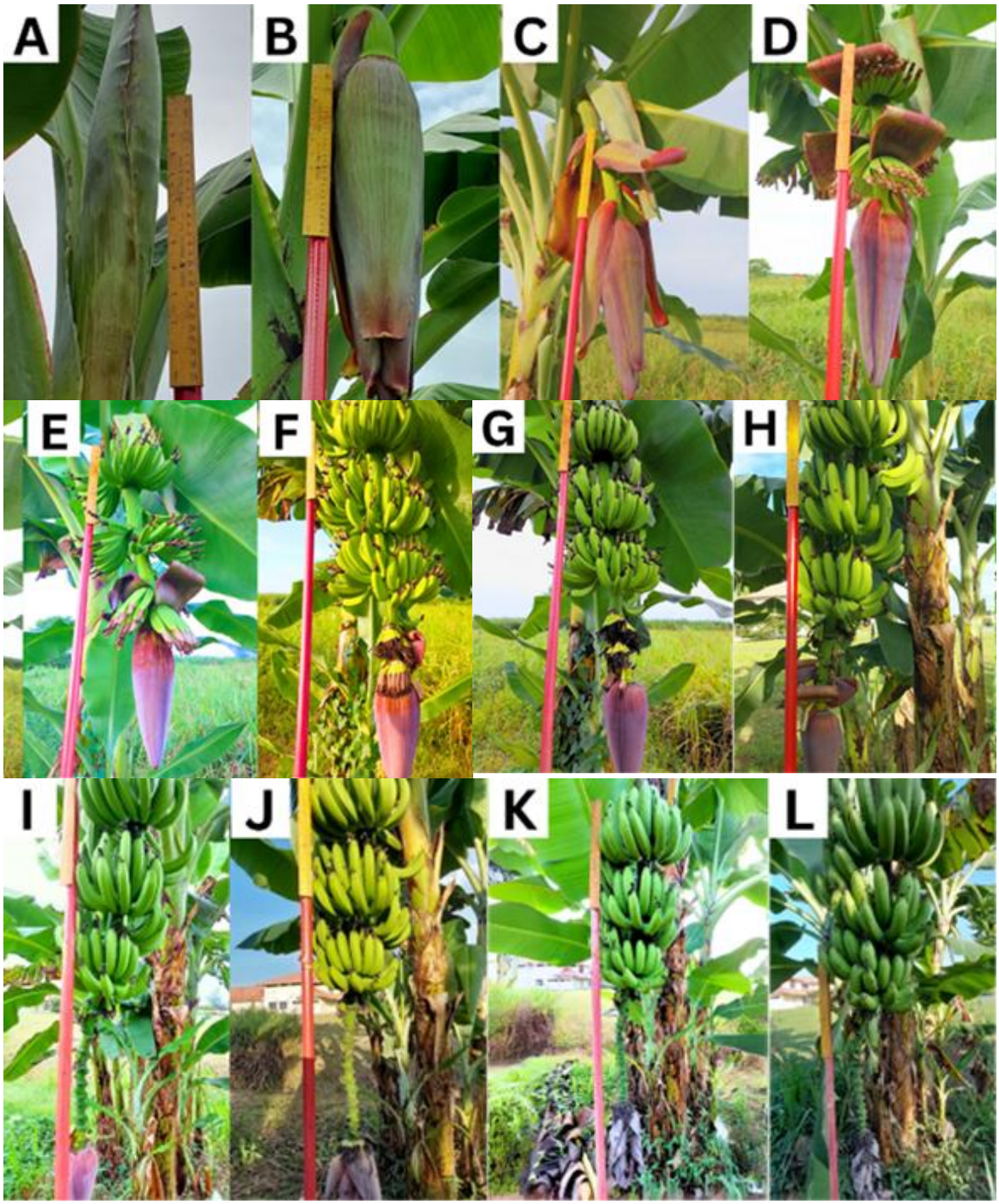

Figure 1. Banana cv. Cavendish fruit development phases from phase 1 to phase 12.

Figure 1(A) in phase 1 showed the beginning of stem formation, which served as the main support structure for the banana plant. This stem provided stability to the plant, allowing it to support the weight of the leaves, flowers, and fruits that would develop in the following phases. The pseudostem is the part of the banana plant that appears like a stem, consisting of a soft central core or false stem wrapped with leaf sheaths. These leaf sheaths detach from the stem and become banana leaves when mature (Paull & Duarte, 2025). This phase is the optimal time to apply fertiliser to the banana plant. At this early stage, the banana fruit was undergoing active growth and required adequate nutrient support, such as potassium fertiliser, to ensure optimal development and produce high-quality fruit (Robinson & Saúco, 2010). The use of appropriate fertiliser at this stage increased fruit size, bunch strength, and overall crop quality.

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In Phase 2, Figure 1(B), the flower or inflorescence showed changes distinct from Phase 1. The immature inflorescence was protected by a purple bract, giving it the appearance of a large bud, and was called the 'bell' (Christelová et al., 2016). The inflorescence was initially upright but soon drooped and pointed downward. This occurred due to the size and weight of the flower, the growth of the peduncle (flower stalk), and the geotropic effect. The geotropic effect played a role, as the plant tended to grow towards gravity, causing the inflorescence to point downward as the flower stalk developed (Doreen, 2024).

Each flower in the inflorescence was protected by purple bracts, which served as shields for the developing flowers in Figure 1(C) (Phase 3). The bracts opened sequentially, with the bracts at the base of the inflorescence opening first and progressing towards the tip. These bracts curved backward (reflexed) before eventually falling off completely (Christelová et al., 2016). The female flowers were clearly visible, appearing green in colour. At the same time, the peduncle began to elongate, with the stalk emerging from the pseudostem to support the developing inflorescence (Robinson & Saúco, 2010). This process exposed the female flowers or other structures within the bracts, creating space for further development, such as fruit formation.

In phase 4, Figure 1(D) the partially rolled bracts, which served as a protective covering, began to reveal the female banana flowers, closely arranged in two layers. This indicated that the banana flowers were developing and starting to create spacing between each other. Additionally, the banana flowers hanging at the end of the cluster showed that their flower stalks had elongated and become heavier due to the formation and development of the flowers and fruits (Robinson & Saúco, 2010).

In Figure 1(E) (Phase 5), many physical changes occurred in the bunch and hands of the banana. The main flower stalk continued to elongate, and some of the female flower bracts began to fall off naturally (Doreen, D.A, 2024). The banana hands expanded, allowing space for fruit formation, while the flower tips darkened. Additionally, the bracts that had opened continued to produce new flowers, which eventually developed into fruit. This process demonstrated how the female flowers systematically developed into bananas through growth and complex structural changes.

In phase 6, Figure 1(F), the female flowers began to curve slightly upwards, and flowers appeared between the nodes of the female and male flowers, containing intermediate structures. These flowers were hermaphroditic, with short ovaries that did not develop into edible fruit. Typically, the appearance of hermaphroditic flowers signalled that the bract would no longer produce female flowers (no further fruit would be produced), and male flowers would dominate the next stage of development. The male flowers remained within the bell-shaped structure (flower bud structure) with their bracts throughout the life of the inflorescence. However, in commercial practice, the flower buds were usually removed to prevent continuous meristem growth and elongation of the peduncle axis (Summerville, 2024).

Moreover, in phase 7, Figure 1(G), the bracts and flowers opened and expanded sequentially, starting from the part of the bracts and flowers closest to the stem (proximal) and moving towards the more distant part (distal). This process caused the peduncle, the flower stalk, to continue elongating. This ensured that the inflorescence developed in an orderly manner, with bracts and flowers opening one by one, while the elongating peduncle supported the upward movement of the inflorescence. Over several weeks, the banana fruit gradually curved upwards due to negative geotropism, a response to gravity regulated by auxin hormones (Summerville, 2024).

In Phase 8, Figure 1(H), the banana fingers clearly displayed their upward growth direction (a manifestation of negative geotropism) (Fabro-Realin et al., 2022), and the pulp filling became more pronounced. This process demonstrated the physiological development of the banana fruit due to the imperfect ovary of the flower (parthenocarpic flower, which produces fruit without

fertilisation). The rachis (flower stalk) supporting the banana bunch underwent significant elongation, resulting in a clearer separation between the male and female flowers. This elongation of the rachis increased the distance between each flower, creating a more organised arrangement and facilitating the pollination process. The male flowers, located at the top of the bunch, became further separated from the female flowers, which were located at the bottom of the bunch (Doreen, 2024).

Furthermore, in Phase 9, in Figure 1(I), the banana fruit became more curved compared to the previous phase. In this phase, the structure of the banana fruit cluster or bunch was explained more clearly. First, the stem containing two rows of female flowers was known as the 'hand', with each 'hand' containing a group of 'fingers'. These fingers were individual bananas that developed from the female flowers and, when combined, formed the entire 'bunch' of bananas. The edible banana bunch consisted of several hands arranged spirally on the thick banana stem (peduncle). The number of hands in each bunch and the number of fingers on each hand were determined early in flower formation, depending on the number of female flowers formed on the banana stem. This process is influenced by several factors, including the banana genome group, the crop cycle and growth period, environmental temperature affecting flower formation, plant health, and the management of banana cultivation and care (Robinson & Saúco, 2010).

From phase 10 in Figure 1(J), the bracts on the banana no longer fall off naturally. Instead, they remain attached to the flower stalk until they eventually decay or dry out. This occurs because the bracts no longer play a role in fruit development. However, bracts that do not fall off can interfere with the maturation process by causing excessive moisture or providing a site for the growth of fungi and bacteria.

In Figure 1(K) for phase 11, the banana bunch approaches maturity, and this phase is called the "Green Life," referring to the period after the banana harvest when the fruit remains green and has not yet fully ripened. At this stage, the bananas show no signs of maturity, and the pulp remains firm and green. This continues until the fruit enters the climacteric phase, marked by a change in fruit colour to yellow and the softening of the pulp.

Finally, for Figure 1(L), phase 12 was the maturity phase, during which the banana fruit reached full maturity, with the skin turning yellow and the pulp becoming softer. The banana peel had turned yellow, which was an early sign that the banana had reached maturity and was ready for harvesting. Additionally, the maturity of the fruit could be determined using the banana maturity index, according to the Department of Agriculture, which was at index 3. This index was used to determine the stage of maturity of the banana before it was harvested or marketed.

3.2 The number of days for the banana flower bract to open and fall

Table 1 shows the development and emergence of the banana inflorescence (flower). Each bract (a leaf-like structure surrounding the flower) opened sequentially, with each bract opening approximately one day apart. This resulted in a continuous or gradual effect on the flowering and fruiting process of the banana plant (Robinson & Saúco, 2010).

Banana bract opening began in phase 2 and continued until phase 12, while in phase 1, the bracts remained closed within the pseudostem. Starting from phase 2, the bracts began to open five days after the appearance of the banana flowers, but during this phase, no bracts naturally fell off. The number of days required between all the phases varied. This can be observed in phases 3 and 4, where the bracts opened within a short period of 9 to 11 days, with the bracts beginning to fall off between days 11 and 12. The duration for the opening and shedding of the bracts gradually increased during the middle phases (phases 5 to 7), taking 13 to 21 days for the bracts to open and 13 to 22 days for them to fall off, starting from the day the first flower appeared. In the following phases (phases 8 and 9), the opening period increased to 34 to 50 days, with shedding occurring between 36 and 46 days. In phases 10 to 12, the duration of bract

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opening continued to increase from 67 to 86 days, but during this phase, no bracts fell off naturally. Only 48 bracts fell off naturally, while the remaining bracts remained attached to the rachis until the banana flower rotted or dried. Day 86 marked the last day of natural bract opening, and the total number of bracts ranged from 100 to 110 for Cavendish bananas. From day 87 to 89, no new bracts opened. Overall, the table showed that bananas required more time to mature as they approached full maturity.

Table 1. The number of days required for the banana bract to open and fall off after the banana flower appeared.

Phase	*Day of bract opening	**Day of bract fall
1	0	0
2	5	0
3	9	11
4	11	12
5	13	13
6	15	16
7	21	22
8	34	36
9	50	46
10	67	-
11	83	-
12	86	-

Note: *The bract stopped opening from day 87 to 89; **On day 48, only 48 bracets fell off naturally. The remaining bracts stayed attached to the rachis until the flower buds rotted or dried out.

3.3 Duration required for each phase to form

Table 2 shows the duration (number of days) required for the banana fruit to reach maturity in each phase, with 12 phases in total, each having a different duration before reaching maturity. In phase 1, the process took 5 days, starting from the first day the banana flower emerged in the middle of the pseudostem until it transitioned to phase 2. Between phases 2 and 6, each phase required only about 2 days to form, making this the shortest period in the entire maturation process. In this study, the appearance of hermaphroditic flowers (flowers that do not produce fruit) in phase 6 marked the appropriate time to cut the banana flower (male bud). Cutting the banana flower focused the plant's energy and nutrients on the growth and development of the banana fruit, ensuring higher-quality yields. Phase 7 then took around 6 days to complete before transitioning to the next phase. The number of days required for the maturation process began to increase from phase 8 to phase 11.

Phase 8 took 13 days to complete, while phases 9 to 11 took longer than the other phases, between 16 and 17 days. In the final phase, Phase 12, the banana ripening process took 6 days, during which the bananas began to show colour changes from green to yellowish green, indicating that the fruit was nearly fully ripe. This entire process showed the development of the fruit from the early phases to the final stage, providing important information to understand the duration and characteristics of each maturation phase. This information was useful for crop management and more accurate harvest timing predictions (Mathew & Nagi, 2017). In conclusion, the time require for a bunch of Cavendish bananas to reach maturity in Sabah was around 85 to 89 days (2 to 3 months). This period was like South Africa, where banana maturity was reached within 85 to 110 days (2 to 3 months) after the emergence of the inflorescence (Robinson & Saúco, 2010).

Table 2. The number of days required for each phase to form.

Phase	Duration of each phase to form
1	5
2	2
3	2
4	2
5	2
6	2
7	6
8	13
9	16
10	17
11	16
12	6
Total number of days	89

3.4 Calculation of the total number of banana hands

The study found that each Cavendish banana produced an average of 7 to 8 hands per bunch, with about 12 to 14 fingers in each hand. However, this number shows a difference compared to the data released by Bojonegoro University in Indonesia, which recorded 8 to 13 hands per bunch, with each hand consisting of 12 to 22 fingers (Suwito & Daud, 2024).

3.5 Calculation of the weight of cavendish bananas

Table 3 shows the average weight per finger for 3 banana plants. The harvested and ripened banana bunches were using a scale to determine the average weight of the bananas. Based on Table 3, Plant 1 recorded an average hand weight of 0.079 kg, Plant 2 recorded 0.101 kg, and Plant 3 recorded 0.135 kg. Overall, the average hand weight of Cavendish bananas in Sabah was around 0.1 kg. This difference was not very significant compared to the average hand weight in neighbouring Indonesia, which recorded around 0.15 kg per hand (Suwito & Daud, 2024). In conclusion, this occurred because the tropical climate in Sabah and Indonesia is similar. Although there is a slight difference in the hand weight between the two locations, the Cavendish banana yield in Sabah is still within a similar range as in neighboring Indonesia and remains at a satisfactory level.

Table 3. Average weight of a Cavendish banana.

Banana plant	Total weight per bunch (kg)	Total number of fingers (per bunch)	Average weight of a finger (kg)
Plant 1	6.30	80	0.079
Plant 2	8.79	87	0.101
Plant 3	14.85	110	0.135

4. Conclusion

In conclusion, the banana cv Cavendish fruit exhibits 12 growth phase before the fruit matured or reaches physiological maturity. The process begins with the bract opening, followed by the development of the flowers and fruit, and concludes with the maturation. Banana cv. Cavendish takes approximately 89 days from fruit set until maturation. Identifying the growth phase and changes during flowering and fruiting provides growers with invaluable information to optimize production planning. Furthermore, this study provided farmers with useful data to determine the optimal time to cut the banana flower, ensuring that fruit growth and development were not disrupted. Understanding the timing and progression of these critical stages throughout

the banana life cycle is essential for maximizing yield and ensuring efficient harvest cycles. These findings are a valuable resource for the banana industry, supporting sustainable farming practices and promoting the production of high-quality banana cv. Cavendish in Sabah and beyond.

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