

# MORPHOLOGICAL, ANATOMICAL, AND PHYSIOLOGICAL CHANGES DURING SEED MATURATION OF SUGAR PALM (*Arenga pinnata* Merr.)

Aswaldi Anwar<sup>1</sup>, Dini Hervani<sup>1</sup>, Dede Suhendra<sup>2</sup>, Muhammad Parikesit Wisnubroto<sup>2\*</sup>, Afrima Sari<sup>1</sup>

<sup>1</sup>Department of Agronomy, Faculty of Agriculture, Universitas Andalas, Pauh, Padang City, West Sumatra, Indonesia 25163

<sup>2</sup>Department of Agroecotechnology, Faculty of Agriculture, Universitas Andalas, Pulau Punjung, Dharmasraya Regency, West Sumatra, Indonesia 27573

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MORPHOLOGICAL, ANATOMICAL, AND PHYSIOLOGICAL CHANGES DURING SEED MATURATION OF SUGAR PALM (*Arenga pinnata* Merr.). *Arenga pinnata* (sugar palm) seeds are classified as seeds that have a long dormancy period. This dormancy can be influenced by the maturity level of the sugar palm fruit. This study aims to characterize the morphology and anatomy at various levels of fruit maturity and its relationship to the dormancy of sugar palm seeds. The research was conducted descriptively, involving data collection through morphological, anatomical, and physiological observations of sugar palm fruits and seeds randomly selected from productive sugar palms in Nagari Andaleh Baruh Bukik, Sungayang Subdistrict. The sampling technique was conducted through the purposive sampling method on 12 productive palm trees aged 10 years and above. The results showed that morphologically, there were changes in the color of the skin of the palm fruit to yellowish when it reached physiological maturity, as well as the texture of the hardened seed shell. Changes did not follow these changes in shell color and seed size. Physiologically, there is an increase in gibberellin hormone levels along with the increase in fruit maturity, and it continues to increase when entering the germination phase. Anatomically, the structure of the seed embryo does not show significant changes since the beginning of the fruit ripening. Based on this, there is a mutual relationship between the morphological and physiological characteristics of the dormancy of sugar palm seeds. The riper the palm fruit is, the harder the seed shell is, so the seed dormancy becomes longer and is known as morphophysiological dormancy.

Keywords: apocol, embryology, morphophysiology, ripening, sugar palm

PERUBAHAN MORFOLOGI, ANATOMI, DAN FISILOGI SELAMA PEMATANGAN BENIH AREN (*Arenga pinnata* Merr.). Benih aren tergolong benih yang memiliki masa dormansi yang panjang. Dormansi ini dapat dipengaruhi oleh tingkat kematangan buah. Penelitian ini bertujuan untuk mengkarakterisasi morfologi dan anatomi pada berbagai tingkat kematangan buah dan hubungannya dengan dormansi benih aren. Penelitian dilakukan secara deskriptif, yaitu pengumpulan data melalui pengamatan morfologi, anatomi, dan fisiologi buah dan benih aren yang dipilih secara acak dari pohon aren produktif di Nagari Andaleh Baruh Bukik, Kecamatan Sungayang. Teknik pengambilan sampel dilakukan dengan metode purposive sampling pada 12 pohon aren produktif yang berumur 10 tahun ke atas. Hasil penelitian menunjukkan bahwa secara morfologi terdapat perubahan warna kulit buah aren menjadi kekuningan saat mencapai kematangan fisiologis dan tekstur cangkang benih yang mengeras. Perubahan tersebut tidak diikuti oleh perubahan warna cangkang dan ukuran benih. Secara fisiologis, terjadi peningkatan kadar hormon giberelin seiring dengan bertambahnya kematangan buah dan terus meningkat saat memasuki fase perkecambahan. Secara anatomi, struktur embrio benih tidak menunjukkan perubahan signifikan sejak awal pematangan buah. Berdasarkan hal ini, terdapat hubungan timbal balik antara karakteristik morfologi dan fisiologis benih aren yang dorman. Semakin matang buah aren, semakin keras cangkang benihnya, sehingga dormansi benih semakin lama dan dikenal sebagai dormansi morfofisiologis.

Kata kunci: apocol, embryology, morphophysiology, ripening, sugar palm

\*Corresponding Author: e-mail: muhammadparikesit@agr.unand.ac.id

## I. INTRODUCTION

The sugar palm stands out as a promising plantation crop with significant potential for development as a raw material for sugar palm and bioethanol production. It can be found across 14 provinces in Indonesia, with the largest cultivation area in West Java covering 13,135 ha (Natawijaya & Sunarya, 2018). Despite its multifunctional nature, the cultivation of the sugar palm has not been widespread, and it primarily relies on wild plants. In certain regions, this plant is a livelihood source, where palm sap is extracted to produce sugar palm. Moreover, the young fruits of the sugar palm can be harvested, and the flesh, referred to as "kolang-kaling," is utilized as an ingredient in various food and beverage preparations (Suhendra et al., 2023). Additionally, sugar palm serves as a valuable restoration plant for polluted lands, particularly those contaminated with heavy metals such as lead (Pb) (Rusnam et al., 2022) and zinc (Zn) (Rusnam & Efrizal, 2016).

The scientific name of sugar palm, locally known as aren, is *Arenga pinnata* Wurmbe Merr. It belongs to the *Araecaceae* family, with the genus *Arenga*, in the sub-phylum *Angiospermae*. In various regions, this plant is referred to by different names, such as aren, aren palm, areng palm, arenga, arengga palm, or sugar palm. Morphologically, the sugar palm grows upright, featuring a round stem with a brownish-green color. Its leaves are arranged in a stem rosette, with pinnate leaflets of light to dark green color. The flowers consist of male flowers fused in one cob, measuring 1-1.2 cm long. The fruit is elliptical with an inwardly curved tip, having a diameter of 3-5 cm. The sugar palm seeds are round and turn black when ripe (Sebayang, 2016). The seed development process in angiosperms typically initiates with double fertilization. In this process, one male cell fertilizes a haploid egg cell, while another fertilizes a homodiploid central cell in the ovule. This process produces diploid embryos and triploid endosperm (Zhang et al., 2021). Over the recent period, the population of sugar palms in their natural

habitat has been declining due to aging trees that are no longer productive. The widespread exploitation of sugar palm trees for starch extraction contributes to this decline, especially in areas with a high concentration of sugar palm trees (Saleh et al., 2007). Regeneration of sugar palm trees poses a significant challenge, primarily due to the prolonged dormancy period of sugar palm seeds.

Sugar palm seeds are categorized as hard seeds with a germination period extending beyond three months from the ripening of the fruit. The ripening process of sugar palm fruit can exceed 24 months after anthesis. A noticeable morphological change during the ripening process is the shift in skin color from green to yellow or yellowish (Widyawati et al., 2010). To date, the criteria for physiological maturity have been established through physical observations of changes in fruit morphology and physiological assessments involving seed germination (Iresniawati et al., 2014). Understanding when seeds reach physiological maturity is crucial because, in this state, they are fully prepared to exhibit their optimal vigor. Seeds harvested before reaching physiological maturity generally have poor physiological quality (Pramono & Rustam, 2017), marked by a reduced germination ability (Widyawati et al., 2010). This is because the embryo lacks the maximum germination capacity, as the formation of food reserves still needs to be completed. Anatomically, mature sugar palm seeds include the endocarp, endosperm/albumen, and embryo, resembling the composition found in *Livistona rotundifolia* (Lam.) Mart (Viana et al., 2016). Sugar palm seeds, on the other hand, may take more than 3-5 months to germinate if the environmental conditions are not conducive. Techniques such as scarification (scraping the seed coat) or chemical soaking can accelerate the germination process in sugar palm seeds with dormancy to accelerate the germination process in palm seeds with dormancy (Aji & Syaputra, 2023). Widyawati et al. (2009) added that sugar palm seeds without scarification treatment produced

0% viability, while seeds with scarification through scraping using sandpaper on the back of the seed shell produced 67-82% germination.

One study mentioned that sugar palm seeds have a hard seed coat structure. The higher the fruit's maturity level, the skin's permeability decreases due to increase in lignin and tannin content. This impacts the difficulty of germinating sugar palm seeds (Widyawati et al., 2009). Furthermore, Elidar (2018) mentioned that some palm seed germination treatments were carried out on physiologically ripe palm fruit to obtain optimal results. Junaedi et al. (2020) also observed the anatomy of sugar palm seed germination, which showed different results in each genotype and maturity level. However, the research has not described how palm fruit's morphological, physiological, and anatomical characteristics at several maturity levels affect seed dormancy. The more mature the palm fruit is, the more it is suspected that morphologically, the skin of the palm fruit is getting harder, gibberellin levels are increasing, and changes in the embryo's position that affect seed dormancy. Therefore, it is important to investigate sugar palm seeds' morphological, physiological, and anatomical changes and their relationship with dormancy. This initial step is very important in determining the proper steps to accelerate the rejuvenation of sugar palm plants.

## II. METHODS

The research was carried out during October and November 2023 in Nagari Andaleh Baruh Bukik, Sungayang Subdistrict, Tanah Datar Regency, West Sumatra, Indonesia (Figure 1), a renowned center for sugar palm production. Qualitative and quantitative methods were used to achieve the objectives of this research. Qualitative methods were used to determine the anatomical characteristics of sugar palm fruits and seeds. Quantitative methods were used on morphology and physiological characteristics. Morphological, physiological, and anatomical characteristics were observed at the Seed

Science and Technology Laboratory, Faculty of Agriculture, Andalas University. Gibberellin hormone levels were assessed at the ICBB Laboratory, PT Biodiversitas Bioteknologi Indonesia, in Bogor, West Java.

Sampling was conducted using the purposive sampling method on 12 palm trees that have entered the productive period and produce palm fruit with a plant age of  $\pm 10$  years. The selection of samples was carried out on several criteria, including strong trunk, dense leaves, and green to yellow fruit skin color. From the 12 plants selected, palm fruit was picked from several different bunches and then composited. Furthermore, the color of the palm fruit skin was grouped based on the maturity level, including M1 (dark green), M2 (light green), M3 (yellowish skin), and M4 (bright yellow). The color category of the fruit skin is based on the color code on the Munsell Color Chart for Plant Tissues (Table 1). Dark green skin is categorized as M1, light green to yellow skin is classified as level M2, yellowish skin is classified as level M3, and bright yellow to dark skin is classified as M4. Various equipment and materials for the research encompass measuring instruments (rulers), cameras, sugar palm fruits, and writing instruments. Anatomical observations were conducted using a microtome and oven. For hormone level monitoring, reagents and tools for gibberellin extraction were utilized. Environmental conditions during the observation were at a normal temperature of 25o C with a relative humidity of 65%.

Morphological observations were made on four samples of sugar palm fruit, including the thickness of the skin and shell of the palm seed and changes in skin color at each maturity level. Physiological observations were made to monitor changes in moisture content (Thermogravimetric Method) (Hakiki & Safitri, 2024), which is related to seed coat permeability, ash content (Gravimetric Method) (Pangestuti & Darmawan, 2021), crude protein (Kjeldahl Method) (Al Kausar & Suryani, 2022), crude fat (Soxhlet Method) (Pargiyanti, 2019), and carbohydrates (Luff School method)

(Ningrum et al., 2024) which are related to seed endosperm levels during the ripening process, which are related to the seed endosperm content during the ripening process of the palm fruit. Breaking the dormancy of sugar palm seeds is done through seed scarification by sanding the back of the seed shell and soaking it in water for 24 hours. Next, these seeds were germinated on moist cotton media. The emerged sprouts were categorized based on the level of fruit maturity and the position of apocol emergence, and their germination was observed. Physiological aspects were carefully examined, with a special focus on the level of the hormone gibberellin.

Anatomical preparations of sugar palm seeds were crafted using the paraffin method, involving the creation of longitudinal sections (Hamim et al., 2019; Nurhayani et al., 2019). The selected sugar palm seed samples were initially fixed in FAA solution, composed of 5 ml formalin, 5 ml glacial acetic acid, and 90 ml 70% alcohol. Subsequently, the samples underwent a series of steps, including dehydration, clarification, and infiltration. The samples fixed in FAA solution were washed with 50% alcohol four times, each lasting 1 hour. The dehydration was done by immersing the samples in the Johansen series solution. The paraffin

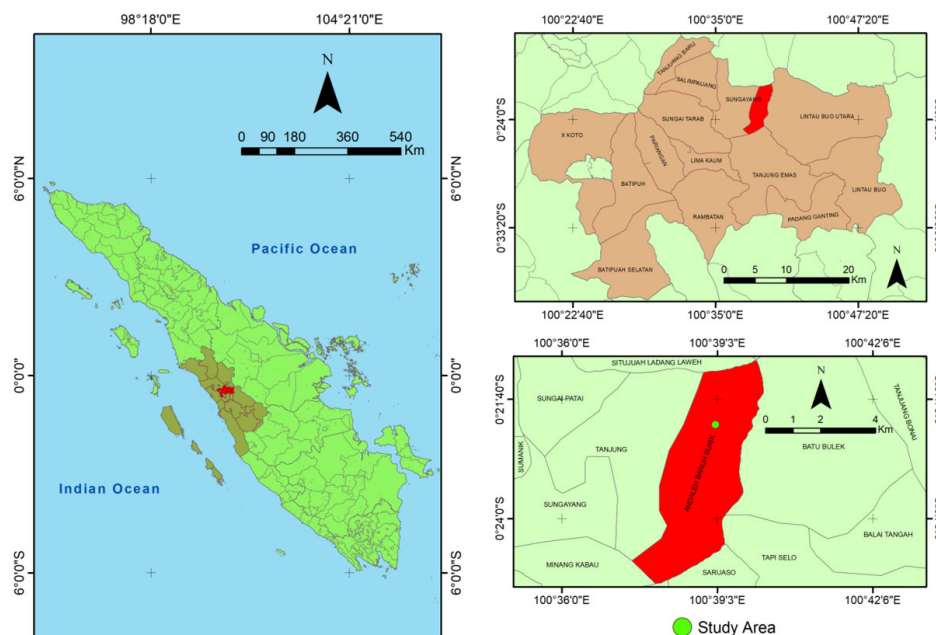


Figure 1. Research location in in Nagari Andaleh Baruh Bukik, Sungayang Subdistrict, Tanah Datar Regency, West Sumatra, Indonesia

Table 1. Color criteria of sugar palm fruit during ripening process using Munsell Color Chart for Plant Tissues

Visual color	Color criteria of sugar palm fruit		
	Hue	Value (ordinate)	Chroma (axis)
Dark green (M1)	5GY	4	4
Light green (M2)	2.5GY	6	8
Yellowish skin (M3)	5Y	8	8
Bright yellow (M4)	7.5YR	7	10

infiltration process occurs in several stages. Frozen paraffin is added to a container with the sample, tertiary butyl alcohol, and paraffin oil. The mixture is left open at room temperature for 1-4 hours and then continued in an oven at 60° C. Subsequently, the blocks are softened by immersing them in Gifford's solution for one week. Thin slices, approximately 10 µm thick, are obtained using a microtome. These paraffin slices are affixed to a glass object using a hot plate at 40° C for 3-5 hours. The subsequent step involves staining with 2% safranin and 0.5% fast green. The stained preparations are covered with a cover glass and observed under a binocular microscope at a specific magnification.

Physiological observations were made on seed germination parameters, especially gibberellin levels in sugar palm seed sprouts. Gibberellin levels were observed by the liquid chromatography method (Nefed'eva & Mazey, 2009). Standard solutions and reagents were gibberellin GA3 with 98% purity, methanol, 98% purity formic acid, distilled water, and a stock solution. Analysis was performed using high-performance liquid chromatography with a reverse-phase separation system equipped with an ultraviolet-visible detector (Shimadzu LC-AT20), 4.6 x 150 mm C18 (ODS) column (GL Science-Japan). The mobile phase used was 60% methanol and 40% water, based on the results of the mobile phase search optimization that had been carried out. The flow rate of the mobile phase was set at 0.5 mL min<sup>-1</sup>. The wavelength used in the KCKT system is 224 nm, based on the maximum wavelength reading that has been done. The sample was filtered using a 0.45 µ syringe filter and then injected into the KCKT instrument with an injection volume of 20 µ L for 40 minutes with isocratic separation conditions on the KCKT (Tsabitah et al., 2024).

The data obtained was input into Microsoft Excel software and then displayed as a histogram equipped with error bars. The difference in the results of each treatment can be seen in the high and low histograms displayed. Data

on seed physiology observations, especially viability, were tested for normality and then subjected to analysis of variance (ANOVA). Significant differences in seed viability at each maturity level were further tested with Duncan's Multiple Range Test (DMRT),  $\alpha = 0.05$ . The analysis used R-Studio software.

### III. RESULTS AND DISCUSSIONS

Lawu Mountain is situated between the CenThe sugar palm, classified in the Palmae family, is a sizable annual plant that can reach heights of up to 12 m with a stem diameter of approximately 65 cm. Its distinctive feature includes a crown of leaves that extends above the stem. The sugar palm fruit is suspended in branched clusters, attaining lengths up to 90 cm. The fruit exhibits a round shape, typical of the Palmae family. Notably, there are noticeable distinctions in the morphology of raw and ripe sugar palm fruits. In its raw state, the fruit's skin (exocarp) is green, transitioning to a yellow hue when fully ripe (Lempang, 2012). The research indicates that during the ripening of sugar palm fruit, there is a gradual transformation in the skin color from green to yellow. This transition is not immediate but occurs progressively, extending up to 24 months after anthesis (Widyawati et al., 2010). As a result, the overall ripening process can be categorized into four distinct levels.

Based on observations of the maturity level of sugar palm fruit and its physical and morphological characteristics, the stages of ripening until the seeds reach physiological maturity can be delineated as follows (Figure 2):

- a) Maturity level 1 (M1): Sugar palm fruit exocarp exhibits a green to dark green.
- b) Maturity level 2 (M2): The exocarp of sugar palm fruit appears light green to yellowish.
- c) Maturity level 3 (M3): Sugar palm fruit exocarp takes on a yellowish hue.
- d) Maturity level 4 (M4): Sugar palm fruit exocarp adopts a dark yellow to slightly reddish.



Figure 2. Changes in the color of sugar palm fruit skin during the ripening process

The sugar palm fruit's endocarp is notably thicker than to the exocarp. The endocarp, the fruit's white flesh, encompasses the embryo (ovule). Sugar palm seeds are deemed physiologically mature when their components, including the seed coat (testa), endosperm, and embryo, have undergone well-developed growth. The sugar palm fruit's testa tissue comprises sclereid cells, while the endosperm and embryo tissue consist of parenchyma cells. The testa portion constitutes dead tissue, while the endosperm contains some living cells. In contrast, the embryo predominantly comprises living cells that are physiologically active and retain substantial moisture content, crucial for sustaining the life of its constituent cells (Widyawati et al., 2009).

The color of the skin is often a primary indicator of the fruit's maturity or ripeness. The

ripening process in sugar palm fruit typically begins with chlorophyll degradation, similar to in dates (Elbar et al., 2022). As the fruit ripens, the plant produces proteins and other vitamins, including ethylene, abscisic acid (ABA), and jasmonic acid. These compounds act as signals to the CCG gene (chlorophyll catabolic gene), hindering its performance. Subsequently, the biosynthesis of new pigments, such as carotenoids, occurs in the chromoplast, changing the fruit's color to yellowish or dark yellow (Kapoor et al., 2022).

Visually, the fruit ripening process presents a significant difference in the skin color of the sugar palm fruit. However, based on other morphological characteristics, such as the thickness of the palm seed shell at all maturity levels, averaged 0.4 mm at all maturities, with an endosperm diameter of 1.6-1.9 mm (Figure 3).

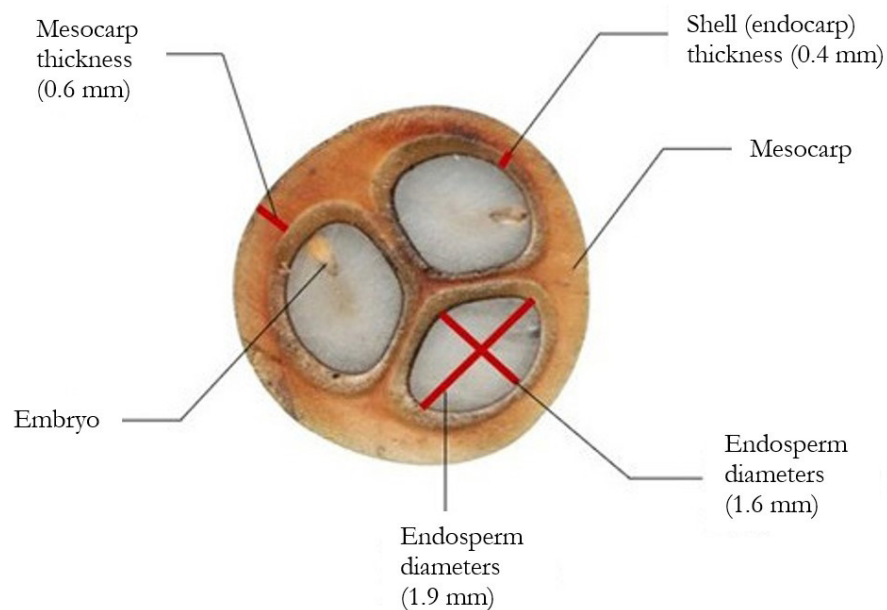


Figure 3. The structure of palm fruits and seeds and the thickness of their parts

Table 2. Viability of sugar palm seeds at different levels of maturity

Maturity levels	Viability (%)
<i>Green (M1)</i>	9.52 b
<i>Yellowish green (M2)</i>	17.72 b
<i>Greenish yellow (M3)</i>	27.72 a
<i>Yellow (M4)</i>	18.20 b
<i>Coefficient of Variance</i>	24.38%

Remark: Different letters in the same column indicate significant differences at the 0.05 according to the DMRT test.

However, the seed coat appeared to have a harder texture as the maturity level increased due to lignin accumulation. Physiologically, it can be seen that each maturity level gives different seed germination values (Table 2).

The analysis showed that the best viability of palm seeds was shown by the M3 maturity level, characterized by a greenish-yellow color of the fruit skin, where the viability reached 27.72% (Table 2). The M3 maturity level produced the length and diameter of the apocol and the diameter of the embryo, which amounted to 105.33 mm, 6.95 mm, and 767 µm until the 47th day of germination. Overall, the length and diameter of the apocol in the germinated seeds looked relatively the same at each maturity level. This indicates that there is no significant difference in the thickness of the seed coat, considering that each fruit has entered the ripening phase, but no color change has occurred. Widyawati et al. (2009) added that changing the color of palm fruit skin from green to yellow occurs gradually up to 2 years, even though it is in the same phase.

Furthermore, no fundamental difference in several parameters was observed, such as moisture content, fat content, carbohydrates,

and so on, as illustrated in Figure 2. As described earlier, the palm kernels have entered the same level, namely the ripening phase, but changing the color of the fruit skin occurs gradually. In plants belonging to the Palmae family, the water content values generally decrease as fruit maturity increases. This phenomenon is observed in oil sugar palm fruit, which exhibits lower moisture content during the physiological ripening phase (Misron et al., 2017). Achieving physiological maturity is crucial for ensuring good seed quality, alongside other considerations, such as seed health, which involves being free from infections and contamination caused by disease pathogens (Anwar et al., 2005). Regarding the color of the seed coat, the different maturity levels did not give a significant change in color pattern (Figure 4). The palm seeds have the same color pattern, which is black-brown skin. This maturity level will have a significant influence on the germination process. Usually, seeds that have reached physiological maturity have optimal nutrient content to support germination. Conversely, not physiologically mature seeds tend to have low germination or even fail to germinate.



Figure 4. Color pattern of sugar palm seeds at different maturity levels

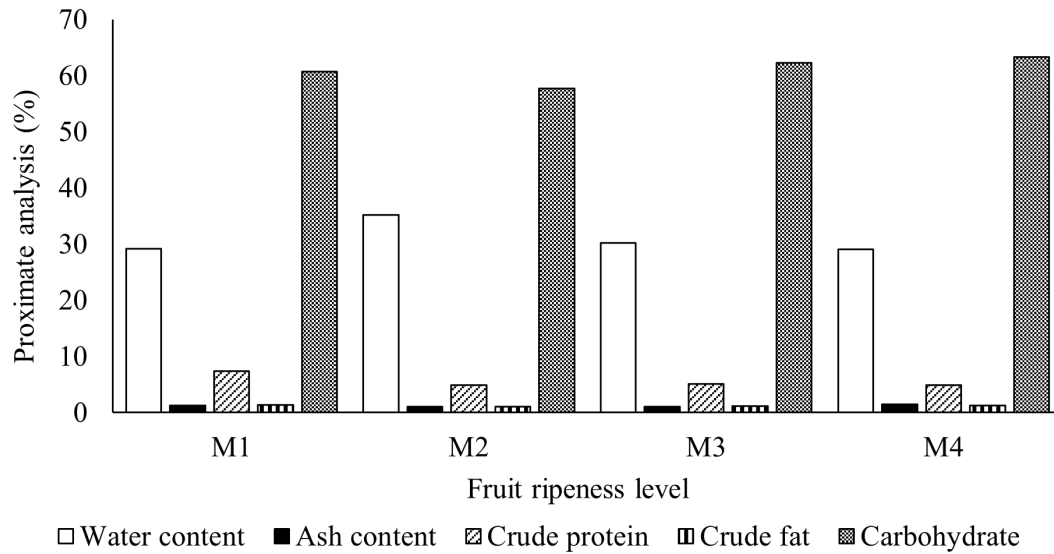


Figure 5. Changes in water content, ash content, crude protein, crude fat and carbohydrates during the sugar

Analyzing Figure 5 reveals notable trends in the sugar palm fruit's chemical composition during ripening. The water content exhibits a decreasing pattern from maturity level M1 to M4, suggesting slight physiological changes but not significant ones. Regarding ash content, M4 stands out with higher levels than M1, M2, and M3. Conversely, the protein content of M1 surpasses that of M2, M3, and M4. However, crude fat and carbohydrate content parameters do not exhibit significant value variations across maturity levels (Figure 5).

The findings of this test align with research on the proximate tests of sugar palm endosperm

composition, as indicated by Torio et al. (2006). They reported that physiologically, ripe sugar palm fruit (aged 22-24 months after anthesis) tends to have lower water content, higher ash and fat content, and decreased fiber content. The description of water content generally characterizes the water status within plant tissue (Wisnubroto et al., 2020; Wisnubroto et al., 2021; Wisnubroto et al., 2024), including fruit. The observed decrease in water content in increasingly ripe sugar palm fruit could be attributed to the breakdown of carbohydrates into energy for the growth and development of sugar palm embryos.

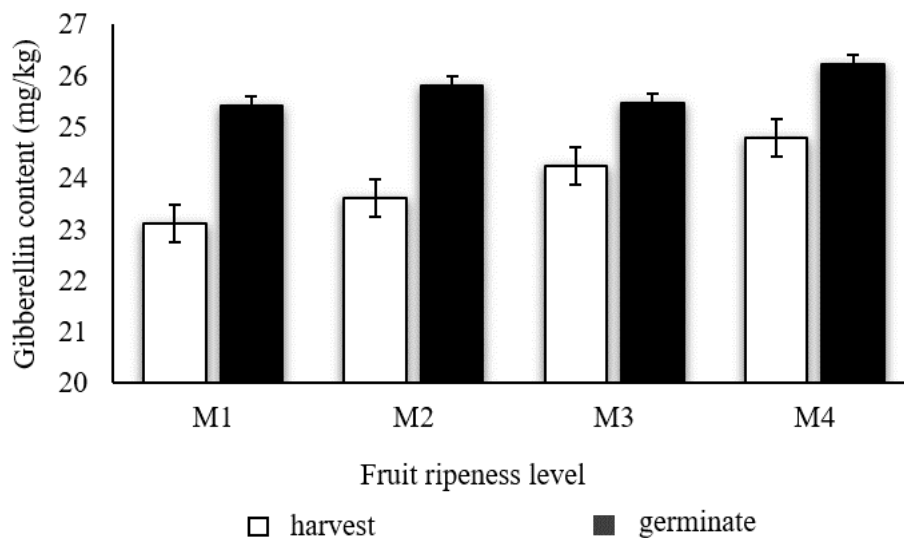


Figure 6. Gibberellin levels at various stages of maturity of sugar palm fruit and sprouts. Symbol (I) indicates the standard deviation of the observed data.

Figure 6 illustrates the gibberellin content during the ripening and germination process. Gibberellin is a crucial hormone that breaks dormancy and initiates cell division, enabling sugar palm seeds to germinate. This hormone is synthesized at the tip of the apical meristem or the actively dividing part of the plant. Gibberellins also play a vital role in elongating stem segments where the tips are still meristematic (Gupta & Chakrabarty, 2013). Additionally, alongside gibberellin, hormones like cytokinin and auxin stimulate cell division activity in roots and shoots, fostering accelerated germination (Anwar et al., 2018).

Figure 6 provides information indicating that the gibberellin levels increase with the higher maturity level of the fruit. The M4 stage of sugar palm fruit maturity exhibits higher levels of gibberellin hormone than M1, M2, and M3. Coincidentally, in this stage, there is a decrease in water content, as observed in Figure 4. A similar correlation was reported in a sugar palm seed technology study by Saleh et al. (2007). The M4 phase of sugar palm fruit maturity suggests that the fruit is physiologically ripe, and the seeds are prepared to germinate after successfully passing through or breaking the dormancy period. The M4 maturity phase during the germination of sugar palm seeds is characterized by high levels of the hormone gibberellin (GA), as depicted in Figure 6. The action of GA is in contrast with abscisic acid (ABA). GA stimulates germination through cell division, while ABA promotes seed dormancy. GA influences germination in two main ways: by enhancing the growth potential of the embryo and by inducing hydrolytic enzymes, particularly  $\alpha$ -amylase. During seed germination, embryonic GA is released, initiating dormancy breaking by stimulating the expression of genes involved in cell expansion and modification (Gupta & Chakrabarty, 2013). Overall, observations on the relationship between palm fruit maturity level and germination variables are still limited to observation of gibberellin levels. However, several references show that the maturity level

significantly effects the germination of palm seeds, germination rate, and vigor index. The more physiologically mature the seeds are, the higher their germination rate and vigor index. This is because physiologically ripe fruits contain enzymes that actively support germination. Aji and Syaputra (2023) added that sugar palm seeds derived from physiologically ripe fruit, characterized by an evenly yellow color, provide better seed growth uniformity than at other maturity levels. The same thing was also shown by Vanitha and Vasudevan (2019), which stated that fruits with a perfect maturity level with characteristics of evenly yellow skins provide optimal germination and germination rates compared to fruits that are not evenly yellow. However, the germination of sugar palm seeds is also influenced by the genotype of the palm plants. Junaedi et al. (2020) stated that varieties in the Pematang Siantar region have a germination rate of 75%, Bengkulu Curup 90%, Cianjur 98%, and East Kutai 89%.

The anatomical characteristics of sugar palm fruit are discerned through a longitudinal incision, followed by observation under a microscope at a specific magnification. This characteristic enables the description of the sugar palm fruit's tissue structure, including its internal parts. The outcomes of anatomical observations offer a relatively straightforward depiction of embryos still developing during maturation (Figure 7).

In general, the anatomy of the sugar palm fruit consists of the exocarp or skin (in the form of cuticle, epidermis, and hypodermis), as well as the mesocarp/endocarp (which is the flesh of the sugar palm fruit), and the embryo (ovule that will develop), as is the anatomy of the date palm fruit (Alsmairat et al., 2023). However, the exocarp of sugar palm fruit is mainly composed of sclereid cells, which are hard like the exocarp of oil palm fruit. Stone cells (sclereids) form sclerenchyma tissue, which develops through lignin deposition into the primary cell walls of parenchyma cells, causing an increase in cell wall thickness (Alsmairat

et al., 2023). Figure 7 shows the embryo is situated in the deepest layer after the exocarp and endocarp. The embryo does not exhibit signs of undergoing a differentiation process, indicating that the sugar palm kernel attains physiological maturity during ripening while still being in the dormancy period. However, as illustrated in Figure 7.d., a meristematic part will eventually differentiate into cotyledons and radicles when the dormancy period concludes or transitions into the germination phase.

As germination progresses, meristematic cells with an irregular arrangement gradually emerge at the bottom of the embryonic cavity, accompanying the growth of the radicle (Luo

et al., 2023). During germination, the embryo enlarges, and the endosperm diminishes. Cotyledons and radicles utilize these food reserves for their growth and development. The transition area between the plumule and radicle undergoes differentiation, giving rise to secondary roots, parenchyma cells, and a group of fiber tissue (Viana et al., 2016). It can be seen in Figure 8 that the germinated sugar palm seeds will show changes in the embryo. The embryo's position in the sugar palm seed is located on the left or right side of the seed back, with the characteristics of a round indentation on the back of the seed (Figure 8.a).

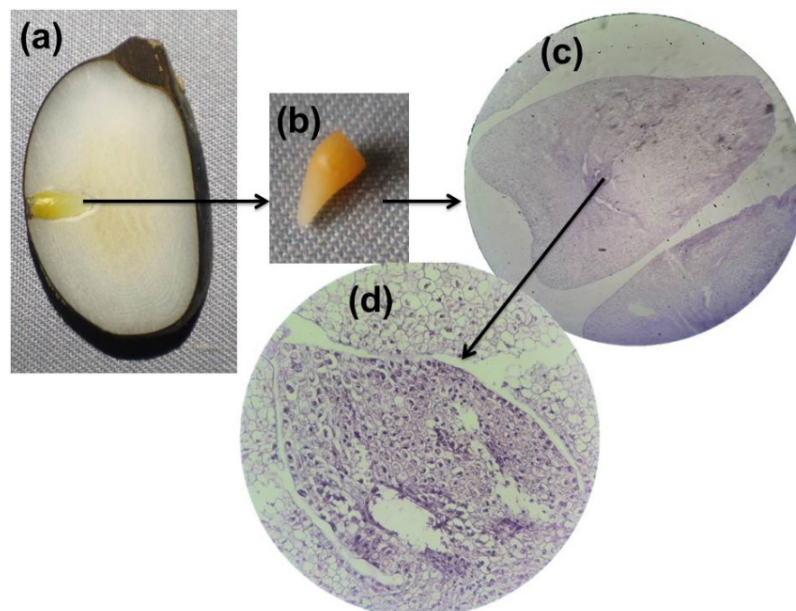


Figure 7. Longitudinal incision of sugar palm fruit seeds observed under a binocular microscope. a) the appearance of a longitudinal incision in the sugar palm seed; b) the sugar palm seed embryo; c) the appearance of sugar palm embryos under a microscope with 10X magnification; and d) the appearance of the future cotyledons and radicle at 40X magnification.

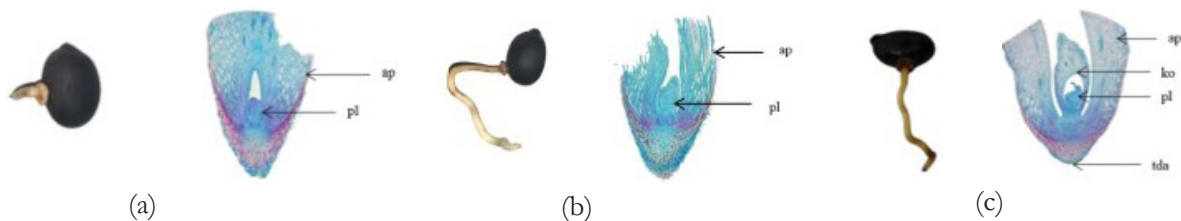


Figure 8. Anatomical development of germination of sugar palm seeds germinated at 10 days interval; a) 10 days; b) 20 days; and c) 30 days after germination; ap: apocol, pl: plumule, ko: coleoptile, tda: root cap.

After 10 days, there are differences in the morphology and anatomy of the germinated sugar palm seeds. The process begins with the appearance of white ring-like tissue on the scarified part (Figure 8.a.). This tissue will develop into a white tube-like shape known as apocol (growing through the operculum) (Figure 8). The apocol will continue to grow in length until the emergence of the primary root (Figure 8.b). As the embryo develops and the plumule (first leaflet) emerges, the diameter of the apocol will increase (Figure 8.b). By the 30th day, the embryo has clearly differentiated into a plumule and the emergence of coleoptiles in the apocol cavity (Figure 8.c). Coleoptile has a role as a plumule protector when it penetrates out of the apocol. Furthermore, the coleoptile will develop into a leaf, and the opening of the first leaf signifies the end of the seed's endosperm function as a food reserve (Suhendra et al., 2023). After 10 days, there will be a transition zone, so the radicle and plumule are clearly visible. The tip of the apocol that grows downward will form the primary root as the first sense (radicle) as shown in Figure 8.c. This primary root is covered by a root cap for protection when it penetrates the soil. The germination of sugar palm is classified as an epigeal type because the cotyledons will emerge to the soil's surface and become the plant's first leaves.

Generally, there is no observable change in anatomy or physiology from the M1 to M4 ripening phases, where water content, protein, and carbohydrate content consistently maintain high values throughout the entire sugar palm fruit ripening process. This prolonged maintenance of high values contributes to the relatively lengthy dormancy phase experienced by sugar palm seeds. Furthermore, based on anatomical information (Figure 7 and 8), it becomes evident that a specific technique or scarification of sugar palm seeds is necessary to shorten the dormancy period. This is crucial for facilitating efforts to germinate and rejuvenate sugar palm plants.

The results of this study significantly impact on sugar palm cultivation activities carried out by farmers. The level of fruit maturity can be an indicator for farmers to have palm fruits that are suitable to be used as planting material or seeds. In addition, it makes it easier for farmers to recognize the characteristics of palm fruits that have reached physiological maturity, thus helping select palm seeds with high germination potential. Physiologically mature seeds produce seeds with optimal germination, thus minimizing seedling failure. Information on seeds' morphological and physiological changes during maturation also allows the identification of the optimal maturity stage for seed harvesting. This is important to ensure high germination and good seedling vigor. These results also provide important basic information for plant breeding programs, especially in selecting superior genotypes based on physiological and anatomical characters of seeds that support the adaptation and productivity of sugar palm plants. During this research, obstacles became limiting factors in the study. One of them is the limited tools in the research. In addition, references or standard operating procedures for making cross-section sugar palm seed are still unavailable, and the number of seed samples used is still limited. However, the results of this study have been able to provide information that the dormancy of sugar palm seeds does not come from outside (exogenous dormancy type) but is caused by embryo differentiation that does not occur during the maturation and germination process. In the future, efforts to break the dormancy of sugar palm seeds should be made mechanically by breaking the hard skin and considering the morphophysiological aspects of sugar palm seeds.

#### IV. CONCLUSIONS

Ripening of the sugar palm fruit initiates the transition of the skin color from green to yellow. However, this color change is not accompanied by a change in the shell of the palm fruit or the size of the seeds, only the hardened shell of the

seeds. Physically, important changes occur in water, carbohydrates, protein, and fat content. In addition, there is considerable variation in the gibberellin hormone content of the palm seeds during the ripening and germination phases. From an anatomical perspective, it is clear that embryo differentiation does not occur during the maturation and germination process. The structure of the sugar palm seed embryo remains consistent, especially from the beginning of ripening until the start of the germination process. There is a reciprocal relationship in which the higher the maturity level, the harder the seed coat structure. This condition is believed to be the main cause of sugar palm seed dormancy, which is categorized as morphophysiological dormancy. Overall, the maturity level of M3 is considered optimal for use as planting material for sugar palm cultivation.

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