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Correlation and principal component analysis of physical properties of tender coconut (*Cocos nucifera* L.) in relation to the development of trimming machine

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Abstract

The physical properties such as tender coconut size, weight, husk thickness, and husk moisture tender content play a vital role in the development of an efficient and ergonomic trimming machine. The important physical properties of tender coconuts of cultivars namely Kulasekaran Green Dwarf (KGD), Andaman Giant Tall (AGT), Ganga Bondam (GB), Malayan Orange Dwarf (MOD), and Chowghat Orange Dwarf (COD) were determined. The important properties including weight, diameter, height, husk thickness, husk moisture content, shell diameter, shell height, and shell thickness were high for nuts of AGT and low for COD nuts. The average bulk density, true density, and porosity of AGT were 332.47 kg·m^{-3}, 1,196.67 kg·m^{-3}, and 72.21%, respectively. The husk weight and volume of water of AGT were 87.77% and 12.39% high, respectively, compared with COD. In the correlation study, the coconut weight correlated positively (r = 0.791) with the diameter and vertical distance between the shell and the fruit base (r = 0.813). The principal component analysis suggested that the cultivars GB, KGD, and MOD have similar physical properties to COD and AGT. Thus, the present investigation documents crucial basic information to design an efficient and superior tender coconut trimming machine.

Practical Applications

Transportation of intact tender coconut is difficult, and thus a manually trimmed tender coconut shape of a cylindrical side with a conical top has gained more importance among the domestic and international consumers owing to its fresh and natural taste and attractive shape. The high transportation cost of tender coconut, shortage of manpower to trim the tender coconut, and the high production cost to make the shape of the cylindrical side with a conical top have created an urgent need for the development of trimming machines. The physical properties of tender coconut and its correlation studies are very important for the designing and development of a trimming machine.

1 | INTRODUCTION

Tender coconut is a nutritious and popular export fruit from India to distant countries (United Arab Emirates, United States, Canada, Australia, Japan, Belgium, and France). Indian coconut water market has been pegged at $9.2 million in 2017 and is projected to grow $25.4 million by 2023 because of the increased health awareness among the consumers (Techsci Research, 2018). The tender coconut comprise an exocarp (skin), mesocarp (composed of a fibrous husk), and an endocarp (shell) that encloses the kernel (flesh) and juice (Figure 1). The coconut husk and shell provide protection to the juice and flesh inside (Harach & Jarimopas, 1995). The tender coconut (immature fruit) juice is sour to sweet depending on the cultivars and flesh is soft like a jelly, while the mature fruit contains too sweet juice and a hard kernel. The advancement in breeding comes along with the modification of important morphological and physical properties of tender coconut. The nuts of Chowghat Orange Dwarf (COD) and Malayan Orange Dwarf (MOD) cultivars are commonly preferred by consumers because of its sweet aromatic juice and flesh.

The tender coconut cultivars with a high volume of sweet juice and soft flesh are constantly gaining economic importance. The transportation cost of a tender coconut is high because of its husk weight. Thus, the husk of tender coconut fruit has to be trimmed to a desired shape (e.g., hexagonal shape) by removing most of the outer husk, treated with an antibrowning solution, and then shrink-wrapped and packed in corrugated boxes for export. Trimming of a tender coconut is done manually, a process that requires a skilled worker, and is time consuming and extremely hazardous. Currently, workers are chopping and/or shearing the husk of the young fruit with a sharp knife. The inner husk is then shaped to form a conical top, a cylindrical body, and a flat base in order to make a pentagonal contour (Jarimopas & Ruttanadat, 2007).

Knowledge of physical characteristics of coconut drupe is crucial for proper design and effective operation of tender coconut processing machinery and equipment (Pandiselvam et al., 2018). Similarly, knowledge of morphological properties forms the basis for the development of postharvest coconut processing machines (Santalla & Mascheroni, 2003). The coconut shell thickness and its hardness are invaluable properties required while designing the deshelling machine. Knowledge of the shape of coconut, testa thickness, moisture content, and dynamic friction of testa is required for the development of testa removing machine for coconut. Coconut kernel parameters including thickness, weight, moisture content, and density play a major role in the design of pulverizing, grating, and slicing machine (Pandiselvam et al., 2018).

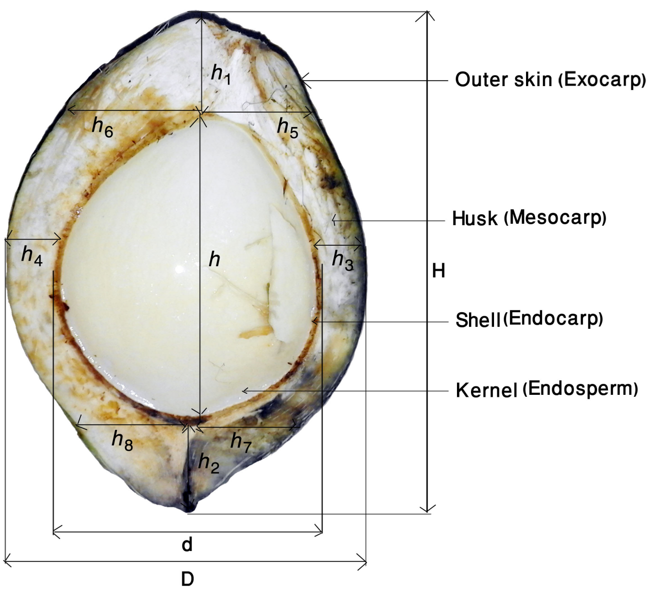

FIGURE 1 Cross-sectional view of tender coconut (cultivar GB)

Few researchers have investigated the engineering properties of matured coconuts for the development of automatic sorting and dehusking machine. For instance, Terdwongworakul, Chaiyapong, Jarimopasa, and Meeklangsaen (2009) correlated the physical, physiological, acoustic, and mechanical properties of *Nahm Wahn* coconuts with their maturity levels and developed the partial least square regression model to design the nondestructive sorting machine based on resonance frequency. A linear regression model developed for husk rupture force, shell firmness, shell rupture force, and wet flesh weight has a better predicting ability of maturity. The relationship between flesh thickness and maturity of coconut was reported by Gatchalian, De Leon, and Yano (1994). Jarimopas, Ruttanadat, and Terdwongworakul (2009) attempted to describe the physical characteristics of young Thailand coconut (var. *Namhom*). This study stated that the mean diameter and height of the intact tender coconut were 153.1 mm and 175.2 mm, respectively. Alonge and Adetunji (2011) studied the physical and frictional properties of Nigerian coconut seed in relation to dehusking operation. This research identified that mean diameter, volume, and coefficient of friction (tested on wood) of the coconut is 18.49 cm, 675 cm^3, and 0.449, respectively. Recently, Pandiselvam et al. (2018) investigated the engineering properties of five cultivars of matured Indian coconuts for the development of efficient husk separator. Matured coconuts showed an extensive diversity in husk thickness, density, shell thickness, and kernel thickness. Hence, the authors concluded that cultivar and/or size-based classification are better than categorization based on weight for efficient dehusking operation.

Thus, the abovementioned studies, except that of Jarimopas et al. (2009), have mainly focused on the physical properties of matured coconuts. Nonetheless, Jarimopas et al. (2009) have described the properties of a Thai cultivar. In order to design an ergonomically superior trimming machine, the engineering properties (size, shape, weight, husk thickness, moisture content, and density) of different cultivars of tender coconut are very imperative. Furthermore, the interrelationship of physical properties with the development of a trimming machine requires to be investigated. Hence, the present research aims to investigate the physical properties of five tender coconut cultivars (KGD, AGT, GB, MOD, and COD) and its correlation.

2 | MATERIALS AND METHODS

2.1 | Raw materials

Sample of 50 young tender coconuts (6 months maturity or 180th day after pollination) from each cultivar namely KGD, AGT, GB, MOD, and

COD (Figure 2) were harvested from the orchard in ICAR-Central Plantation Crops Research Institute (ICAR-CPCRI), Kasaragod, India. The maturity of the coconuts was ascertained based on the information recorded in the label or tag placed during pollination. Freshly harvested tender coconuts of uniform size were transported to the Agro Processing Complex, ICAR-CPCRI, Kasaragod, for the measurement of different physical properties.

2.2 | Weight

The electronic weighing balance (M/s. Atlas Weighing, sensitivity—0.5 g) was used to measure the intact tender coconut weight. The tender coconut husk was removed manually using a traditional tool, a crowbar placed vertically by driving into the ground. The weight of husk was measured using a weighing balance (sensitivity—0.5 g).

2.3 | Diameter and height

The circumference of the middle section of intact tender coconut was measured using a measuring tape. The sensitivity of measuring tape was 1 mm. The shape of the tender coconut was ellipsoid/prolate spheroid, and hence, only the horizontal circumference of the nut was measured. The diameter of the tender coconut was calculated using Equation (1):

$$d = \frac{C}{\pi}, \tag{1}$$

where d is the tender coconut diameter (mm) and C is the tender coconut circumference (mm).

The young coconut height, shell diameter, and shell height were measured using a digital Vernier caliper with an accuracy of ±0.01 mm.

2.4 | Densities and porosity

The densities such as bulk density (ρ_b) and true density (ρ_t) of tender coconut were determined by following the procedure of Pandiselvam et al. (2018). The bulk density ρ_b (kg·m^{-3}) of tender coconut was determined from the coconut mass (kg) and the occupied volume (m^{-3}) including pore space. The volume of the cylindrical container used for the determination of bulk density was 0.0342 m^3.

The true density ρ_t (kg·m^{-3}) was calculated by the ratio of the mass of coconut, as the density of toluene and mass of toluene was displaced by the coconut (Mohsenin, 1986). For each replication, four tender coconuts were immersed in toluene. Toluene was used in this study in order to avoid absorption on the surface of tender coconuts during the experiment.

Porosity was calculated using the relationship between bulk density (ρ_b) and true density (ρ_t) (Mohsenin, 1986):

$$\text{Porosity}\,(\%) = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100. \tag{2}$$

2.5 | Thickness

The intact coconuts were cross-sectioned along the axis of perianth using a tender coconut cutter developed by ICAR-CPCRI, Kasaragod, India (Manikantan, Pandiselvam, Beegum, & Mathew, 2018). Following this, the principal dimensions of husk thickness (h_1, h_2, h_3, h_4, h_5, h_6, h_7, and h_8), shell thickness, and flesh thickness (as shown in Figure 1) were measured by using a digital Vernier caliper with a sensitivity of ±0.01 mm. Here, h_1 is the vertical distance between the perianth and the shell, h_2 is the vertical distance between the shell and the fruit base, h_3 is the horizontal distance between the fruit skin and the shell on the right side, h_4 is the horizontal distance between the fruit skin and the shell on the left side, h_5 is the shell top right husk thickness, h_6 is the shell top left husk thickness, h_7 is shell bottom right husk thickness, and h_8 is the shell bottom left husk thickness (Figure 1).

2.6 | Moisture content

The moisture content of tender coconut husk was determined by using the oven method described by Varghese, Francis, and Jacob

FIGURE 2 Five cultivars of tender coconuts used in this study

(2016). Briefly, 30 g husk was dried in the oven at 106 ± 1°C for 24 hr and the moisture content was expressed in % w.b.

2.7 | Volume of water

The tender coconut water was extracted using the tender coconut punching tool developed by ICAR-CPCRI, Kasaragod, India (Manikantan et al., 2018). The volume of tender coconut water was measured using a measuring cylinder.

2.8 | Statistical analysis

The data were initially subjected to analysis of variance (ANOVA) using the AGRES (7.01) software. The effect of five different cultivars on the engineering properties of tender coconut was compared at the significance levels of $p < .05$ and $p < .01$. Critical difference (CD) and coefficient of variations (CV) were also calculated using the AGRES software.

The statistical software R was used for further data analysis and graphical representation (Kabacoff, 2011). The R-function "cor()" was used for conducting Pearson's correlation analysis of the properties that were found to be significant based on the ANOVA analysis. Besides the correlation analysis, principal component analysis (PCA) was also conducted to identify the properties of similar and non-similar nature. Scaling of the data pertaining to various properties was a requisite before conducting PCA since the data have different units of measurements. The R-functions "scale()" and "prcomp()" were used for scaling and PCA analysis, respectively. Graphical representations of these statistical analyses were generated through the R-modules such as "ggplot()", ggbiplot(), and "corrplot()".

3 | RESULTS AND DISCUSSION

3.1 | Weight, diameter, and height

The distribution pattern of weight, diameter, and height of intact tender coconut of five cultivars is summarized in Table 1. It was observed that the average weight, diameter, and height were the highest for the tender nuts of AGT cultivar. However, the nuts with the least weight (1.32 ± 0.24 kg), diameter (109.10 ± 2.21 mm), and height (141.21 ± 3.75 mm) were observed in COD cultivar. The height of the young Thai coconut (var. *Namhom*) reported by Jarimopas et al. (2009) was high (179.7 ± 5.3 mm) compared to the five cultivars analyzed in this study; nevertheless, no significant change in the diameter of nuts was found. The matured Nigerian coconut seeds had a higher diameter (184.93 mm) (Alonge & Adetunji, 2011) than AGT and young Thai coconut. The average weight of the MOD and COD coconuts of 12-month maturity reported by Pandiselvam et al. (2018) was low (1.02 ± 0.27 kg and 1.01 ± 0.06 kg) compared with the young (6 months maturity) MOD and COD coconut (1.35 ± 0.03 kg and 1.04 ± 0.13 kg).

The fruit holder, body-trimming knife, shoulder-trimming knife, and base-cutting knife are the essential components for the development of a trimming machine (Jarimopas & Ruttanadat, 2007). The data pertaining to the abovementioned physical properties (weight, diameter, and height) were the fundamental requisites for the design of the coconut holder and knife angle settings. The length of the coconut body trimming knife, height of the shoulder, and base-cutting knives were based on the height of the coconut. Hence, knife settings have to be adjusted based on the cultivar. Furthermore, incorporation of a spring mechanism in the coconut holder and knives may provide the automatic adjustment based on the size of the tender coconuts.

TABLE 1 Weight, diameter, and height of five cultivars of tender coconuts

Sl. No	Variety	Weight (kg)	Diameter (mm)	Height (mm)
1	KGD	1.48 ± 0.24	140.21 ± 10.10	162.01 ± 8.20
2	AGT	2.34 ± 0.46	170.21 ± 2.08	186.32 ± 6.08
3	GB	1.64 ± 0.21	134.75 ± 3.24	176.91 ± 5.86
4	MOD	1.53 ± 0.32	132.30 ± 1.84	169.21 ± 4.35
5	COD	1.32 ± 0.24	109.10 ± 2.21	141.21 ± 3.75

Abbreviations: KGD, Kulasekaran Green Dwarf; AGT, Andaman Giant Tall; GB, Ganga Bondam; MOD, Malayan Orange Dwarf; COD, Chowghat Orange Dwarf.

TABLE 2 The densities and porosity of five cultivars of tender coconuts

Sl. No.	Variety	Bulk density (kg·m^{-3})	True density (kg·m^{-3})	Porosity (%)
1	KGD	256.35 ± 9.32	1,291.62 ± 94.27	80.15 ± 1.81
2	AGT	332.47 ± 12.95	1,196.67 ± 62.95	72.21 ± 0.65
3	GB	284.26 ± 6.51	1,542.33 ± 41.32	81.56 ± 1.02
4	MOD	356.33 ± 10.16	1,257.36 ± 25.29	71.66 ± 0.86
5	COD	317.28 ± 9.54	1,685.67 ± 31.23	81.17 ± 0.54

Abbreviations: KGD, Kulasekaran Green Dwarf; AGT, Andaman Giant Tall; GB, Ganga Bondam; MOD, Malayan Orange Dwarf; COD, Chowghat Orange Dwarf.

3.2 | Densities and porosity

The densities and porosity of five cultivars of intact tender coconut are presented in Table 2. Remarkably, high bulk density (356.33 ± 10.16 kg·m^{-3}), true density (1,685.67 ± 31.23 kg·m^{-3}), and porosity (81.56 ± 1.02%) were observed in the MOD, COD, and GB, respectively. The other extremities in these properties were observed in the cultivars KGD (256.35 ± 9.32 kg·m^{-3}), AGT (1,196.67 ± 62.95 kg·m^{-3}), and MOD (71.66 ± 0.86%), respectively. The bulk density of MOD was 39% more than KGD. Similarly, the true density of COD was 40.86% more than AGT. These findings reveal that the tender coconuts display relatively a more density than that reported by Pandiselvam et al. (2018) and Alonge and Adetunji (2011) who studied the Indian and Nigerian matured coconuts, respectively. The high density liberates more mass per unit volume on the holder, warranting more torque to trim the coconut. Also, the densities and porosity play a vital role in the design of a packaging box for tender coconut.

3.3 | Husk thickness

The husk thickness is the most important parameter influencing the design of a trimming machine. The husk characteristics of tender coconut of five cultivars are depicted in Table 3. The longitudinal distance between the perianth and the shell (h_1) was the highest for MOD, whereas the highest longitudinal distance between the shell and fruit base (h_2), lateral distance between fruit skin and the shell on the right side (h_3), and the lateral distance between fruit skin and the shell on the left side (h_4) were observed in AGT cultivar. The lowest h_1, h_2, h_3, and h_4 were noticed in COD cultivar. The magnitude of the husk thickness of matured MOD and COD reported by Pandiselvam et al. (2018) is significantly less compared to that of the young MOD and COD. The highest husk thickness was observed in top orientation (pedicel end), followed by bottom orientation (fruit base), left orientation, and right orientation. These findings are in accordance with the report of Jarimopas et al. (2009) who studied the properties of young Thai coconut. Hence, more thickness should be trimmed in the top and bottom orientations of coconut and less in the periphery region of the coconut. More care should be taken while trimming COD cultivar because of less husk thickness. While shaping the tender coconut to hexagonal shape, the base cutting (flat shape) is performed at top orientation.

It was also observed that shell top right husk thickness (h_5) and shell top left husk thickness (h_6) were the highest for MOD, and shell bottom right husk thickness (h_7) and shell bottom left husk thickness (h_8) were high for AGT. The lowest h_5 and h_6 were noticed for GB and h_7 and h_8 were low for COD. The design of the shoulder-trimming knife shall be based on h_7 and h_8. The depth of trimming should be less than 33 mm for COD and less than 36 mm for MOD in the shoulder portion of the coconut. Otherwise, excessive trimming could damage the shell leading to the leakage of coconut water.

3.4 | Husk moisture content and husk weight

The husk moisture content and husk weight are presented in Table 4. The highest husk weight and moisture content were noticed in AGT and GB, respectively, whereas both these characteristics were found to be low for COD. The husk weight should be reduced as much as possible by trimming operation to save the transportation cost. Based on our observation during manual trimming operation, a minimum of 20–35% of the coconut weight can be reduced by performing trimming operation. The moisture content of the husk may influence the cutting strength of the husk. Also, the layer of trimming/thickness of trimming would influence the trimming force. The moisture of the husk of all the five cultivars were >83% (w.b.). Terdwongworakul et al. (2009) observed that green (young) coconut fiber requires a higher rupture force compared with the brown (206th day after pollination) coconut fiber. The authors concluded that toward maturity the husk fiber loses moisture, thereby leaving empty spaces in the spongy

TABLE 3 Husk thickness values of five cultivars of tender coconuts

Variety name	h_1 (mm)	h_2 (mm)	h_3 (mm)	h_4 (mm)	h_5 (mm)	h_6 (mm)	h_7 (mm)	h_8 (mm)
KGD	37.52 ± 4.04	27.49 ± 2.15	16.89 ± 1.26	15.14 ± 3.04	45.67 ± 8.87	44.12 ± 3.18	34.53 ± 6.08	41.23 ± 12.92
AGT	39.10 ± 2.86	29.54 ± 2.17	26.20 ± 2.46	32.04 ± 3.45	53.62 ± 7.14	54.62 ± 8.29	58.16 ± 8.54	58.37 ± 16.82
GB	37.12 ± 2.10	27.19 ± 3.64	16.65 ± 2.88	17.41 ± 3.38	33.24 ± 8.08	38.06 ± 6.08	39.26 ± 4.73	36.36 ± 12.49
MOD	45.62 ± 1.23	29.12 ± 2.30	23.14 ± 2.98	27.27 ± 3.14	54.06 ± 7.03	55.20 ± 8.89	36.62 ± 4.04	40.52 ± 9.54
COD	27.34 ± 3.14	21.43 ± 3.10	13.10 ± 4.24	12.27 ± 1.21	34.67 ± 6.13	42.67 ± 5.43	33.18 ± 1.15	34.34 ± 8.56

Note: h_1, vertical distance between the perianth and the shell; h_2, vertical distance between the shell and the fruit base; h_3, horizontal distance between the fruit skin and the shell on the right side; h_4, horizontal distance between the fruit skin and the shell on left side; h_5, shell top right husk thickness; h_6, shell top left husk thickness; h_7, shell bottom right husk thickness; h_8, shell bottom left husk thickness.
Abbreviations: KGD, Kulasekaran Green Dwarf; AGT, Andaman Giant Tall; GB, Ganga Bondam; MOD, Malayan Orange Dwarf; COD, Chowghat Orange Dwarf.

TABLE 4 Husk, shell, and flesh and/or kernel properties of five cultivars of tender coconuts

Variety	Husk moisture content (%; w.b.)	Husk weight (kg)	Shell diameter (mm)	Shell height (mm)	Shell thickness (mm)	Kernel/flesh thickness (mm)	Volume of water (ml)
KGD	83.73 ± 2.63	0.92 ± 0.20	96.28 ± 5.60	98.14 ± 9.71	3.10 ± 0.21	3.19 ± 0.26	325.31 ± 84.23
AGT	89.28 ± 0.03	1.69 ± 0.10	102.23 ± 1.86	99.52 ± 3.81	4.30 ± 0.18	1.01 ± 0.05	452.67 ± 58.37
GB	87.91 ± 0.23	1.12 ± 0.27	97.05 ± 1.21	90.33 ± 2.01	3.20 ± 0.04	2.93 ± 0.24	392.50 ± 38.24
MOD	86.76 ± 0.58	0.84 ± 0.11	95.82 ± 2.01	93.12 ± 4.45	3.00 ± 0.06	3.82 ± 0.31	327.33 ± 58.12
COD	83.62 ± 1.57	0.90 ± 0.23	94.20 ± 3.14	90.15 ± 7.20	2.23 ± 0.04	3.17 ± 0.12	402.76 ± 99.69

Abbreviations: KGD, Kulasekaran Green Dwarf; AGT, Andaman Giant Tall; GB, Ganga Bondam; MOD, Malayan Orange Dwarf; COD, Chowghat Orange Dwarf.

tissue that deforms more easily, and thus, requires less strength to rupture. But, higher husk moisture and soft nature of husk spongy tissue (the portion between the outer husk and the shell) may facilitate the achievement of smooth-surfaced finishing while trimming.

3.5 | Shell diameter, shell height, and shell thickness

The shell diameter, shell height, and shell thickness of AGT were significantly higher than those of other cultivars. The shell characteristics of AGT and GB found in this study were definitely in the higher range of what was reported by Jarimopas et al. (2009). Mizera, Hrabe, and Herák (2017) noticed that the coconut shell is thinner and softer in the longitudinal direction than in the latitudinal direction. We have observed that the tender coconut shell is soft in nature. Even a mild force can penetrate the shell. Thus, while trimming utmost care should be taken in order to avoid the damage of the shell. Analyses of the volume of coconut water and flesh thickness of five cultivars of tender coconut are presented in Table 4. The volume of water and flesh thickness was significantly higher for AGT and MOD, respectively. The lowest volume of water and flesh thickness was noticed in KGD and AGT, respectively. It was also observed that the shell diameter is directly proportional to the volume of water. In AGT, the highest shell volume share resulted in higher water content. The kernel thickness and volume of water was dependent on the maturity of the coconut. In our previous study (Pandiselvam et al., 2018), we have observed that the high kernel thickness and less volume of water in 12-month matured MOD and COD cultivars compared with the coconuts (MOD and COD) of 6-month maturity presented in this study. The flesh thickness and/or kernel thickness increases, and the volume of water decreases with maturity (Jayalekshmy, Arummaghan, Narayanan, & Mathew, 1986).

3.6 | Statistical significance

ANOVA of the effect of cultivars on different physical properties of tender coconuts is shown in Table 5. The *F* values of 11 dependent parameters (weight, diameter, height, bulk density, true density, porosity, h_1, h_7, husk weight, the moisture content of husk, and flesh thickness) were significant at 1% level ($p < .01$) and h_2, h_3, h_4, shell diameter, shell height, and volume of water were significant at 5% ($p < .05$).

From Table 5, it is understood that h_5, h_6, and h_8 do not significantly vary between the cultivars. Hence, the relevant physical properties such as coconut weight, diameter, height, densities, husk weight, moisture content of husk, and husk thickness (h_1, h_2, h_3, h_4, and h_7) should be considered for the designing of trimming machine. Otherwise, the automatic and/or pneumatic adjustment of holder and knife setting based on the size of the tender coconuts may improve the efficiency of the trimming or the image processing/machine vision-based settings for trimming knife may increase the efficiency and capacity of the trimming machine.

CV values of 21 physical properties of tender coconut ranged from 1.46% (for porosity) to 34.93% (for flesh thickness). The lower CV values imply a more accurate estimate. However, the CV values of the important physical parameters required for design and development of trimming machine including intact coconut diameter, height, density, husk thickness, and moisture content were in the acceptable range compared with flesh thickness (34.93%). Özgen, Serçe, and Kaya (2009) reported wide range of CV values (30% and 214%) for

TABLE 5 ANOVA for different physical properties of tender coconuts

	df	Weight	Diameter	Height	Bulk density	True density	Porosity	h_1	h_2	h_3	h_4
C	4	15.59**	8.15**	24.66**	20.35**	23.87**	31.92**	33.48**	6.09*	5.91*	5.65*
SEd		0.1316	6.61	4.36	10.62	58.59	0.94	2.89	1.95	1.13	2.62
CD (.05)		0.3035	15.24	10.06	24.49	135.11	2.17	6.66	4.51	2.62	6.03
CD (.01)	8	0.4416	22.17	14.63	35.63	196.60	3.15	9.69	6.56	3.81	8.77
CV (%)	-	10.80	5.73	3.32	4.56	5.24	1.46	10.39	9.14	9.15	20.65

	h_5	h_6	h_7	h_8	Husk weight	Moisture content	Shell thickness	Kernel/flesh thickness	Shell diameter	Shell height	Volume of coconut water
C	2.62NS	2.28NS	9.34**	1.56NS	19.13**	7.51**	2.25NS	13.00**	5.33*	3.81*	0.029*
SEd	6.55	6.26	4.53	10.81	0.0933	1.1188	0.5869	0.7985	5.9684	10.2946	61.57
CD (.05)	15.09	14.44	10.46	24.93	0.2151	2.5801	1.3534	1.8413	13.7634	23.7395	137.19
CD (.01)	21.96	21.02	15.22	36.28	0.3130	3.7543	1.9693	2.6792	20.0269	34.5430	195.15
CV (%)	18.36	16.80	14.03	32.57	12.97	1.60	21.56	34.93	7.27	13.24	21.18

Note: h_1, vertical distance between the stem and the shell; h_2, vertical distance between the shell and the fruit base; h_3, horizontal distance between the fruit skin and the shell on the right side; h_4, horizontal distance between the fruit skin and the shell on left side; h_5, shell top right husk thickness; h_6, shell top left husk thickness; h_7, shell bottom right husk thickness; and h_8, shell bottom left husk thickness.
NS, Nonsignificant. C, cultivar.
***p* is significant at .01 level, **p* is significant at 0.05 level.

the mulberry color characteristics. The CD at 5% significant level ($p < .05$) varied from 0.2151 (for weight) to 137.19 (for volume of coconut water). Al-Abdoulhadi et al. (2011) assessed the physical and textural characteristics of Saudi Arabia date fruit to regulate quality norms. They have reported the CD ($p < .05$) values of 0.15 for fruit weight and 2,102.93 for hardness.

3.7 | Correlation matrix

The general correlation matrix between the significant relevant physical properties is provided in a plot form in Figure 3. The plot consists of circles with shaded blue or red based on the sign of correlation: blue—positively correlated and red—negatively correlated. The results of correlation reveal that high positive correlation for weight was found with diameter (r = 0.791) and h_2 (r = 0.813). It could be due to the increased volume of water and husk thickness observed in larger nuts. The husk thickness h_1 displayed a negative correlation with all the compared properties except for height and husk moisture content, while the husk thickness h_4 was highly positively correlated with the husk weight (r = 0.784). Increase in husk thickness would cause gain in the tissue/spongy layer or fiber dimension in the mesocarp section resulting in increased husk weight. Correlation of the bulk and true density followed the same behavior as the other properties; they exhibit a negative correlation with almost all the other physical properties. Although bulk density positively correlated with one property, husk thickness h_7, the correlation was observed to be not significant. Among the other properties, the husk moisture content is highly positively correlated to the husk weight (r = 0.738). Coconut fiber has been characterized with high water-holding capacity, ultimately the presence of more moisture content in the mesocarp tissue or husk could contribute to more husk weight. From these observations, it is evident that the true and bulk densities are inversely correlated with the other properties considered in this study.

3.8 | Principal component analysis

The PCA was used to differentiate the tender coconut cultivars based on their physical properties. The PCA variation results are given in a biplot form in Figure 4, where the principal component 1 (PC1) represents 50.5% and principal component 2 (PC2) represents 18.9% of the total variations in the selected physical properties. The biplot includes the loading and the score plot where the coconut cultivars are color coded. The biplot consists of arrows representing each property considered for analysis.

The properties h_7, h_3, diameter, weight, h_4, husk weight, husk moisture content, h_2, and height are explained by PC1, which translates that the correlation between these variables and PC1 is positive, while the variables true and bulk density are explained by PC2. Therefore, the variables explained by PC1 are negatively correlated with the variables explained by PC2, and this is consistent with the results obtained from Pearson's correlation analysis. Reduction in the variable quantity results in a simpler and straightforward approach, and it is

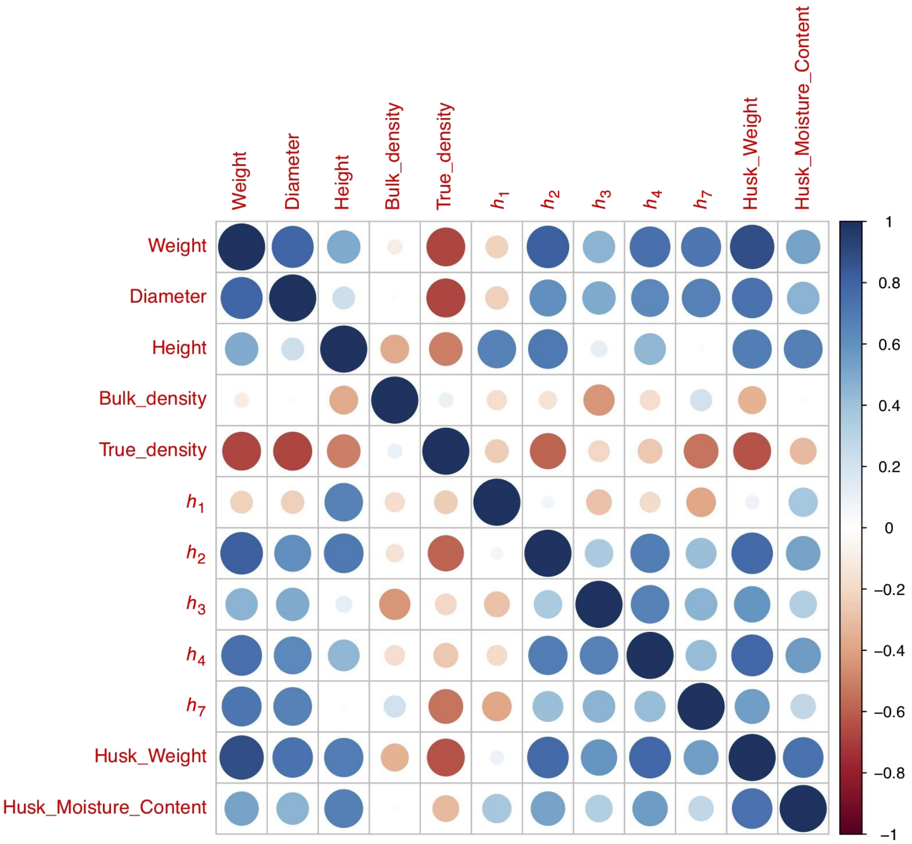

FIGURE 3 Pearson's correlation matrix for the measured physical properties of tender coconut cultivars—blue circle indicates positive correlation and the red circle indicates a negative correlation

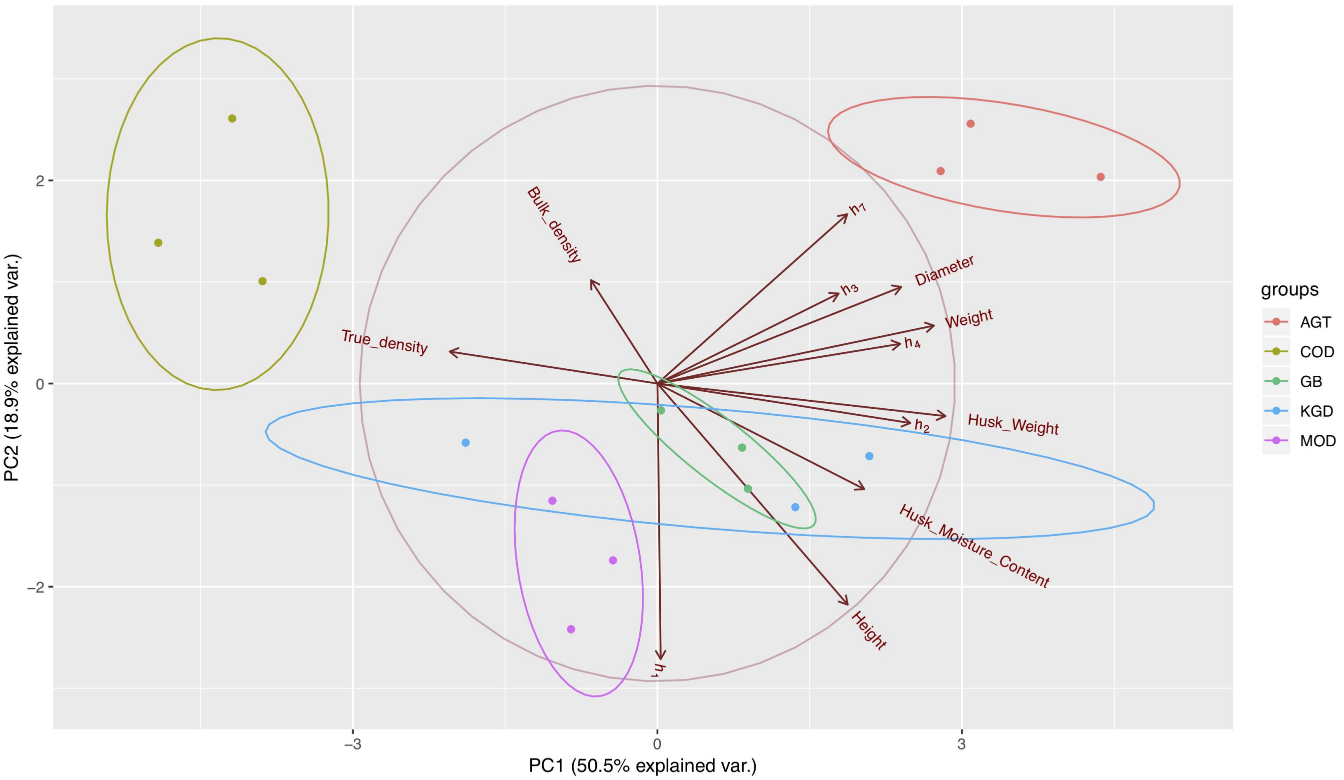

FIGURE 4 PCA biplot for measured tender coconut physical properties. The plot displays score and loading. PC1 = 50.5% and PC2 = 18.9%. PCA, principal component analysis

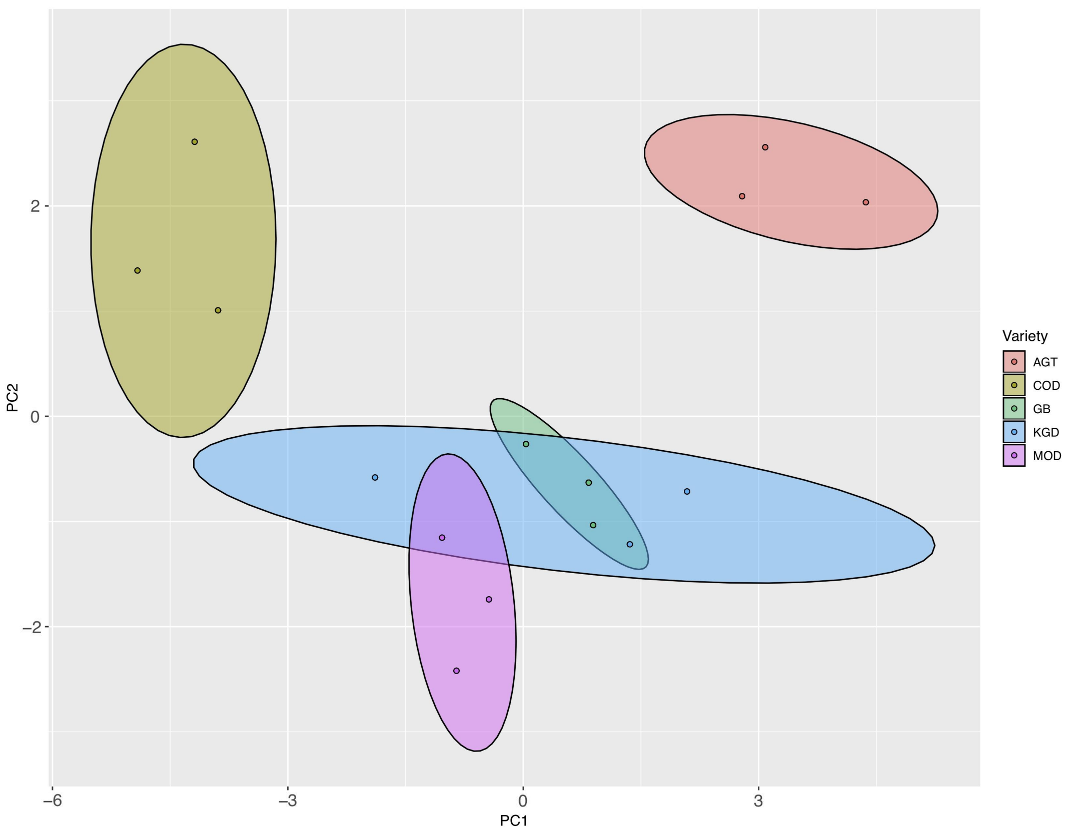

FIGURE 5 The tender coconut cultivar clusters of PCA displayed with different color codes. PCA, principal component analysis

evident from the biplot (Figure 4) that the properties coconut weight and husk thickness h_4 are highly positively correlated, which is also congruous to the correlation result (r = 0.745). Owing to the high correlation, the variable husk thickness was considered while the coconut weight was dropped. In addition, it can also be observed that the properties bulk density and h_3 are orthogonal, which indicates that the properties are not likely correlated (positive or negative).

Through cluster analysis, the cultivars were grouped into five different clusters, which are encircled and color coded (Figure 5). Those five clusters denote the cultivars, AGT, COD, GB, KGD, and MOD. Clear differences in the clusters were observed for the cultivar COD and AGT. However, no clear demarcation was observed between the clusters GB, KGD, and MOD. This might indicate that the cultivars GB, KGD, and MOD have similar physical properties to COD and AGT.

4 | CONCLUSIONS

The tender coconuts of five cultivars (KGD, AGT, GB, MOD, and COD) investigated here, clearly supplemented the variability of the physical properties of previously characterized young Thai coconuts (*Namhom*). In particular, the husk thickness of cultivars reported here was less than that of *Namhom* coconuts. The husk thickness parameters such as h_1, h_2, h_3, and h_4 of AGT were 43.01%, 37.84%, 100%, and 161.12%, respectively, more compared with the values of COD. ANOVA results showed that engineering properties of different cultivars such as weight, diameter, height, densities, porosity, h_1, h_7, husk weight, moisture content, and flesh thickness were significantly (p < .01) different. The natural variability in the physical and morphological characteristics of the tender coconut warrants an effectively performing trimming machine. Furthermore, the outcome of statistical analysis performed through correlation and PCA agreed with each other and aided in variable reduction. Cluster analysis suggested that for the cultivars GB, KGD, and MOD, a trimming machine can be designed in such a manner with little or no adjustments in the settings during the operation. The physical dimensions of tender coconut, densities, and mesocarp/husk profile enumerated in this study provide invaluable baseline information that would help in the development of the trimming knife and its settings (trimming angle) on the machine.

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