

Influence of Mother Palm Age and Harvesting Maturity Seed Nut on Seed Quality and Germination of Aromatic Pandan Coconut

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ABSTRACT

Aromatic Green Dwarf (AROD), commonly known in Malaysia as aromatic pandan coconut, is a dwarf type of coconut that has a unique aroma and flavour, and originated from Thailand. Aromatic pandan coconut is a popular coconut variety in Southeast Asia, particularly in Thailand and Malaysia, where it is widely consumed fresh. This popularity has led to an increasing demand for high-quality planting materials to support its commercial cultivation. Currently, the germination rate of aromatic pandan coconut seed nuts is around 40% under commercial practice, where matured seed nuts were harvested at 12 months after pollination (MAP) for germination. Thus, this study was conducted to improve the seed nuts' germination performance by evaluating the effect of mother palm age and optimising the harvesting maturity stage of seed nuts harvested. In this study, aromatic pandan coconut seed nuts harvested at 10, 11, and 12 MAP were evaluated using two mother palm ages (10 years and 30 years). Seed germination performance was assessed at Tun Abdul Razak Agricultural Research Centre (Pusat Penyelidikan Pertanian Tun Abdul Razak, PPPTAR), Jengka, Pahang, using several parameters, including final germination rate after

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a four-month germination period, germination index, mean germination time, germination rate index, time spread of germination and seedling vigour index. The results showed that aromatic pandan coconut seed nuts harvested at 10 MAP achieved the highest final germination rate at 10 and 30 year-old mother palms, (60.7% and 65.3% respectively), followed by 11 MAP (56.0% and 51.3%) and 12 MAP (45.3% and 41.0%).

Keywords: Aromatic pandan coconut, harvesting maturity seed nut, seed germination

INTRODUCTION

Coconut (*Cocos nucifera* L.) is a perennial tropical crop of major cultural, nutritional, and economic importance. It is widely known as the “tree of life” because almost every part of the palm can be utilised, including the stem for timber, leaves for roofing and handicrafts, sap for sugar and beverages, kernel for oil and milk, husk for fibre, and shell for charcoal and crafts (Mohd Effendi et al., 2023). Coconut palms are broadly classified into tall and dwarf types, in which tall varieties are mainly cross-pollinated, while dwarf varieties are largely self-pollinated (Perera et al., 2003). Among the dwarf coconuts, aromatic pandan coconut, known internationally as Aromatic Green Dwarf (AROD), is valued for its unique pandan-like aroma and flavour. Originating from Thailand, it is widely consumed fresh and considered a premium coconut in Southeast Asia and other coconut-growing regions (Bourdeix et al., 2010; Labouisse et al., 2005). The commercial planting of aromatic pandan coconut has grown quickly, increasing the need for high-quality planting materials, but the information on the germination behaviour and seed quality is still limited. In general, basic knowledge on palm seed dormancy and germination, including in coconut, also remains limited (Baskin & Baskin, 2014). Although recent advances in embryo culture and somatic embryogenesis demonstrate that clonal propagation of coconut is technically possible, these methods remain limited in large-scale field application. Therefore, commercial coconut production continues to depend mainly on seed nuts, making seed quality and germination performance critical for nursery success and field establishment. Seed germination is an important stage in coconut propagation because coconut seeds are recalcitrant and continue to remain physiologically active after harvest. It is also affected by maternal and developmental factors (Baskin & Baskin, 2014; Beveridge et al., 2022; Paull & Ketsa, 2015). Coconut produces a large, effectively viviparous seed, in which the embryo continues to develop after fruit maturity and rapidly loses viability when moisture is reduced (Harries, 2012). Fruit development generally requires about 330 to 420 days after pollination, after which the embryo nuts harvested too early may not be physiologically mature, while over-mature nuts may lose moisture and become less viable due to metabolic changes. (Beveridge et al., 2022). Evidence from other palms supports the importance of the harvest stage and internal seed condition. In oil palm (*Elaeis guineensis*), seeds harvested at optimal maturity

stages show higher germination percentages and more uniform emergence than those collected too early or too late (Norsazwan et al., 2023). Similar patterns have been reported in macaw palm (*Acrocomia aculeata*), in which delayed or irregular germination is closely linked to physiological dormancy and hormonal imbalance within the seed (Ribeiro et al., 2015) and in date palm (*Phoenix dactylifera*), where seed maturity and moisture status also determine germination success and early seedling growth (Mohammed & Said, 2018). These findings indicate that, within the *Arecaceae*, harvest stage and internal seed condition are key determinants of seed performance. In addition to harvest maturity, characteristics associated with the mother palm may influence seed quality. In perennial crops and palms, seed size, nutrient reserve, and early seedling vigour often vary with plantation age. Several studies report superior seed characteristics from palms in their optimum productive stage compared with very young or old stands (Kome & Tabi, 2020; Lyngdoh et al., 2014). Similar patterns have been reported in other long-lived species, where middle-aged mother plants tend to produce offspring with higher vigour and better early growth, and very old plants may show declining reproductive performance (Alejano et al., 2019; Pardos et al., 2022). However, there is still a lack of information on how mother palm age affects coconut seed germination, particularly for high-value varieties such as aromatic pandan coconut. Most nursery practices rely on general recommendations without considering physiological differences among palms of different ages. The present study addresses this gap by evaluating the combined effects of mother palm age and nut harvest maturity on seed performance in aromatic pandan coconut. Two palm ages were selected to represent different physiological stages of production, which are 10-year-old palms corresponding to the early productive phase and 30-year-old palms representing fully mature palms in commercial plantations. Nuts were harvested at 10, 11, and 12 months after pollination based on the normal development period of coconut fruits. In commercial practice, seed nuts are usually harvested at around 12 months after pollination, while 10 and 11 months represent stages just before full maturity. These stages were included to evaluate whether earlier harvesting within the mature fruit window could improve germination performance (Beveridge et al., 2022; Paull & Ketsa, 2015). The findings are expected to identify suitable harvesting stages and palm age sources for producing high-quality planting materials, thereby providing practical guidance for nursery management and sustainable cultivation of these high-value coconut varieties.

MATERIALS AND METHODS

Plant Material and Experimental Site

The study was conducted at the Aromatic Pandan Coconut Seed Garden and Nursery operated by FGV Agri Services at the Tun Abdul Razak Agricultural Research Centre (Pusat Penyelidikan Pertanian Tun Abdul Razak, PPPTAR), Jengka, Pahang, Malaysia (3.8822° N, 102.5315° E).

The seed garden consisted of around 2,400 aromatic pandan coconut palms managed under standard commercial practices. Seed germination and nursery management were carried out at the Aromatic Pandan Coconut Nursery within the same research complex. Aromatic pandan coconut is a self-pollinated dwarf variety, and controlled hand pollination was not performed. All seed nuts resulted from natural pollination under field conditions.

Seed Nut Sampling and Harvest Maturity Evaluation

Aromatic pandan coconut seed nuts were collected from the study site described above. Seed nuts were harvested from mother palms of two age groups (10 and 30 years after planting) at three maturity stages, namely 10, 11, and 12 months after pollination (MAP). Harvest maturity was determined based on exocarp colour following the Department of Agriculture (DOA) Malaysia Standard Operating Procedure for the Production of Aromatic Pandan Coconut Seedlings (DOA, 2011). To validate the relationship between nut age and exocarp colour, 100 aromatic pandan coconut inflorescences (bunches) were tagged at pollination and monitored daily to observe changes in exocarp colour from the button stage through to the development of a dark brown exocarp, corresponding to nut maturity. Seed nuts were harvested randomly from multiple bunches of aromatic pandan coconut across the seed garden to minimise sampling bias. Figure 1 shows the images of seed nuts at three maturity stages.

Nursery Preparation and Seed Sowing

Seed nuts were sown in a shaded nursery under 50% shade netting following the Standard Operating Procedure for Aromatic Pandan Coconut Seedling Production (DOA, 2011). Prior to sowing, seed nuts were mechanically scarified to facilitate water uptake and promote uniform germination. Scarification was performed by carefully removing excess husk material around the germination pore region without damaging the endocarp or embryo.



Figure 1. Aromatic pandan coconut seed nuts harvested at 10, 11, and 12 months after pollination (left to right), showing differences in exocarp colour with increasing maturity stage

This procedure was applied uniformly to all seed nuts in line with the Department of Agriculture (DOA) Malaysia guidelines, after which the seed nuts were immediately sown on sand beds. Nursery beds were prepared using raised sand beds to ensure sufficient drainage and uniform moisture conditions, with seed nuts placed horizontally in the sand. Irrigation was supplied using a mist irrigation system applied twice daily in the morning (0800-0900 h) and evening (1600-1700 h). Each irrigation cycle lasted approximately 10-15 minutes, maintaining consistently moist but non-waterlogged conditions throughout the germination period. No fertiliser was applied during germination, and weed control was carried out manually as required.

Experimental Design

Three levels of seed nut maturity (10, 11, and 12 months after pollination) and two mother palm age groups (10 and 30 years) were evaluated using a factorial randomised complete block design (RCBD). The experiment consisted of six treatment combinations with three replications of 100 seed nuts for each treatment, giving a total of 1,800 seed nuts used in the study. The sand beds were arranged into blocks according to the direction of sunlight exposure within the nursery to minimise environmental variation.

Seed Germination Assessment

Germination was monitored weekly for 16 weeks after sowing. A seed nut was considered germinated upon visible emergence of the plumule. Final germination percentage (FGP) was determined 16 weeks after sowing, when germination had stabilised, and no further seed emergence was observed. This was consistent with standard nursery practices for aromatic pandan coconut and reported coconut germination behaviour (Beveridge et al., 2022; DOA, 2011). Germination parameters were calculated following the method described by Ranal et al. (2009). These parameters included final germination percentage (FGP), germination index (GI), mean germination time (MGT), germination rate index (GRI), time spread of germination (TSG), and seedling vigour index (SVI), as defined in the equations in Table 1.

Seed Morphological Measurements

Morphological analysis was conducted using nine seed nuts randomly selected for each mother palm age across the three maturity stages (three nuts per maturity stage), resulting in 18 seed nuts for morphological analysis. Data were collected on fruit dimensions, fruit mass, volume, component mass and component thickness of aromatic pandan coconut, as illustrated in Figure 2. Husk thickness was measured by cutting each fruit longitudinally and recording measurements at four fixed positions around the fruit (H1-H4: top, bottom, and two side positions).

Table 1
List of equations and parameters

No.	Parameter	Formula and description
1	Final germination percentage, FGP (%)	$FGP = \frac{\text{Total seeds germinated at the end of the trial}}{\text{Number of initial seeds used}} \times 100\%$ [1]
2	Germination index, GI (%/day)	$GI = \sum_{i=1}^n \frac{G_i}{D_i}$ [2] where G_i is the number of seeds germinated on day D_i and D_i is the i^{th} day of germination
3	Mean germination time, MGT (day)	$MGT = \frac{\sum Fx}{\sum F}$ [3] where F is the number of seeds germinated on day x
4	Germination rate index, GRI (% / day)	$GRI = \frac{G_1}{1} + \frac{G_2}{2} + \dots + \frac{G_i}{i}$ [4] where G_i is the germination percentage on i^{th} day.
5	Time spread of germination, TSG (day)	$TSG = \text{Final day of germination} - \text{First day of germination}$ [5]
6	Seedling vigour index, SVI	$SVI = \text{Seedling length (cm)} \times \text{germination (\%)} $ [6]

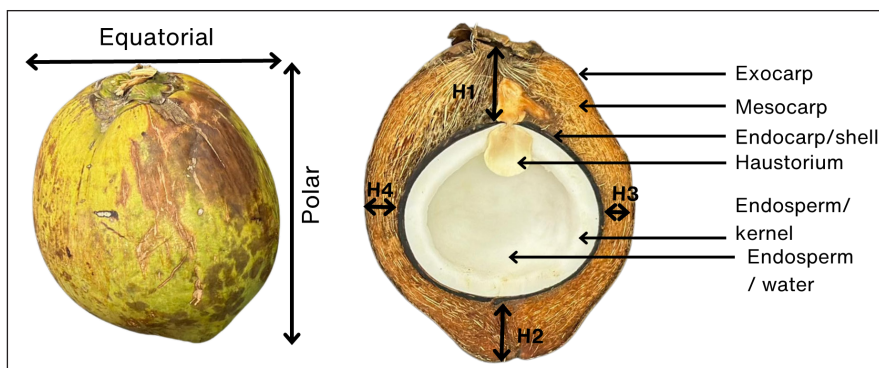


Figure 2. Fruit dimensional and component thickness parameters of aromatic pandan coconut

The average of H1-H4 was used as the husk thickness for each fruit. Kernel thickness was measured at one standard position next to the endosperm, as shown in Figure 2, because the kernel layer is generally uniform around the fruit.

Seedling Physiological Measurements

Seedling physiological parameters were measured at 16 weeks after sowing using a LI-COR LI-6400XT Portable Photosynthesis System (LI-COR, Inc., Lincoln, Nebraska, USA). The parameters measured included net photosynthetic rate ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$), intercellular CO_2 concentration ($\mu\text{mol CO}_2 \text{ mol}^{-1}$) and transpiration rate ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$). For each treatment, three healthy and uniformly growing seedlings were randomly selected from the germinated population. Measurements were taken from the middle portion of the third fully expanded leaf, with five readings recorded per leaf to obtain an average value per seedling. Data collection was conducted between 0800 and 1100h to minimise potential variation associated with midday stomatal closure.

Statistical Analysis

Data were analysed using two-way analysis of variance (ANOVA) with a factorial Randomised Complete Block Design (RCBD) to evaluate the main effects of mother palm age (10 and 30 years) and harvesting maturity stage (10, 11 and 12 months after pollination) as well as their interaction on seed germination, seed morphological traits and seedling physiological parameters. Normality and homogeneity of variance were verified using Shapiro-Wilk and Levene's tests, respectively. When significant effects were detected, treatment means were compared using Tukey's Honest Significant Difference (HSD) test at a 5% significance level ($P \leq 0.05$). All statistical analyses were performed using R software and XLSTAT.

RESULTS

Seed Germination

In the present study, findings showed that harvesting maturity strongly affected final germination percentage (FGP) and mean germination time (MGT), while palm age had a smaller effect on seed germination parameters. The interaction between palm age and harvesting maturity was mainly seen for FGP and MGT ($p < 0.05$), indicating that the effect of harvesting stage showed small differences with the age of the mother palm. Seeds harvested at 10 months produced the highest germination for both palm ages. The highest FGP was recorded from 30-year-old palms at 10 months (65.33%), followed by 10-year-old palms at the same stage (60.67%) (Table 2).

Table 2

Final germination percentage (FGP), germination index (GI), germination index rate (GRI), mean germination time (MGT), time spread of germination (TSG) and seedling vigour index (SVI) for seeds germinated at 10, 11 and 12 months after pollination at 10 years and 30 years of mother palm age value were presented in mean \pm standard error (SE)

Palm Age (years)	Harvesting Maturity (months)	FGP (%)	GI	GRI (%/day)
10	10	60.67 \pm 2.73 ^{ab}	1.02 \pm 0.07 ^a	6.04 \pm 0.50 ^a
	11	56.00 \pm 4.58 ^{abc}	1.47 \pm 0.02 ^a	8.97 \pm 0.21 ^a
	12	45.33 \pm 0.88 ^{bc}	1.84 \pm 0.22 ^a	9.63 \pm 0.76 ^a
30	10	65.33 \pm 2.91 ^a	1.15 \pm 0.07 ^a	7.03 \pm 0.43 ^a
	11	51.33 \pm 1.76 ^{abc}	1.46 \pm 0.04 ^a	8.57 \pm 0.21 ^a
	12	41.00 \pm 7.21 ^c	1.95 \pm 0.41 ^a	9.69 \pm 2.03 ^a

Palm Age (years)	Harvesting Maturity (months)	MGT (day)	TSG (day)	SVI
10	10	63.00 \pm 2.08 ^a	65.33 \pm 6.17 ^a	2908.90 \pm 201.60 ^a
	11	44.33 \pm 1.86 ^b	72.33 \pm 6.17 ^a	3256.11 \pm 194.18 ^a
	12	35.67 \pm 2.73 ^{bc}	77.00 \pm 10.69 ^a	2869.14 \pm 134.16 ^a
30	10	59.33 \pm 0.67 ^a	67.67 \pm 6.17 ^a	3440.85 \pm 183.14 ^a
	11	43.33 \pm 2.33 ^b	84.00 \pm 4.04 ^a	3092.10 \pm 89.78 ^a
	12	32.33 \pm 2.73 ^c	86.33 \pm 12.35 ^a	2728.08 \pm 625.51 ^a

Note. Means followed by different letters within the same column across all treatments (all palm ages and harvesting maturities) are significantly different at $p < 0.05$ (Tukey's HSD test)

In contrast, seeds harvested at 12 months showed the lowest FGP for both 10-year-old (45.33%) and 30-year-old palms (41.00%). This pattern clearly shows that later harvesting reduces germination regardless of palm age. Germination index (GI) and germination rate index (GRI) did not differ significantly among treatments. Although these values increased slightly with harvesting maturity, the differences were not significant, indicating that the speed of germination was similar across all treatments. Mean germination time (MGT) was strongly influenced by harvesting maturity. Seeds harvested at 10 months took the longest time to germinate, with 63.00 \pm 2.08 days for 10-year-old palms and 59.33 \pm 0.67 days for 30-year-old palms. In contrast, seeds harvested at 12 months germinated much faster with MGT values of 35.67 \pm 2.73 days and 32.33 \pm 2.73 days for 10 and 30-year-old palms, respectively. This shows that more mature seeds begin germination earlier, even though fewer seeds finally germinate.

Time spread of germination (TSG) and seedling vigour index (SVI) showed no significant differences among treatments. No interaction between palm age and harvesting maturity was detected for these parameters.

Seed Morphology

Fruit Dimensional Parameters

Table 3 summarises the dimensional parameters of aromatic pandan coconut in relation to mother palm age and harvesting maturity stage. Statistical analysis showed that mother palm age had a significant effect ($p < 0.05$) on all measured dimensional parameters, including equatorial circumference, polar circumference, equatorial diameter, and polar diameter. In contrast, harvesting maturity stage (10, 11, and 12 months after pollination) did not significantly affect these parameters ($p > 0.05$), and no significant interaction between palm age and harvesting maturity was detected ($p > 0.05$). Across all maturity stages, fruits from 30-year-old palms were consistently larger than those from 10-year-old palms. For the 30-year-old palms, fruit dimensions generally increased with advancing harvesting maturity, with the highest values for equatorial circumference (49.30 ± 0.64 cm), polar circumference (51.71 ± 0.94 cm), and polar diameter (16.77 ± 0.44 cm) recorded at 12 months after pollination. In contrast, fruits from 10-year-old palms showed smaller dimensions and no clear increasing trend with harvesting maturity, indicating more limited fruit expansion in younger palms.

Table 3

Dimensional parameters of aromatic pandan coconut fruit harvested at 10, 11 and 12 months after pollination from 10 and 30-year-old mother palms (mean \pm SE)

Palm Age (years)	Harvesting Maturity (months)	Equatorial Circumference (cm)	Polar Circumference (cm)	Equatorial Diameter (cm)	Polar Diameter (cm)
10	10	47.53 ± 0.55^{ab}	49.02 ± 0.50^{ab}	14.77 ± 0.16^{ab}	15.61 ± 0.30^b
	11	45.53 ± 1.29^b	47.84 ± 1.07^b	13.83 ± 0.41^b	15.58 ± 0.28^b
	12	44.81 ± 0.62^b	47.64 ± 0.59^b	13.82 ± 0.33^b	15.53 ± 0.33^b
30	10	48.66 ± 0.42^a	50.38 ± 0.39^a	15.08 ± 0.17^a	16.68 ± 0.23^a
	11	49.11 ± 0.63^a	50.50 ± 0.87^a	15.07 ± 0.22^a	16.30 ± 0.35^a
	12	49.30 ± 0.64^a	51.71 ± 0.94^a	14.88 ± 0.19^{ab}	16.77 ± 0.44^a

Note. Means followed by different letters within the same column across all treatments (all palm ages and harvesting maturities) are significantly different at $p < 0.05$ (Tukey's HSD test)

Fruit mass, Volume, and Component Mass

The fruit mass, volume and component mass are summarised in Table 4. The results showed that mother palm age and harvesting maturity significantly affected most parameters ($p < 0.05$),

with a significant interaction for selected components. Total fruit mass decreased with increasing harvesting maturity in both palm ages. In 10-year palms, fruit mass declined from 874.89 g at 10 MAP to 579.89 g at 12 MAP, while in 30-year palms it decreased from 868.11 g to 726.89 g. This reduction was mainly due to a strong decrease in husk mass across maturity stages. Harvesting maturity also significantly affected dehusked fruit mass without water, but the pattern differed by palm age. In 10-year palms, values decreased slightly with maturity, whereas in 30-year palms they increased at 11 to 12 MAP compared with 10 MAP. This shows that later maturity reduces husk contribution, but solid internal mass is better maintained in fruits from older palms.

Table 4

Palm age differences in fruit mass and volume of the component (husk, kernel, and shell) mass of aromatic pandan coconut fruit value were presented in mean \pm standard error

Palm Age (years)	Harvesting Maturity (months)	Fruit Mass (g)	Fruit Mass without Water (g)
10	10	874.89 \pm 17.74 ^a	735.56 \pm 16.48 ^a
	11	698.22 \pm 81.75 ^{ab}	554.89 \pm 32.20 ^{bc}
	12	579.89 \pm 24.78 ^b	540.22 \pm 19.86 ^c
30	10	868.11 \pm 13.93 ^a	745.22 \pm 11.41 ^a
	11	854.67 \pm 49.08 ^a	695.89 \pm 36.92 ^a
	12	726.89 \pm 26.74 ^{ab}	648.22 \pm 19.70 ^{ab}

Palm Age (years)	Harvesting Maturity (months)	Dehusked Fruit without Water (g)	Mass of Fruit Husk (g)
10	10	384.22 \pm 8.84 ^{bc}	351.33 \pm 15.79 ^a
	11	355.33 \pm 19.53 ^{bc}	199.56 \pm 19.76 ^c
	12	353.89 \pm 12.52 ^c	186.33 \pm 7.63 ^c
30	10	400.67 \pm 9.18 ^{ab}	344.56 \pm 7.38 ^a
	11	431.00 \pm 14.53 ^a	264.89 \pm 23.07 ^b
	12	410.67 \pm 13.37 ^a	237.56 \pm 9.50 ^b

Note. Means followed by different letters within the same column across all treatments (all palm ages and harvesting maturities) are significantly different at $p < 0.05$ (Tukey's HSD test)

Husk and Kernel Thickness

The ANOVA findings and summary of coconut component thickness are stated in Table 5. The result showed that shell, kernel, H2 and H4 thickness are not significantly affected by

palm age and harvesting maturity stage ($p>0.05$), while the H1 and H3 thickness have a significant effect ($p<0.05$) in palm age. As the stage of maturity in harvesting increased, shell and kernel thickness for 30-year-old palm age of coconut also increased, while the 10-year-old palm age coconut showed decreased thickness in shell and kernel dimensions. The 30-year-old palm age coconut in 12 months of maturity stage at harvesting has the highest thickness in shell ($3.44\pm 0.51\text{mm}$) and kernel ($11.66\pm 1.29\text{mm}$). Mature coconut showed the highest husk thicknesses, H1 ($4.40\pm 1.01\text{mm}$), H2 ($3.12\pm 0.45\text{mm}$) in 12 months' maturity of harvesting, while H3 ($2.07\pm 0.26\text{mm}$) and H4 ($25.25 \pm 4.23 \text{ mm}$) were highest in 11 months and 10 months' maturity of harvesting.

Table 5

Palm age differences in the thickness of the components (husk, kernel, and shell) of aromatic pandan coconut fruit value were presented in mean \pm standard error

Palm Age (years)	Harvesting Maturity (months)	Husk Thickness, H1 (cm)	Husk Thickness, H2 (cm)	Husk Thickness, H3 (cm)	Husk Thickness, H4 (cm)
10	10	4.08 ± 0.24^{ab}	2.51 ± 0.11^b	1.97 ± 0.10^{ab}	1.93 ± 0.09^a
	11	3.92 ± 0.16^{ab}	2.63 ± 0.18^{ab}	1.66 ± 0.08^{ab}	1.82 ± 0.13^a
	12	3.47 ± 0.18^b	2.79 ± 0.09^{ab}	1.56 ± 0.09^b	1.79 ± 0.10^a
30	10	4.26 ± 0.18^a	2.58 ± 0.11^{ab}	1.91 ± 0.09^{ab}	2.02 ± 0.10^a
	11	4.04 ± 0.28^{ab}	2.72 ± 0.17^{ab}	2.07 ± 0.09^a	1.86 ± 0.12^a
	12	4.40 ± 0.34^a	3.12 ± 0.15^a	1.99 ± 0.15^a	1.97 ± 0.12^a

Palm Age (years)	Harvesting Maturity (months)	Shell Thickness (mm)	Kernel Thickness (mm)
10	10	2.82 ± 0.22^{ab}	11.24 ± 0.32^a
	11	2.80 ± 0.06^{ab}	11.02 ± 0.85^a
	12	2.58 ± 0.20^b	10.61 ± 0.29^a
30	10	2.61 ± 0.28^b	11.03 ± 0.12^a
	11	2.91 ± 0.12^{ab}	11.02 ± 0.41^a
	12	3.44 ± 0.17^a	11.66 ± 0.43^a

Note. Means followed by different letters within the same column across all treatments (all palm ages and harvesting maturities) are significantly different at $p < 0.05$ (Tukey's HSD test)

Seedling Physiology

The ANOVA showed that there is no significant relationship ($p > 0.05$) of mother palm age with nut harvesting maturity stage on all physiology parameter, as shown in Table 6. The net photosynthesis values ranged from 8.21 to 11.28 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ for 10-year-old palm age, and 11.73 to 13.18 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ for seeds harvested from 30-year-old palm age. A similar pattern was observed for stomatal conductance, intercellular concentration and transpiration rate parameters.

Table 6

Net photosynthesis, stomatal conductance, intercellular concentration and transpiration rate for seeds germinated at 10, 11 and 12 months after pollination at 10-year-old and 30-year-old mother palm ages were presented in mean \pm standard error

Palm Age (years)	Harvesting Maturity (months)	Net Photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)	Stomatal Conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$)
10	10	10.95 \pm 0.11 ^a	1.02 \pm 0.07 ^a
	11	8.21 \pm 2.38 ^a	1.47 \pm 0.02 ^a
	12	11.28 \pm 1.92 ^a	1.84 \pm 0.22 ^a
30	10	11.73 \pm 0.42 ^a	1.15 \pm 0.07 ^a
	11	13.02 \pm 0.49 ^a	1.46 \pm 0.04 ^a
	12	13.18 \pm 0.53 ^a	1.95 \pm 0.41 ^a

Palm Age (years)	Harvesting Maturity (months)	Intercellular concentration ($\mu\text{mol CO}_2 \text{ mol}^{-1}$)	Transpiration rate ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$)
10	10	257.73 \pm 20.11 ^a	0.002 \pm 3.280 $\times 10^{-4}$ ^a
	11	260.36 \pm 9.43 ^a	0.001 \pm 7.569 $\times 10^{-4}$ ^a
	12	203.96 \pm 40.85 ^a	0.002 \pm 7.064 $\times 10^{-4}$ ^a
30	10	298.94 \pm 7.26 ^a	0.003 \pm 3.461 $\times 10^{-4}$ ^a
	11	271.37 \pm 7.96 ^a	0.003 \pm 3.404 $\times 10^{-4}$ ^a
	12	273.26 \pm 13.10 ^a	0.003 \pm 3.578 $\times 10^{-3}$ ^a

Note. Means followed by different letters within the same column across all treatments (all palm ages and harvesting maturities) are significantly different at $p < 0.05$ (Tukey's HSD test)

DISCUSSION

The present study demonstrates that harvesting maturity is the primary factor influencing seed germination in aromatic pandan coconut (*Cocos nucifera* L.), regardless of mother palm age. Nuts harvested at 10 months after pollination consistently produced the highest

final germination percentage (FGP) for both 10 and 30-year-old palms. This directly supports the conclusion that 10 months is the optimal harvesting stage for seed nuts, as it yields the highest percentage of viable seeds. Although seeds harvested at later stages showed shorter mean germination time (MGT), their FGP was significantly lower. Hence, faster emergence at later maturity does not reflect better seed quality. Based on the present data, 10 months provides the best balance between high germination success and acceptable germination behaviour.

Coconut is a recalcitrant seed, and its viability is closely linked to the physiological condition at harvest. Paull and Ketsa (2015) reported that coconut reaches physiological maturity between 10 and 12 months after pollination. Delaying harvesting for the palm beyond this optimal period may cause nuts to age, dehydrate, and undergo biochemical degradation, all of which reduce embryo viability. Ibrahim et al. (2022) similarly showed that coconut seeds harvested beyond the optimal stage recorded reduced germination due to ageing and moisture loss. These mechanisms are characteristic of recalcitrant seeds, which rapidly lose viability when physiological integrity declines. Comparable responses have been reported in other perennial palms. Norsazwan et al., (2023) demonstrated that oil palm seeds harvested at the optimal stage (20 weeks after pollination) achieved the highest germination (85.1%) compared to the 70.5% observed at 18 WAP and 80.9% at 22 WAP. This closely mirrors the present findings, where the highest FGP occurred at approximately 10 months. This evidence suggests that the optimal maturity stage for harvesting oil palm seeds aligns closely with the observation in the current study, where the highest final germination percentage (FGP) was noted for nuts collected at around 10 months. Therefore, both studies conclude that harvest maturity plays a critical role in seed viability, reinforcing the idea that optimal harvesting can yield seeds with greater germination performance.

Fruit morphology in coconut varies widely among cultivars and developmental stages (Kouadio et al., 2023; Rajesh et al., 2014). In the present study, fruit dimensional and mass-related parameters were strongly influenced by mother palm age. Fruits from 30-year-old palms were consistently larger and heavier across all maturity stages, indicating a greater capacity for assimilate supply and fruit filling in older palms. In contrast, fruits from 10-year-old palms showed reduced dimensions with advancing maturity, suggesting that younger palms may experience limitations in sustaining fruit growth during later developmental stages. Similar increases in equatorial and polar circumferences with advancing maturity across coconut varieties have been reported by Kouadio et al. (2023), supporting the patterns observed in this study. Across both palm ages, fruit mass and component mass declined with increasing harvesting maturity, particularly for husk and water content. Beveridge et al. (2022) reported that coconut water volume decreases as nuts mature, with internal spaces gradually replaced by gases, explaining the reduction in fruit mass observed at later stages. In this study, husk and kernel thickness were highest

at 12 months, confirming that later harvesting stages are associated with thicker structural components, as also reported by Kouadio et al. (2023). Harries (1981) and Odufale et al. (2024) showed that fruit weight, size, and coconut water volume are positively correlated with germination, whereas husk thickness, husk weight, and shell thickness are negatively correlated. A similar pattern was observed in this study, where nuts harvested at 10 months had greater fruit mass and produced higher germination than those harvested at 12 months. However, the relationship was not uniform across all fruit components, suggesting that harvest stage rather than size alone determines germination success.

Despite clear differences in fruit morphology and seed performance, seedling physiological traits, including net photosynthesis, stomatal conductance, intercellular CO₂ concentration, and transpiration, were not significantly affected by palm age or harvesting maturity, nor by the interaction between both factors. The values recorded fall within the range commonly reported for coconut seedlings, which is approximately 2-15 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ (Jayasekara et al., 2010). Stable photosynthetic performance across treatments indicates that, once germination has occurred and seedlings establish functional leaves, physiological activity becomes relatively uniform. This suggests that maternal and developmental effects are observed mainly at the fruit and seed level and do not translate into early physiological disadvantages during seedling establishment.

CONCLUSION

This study demonstrates that harvesting maturity is the primary factor influencing germination performance of aromatic pandan coconut seed nuts, while mother palm age has only a minor effect. Nuts harvested at 10 months after pollination consistently produced the highest final germination percentage for both 10 and 30-year-old palms. However, seeds harvested at later stages germinated in a shorter time but resulted in lower final germination percentages, indicating a relationship between germination speed and total germination success. It is therefore suggested to harvest the seed nut at 10 months after pollination to obtain a higher final germination percentage.

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