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Fruit morphological characteristics at different maturity stages of coconut (*Cocos nucifera* L.) improved hybrids (PB113$^+$, PB121$^+$) and their parent males (RIT$^+$, WAT$^+$)

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***Cocos nucifera* L. is an important coastal crop in Côte d'Ivoire, with 53 coconut cultivars. The present study was carried out to compare the morphophysical characteristics of *C. nucifera* L. fruit of the improved parents Rennell Island Tall (RIT$^+$) and West Africa Tall (WAT$^+$) and their hybrids PB113$^+$ and PB121$^+$, harvested at different maturity. The ANOVA results showed that cultivar and maturity had a significant effect ($p < 0.05$) on all morphological characteristics studied, except for sphericity, H_2, H_3, and H_4 where maturity was not statistically significant ($p \geq 0.05$). The morphological parameters of RIT$^+$ coconuts were statistically different from those of WAT$^+$, PB113$^+$ and PB121$^+$ ($p < 0.05$). The WAT$^+$ coconuts had high kernel thickness. The hybrid PB121$^+$ was more spherical than other fruits and had a higher shell thickness. Improved Rennell Island Tall as a parent had good kernel water mass and large shape, while the improved West Tall Africa had good kernel thickness. Concerning PB113$^+$ and PB121$^+$ hybrids, they were similar in dimensional parameters. However, PB121$^+$ fruits had the highest mass and volume, kernel mass, and shell mass compared to PB113$^+$. This study showed variabilities between the improved cultivars WAT$^+$, RIT$^+$ and the PB121$^+$ and PB113$^+$ hybrids.**

Key words: *Cocos nucifera* L., fruit, cultivar, maturity morphological, Côte d'Ivoire, germplasm.

INTRODUCTION

Côte d'Ivoire is a coconut-producing country, where this crop helps to sustain the livelihoods of farmers along the Ivorian coast. Wide morphological variability has been observed in these indigenous coconut populations in different coconut-growing countries of the world. They are grown for their superior longevity, high yield, hardiness, wind resistance, and high genetic variability and diversity of nuts, shell, kernel and oil yield (COGENT, 2017; Koffi

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et al., 2019; Pandiselvam et al., 2018; Rajesh et al., 2014). The genetic improvement work carried out at the Ivorian Coconut Research Station has made it possible to develop numerous disease-resistant and high-yielding coconut hybrids from crosses between Tall and Dwarf varieties (Bourdeix et al., 1992; Koffi et al., 2014). Thus, 53 cultivars have been developed at the Marc Delorme Coconut research station in order to provide farmers with planting material with high disease tolerance and good agronomic characteristics. Among these cultivars, the improved Port Bouët, PB121$^+$ and PB113$^+$ are among the local hybrids popularised worldwide. These hybrids have vigorous growth and higher yields, which has led to an increase in copra production to 4 t/ha/year under ideal management (Konan et al., 2010). Some work on the morphological characterisation of coconut fruit cultivars has been done by researchers (Assa et al., 2010; Deffan et al., 2011; Kodjo et al., 2015; Koffi et al., 2019). Despite this, some cultivars have not been examined morphologically and there are few comparative studies on the morphological characteristics of parent cultivars and their progeny. The objective of the study was therefore, to compare the morphological characteristics of the improved cultivars West African Tall (WAT$^+$) and Rennell Island Tall (RIT$^+$) and their progeny hybrids PB121$^+$ and PB113$^+$. Quantitative variables were used to identify existing variabilities.

MATERIALS AND METHODS

Materials sampling

The coconut tree material selected was constituted of improved male parents, West African Tall (WAT$^+$) and Rennell Island Tall (RIT$^+$) with their progeny hybrids Port-Bouët (PB), PB121$^+$ (Malayan Yellow Dwarf × West African Tall$^+$) and PB113$^+$ (Cameroon Red Dwarf × Rennell Island Tall$^+$) harvested in experimental fields from International Coconut Genebank for Africa and Indian Ocean (ICG-AIO) located in Marc Delorme coconut research station (N 5°14.5' - W 3°54.5' and 20 m above sea), Abidjan, Southern Côte d'Ivoire, respectively on save experimental plots No. 0.81, 0.91, 050, and 052. During the period November 2020 - January 2021, a sampling of 216 mature coconut fruits (3 fruits × 3 maturities × 6 coconut trees × 4 cultivars) from 3 different maturity stages (10, 11, and 12 months after pollination) were randomly harvested from healthy adult, asymptomatic and selected palms, all same age and under similar management practices. The climate is equatorial with 2 rainy seasons and 2 dry seasons. The meteorological data for the harvest year show an average temperature between 24.70 and 28.30°C. The total insolation reached 2331.6 h during the year with an average moisture content between 84.2 and 90.7% with an annual rainfall of about 1839.2. The soil of the experimental site is of tertiary type with a pH of 5.7, consisting of coarse sand with organic matter content and rich in nutrients, including 690 ppm of phosphorus.

Determination of *Cocos nucifera* L. fruit dimensional parameters

The circumference (equatorial and polar) of the coconut was determined using a tape measure (1 mm sensitivity). The tape was wrapped around the circumference of the coconut using some author's methods (Pandiselvam et al., 2020; Toure et al., 2020). The polar diameter as length, equatorial diameter as width, and thickness of the coconut were measured according to the descriptors in the descriptive list of the International Plant Genetic Resources Institute (IPGRI, 1995) adopted by Sasikumar et al. (2021) and Sheikh et al. (2021). Polar diameter (length) and equatorial diameter (width) were determined using a height gauge (ME-HG-600 mm, 24 inches). Thickness was measured using a caliper gauge (Kanon instrument, Japan, with an accuracy of ±0.01 mm). The length, width, and thickness of coconuts are presented as major, minor, and intermediate axes, respectively (Figure 1A). The sphericity of coconuts was determined by the method practiced by Sasikumar et al. (2021) and Wodajo et al. (2021).

Determination of *C. nucifera* L. fruit mass, volume and component mass

Subtracting the initial volume (V_1) of displaced water by the final volume (V_2) determined by the water displacement method using a graduated bucket determined the volume (V) of the fruit as practiced by Alonge and Adetunji (2011). The mass of coconut (W_0), dehusked coconut (W_1), dehuskedcoconut without water (W_2), and coconut kernel mass (W_3) was measured using a balance (RADWAG PS 6000.R1 precision balance, 6000 g × 0.01 g). The mass (W_4) of coconut husk was determined by subtracting W_1 from W_0. The coconut water mass (W_5) was determined by subtracting W_2 from W_1 and the mass of coconut shell (W_6) was determined by subtracting W_3 from W_2.

Determination of *C. nucifera* L. component husk, shell, and kernel thickness

The coconut was sectioned along the longitudinal axis of the perianth. The thicknesses of the husk were determined from the vertical distances between the perianth and the shell (H_1), between the shell and the base of the fruit (H_2), the horizontal distance between the epicarp and the shell on the right side (H_3) and between the epicarp and the shell on the left side (H_4), using Kanon instrument (Japan), with an accuracy of ±0.01 mm (Figure 1B). The shell and kernel were then removed manually and thickness measurements were determined using a 0.02 µm (IPGRI, 1995; Pandiselvam et al., 2018).

Statistical analysis

Results are expressed as mean ± standard deviation (SD). Two-way analysis of variance (ANOVA) was performed on the complete data set to account for the main effects of cultivar and maturity on the morphophysical characteristics of mature coconut. Means with significant differences were separated using Student Newman Keuls post hoc test in the XLSTAT software, using a complete analysis and statistics add-in for Excel.

RESULTS

C. nucifera L. fruit dimensional parameters

The dimensional parameters of coconut in relation to maturity are summarized in Table 1. Moreover, the ANOVA results showed that cultivar and maturity factors had significant effect on all studied dimensional

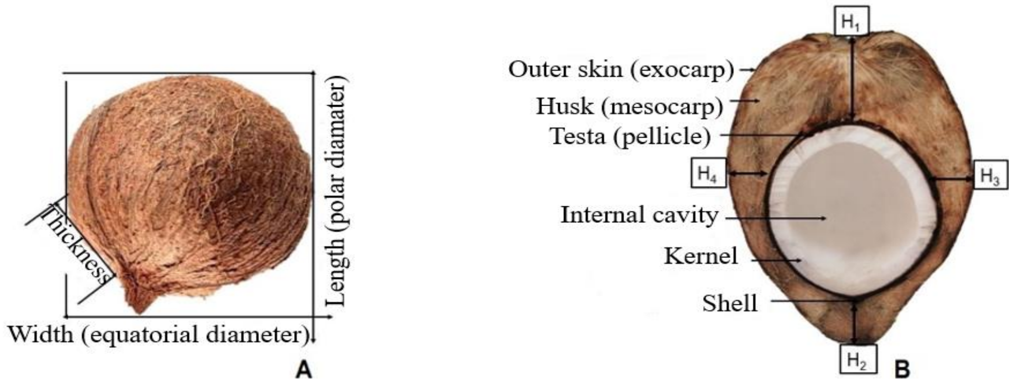

Figure 1. Dehusked coconut (A) and longitudinal cross section of mature coconut (B).

Table 1. Inter-cultivar differences in dimensional parameters of *Cocos nucifera* L fruit.

Cultivar	Month	Equatorial C. (cm)	Polar C. (cm)	Length (cm)	Width (cm)	Thickness (cm)	Sphericity (%)	Porosity (%)
	10	56.84 ± 3.67[a]	65.06 ± 4.87[b]	22.46 ± 1.75[c]	16.22 ± 1.16[c]	12.47 ± 1.16[c]	73.92 ± 5.61[b]	78.62 ± 3.15[d]
RIT[+]	11	58.59 ± 4.26[a]	67.71 ± 2.84[a]	24.05 ± 1.31[b]	17.70 ± 1.66[b]	13.95 ± 1.66[b]	75.41 ± 6.91[b]	80.28 ± 3.11[c]
	12	59.00 ± 2.44[a]	68.75 ± 3.97[a]	25.65 ± 2.50[a]	18.81 ± 1.46[a]	15.06 ± 1.46[a]	75.84 ± 6.66[b]	81.63 ± 2.48[b]
	10	41.70 ± 4.72[c]	51.86 ± 4.63[c]	17.57 ± 1.86[e]	11.51 ± 0.97[f]	8.76 ± 0.97[g]	72.72 ± 5.33[b]	89.57 ± 1.23[a]
WAT[+]	11	43.81 ± 3.15[cd]	51.81 ± 4.38[c]	17.88 ± 1.73[e]	12.56 ± 1.21[e]	9.81 ± 1.21[f]	73.13 ± 8.13[b]	90.46 ± 1.03[a]
	12	44.14 ± 3.59[cd]	52.28 ± 3.84[c]	18.06 ± 1.73[e]	13.11 ± 1.21[de]	10.36 ± 1.21[ef]	74.92 ± 6.98[b]	91.00 ± 1.47[a]
	10	43.87 ± 2.01[cd]	50.91 ± 3.95[c]	17.94 ± 1.27[e]	12.47 ± 1.11[de]	11.31 ± 0.52[de]	76.09 ± 5.03[a]	90.54 ± 2.45[a]
PB113[+]	11	44.36 ± 2.27[cd]	53.28 ± 3.08[c]	18.61 ± 1.03[e]	12.74 ± 1.84[de]	11.11 ± 0.58[de]	75.58 ± 4.25[a]	90.64 ± 2.94[a]
	12	45.34 ± 4.33[b]	54.53 ± 4.41[c]	19.71 ± 1.74[d]	12.94 ± 1.03[d]	11.98 ± 0.79[cd]	77.21 ± 6.07[a]	90.89 ± 1.73[a]
	10	42.94 ± 2.72[cd]	50.76 ± 2.57[c]	17.55 ± 0.72[e]	12.09 ± 0.95[e]	10.77 ± 0.36[e]	78.86 ± 5.13[a]	89.92 ± 2.55[a]
PB121[+]	11	43.60 ± 4.12[de]	51.46 ± 4.62[c]	17.72 ± 1.22[e]	13.69 ± 0.97[d]	11.01 ± 0.92[e]	79.46 ± 8.24[a]	90.03 ± 2.96[a]
	12	45.79 ± 1.78[b]	51.53 ± 4.48[c]	18.03 ± 1.84[e]	13.99 ± 0.97[d]	11.19 ± 0.79[de]	80.10 ± 7.33[a]	90.87 ± 2.62[a]
Statistical significance of the sources of variation (probability> F) from ANOVA								
Cultivar (C)		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Month (M)		<0.05	<0.05	<0.0001	<0.0001	<0.0001	<0.0001	NS
C×M		NS	NS	<0.05	<0.05	<0.0001	<0.0001	NS

WAT: West African Tall, RIT: Rennell Island Tall, PB: Port-Bouët, C.: circumference, NS: Not Statistically Significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different ($p < 0.05$).
Source: Authors.

Table 2. Inter-cultivar differences in fruit mass and volume of component (husk, water, kernel, and shell) mass of *Cocos nucifera* L fruit.

Cultivar	Month	Coc. Mass (g)	Coc. Volume (cm^3)	Husk Mass (g)	Water Mass (g)	Kernel Mass (g)	Shell Mass (g)
RIT+	10	2725.00 ± 352.82[a]	4383.33 ± 645.57[a]	1702.78 ± 220.61[a]	599.44 ± 73.04[a]	276.22 ± 37.58[cd]	157.89 ± 20.38[b]
	11	2584.44 ± 395.05[a]	4044.44 ± 637.29[b]	1410.94 ± 178.07[b]	403.78 ± 56.89[b]	504.17 ± 37.91[b]	175.67 ± 26.96[a]
	12	2333.17 ± 265.20[b]	3766.67 ± 508.75[c]	1353.33 ± 150.10[b]	335.94 ± 43.05[c]	713.17 ± 10.57[a]	177.94 ± 23.75[a]
WAT+	10	1537.83 ± 247.69[de]	2138.89 ± 252.37[d]	937.33 ± 133.32[c]	300.56 ± 44.54[d]	150.78 ± 18.71[f]	111.28 ± 10.83[e]
	11	1459.44 ± 185.70[ef]	1955.56 ± 212.05[d]	794.11 ± 118.34[d]	211.06 ± 18.31[f]	278.78 ± 30.22[cd]	139.50 ± 12.49[c]
	12	1335.28 ± 154.38[f]	1844.44 ± 301.41[d]	732.17 ± 77.37[d]	125.72 ± 14.77[g]	315.56 ± 27.33[c]	145.00 ± 17.09[c]
PB113+	10	1509.94 ± 160.88[de]	1866.67 ± 149.51[d]	769.72 ± 71.40[d]	280.94 ± 34.69[de]	175.33 ± 19.14[f]	116.67 ± 20.76[fg]
	11	1562.89 ± 113.15[de]	1919.44 ± 191.85[d]	775.33 ± 54.53[d]	213.11 ± 28.24[f]	234.78 ± 40.14[e]	129.50 ± 19.52[cde]
	12	1609.17 ± 127.06[cde]	1938.89 ± 183.64[d]	755.44 ± 75.71[d]	191.44 ± 21.97[f]	281.67 ± 49.55[cd]	138.89 ± 17.41[c]
PB121+	10	1690.22 ± 136.04[cd]	1872.22 ± 127.44[d]	718.00 ± 84.77[d]	260.83 ± 23.30[e]	164.28 ± 13.77[f]	118.89 ± 11.47[def]
	11	1715.50 ± 169.32[cd]	2044.44 ± 197.70[d]	734.50 ± 88.33[d]	200.39 ± 11.49[f]	244.39 ± 23.72[de]	132.33 ± 10.40[cd]
	12	1784.22 ± 124.69[c]	2066.67 ± 113.76[d]	708.50 ± 88.77[d]	188.22 ± 10.83[f]	299.28 ± 27.80[c]	139.11 ± 11.60[c]
Statistical significance of the sources of variation (probability> F) from ANOVA							
Cultivar (C)		<0.0001	<0.0001	<0.0001	<0.05	<0.05	<0.0001
Month (M)		<0.05	<0.05	<0.0001	<0.05	<0.05	<0.0001
C×M		<0.0001	<0.0001	<0.0001	<0.05	<0.05	NS

WAT: West African Tall, RIT: Rennell Island Tall, PB: Port-Bouët, Coc.: coconut, NS: Not Statistically Significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different ($p < 0.05$).
Source: Authors.

parameters ($p < 0.05$), except the porosity where maturity had no significant effects. The RIT+ coconut at 12-month point had maximum equatorial circumference (59.00 ± 2.44 cm), polar circumference (68.75 ± 3.97 cm), length (25.65 ± 2.50 cm), width (18.81 ± 1.46 cm) and fruit thickness (15.06 ± 1.46 cm). The hybrid PB121+ coconut was more spherical (80.10%) while the WAT+ was more porous (91.00 ± 1.47%). The results showed that the parental cultivar, RIT+, was significantly different ($p < 0.05$) to WAT+ and hybrids PB121+ and PB113+. There was no significant difference ($p > 0.05$) between hybrids PB113+ and PB121+. The results showed an increase in dimensional parameters during coconut maturation.

C. nucifera L. fruit mass, volume and component mass

Data on coconut and component mass with coconut volume as a function of maturity are tabulated in Table 2. The ANOVA results showed that cultivar and maturity factors had significant effects ($p < 0.05$) on coconut mass, coconut volume, and component mass. The RIT+ coconut fruits showed highest mass (2725.00 ± 352.82 g), volume (4383.33 ± 645.57 cm^3), water (599.44 ±73.04 g) and husk (1702.78 ± 220.61 g) at 12-month point. Maximal mass values of kernel (713.17 ± 10.57 g) and shell (177.94 ± 23.75 g) were at 12-month point for RIT+ coconut. The data showed that the RIT+ coconuts were significantly different ($p < 0.05$) to WAT+ and hybrids PB121+ and PB113+. The hybrids PB113+ and PB121+

Table 3. Inter-cultivar differences in the thickness of the components (husk, kernel, and shell) of *Cocos nucifera* L fruit.

Cultivar	Month	Kernel (mm)	Shell (mm)	H_1 (mm)	H_2 (mm)	H_3 (mm)	H_4 (mm)
	10	10.13 ± 1.19^{e}	4.49 ± 0.54^{de}	61.74 ± 8.33^{c}	40.30 ± 6.10^{a}	30.17 ± 2.99^{a}	22.56 ± 3.81^{abc}
RIT+	11	11.06 ± 1.45^{d}	5.02 ± 0.48^{c}	67.74 ± 11.82^{b}	39.37 ± 4.56^{a}	29.97 ± 3.43^{a}	23.78 ± 4.40^{abc}
	12	12.56 ± 1.63^{bc}	5.71 ± 0.69^{a}	72.93 ± 10.81^{a}	41.02 ± 4.41^{a}	30.50 ± 2.91^{a}	24.48 ± 4.11^{abc}
	10	9.77 ± 1.22^{e}	4.12 ± 0.43^{e}	50.57 ± 4.17^{c}	30.58 ± 2.59^{b}	20.58 ± 2.45^{c}	21.13 ± 2.40^{c}
WAT+	11	11.42 ± 0.86^{d}	4.58 ± 0.54^{d}	49.72 ± 5.40^{c}	30.13 ± 2.70^{b}	21.94 ± 1.77^{bc}	21.71 ± 2.42^{bc}
	12	13.43 ± 1.02^{a}	5.46 ± 0.67^{ab}	50.19 ± 5.48^{c}	30.32 ± 3.22^{b}	21.78 ± 3.87^{bc}	22.47 ± 2.48^{abc}
	10	7.79 ± 0.40^{f}	4.20 ± 0.32^{de}	42.17 ± 5.62^{b}	26.89 ± 3.41^{c}	22.43 ± 3.19^{bc}	21.08 ± 2.81^{c}
PB113+	11	10.01 ± 0.61^{e}	5.11 ± 0.19^{bc}	42.86 ± 4.04^{b}	25.52 ± 3.47^{c}	22.88 ± 2.90^{bc}	21.43 ± 2.02^{c}
	12	12.10 ± 0.55^{c}	5.69 ± 0.46^{a}	44.92 ± 4.91^{bc}	24.42 ± 3.09^{c}	23.78 ± 3.72^{b}	21.87 ± 3.23^{b}
	10	7.88 ± 0.50^{f}	4.52 ± 0.47^{de}	44.44 ± 3.51^{bc}	23.31 ± 3.65^{c}	22.25 ± 3.24^{bc}	25.25 ± 4.23^{a}
PB121+	11	11.06 ± 1.08^{d}	5.13 ± 0.39^{bc}	44.28 ± 6.86^{bc}	24.05 ± 3.40^{c}	23.07 ± 3.24^{bc}	25.44 ± 3.51^{a}
	12	12.95 ± 0.81^{ab}	5.83 ± 0.44^{a}	44.47 ± 5.66^{bc}	23.67 ± 3.73^{c}	23.32 ± 2.78^{bc}	25.83 ± 3.66^{a}
		Statistical significance of the sources of variation (probability> F) from ANOVA					
Cultivar (C)		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Month (M)		<0.0001	<0.0001	<0.05	NS	NS	NS
C×M		<0.0001	<0.05	<0.05	NS	NS	NS

WAT: West African Tall, RIT: Rennell Island Tall, PB: Port-Bouët, NS: Not Statistically Significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different ($p < 0.05$).
Source: Authors.

had similar mass and volume of nuts and components. The mass and volume of tall cultivar coconuts decreased during coconut maturation, while that of the hybrids increased.

C. nucifera L. fruit component thickness

The thickness of kernel, shell and husk (H_1, H_2, H_3, and H_4) are tabulated in Table 3. The maximum kernel thickness was for WAT+ (13.43 ± 1.02 mm). The hybrid PB121+ showed the highest shell thickness (5.83 ± 0.44 mm). The husk thicknesses H_1 (72.93 ± 10.81 mm), H_2 (41.02 ± 4.41 mm), and H_3 (30.50 ± 2.91 mm) were maximal in RIT+, while H_4 (25.25 ± 4.23 mm) was highest in the hybrid PB121+. All component thicknesses were highest at the 12-month point. The results showed that the parental cultivar's WAT+ kernel thickness significantly differed ($p < 0.05$) from RIT+ and hybrids PB121+ and PB113+. Moreover, the PB113+ and PB121+ hybrids showed comparable component thickness. The component thicknesses, kernel, shell, and husk increased during coconut maturation. The ANOVA results showed that cultivars had a significant effect ($p < 0.05$) on all component thickness metrics, while maturity had a significant effect ($p < 0.05$) only on kernel, shell and husk H_1 thickness

DISCUSSION

Morphophysical characteristics as criteria of coconut (*C nucifera* L.) classification determined in this study showed a broad variability among the coconut fruit cultivars. Coconuts show extraordinary morphological and physiological phenotypic diversity (COGENT, 2017; Rajesh et al., 2014). Indeed, it is well recognized generally that coconut fruit from tall palms are higher to other varieties. Previous observations on WAT and PB121$^+$ cultivars showed similar kernel mass (270.60 - 281.10 g) at 11 months (Assa et al., 2010). The same authors found lower kernel thickness for WAT (13 mm) and higher PB121$^+$ (12 mm) compared to our results. The increase in the mass of the coconut kernel during maturation was established in accordance with the findings of the authors (Assa et al., 2010). This could be due to the active proliferation of endosperm cells which, under the action of enzymes, gradually transform the liquid endosperm (coconut water) into solid endosperm (kernel). Coconut hybrids (Malayan yellow dwarf × Vanuatu tall) and PB121$^+$ showed inferior values of coconut mass (1160.41 g), coconut volume (963.24 cm^3), length (17.60 cm) and similar width (14.02 cm) compared to our results (Kodjo et al., 2015). The coconut fruits studied here have higher masses compared to those of hybrids resulting from tall × tall crosses (956.25 - 1148.75 g) and the masses of the tall parent fruits used for the cross (802 - 1200.83 g), as reported by the authors (Koffi et al., 2019). This difference in mass can be explained by the type of hybridization, as these hybrids are derived from the Tall × Tall cross, unlike our hybrids derived from the Dwarf × Tall cross. In India, the hybrid coconuts studied were larger in length (21.9 - 24.2 cm) and width (13.5 - 16.2 cm) compared to our studied hybrids (Sahoo et al., 2021). The Ghanaian coconut shell masses (250 - 340 g) studied were well above our value (Obeng et al., 2020). The average sphericity values of RIT$^+$, WAT$^+$, and PB113$^+$ coconuts are slightly similar. Sphericity values below 80% indicate that the fruits are less spherical and tend to have an elongated shape, unlike PB121 which has a spherical shape at 12 months. The coconut fruits studied by Alonge and Adetunji (2011) have the same sphericities as WAT$^+$ coconut, probably because they share the same West African origin. Hybrid fruits from Tall × Tall crosses had less husk mass (319 - 405 g), more shell mass (132.50 - 170.35 g), less water mass (141.25 - 168.33 g) and more kernel mass (368.75 - 426.25 g) than our hybrids (Koffi et al., 2019). This suggests that the type of cross affects coconut fruit component mass. The studied coconut cultivars, grown under the same environmental conditions, exhibited remarkably different dimensional parameters. The difference between our results and those of other authors could be explained by several factors, such as: the genetic diversity of the coconut, fruit maturity during the harvest period, cell divisions, the enlargement of the mesocarp and albumen during the final stages of fruit growth, the production area and, finally, environmental factors (COGENT, 2017; Souza et al., 2019; Wetzstein et al., 2011). Measurements of coconut morphological parameters allow the detection of hidden defects caused by insect damage during harvesting. They are also important in determining the shape and size of coconuts, which is an important criterion influencing the economic value of coconuts during their marketing, as well as providing important data for the design of harvesting tools and post-harvest handling, packaging, storage and transportation tools (Sasikumar et al., 2021; Sheikh et al., 2021; Wodajo et al., 2021). The determination of coconut edible fraction, such as kernel and internal liquid (coconut water), is also essential for coconut breeders who are looking for coconuts with an elevated edible fraction in breeding programs. This data is also needed by manufacturers of coconut kernel-based food products. Furthermore, the high mass of non-food coconut parts, such as coconut husk and shell, found in this study is important for promoting green energy and would provide an essential source of biomass that can be converted into high energy carriers, such as bioelectricity and biofuels for transport. The mean mass (kg) values for husk (0.80 - 1.12) and shell (0.25 - 0.34) found by Obeng et al. (2020) which are higher than our values for improved hybrids and WAT, indicate that 62 to 66% of the coconut fruit is likely to be generated as waste husk and shell, which can be considered as a useful bio-resource for sustainable energy production for poor communities.

Therefore, good management of coconut husk and shell can be considered as a renewable energy source with high potential in contributing to the energy needs of families living in coastal areas of developing countries. In addition, during the maturation period studied, the diameter, circumference, thickness, porosity, mass and volume of the fruit and the mass of the shell and kernel components increased, while the mass of the husk and coconut water decreased. This study shows that at the 12-month maturity stage, there is a large mass of kernels suitable for food use such as the production of vegetable, coconut kernel milk, virgin coconut oil, and coconut kernel flour. Moreover, the significant mass of water could be used as a beverage, as in the case of drinks based on coconut water from immature fruits.

Conclusion

The study shows a statistically significant effect ($p \leq 0.05$) of cultivar and maturity on coconut fruit characteristics. For all parameters, there were morphological variabilities between the fruits of the compared parents (RIT$^+$ and WAT$^+$) and between the parents and the hybrids (PB113$^+$ and PB121$^+$) fruits. For PB121$^+$ and PB113$^+$ hybrids, the characteristics were statistically similar ($p > 0.05$), except for polar circumference and fruit thickness ($p \leq 0.05$).

The results of fruit morphophysical characteristics of Dwarf × Tall-hybrid indicated that during the maturation period studied, the diameter, circumference, thickness, porosity, mass and volume of the fruit and the mass of the shell and kernel components increased, while the mass of the husk and coconut water decreased. This study shows that at the 12-month maturity stage, there is a large mass of kernels suitable for food use such as the production of vegetable, coconut kernel milk, virgin coconut oil, and coconut kernel flour. Moreover, the significant mass of water could be used as a beverage, as in the case of drinks based on coconut water from immature fruits. In addition to the potential food value of coconuts, the considerable mass of coconut husk and shell components can be converted as an alternative energy source to firewood in poor communities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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