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Engineering properties of five varieties of coconuts (*Cocos nucifera* L.) for efficient husk separation

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ABSTRACT

Coconut husk is used as a natural fiber, and it is constantly gaining economic importance including in organic farming. Yet, there are major knowledge gaps regarding the engineering properties of coconut to design efficient coconut dehusking and coir manufacturing process. A sample of 40 coconuts of each variety, namely Malayan Yellow Dwarf, Malayan Orange Dwarf, Kera Shankara, Chowghat Orange Dwarf, and Chowghat Green Dwarf, were divided into two groups (20 dry and 20 green coconuts), and different engineering properties were measured. It was observed that coconuts show an extensive diversity in size, density, husk thickness, husk weight, shell thickness, shell weight, and kernel thickness, depending on variety and maturity. The present investigation provides necessary information and the need for classifying the coconut fruits based on size/variety rather than weight to design superior coconut dehusking machine.

KEYWORDS

Coconut; bulk density; true density; husk thickness; shell thickness

关键词

椰子; 体积密度; 真密度; 果壳厚度; 壳体厚度

摘要

椰子壳被用作天然纤维，它在有机农业中不断获得经济上的重要性。然而，关于椰子的工程性质，设计有效的椰子脱壳和椰壳制造工艺存在重大的知识空白。将40个椰子品种Malayan Yellow Darf MYD）、MalayanOrange Dwarf（MOD）、KeraShankara（KS）、Chowghat Orange Dwarf（COD）和 Chowghat-Green-Dwarf (CGD) 的样品分为两组（20干和20绿椰子），并测定不同的工程性质。据观察，椰子在大小、密度、壳厚度、壳重、壳厚度、壳重和核厚度上表现出广泛的多样性，这取决于遗传多样性和成熟度。本次调查提供了必要的信息和需要分类的椰子果实的大小/品种，而不是重量设计优良椰子去壳机。

Introduction

Coconut palm (*Cocos nucifera* L.) is referred to as the “tree of life” because of its multitude of uses including food, fuel, and fiber. Its husk or, botanically, mesocarp is composed of fibers called coir. Endocarp (shell) is the hardest part of the nut enclosing a brown layer (testa) and kernel. The husk and shell become harder with maturity (Mizera, Hrabe, and Herák 2017). Coconut coir fiber is being used as ropes and binderless board production (van Dam et al. 2006), as shell for buttons, as charcoal, and in decorative carving. Activated carbon derived from the coconut husk is characterized

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with high percentage of micropores that help in removing odorous and volatile organic compounds. Coconut kernel or endosperm is used for production of oil and coconut milk-based products.

Until now, the traditional coconut varieties are commercially grown; however, varieties with high kernel weight are constantly gaining economic importance. The progress in breeding comes along with the modification of physical properties of both husk and kernel. Up-to-date knowledge of these properties is crucial for proper design and effective operation of agricultural processing machinery and equipment (Munder, Argyropoulos, and Muller 2017). Knowledge of morphology and the distribution of morphological characteristics is the basis for all post-harvest coconut processes (Santalla and Mascheroni 2003), such as dehusking, deshelling, testa removing, milk extraction, slicing, and drying. Dehusking of coconut is an important unit operation in coconut processing industries. Traditional tools used for dehusking of coconuts in India were chopping knife and crowbar. It is done by impaling the coconut on the sharp point with a strong-determined movement. The physical properties of the coconut fruits such as weight, size, shape, husk thickness, moisture content, and density are very important for designing ergonomically superior dehusking machine. Shape, shell thickness, and shell moisture content also affect the deshelling efficiency and capacity. Knowledge of testa thickness, sphericity, and static and dynamic friction is invaluable in the design of testa removing machine. Coconut kernel parameters such as weight, thickness, density, and moisture content play a major role in design of grating, pulverizing, slicing, and milk extraction machine. Hence, understanding of the physical properties of young and matured nuts is a prerequisite for efficient post-harvesting operations of coconuts.

Studies delineating the physical properties of young and matured coconuts were very few. Jarimopas, Ruttanadat, and Terdwongworakul (2009) focused on the description of the physical properties of coconut (var. Namhom) for developing an automatic trimming machine for young coconut fruit. This study reported that average, intact fruit was 180 mm in height and 160 mm in diameter. Alonge and Adetunji (2011) investigated the physical properties of 100 randomly selected Nigerian coconuts with varied husk characteristics (green when mature and brown when ripe). This investigation identified that major diameter of the coconut seed is between 17.36 and 19.70 cm.

Varghese, Francis, and Jacob (2016) tested the correlation of randomly selected 70 dry and green coconuts mainly grown in India. They followed a methodology very similar to Jarimopas, Ruttanadat, and Terdwongworakul (2009); nevertheless, variety-wise description of physical properties was not made. Even though the study explicitly stated classification of three size categories (large, medium, and small) and provided the ranges of coconut husk and shell dimensions, the effects of variety on dimensions and physical properties have not been made available yet.

The abovementioned studies of Jarimopas, Ruttanadat, and Terdwongworakul (2009), Alonge and Adetunji (2011), and Varghese, Francis, and Jacob (2016) mainly focused on the effect of size and husk color on physical properties of coconuts. They established different size classes based on visual observation but did not relate these size classes to physical properties or dehusking efficiency. Coconuts show a wide diversity in size, shape, weight, and color, depending on genetic variety and maturity of the nut at harvest (Ohler 1999). A method of classification of varieties based on these physical properties is imperative. Furthermore, interrelationship of these properties with dehusking or deshelling efficiency requires to be investigated.

Dehusking is an important unit operation in coir manufacturing that requires to be carried out with minimum effort. For designing an innovative, ergonomically better coconut dehusking and fiber extraction machine, it is vital to identify the engineering properties of coconut. Therefore, the aim of this study was to establish a classification based on cultivar and nature of husk and to measure how the physical properties of coconuts assigned to these classes would differ.

Raw materials

A sample of 40 coconuts from each variety, namely Malayan Yellow Dwarf (MYD), Malayan Orange Dwarf (MOD), Kera Shankara (KS), Chowghat Orange Dwarf (COD), and Chowghat Green Dwarf

(CGD), were taken from the Farm Section, ICAR – Central Plantation Crops Research Institute, Kasaragod, Kerala, India, and graded on the basis of maturity (green [12 months maturity] and dried [13 months maturity] coconuts). The tag was placed after fruit setting to identify the maturity of coconut. The green and dry coconuts were harvested from the same tree at the same time from different bunch having different maturity.

Weight

Samples of 20 dry coconuts and 20 green coconuts from each variety were selected for determining the weight. The weight of the coconut at each processing stage, namely whole coconut, nut after dehusking, nut after deshelling, and nut after removing the testa, was measured using an electronic weighing balance having sensitivity of 0.5 g (M/s. Atlas Weighing, maximum capacity 3 kg, minimum capacity 10 g).

Diameter and height

The diameter of the intact coconut at each processing stage was determined by measuring the circumference of the nut using a measuring tape. The tape was wrapped along the circumference of the coconut, and the diameter was calculated by using the equation:

$$d = \frac{C}{\pi}$$

where
d = diameter of the nut, mm
C = circumference of the nut, mm
The height of the coconut was measured using tape.

Bulk density

The bulk density (kg.m^{-3}) was determined from the coconut mass (kg) and the occupied volume (m^{-3}) including pore space. The volume of the container used for determination of bulk density was 0.0161 m^3.

True density

The true density ρ_t (kg.m^{-3}) was calculated by the ratio of mass of coconut, as the density of toluene and mass of toluene displaced by the coconut (Mohensin 1986). Toluene was used in this study in order to avoid absorption of water on the surface of coconuts during experiment.

Porosity

Porosity can be calculated as a function of true (ρ_t) and bulk density (ρ_b) using the fallowing relationship (Mohensin 1986):

$$\text{Porosity}(\%) = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100$$

Husk thickness

The principal dimensions such as husk thickness (vertical distance between the perianth and the shell (V_1) – pedicel end, vertical distance between the fruit base and the shell (V_2) – apex, horizontal distance between the shell and the fruit skin on the left side (H_1), and horizontal distance between the shell and fruit skin on the right side (H_2)) were measured with a digital vernier caliper with an accuracy of ±0.01 mm.

Husk weight

The total husk weight was measured using an electronic balance having a sensitivity of 0.5 g.

Moisture content

The moisture content of coconut husk was measured from samples of 30 g by oven-drying at 106 ± 1°C for 24 h and expressed in % w.b. (Varghese, Francis, and Jacob 2016).

Shell parameters

The deshelled coconut obtained would be intact in shape with the kernel and testa as outer skin.

Shell weight

A coconut deshelling machine detaches the hard coconut shell from the dehusked coconut by using a rotating disc cutter. The detached shell pieces are collected, and the total weight was measured in an electronic weighing balance having an accuracy of 0.01 g and maximum capacity of 200 g (M/s. KERN & Sohn GmbH, Model-EMB 200-2, Balingen, Germany). Hence, it is not suitable to measure the weight of whole coconut that exceeds 200 g.

Shell thickness

The thickness of the coconut shell varies with variety and stage of maturity. After deshelling, the detached shell pieces are collected and the thickness of each piece is measured using a digital vernier caliper of least count 0.01 mm. The mean value was recorded.

Testa parameters

A thin brown-colored layer adhering on the outer side of the kernel can be removed by paring using a testa removing machine.

Testa weight

The scattered testa in the form of powder is collected and weighed in an electronic weighing balance of resolution 0.01 g.

Testa thickness

As the coconut matures, the thickness of testa increases and gives a brown color to the bottom layer of the kernel. Testa thickness can be calculated by subtracting the white kernel thickness from the total thickness (kernel + testa).

Kernel weight and thickness

The kernel obtained after the testa removing process was weighed, and the average thickness was measured using the electronic weighing balance having a sensitivity of 0.01 g and digital vernier caliper of least count 0.01 mm, respectively.

Data analysis

All data analyses including mean and standard deviation were conducted using Microsoft Excel, 2003. ANOVA was performed using AGRES (7.01) software. The effect of variety, nature of husk, and their interactions on 19 engineering properties of coconuts were compared at $P < 0.01$ and $P < 0.05$ levels. Coefficient of variations (CV) was also calculated using AGRES software and expressed as percentages.

Results and discussion

The weight, diameter, and height of intact coconuts including green and dry coconut of five varieties were determined and summarized in Table 1. In comparison with the randomly selected green and dry Indian coconuts analyzed by Varghese, Francis, and Jacob (2016), the nut diameter was low for the five varieties; however, no significant change in the weight of nuts was found. It was observed that diameter (156.7 ± 4.3 mm) and height (206.6 ± 12.2 mm) were highest for MOD (green) variety. However, diameter was lowest (109.8 ± 2.8 mm) for CGD (dry) variety and least height (145.9 ± 14.1 mm) was seen in MYD (dry) variety. The Nigerian coconuts have slightly higher diameter (184.93 mm) (Alonge and Adetunji 2011) than MOD. Alonge and Adetunji (2011) pointed out that intact coconut tends to have the shape of a sphere (0.834) with a major diameter significantly higher than the intermediate diameter, but intermediate diameter and the minor diameter have the same mean value. Commercially available coconut dehusking machine has two spike tooth rollers to separate the husk from coconuts. Clearance between the coconut dehusking rollers affects the capacity and efficiency of the machine. Hence, the determination of diameter/circumference of coconuts plays a vital role in deciding the clearance. If coconut size is less than the clearance between the rollers, then sufficient shearing and impact force are not exerted on the surface of the coconut husk. Thus, it is likely that coconuts rotate in between the rollers, leading to no dehusking or partial dehusking that affecting the capacity and efficiency of the dehusking machine. Hence, the clearance has to be adjusted based on the cultivar and maturity stage. Further, incorporation of a spring mechanism in dehusking operation might provide the automatic adjustment of clearance between dehusking rollers based on the size of the coconuts.

The density and porosity of intact coconut are given in Table 2. Remarkably, high bulk density was observed in the COD (green) – the dwarf variety. The other extreme is found in the most voluminous variety MOD (dry). These findings reveal that nuts display relatively less density than what was reported by Alonge and Adetunji (2011) who studied Nigerian coconuts. It was also observed that true density was highest for COD (green) variety and porosity was high for MOD (dry) variety. The lowest true density and porosity were seen with CGD (dry) and KS (dry), respectively. True density implies mass of coconut per unit volume excluding the pore space. Thus, high-density coconuts liberate more weight per unit volume on the dehusking roller, causing more shearing

Table 1. Diameter and height of five varieties of coconuts.

Sl. No.	Variety	Nature of husk	Average weight (kg)	Average diameter (mm)	Average height (mm)
1	MYD	Green	0.74 ± 0.11	152.6 ± 5.1	173.8 ± 8.0
2	MYD	Dry	0.65 ± 0.04	132.5 ± 2.1	145.9 ± 14.1
3	MOD	Green	1.02 ± 0.27	156.7 ± 4.3	206.6 ± 12.2
4	MOD	Dry	0.83 ± 0.16	152.3 ± 7.0	190.6 ± 8.9
5	COD	Green	1.01 ± 0.06	145.6 ± 3.2	170.3 ± 6.4
6	COD	Dry	0.86 ± 0.08	142.8 ± 4.8	167.7 ± 5.2
7	CGD	Green	0.48 ± 0.14	113.6 ± 3.2	197.9 ± 6.1
8	CGD	Dry	0.30 ± 0.01	109.8 ± 2.8	190.4 ± 4.1
9	KS	Green	0.81 ± 0.13	133.2 ± 2.7	198.4 ± 9.2
10	KS	Dry	0.56 ± 0.11	129.7 ± 4.6	200.1 ± 10.2

Table 2. The densities and porosity of five varieties of coconuts.

Sl. No.	Variety	Nature of husk	Bulk density (kg.m^{-3})	True density (kg.m^{-3})	Porosity (%)
1	MYD	Green	340.37 ± 78.49	947.6 ± 157.5	60.5 ± 7.9
2	MYD	Dry	303.11 ± 62.14	639.6 ± 81.2	51.9 ± 6.7
3	MOD	Green	324.22 ± 109.18	584.0 ± 182	39.8 ± 19.3
4	MOD	Dry	222.58 ± 62.66	569.4 ± 53.3	62.6 ± 4.6
5	COD	Green	375.77 ± 114.84	974.6 ± 137.9	60.8 ± 5.2
6	COD	Dry	348.83 ± 106.28	726.4 ± 126.3	52.2 ± 7.8
7	CGD	Green	273.42 ± 62.94	393.3 ± 56.2	44.6 ± 13.4
8	CGD	Dry	234.78 ± 81.16	327.9 ± 68.4	38.4 ± 12.6
9	KS	Green	335.13 ± 98.72	643.02 ± 112.6	47.1 ± 14.9
10	KS	Dry	323.33 ± 49.23	452.30 ± 56.76	27.6 ± 9.1

Table 3. Husk properties of five varieties of coconuts.

Sl. No.	Variety name	Nature of husk	V_1 (mm)	V_2 (mm)	H_1 (mm)	H_2 (mm)	Moisture content (%)	Husk weight (kg)
1	MYD	Green	46.31 ± 7.44	25.57 ± 4.3	14.39 ± 2.73	14.44 ± 2.05	55.71	0.264 ± 0.02
2	MYD	Dry	23.5 ± 6.91	20.85 ± 2.61	13.58 ± 3.27	13.02 ± 4.78	34.12	0.178 ± 0.01
3	MOD	Green	35.39 ± 1.14	27.3 ± 4.9	22.01 ± 3.15	23.76 ± 5.75	63.26	0.428 ± 0.04
4	MOD	Dry	30.88 ± 3.81	24.47 ± 5.67	18.30 ± 3.2	16.49 ± 3.15	35.58	0.218 ± 0.01
5	COD	Green	20.76 ± 5.99	24.36 ± 3.38	16.67 ± 3.85	16.31 ± 1.74	65.64	0.372 ± 0.01
6	COD	Dry	17.43 ± 3.26	19.24 ± 1.29	14.32 ± 2.57	13.90 ± 2.12	26.38	0.139 ± 0.02
7	CGD	Green	66.28 ± 4.72	38.49 ± 4.36	22.18 ± 3.84	18.83 ± 2.93	53.67	0.397 ± 0.03
8	CGD	Dry	57.42 ± 9.85	32.91 ± 7.86	17.7 ± 3.84	14.52 ± 4.04	24.04	0.156 ± 0.02
9	KS	Green	60.63 ± 8.62	34.14 ± 4.66	18.64 ± 3.4	17.84 ± 3.71	60.18	0.358 ± 0.03
10	KS	Dry	54.86 ± 6.91	27.80 ± 3.8	18.05 ± 2.22	18.18 ± 1.27	28.41	0.182 ± 0.03

V_1: vertical distance between the perianth and the shell; V_2: vertical distance between the shell and the fruit base; H_1: horizontal distance between the fruit skin and the shell on left side; H_2: horizontal distance between the fruit skin and the shell on the right side.

action which in turn leads to complete and quick removal of husk. Also, the densities of coconuts are vital parameters required for the design of storage structures including godowns.

The husk properties of five varieties of coconuts are described in Table 3. The vertical distance between the perianth and the shell (V_1) and vertical distance between the fruit base and the shell (V_2) were highest for CGD (green) variety, whereas lowest was observed in COD (dry) variety. The highest thickness was noticed in top orientation (vertical distance between the stem and the shell), followed by bottom orientation (vertical distance between the fruit base and the shell) and left orientation. Intact coconuts cracked more easily in transverse orientation, while top and bottom sides of coconut provide more cushioning effect during harvesting. The results are in accordance with the findings of Jarimopas, Ruttanadat, and Terdwongworakul (2009) who studied Namhom young coconut. The magnitude of husk thickness in horizontal orientation is similar to the findings of Varghese, Francis, and Jacob (2016). The size of the spike tooth on the surface of dehusking roller is decided by the thickness of the husk. More husk thickness ensures less efficiency and capacity, whereas less husk thickness results in damage of coconuts.

The moisture content of COD (green) husk was significantly higher than that of other dry coconuts. The moisture content of dry husk found in this study was definitely in the higher range of what was reported by Varghese, Francis, and Jacob (2016).The differential forces including impact, shearing and/or friction applied on whole green coconuts leads to ease in dehusking than dry coconuts. This could be attributed to the moisture content and fiber density of husk. Lomelí-Ramírez et al. (2018) reported that fiber of the green coconuts has lower tensile properties compared to the brown fibers. Thus, the green coconuts may require less force for dehusking.

Shell and testa properties of five varieties of coconuts showed that the shell thickness was highest for COD (green) variety and lowest for MOD (dry) (Table 4). Mizera, Hrabe, and Herák (2017) reported that the coconut shell is thicker and harder in latitudinal direction than longitudinal

Table 4. Shell and testa properties of five varieties of coconuts.

SL. No.	Variety	Nature of husk	Shell thickness (mm)	Shell weight (g)	Testa thickness (mm)	Testa weight (g)
1	MYD	Green	3.74 ± 0.19	98.8 ± 12	1.87 ± 0.40	15.6 ± 2.6
2	MYD	Dry	2.76 ± 0.76	70.6 ± 8	0.51 ± 0.18	9.48 ± 2.5
3	MOD	Green	3.42 ± 0.47	132 ± 13	0.76 ± 0.44	23.2 ± 2.2
4	MOD	Dry	2.32 ± 0.68	115 ± 19	0.66 ± 0.14	17.4 ± 1.6
5	COD	Green	3.98 ± 0.35	161 ± 13	0.97 ± 0.72	19.35 ± 5.3
6	COD	Dry	2.74 ± 0.26	134 ± 11	0.73 ± 0.37	16.53 ± 2.7
7	CGD	Green	3.06 ± 0.24	49 ± 3.6	0.83 ± 0.52	6.24 ± 3.4
8	CGD	Dry	2.44 ± 0.21	36 ± 4.5	0.69 ± 0.23	3.32 ± 1.2
9	KS	Green	3.83 ± 0.27	108 ± 16	1.97 ± 0.89	17.1 ± 1.4
10	KS	Dry	3.36 ± 0.43	97.2 ± 16	1.85 ± 0.32	15.2 ± 5.0

Table 5. Kernel properties of five varieties of coconuts.

SL. No.	Variety name	Nature of husk	Volume of coconut water collected (mL)	White kernel thickness (mm)	White kernel weight (g)
1	MYD	Green	180 ± 84	10.79 ± 0.63	274.47 ± 36
2	MYD	Dry	176 ± 43	9.93 ± 0.51	200.25 ± 22
3	MOD	Green	236 ± 106	12.57 ± 0.38	316.32 ± 28
4	MOD	Dry	186 ± 94	12.19 ± 0.61	292.68 ± 47
5	COD	Green	169 ± 63	9.84 ± 1.26	250.84 ± 30
6	COD	Dry	151 ± 44	7.98 ± 0.58	224.17 ± 24
7	CGD	Green	118 ± 26	11.09 ± 0.31	104.87 ± 21
8	CGD	Dry	86 ± 29	10.16 ± 0.36	96.42 ± 19
9	KS	Green	59 ± 32	11.34 ± 0.47	228.13 ± 26
10	KS	Dry	40.5 ± 23	10.72 ± 0.53	198.86 ± 33

direction. Therefore, it is suggested that feeding of the shell in the grating machine should be in the latitudinal direction for ease of coconut cracking. Highest and lowest shell weights were observed in COD (green) and CGD (dry), respectively. Thus, it can be inferred that a heavier intact coconut shows a high shell weight. Testa thickness was highest for KS (green) and lowest for MYD (dry) varieties, whereas MOD (green) variety has the highest testa weight and CGD (dry) variety has the lowest testa weight. Commercially available coconut deshelling machine works on the principle of impact and friction. Coconut shell thickness influences the design of the deshelling rotor. The size of the deshelling rotor tip and speed depends on the shell thickness. If the shell thickness is very less, breakage of the whole coconuts may be happen.

Analyses of volume of coconut water collected and kernel of five varieties of coconuts are presented in Table 5. The volume of water collected, kernel thickness, and kernel weight were significantly higher for MOD (green) variety. The lowest volume of water collected, white kernel thickness, and white kernel weight were for KS (dry), COD (dry), and CGD (dry) varieties, respectively. Quantity of coconut kernel increases and the volume of water decreases with maturity (Jayalekshmy et al. 1986). The percentage of fatty acids (medium) increases with maturity (Appaiah et al. 2015). Coconut kernel contains 50–60% of fat (Bhatnagar et al. 2009). More kernel weight of MOD variety may yield more oil than that of other four varieties. In CGD (dry), a decrease in the kernel weight is generally expected to result in increased husk thickness and husk weight share and, thus, lower the oil content.

Table 6 depicts the ANOVA of effect of variety and nature of husk on different engineering properties of coconuts. The *F*-values of 17 dependent parameters versus variety were significant at 1% level ($P < 0.01$), and bulk density and moisture content were significant at 5% ($P < 0.05$), as presented in Table 6. It was observed that variety has to be considered as a significant ($P < 0.01$) variable for the development of efficient coconut processing machines. Nature of husk has significant ($P < 0.01$) effect on the properties of weight, diameter, true density, porosity, husk weight, shell thickness, and white kernel thickness. From Table 6, it is understood that the interaction between variety and nature of husk has more significant effect on size (diameter and height)-based

Table 6. Two-factors ANOVA for different engineering properties of coconuts.

	df	Weight	Diameter	Height	Bulk density	True density	Porosity	V_1	V_2	H_1	H_2
V	4	16.62**	87.28**	26.87**	3.08*	12.87**	11.02**	68.69**	16.39**	6.49**	4.83**
N	1	17.71**	10.59**	0.01 NS	3.82 NS	14.48**	13.30**	3.16NS	0.56NS	0.58NS	0.00NS
VN	4	3.02*	32.53**	6.37**	0.46 NS	1.24 NS	5.41**	6.43**	2.55NS	1.81NS	1.88NS
Error	18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	29	4.11	17.53	5.23	1.27	3.09	3.51	11.11	3.31	2.28	1.58
CV (%)	-	23.46	3.08	4.38	19.79	17.97	13.18	13.71	12.85	16.71	16.46

	df	Husk weight	Shell thickness	Shell weight	Testa thickness	Testa weight	Volume of coconut water collected	White kernel thickness	White kernel weight	Moisture content
V	4	24.63**	10.76**	77.31**	4.27**	36.80**	28.58**	33.64**	37.12**	3.55*
N	1	699.14**	21.90**	4.92*	0.44NS	0.28NS	7.15*	13.10**	0.22NS	260.08*
VN	4	18.22**	9.92**	7.00**	1.56NS	7.14**	11.92**	0.24 NS	4.64**	2.73 NS
Error	18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	29	30.69	4.27	12.50	1.47	6.80	7.12	5.76	6.50	10.48
CV (%)	-	7.72	8.66	13.50	28.78	17.17	22.75	6.05	15.49	10.42

**P is significant at 0.01 level, *P is significant at 0.05 level.
NS: nonsignificant; V: variety; N: nature of husk; V_1: vertical distance between the perianth and the shell; V_2: vertical distance between the shell and the fruit base; H_1: horizontal distance between the fruit skin and the shell on left side; H_2: horizontal distance between the fruit skin and the shell on the right side.

classification ($P < 0.01$) compared to weight-based classification ($P < 0.05$). CV values of 19 engineering properties of coconut ranged from 3.08% (for diameter) to 28.78% (for testa thickness). The lower CV values signify more precise estimate. However, our approach is size-based classification rather than weight based. Hence, the CV values obtained for diameter (3.08%) and height (4.38%) are within the acceptable range compared to weight (23.46%). Moreover, several researchers including Ozgen, Serçe, and Kaya (2009) have reported wide CV values (30% and 214%) for the measurements of mulberry fruit color characteristics.

Conclusions

The five varieties of coconuts (MYD, MOD, KS, CGD, and COD) investigated in this study clearly added different dimensions or variability to the physical properties from what was found in the literature for Nigerian and Namhom varieties. Especially, the coconut husk was thinner and the kernel was thicker than that reported in other studies. Physical properties shall be further explored considering more number of varieties to assess whether a general alteration of physical properties occurred. If our hypothesis-that natural variability in the physical properties of the coconut is true it warrants performance analysis of current coconut processing equipment, namely dehusking, deshelling, and testa removing machines, in order to evaluate their universal applicability or the need for adoption. A superiority of size-/variety-based classification than weight-based one is proposed for efficient dehusking and deshelling; however, a direct comparison of both the methods and development of size-based grader for coconut could be a future line of work.

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