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PHENOLOGICAL STUDIES OF MATOA (*Pometia pinnata*) FLOWERING AND FRUIT DEVELOPMENT

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ABSTRACT

Matoa (*Pometia pinnata* J.R. Forst. & G. Forst.) is an underutilized fruit species native to Indonesia, primarily found in the lowland subtropical and tropical regions of the Asia-Pacific. Despite its potential as a source of fresh fruit, processed products, and bioactive compounds such as antioxidants and antimicrobials, limited research has been conducted on its phenology. This study aimed to investigate the flowering and fruit development of matoa at the Mekarsari Fruit Garden in Cileungsi, Bogor, to provide essential data for its cultivation and breeding. The generative cycle of matoa begins with floral initiation at the onset of the dry season (late June to early July), followed by full bloom in September. The panicle flowers, ranging from 8 to 30 cm in length, exhibit 4 to 16 flower branches in monopodial inflorescences. The average duration from generative bud emergence to blooming is 56 days, and ovary formation occurs approximately 9 to 12 days after anthesis. The fruit development period, from anthesis to maturity, lasts around 12 weeks, with an average fruit set rate of 2.51%. This phenological data provides crucial insights into matoa's reproductive cycle, essential for improving cultivation practices and exploring its agricultural potential.

Keywords: Flowering, Fruit development, Microclimate, Phenology

Matoa (*Pometia pinnata*), a tree species belonging to the Sapindaceae family, is distributed across tropical regions up to an altitude of 1200 meters above sea level, primarily between latitudes 14°N and 20°S (Lim, 2013). This species has become an iconic flora of Papua Province, Indonesia. The ripe fruit of matoa is distinguished by its skin, which can range in color from red to yellow to green. The texture of the fruit's aril is classified into two main types: '*matoa kelapa'* and '*matoa papeda'*. '*Matoa kelapa'* features firm, non-sticky flesh with a fruit diameter ranging from 2.2 to 2.9 cm, while '*matoa papeda'* is characterized by a softer, stickier aril texture and a smaller fruit diameter of 1.4 to 2.0 cm. The flesh of the matoa fruit emits a distinctive aroma and flavor, often described as a blend of rambutan, longan, and durian (BPTP, 2014).

Matoa has a wide range of applications, including use as building material, handicrafts, fresh fruit, medicine, and ornamental plants. Additionally, it has been utilized for traditional remedies to treat burns and smallpox (Sada and Tanjung, 2010; Thomson and Thaman, 2006). The antioxidant activity of matoa fruit peel, as measured by DPPH radical scavenging, lipid peroxidation inhibition, and total phenolic content, surpasses that of soursop and salak fruit peels, positioning matoa as a potent source of antioxidants (Fitri, 2015). Furthermore, a study by Zanuary (2014) demonstrated that matoa leaf extract, when used as a mouthwash, effectively inhibits the growth of *Streptococcus mutans*, a bacterium associated with dental caries. Matoa plants are rich in bioactive compounds, including phenolics, triterpenoids, steroids, saponins, coumarins, and flavonoids (Matuputun *et al.*, 2013; Trimedona *et al.*, 2017). Notably, the ethanol extract of matoa has been identified to contain proanthocyanidins, which act as inhibitors of HIV integrase (Suedee *et al.*, 2013).

The significant potential of matoa, with its numerous benefits, necessitates further research to provide essential information for its cultivation. While the general potential and advantages of matoa are widely acknowledged, knowledge about cultivar characteristics, flowering patterns, and fruiting seasons remains limited (Wambrauw, 2011). According to Tabla and Vargas (2004), phenological observations are crucial for understanding the plant's life cycle, from generative initiation to fruit ripening, as well as its responses to environmental conditions. Therefore, this study aims to investigate the phenology of flowering, fruit development, and the quality characteristics of matoa fruit.

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MATERIALS AND METHODS

The red-skin variety of matoa fruit was planted in 1995 at the Mekarsari Fruit Garden in Bogor, located at geographic coordinates 6.50000°S latitude and 106.75000°E longitude, approximately 70 meters above mean sea level. The study focused on four 24-year-old, healthy, and normally growing trees. Plant care, including fertilization, weeding, and pruning, was conducted annually. The preparation of materials and the analysis of the physical and chemical quality characteristics of the fruit were carried out at the Postharvest Laboratory within the Department of Agronomy and Horticulture, IPB University. Soil and leaf nutrition assessments were performed at the Soil Laboratory in the Department of Soil and Land Resources, IPB University.

The flowering phase was observed every six days, starting from the emergence of generative panicle buds until the flowers bloomed. The fruiting phase was monitored every two weeks after anthesis. Eight panicles from the four tree samples were selected for analysis. The observation period aligned with the morphological stages of flower and fruit development. As noted by Yulia (2007), plant phenology observations follow distinct periods of morphological change. The flowering and fruiting phases were categorized according to the criteria outlined in Table 1 (Dafni, 1993).

Table 1. Flower and fruit development phase of matoa

Phases	Symbol	Description
Generative bud initiation	IM	Generative initiation marked by the emergence of panicles from apical/lateral twig branhes
Panicle enlargement	AM	Flower panicle seedlings that grow wide from the main stem of the panicle as a characteristic flower inflorescence
Mature flower bud	KB	A flower petals that has formed but is still wrapped with sepal
Anthesis	AN	A full blooming flowers that marks the flower pollination as the beginning of fruit formation
Fruit bud	BK	The polination has occurred which is marked by the fall of petals and enlarged ovaries
Arilloide Form	BM	The fruit has a arill layer but still have green-colored fruit skin
Mature	M	The fruit skin turning red
Overripe	BL	The fruit is overipe marked by the fruit skin color turning darker and harder

(Dafni, 1993)

Soil nutrient status: Soil nutrient analysis was conducted during the emergence of generative buds in the matoa trees. Soil samples were collected from the root zone beneath the canopy of the trees, at a distance of 1 to 2 meters from the edge of the plant's crown, and at a depth of more than 50 cm. The collected soil was air-dried and sieved using a 2 mm mesh to ensure uniform particle size (Liferdi, 2007).

Leaf nutrient status: To assess the physiological status of the matoa trees, leaf nutrient analysis was performed to monitor the nutrient dynamics during flowering and fruit development. Leaf samples were collected every 30 days, and the analysis included both macronutrients and micronutrients, such as Boron (B), Zinc (Zn), and Calcium (Ca). Sixteen fully developed, healthy, and undamaged leaves were selected for sampling, evenly distributed across the four cardinal directions (Liferdi, 2007).

Growing climate: The growing climate was monitored in real-time using Encomotion data logger devices, which measured temperature, humidity, and light intensity. Additional climatic data, including rainfall, were obtained from the Bogor Climate Station through online reports from the Meteorology, Climatology, and Geophysical Bureau.

Heat unit: The heat unit was calculated as the degree of growing days (GDD), which is calculated from the air temperature of flowering and fruit development periods with the equation:

$$HUA = \sum (T_{max} + T_{min}/2) - T_b$$

HUA = heat unit accumulation

T_{max} = maximum daily temperature (°C)

T_{min} = minimum daily temperature (°C)

T_b = fruit base temperature (lychee, sapindaceae 10° C (*Batten* and Lahav 1994)

Stage of flower development: Flower development was observed from the initiation stage through to anthesis. The study tracked the morphological changes of eight flower panicles from four sampled trees, focusing on flower buds with lengths of less than 1 cm. All observations were recorded on the same day. During the early stages, observations were conducted every six days, and every three days during the anthesis phase. Key parameters measured included panicle length and diameter, the number of panicle branches, the timing of anthesis, and the number of flowers reaching anthesis.

Fruit development: Fruit development observations included assessments of fruit set, physical quality (such as fruit length, diameter, aril thickness, fruit weight, and fruit firmness), and chemical quality (including total titratable acidity (TTA) and total soluble solids (TSS)). These observations were based on three samples of flower panicles from different branches. The observation of fruit set using equation below:

$$\text{Fruit set (\%)} = \frac{\text{Number of fruit}}{\text{Total flowers}} \times 100$$

The fruit firmness level was measured using penetrometer model H-2529 (Paul N. Gardner, BYK Instruments Co.) with a load period of 252 grams, a retention time of 30 seconds, with a depth of 10 mm.

$$\text{Frimness (mm g}^{-1}\text{ s}^{-1}\text{)} = \frac{\text{average (base, middle, and tip penetration value} \times 0.1}{\text{ballast mass} \times \text{retention time}}$$

Total soluble solids (TSS) were conducted in the arillode juice using a digital hand-held refractometer PAL-1 (ATAGO). Total titratable acidity (TTA) was conducted in arillode juice using titration method and calculated by the following equation:

$$\text{TTA (\%)} = \frac{\text{ml NaOH} \times \text{N NaOH} \times \text{df} \times \text{WE} \times 100}{\text{sample (g)}}$$

TTA = Total titrable acidity
ml NaOH = Volume of NaOH
N NaOH = NaOH normality
df = Dilution factor
WE = Citric acid molecular weight (192/3=64)

RESULTS AND DISCUSSION

General conditions: Microclimate and nutrient status in leaf and soil

Microclimate data retrieval for matoa cultivation focused on rainfall patterns as the plant approached its flowering season in July, based on the findings of Wambrauw (2011) and reports from the Research and Development Division of the Mekarsari Fruit Garden. Rainfall data from the Meteorology, Climatology, and Geophysical Agency (BMKG) (Fig. 1a) show a decrease in the number of rainy days in July compared to June, with this reduction continuing through mid-August. The initiation of generative bud formation coincided with the onset of this decline in rainfall in mid-July. As noted by Fauzi *et al.* (2017), drought stress is often linked with flowering in tropical fruit plants.

Temperature data collected from the Encomotion data logger (Fig. 1b) illustrates the accumulation of heat units necessary for matoa to reach fruit maturity, both visually and physiologically. Relative humidity remained consistently between 75% and 90% from the initiation of generative buds until the fruit became overripe (Fig. 1c). The duration of sunlight exposure showed a decrease from September to January, likely influenced by increased rainfall intensity during this period (Fig. 1d).

Soil sampling was conducted during the flowering phase of the matoa tree to assess soil characteristics and fertility. The results of the soil analysis were evaluated according to the standards set by the Indonesian Soil Research Center (1983). The chemical analysis of the soil (Table 2) indicates suboptimal conditions, characterized by an acidic pH and generally poor fertility. Organic carbon (C) and total nitrogen (N) levels are classified as low, while phosphorus (P) and essential cations, including magnesium (Mg), potassium (K), and sodium (Na), are found to be very low. The cation exchange capacity (CEC) is also on the lower end of the scale, suggesting limited nutrient-holding capacity. Furthermore, base saturation (KB), which measures the proportion of exchangeable cations, is

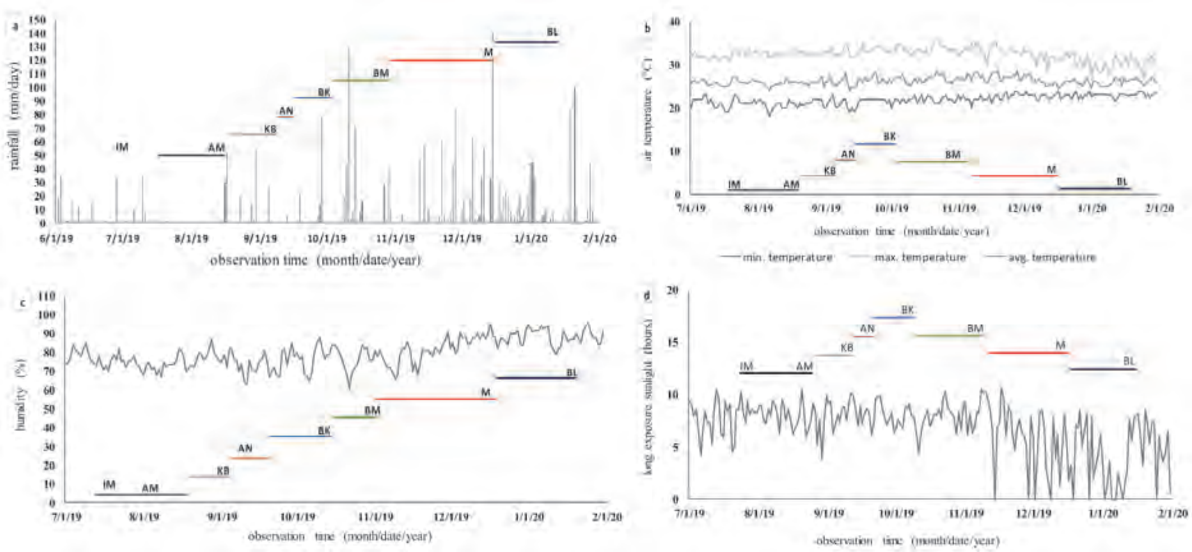

Fig. 1. Daily climate data (a) rainfall, (b) daily temperature, (c) air humidity, (d) exposure sunlight
Source: Rainfall (BMKG); daily temperature, air humidity, exposure sunlight (Encomotion data-logger)

critically low, reflecting a limited availability of nutrients for plant uptake.

Despite these unfavorable soil conditions, the matoa tree's ability to initiate flowering in July suggests a level of tolerance to nutrient deficiencies and soil acidity. As noted by the Soil Research Center (1983), while poor soil fertility can negatively impact overall plant health and productivity, the initiation of generative phases such as flowering remains possible, especially when other environmental factors, such as temperature, humidity, and drought stress, are favorable. This observation aligns with previous findings on the adaptability of tropical fruit plants to suboptimal soil conditions.

The analysis of matoa leaf nutrient status (Table 3) reveals significant changes throughout the fruiting period, particularly in the C/N ratio, which decreases notably after fruit ripening in December. This decline indicates a higher accumulation of nitrogen relative to carbon, a common characteristic of reproductive stages as the plant prepares for seed and fruit development. Nutrients such as phosphorus (P), calcium (Ca), sulfur (S), and zinc (Zn) also increase following the ripening phase, highlighting their role in supporting post-reproductive growth, enhancing fruit quality, and facilitating the development of storage organs. Zinc, in particular, plays a critical role in enzyme activation and protein synthesis, underlining its importance during fruit maturation.

Boron (B) concentrations peak during the fruit ripening stage in November, followed by a decline as the plant transitions back to the vegetative phase in January and February. This pattern aligns with boron's essential role in reproductive processes, such as cell wall formation and pollen tube growth. As noted by Bernier *et al.* (1993), while genetic factors contribute to the initiation of flowering and fruiting, environmental factors such as light, rainfall, temperature, humidity, and nutrient availability, are critical determinants of the

Table 2. Soil nutrient status of matoa trees

Parameters	Value*	Soil trait (PPT 1983)	Fertility status (PPT 1983)**
pH H_20	4.51	4.50-5.50	acidic
C organic (%)	1.36	1.00-2.00	low
N total (%)	0.16	0.10-0.20	low
P (ppm)	9.53	< 10	very low
Ca (cmol/kg)	2.26	2.0-5.0	low
Mg (cmol/kg)	0.13	< 0.30	very low
K (cmol/kg)	0.08	< 0.10	very low
Na (cmol/kg)	0.07	<0.10	very low
KTK (cmol/kg)	16.30	5-17	low
KB (%)	15.62	< 20	very low

*The Laboratory of Soil and Land Resources, Faculty of Agriculture, IPB University
**Soil Research Center (1983)

Table 3. Characterization of the nutrient status in matoa leaves

Observation	July	August	September	October	November	December	January
	Flower development		Anthesis		Fruit development		
C (%)	55.11	54.49	54.65	54.65	55.11	54.56	54.67
N (%)	0.88	0.87	0.79	0.94	0.83	0.83	1.77
C/N Ratio	62.63	62.63	69.18	58.62	65.73	30.89	33.68
P (%)	0.18	0.18	0.16	0.15	0.12	0.39	0.35
K (%)	0.69	0.65	0.65	0.74	0.62	0.64	0.60
Ca (%)	0.89	1.17	1.27	1.02	1.23	1.68	2.01
Mg (%)	0.19	0.22	0.22	0.24	0.17	0.16	0.27
S (%)	0.20	0.13	0.15	0.13	0.14	0.59	0.49
Zn (ppm)	35.02	31.00	28.47	29.19	26.46	30.65	34.54
B (ppm)	16.55	18.32	20.08	11.25	13.90	118.83	127.67

success of these stages. Thus, the observed nutrient fluctuations suggest that effective management of soil fertility and environmental conditions is crucial for optimizing growth and fruit production in matoa.

Generative phases in matoa: Phenological observations

Flower and fruit development are critical reproductive stages that plants must undergo to achieve sexual propagation. These stages consist of several phases that occur cyclically, signaling the plant's transition into the generative period. The development of flowers, from the emergence of generative buds to full bloom at anthesis, takes approximately 56 days following initiation. The subsequent fruit development, from anthesis to maturity, spans about 140 days after initiation (Table 4).

Flowering observations on July 15th, 2019, revealed that generative bud initiation (IM) began with bud lengths of less than 1 cm, progressing to full bloom, where the flowers displayed a reddish hue in the panicle. Fruit development commenced once the flowers had bloomed, reaching the anthesis (AN) stage. The development of the fruit pulp (arilloide), which surrounds the seed, occurred approximately 28 days after the fruit bud (BK) stage, marking the formation of young matoa fruit (BM). Initially, the fruit skin was uniformly red, transitioning to a darker and duller appearance (BL) after reaching the mature stage (M) (Fig. 2). Gunawan (2013) emphasized that agro-climatic factors, particularly rainfall, play a significant role in influencing plant productivity and metabolic activity. Similarly, Dambreville (2013) highlighted the combined impact of external factors, such as the growth environment, and

Table 4. Observation of flower and fruit development in matoa at each stage

Stage	Symbol	Duration (day)	DAI*
Generative bud initiation	IM	0	0
Panicle enlargement	IM - AM	30	30
Mature flower bud	AM – KB	20	50
Anthesis	KB – AN	6	56
Fruit bud	AN – BK	14	70
Arilloide Form	BK – BM	28	98
Mature	BM – M	42	140
Overripe	M – BL	14	154

*Day after Initiation

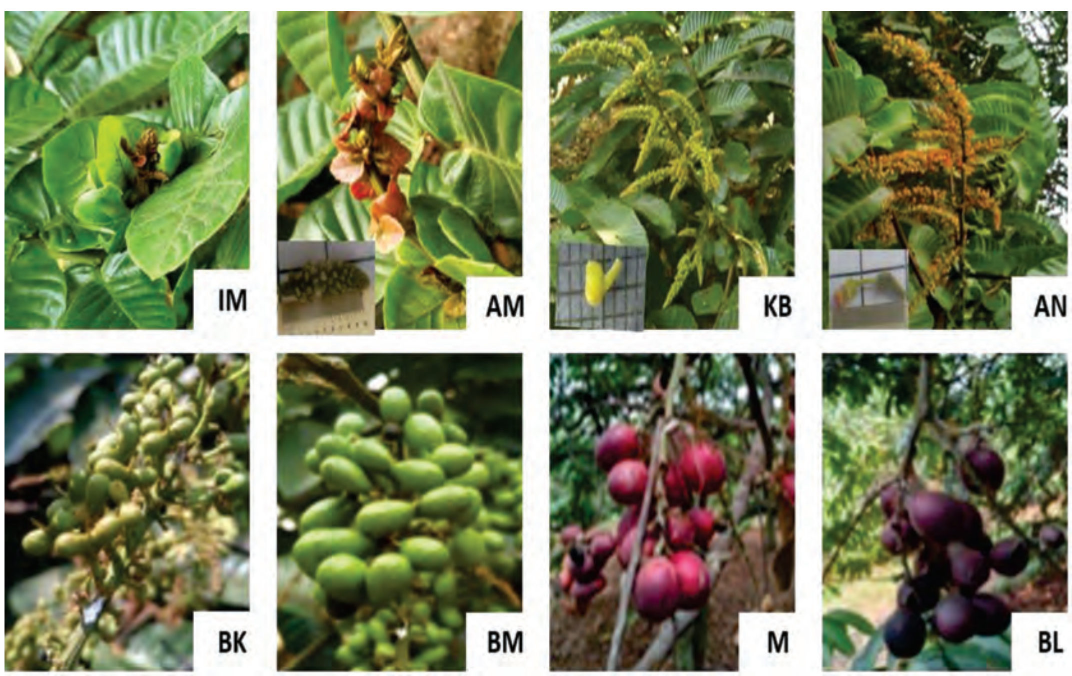

Fig. 2. Stages of development, including generative bud initiation (IM), panicle enlargement (AM), mature flower bud (KB), anthesis (AN), fruit bud (BK), aril development (BM), mature fruit (M), and overripe fruit (BL)

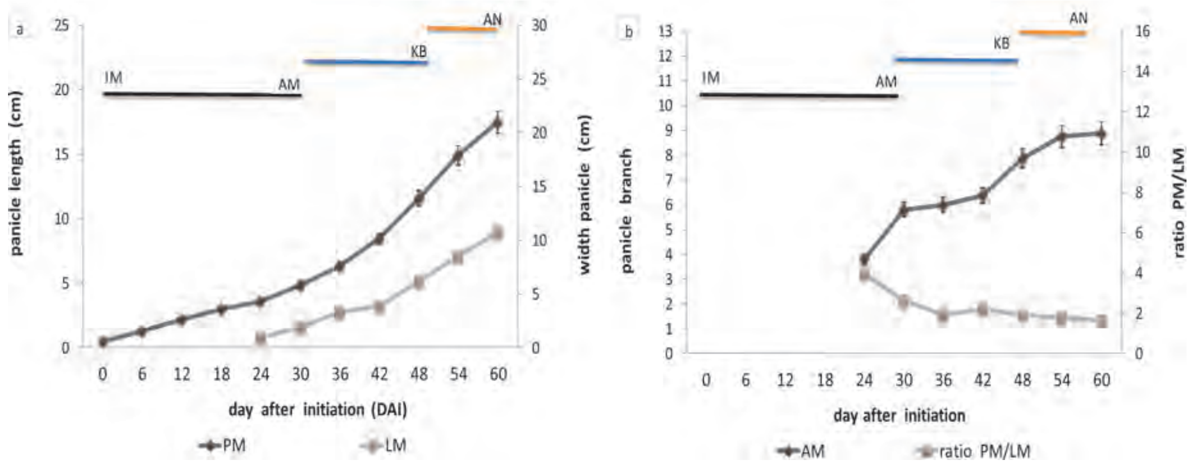

Fig. 3. Development (a) length and width of panicles, (b) panicle branch and ratio
PM: Panicle length, LM: Width panicle, AM: Panicle branch

internal factors, such as plant physiology, in shaping the development of flowers and fruits.

Flower development and fruit set

The flower development process in matoa progresses through several stages, from initiation to anthesis. The number of flowers in a panicle is influenced by environmental growth conditions, with optimal conditions leading to a higher flower count. During the initiation phase, the bud length was less than 1 cm (Fig. 3a). At the panicle branching stage, the panicle length measured approximately 4 cm, with a width of less than 1 cm and three branches. By the anthesis stage, the panicle length increased to around 17 cm, and the width expanded to more than 10 cm, with nine branches observed (Fig. 3b). This pattern of flower development aligns with the description of matoa's monopodial inflorescence, as noted by Desmond *et al.* (1997). Flower buds continue to develop and form lateral flowers as they approach the anthesis stage.

Table 5. Fruitset during flowering development of matoa

Observation	Duration (DAI)*	Amount (No.)
Anthesis flower (A)	56	517.67±97.01
Maturity (B)	140	13.00±2.65
Ratio A/B		2.51%

*Days after initiation

The fruit set of Matoa occurs around 56 days after flower initiation, with a fruit set ratio of 2.51% (Table 5). The anthesis stage marks the period when flowers are open and ready for pollination, occurring at approximately 56 days after initiation, with an average of 517.67 ± 97.01 flowers. The maturity stage is reached around 140 days after initiation, when the fruit develops fully, with an average of 13.00 ± 2.65 mature fruits. The ratio of anthesis to maturity (A/B ratio) is 2.51%, indicating that only a small percentage (2.51%) of the flowers transition into mature fruits, which reflects the reproductive success of the species. Environmental factors, such as temperature, humidity, rainfall, and light intensity, significantly influence the fruit set process, as discussed by Ogaya and Peñuelas (2007).

Fruit development and heat unit calculation

The development of matoa fruit progresses through distinct stages, beginning with anthesis (AN) and culminating in the overripe stage (BL) (Fig.4). At anthesis, flowers are fully developed and ready for pollination, marking the initial phase of fruit formation. The subsequent stage, small fruit (BK), is characterized by the emergence of immature fruits, which are green and exhibit minimal development of the aril and seed. As the fruit transitions to the young fruit stage (BM), its size increases significantly, and the aril begins to form, covering the seed with a thin, gelatinous layer. During this stage, the fruit's outer skin remains green, and the internal seed structure becomes more defined. In the mature fruit stage (M), the fruit undergoes substantial changes in color, size, and texture. The skin transitions to a reddish hue, signaling physiological maturity. The aril becomes thicker and fully develops, providing a translucent, juicy covering around the seed, while the seed itself hardens. In the overripe stage (BL), the fruit's skin darkens to a purplish-black color, and the aril softens, indicating senescence. The seed remains intact but may show slight discoloration.

Table 6 summarizes the accumulation of heat units during the flower and fruit development stages of matoa. Heat unit calculation commenced from panicle initiation on July 15, 2019, until fruit maturity after 140 days in December 2019, totaling 2585.9 °C days. Flower development stages, from initiation (IM) to anthesis (AN), accumulated 1014.15 °C days over 56 days,

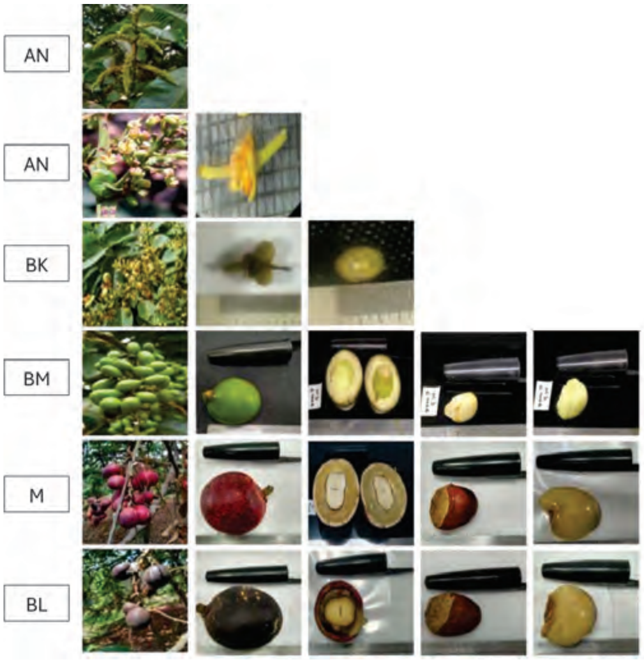

Fig. 4. Fruit development stages of matoa: Anthesis (AN), fruit bud (BK), arillode form (BM), mature (M) and overripe (BL)

with a weak correlation (*r = 0.29*, *p = 0.70*) between heat unit accumulation and duration. Meanwhile, fruit development stages, from anthesis (AN) to maturity (M), required an additional 2585.9 °C days over 140 days, with a strong positive correlation (*r = 0.99, p = 0.07*). These results highlight the significance of temperature in driving energy availability for growth and development, aligning with findings by Koesmaryono *et al.* (2002). Heat unit calculation offers a robust method for phenological observations, minimizing the influence of location and planting time variability.

Physical and chemical fruit quality

The physical development of matoa fruit can be observed as early as two weeks after anthesis (WAA). During this period, the fruit undergoes steady increases in both length and diameter until approximately 12 WAA, corresponding to the formation of the aril, a thin gelatinous membrane that encloses the seed. The thickness and diameter of the aril continue to expand up to 12 WAA, marking a significant phase in the fruit's development. As highlighted by Khandaker and Boyce (2016), indicators of fruit ripeness include changes in fruit shape, skin color, texture, and weight. In matoa, a marked reduction in weight occurs as the fruit ripens, with a decline from 19.50 g at 12 WAA to 11 g by 14 WAA (Fig. 5a). This reduction is particularly evident in the pulp, where the weight drops dramatically from 9 g at 12 WAA to 2-3 g by 14 WAA (Fig. 5b). Seed formation becomes discernible at 4 WAA, as the seed detaches from its coat (Fig. 5c). Concurrently, the fruit's skin hardens progressively, indicating increased firmness with maturity (Fig. 5d).

The chemical properties of matoa fruit were assessed through the measurement of total titratable acidity (TTA) and total soluble solids (TSS) in the fruit pulp. TTA values showed an increasing trend up to 8 WAA, followed by a gradual decline through 16 WAA (Fig. 6a). Meanwhile, TSS levels reached their peak at 12 WAA before decreasing subsequently (Fig. 6b). The ratio of TSS to TTA, a key indicator of fruit sweetness and flavor balance, showed a consistent increase from 8 WAA to 16 WAA (Fig. 6c). These patterns correspond to the physiological maturation of the fruit, with 12 WAA being marked by a visible change in skin color to red, signifying optimal ripeness. According to Santoso *et al.* (2011), the maximum accumulation of

Table 6. Accumulation of heat units for matoa flower and fruit development

Observation	Stage	Duration (days)	DAI*	Heat units**
Flower development	IM	0	0	16.20 °C day
	IM – AM	30	30	518.40 °C day
	AM – KB	20	50	894.25 °C day
	KB – AN	6	56	1014.15 °C day
Correlation (r)				*0.29*
p-value				*0.70*
Fruit development	AN – BK	14	70	1297.65 °C day
	BK – BM	28	98	1816.10 °C day
	BM – M	42	140	2585.90 °C day
Correlation (r)				*0.99*
p-value				*0.07*

*Days after initiation
**Source: Encomotion Data-logger

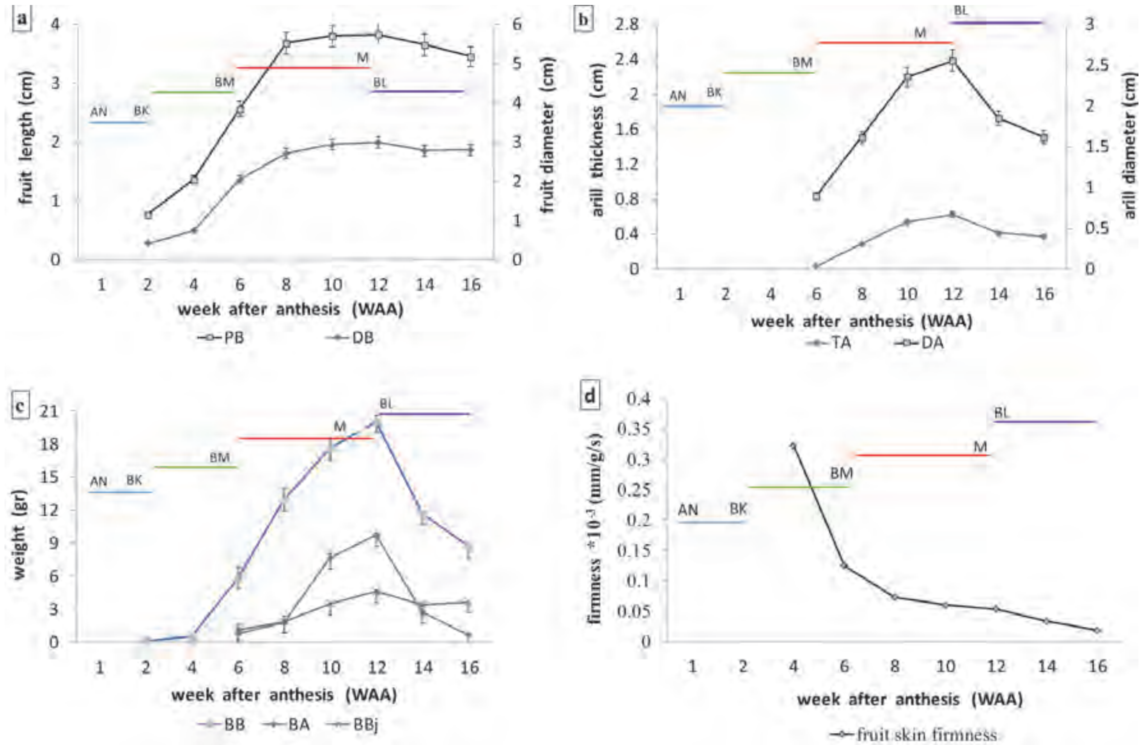

Fig. 5. Fruit development of matoa, (a) fruit, (b) aril, (c) weight, (d) fruit skin firmness

PB: Fruit length, DB: Fruit diameter, TA: Aril thickness, DA: Aril diameter, BB: Fruit weight, BA: Aril weight, BBj: Seed weight

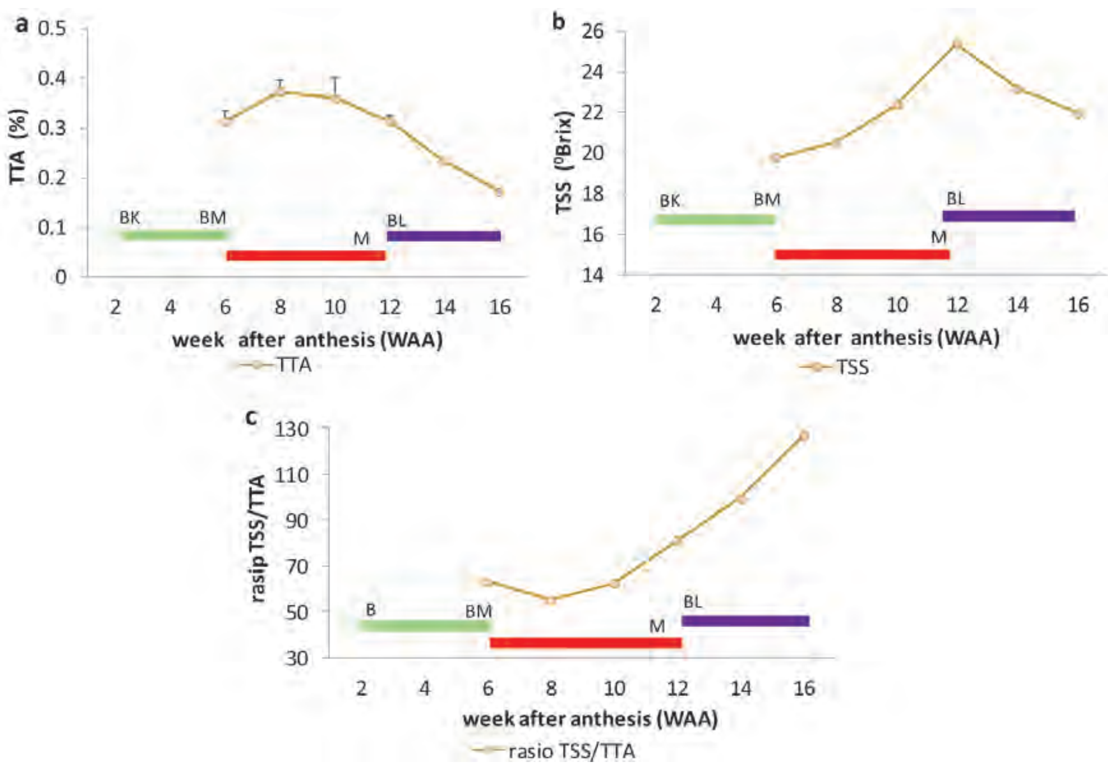

Fig. 6. Fruit chemical quality of matoa (a) TTA content, (b) TSS content, (c) ratio TSS/TTA

TTA: Total titratable acidity, TSS: Total soluble solid

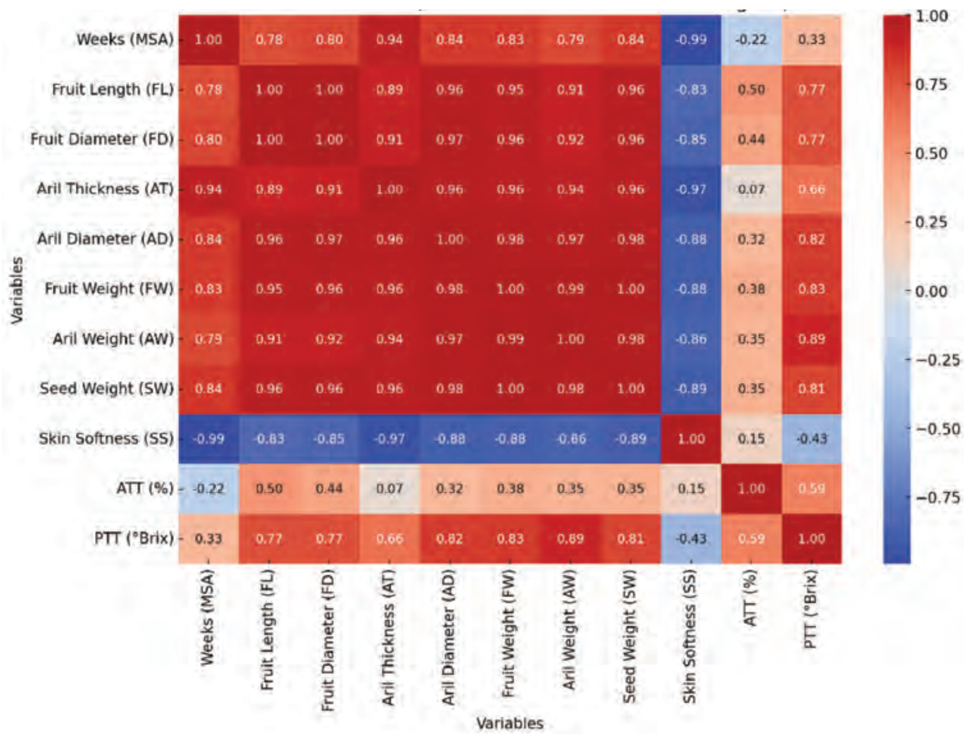

Fig. 7. Correlation between physical and chemical properties of matoa fruit

specific biochemical compounds in the fruit signifies its readiness for harvest.

The ripening of matoa fruit follows trends commonly observed in other tropical fruits. Ribeiro and de Freitas (2019) noted similar patterns in acerola cultivars, where TTA values decline consistently during ripening as the fruit transitions toward a sweeter and less acidic state. This progression reflects typical biochemical transformations associated with fruit maturation, including the breakdown of organic acids and the accumulation of sugars. These observations align with the physiological and morphological changes seen in matoa fruit, from early aril formation to the development of a fully mature, red-skinned fruit at 12 WAA.

Correlation between physical and chemical properties of fruit

The correlation heatmap provides insights into the relationships between physical and chemical quality parameters of matoa fruit across different stages of fruit development (Fig 7.). Strong positive correlations were observed among most physical attributes, such as fruit length (FL), fruit diameter (FD), aril thickness (AT), aril diameter (AD), fruit weight (FW), aril weight (AW), and seed weight (SW), with correlation coefficients (r) exceeding 0.9. This indicates that as the fruit grows, these parameters develop proportionally, reflecting uniform physical growth. Notably, aril weight (AW) showed a near-perfect correlation with fruit weight (FW) ($r = 0.99$), suggesting that aril contributes significantly to the overall fruit mass. In contrast, skin softness (SS) demonstrated a strong negative correlation with most physical attributes ($r \approx -0.9$), indicating that larger and more developed fruits tend to have softer skin, likely due to advanced maturation. Additionally, skin softness was moderately negatively correlated with total soluble solids (TSS, ATT %) ($r = -0.43$), implying that the softening of the skin might coincide with sugar accumulation in the fruit.

Regarding chemical quality, TSS (ATT %) exhibited moderate to strong positive correlations with aril weight (AW) ($r = 0.83$) and fruit weight (FW) ($r = 0.82$), suggesting that larger fruits are associated with higher sugar content. However, the correlation between TSS and weeks after flowering (MSA) was weaker ($r = 0.33$), indicating that sugar accumulation is influenced by factors beyond harvest timing, such as genetic traits or environmental conditions.

CONCLUSION

This study provides a comprehensive overview of the phenological stages of flowering and fruit development in *Pometia pinnata* (matoa). Flower development, from generative bud initiation to anthesis, occurs over 56 days, with panicle lengths reaching approximately 17 cm and inflorescences characterized by monopodial branching. Fruit development spans approximately 140 days post-initiation, with a fruit set ratio of 2.51%. The study highlights the critical role of environmental factors, such as rainfall and heat accumulation (2620.05 °C days), in driving the reproductive success of matoa. These findings contribute valuable insights into the reproductive biology of matoa, offering a foundation for improved cultivation practices and sustainable utilization of this underutilized tropical fruit species. Further research is recommended to optimize agronomic strategies and explore the genetic diversity of matoa for enhanced productivity and resilience.

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