



## Textural Properties of Coconut Meat: Implication on the Design of Fiber Extraction and Coconut Processing Equipment

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### ABSTRACT

The textural properties of coconut meat such as punching force, cutting force, punching energy, and cutting energy are the salient parameters for the efficient and ergonomic design of the fiber extraction machine and processing equipments such as coconut chips slicing machine and grating machine. As literature on these textural properties of coconut meat is limited, our study analyzed these textural properties at three different positions viz. eye, middle and bottom position of 9, 10, and 11 months maturity old Malayan Yellow Dwarf (MYD), Malayan Orange Dwarf (MOD), and Chowghat Orange Dwarf (COD) cultivars. Statistical analysis revealed that cultivar, maturity and loading position are the major factors that significantly affect the textural properties of coconut meat. MOD was reported to be the toughest cultivar followed by MYD and COD. The amount of force and energy needed to punch and cut the coconut meat was found to increase with maturity (11 months > 10 months > 9 months) and loading position (bottom section > middle section > eye section), respectively. The highest punching force was observed for the meat of cultivar MOD of 11 months maturity with  $18.41 \pm 1.53$  N,  $36.70 \pm 5.72$  N, and  $39.12 \pm 6.65$  N for the eye, middle and the bottom sections, respectively. The highest punching and cutting energy of  $168.89 \pm 7.37$  J and  $254.21 \pm 28.14$  J was documented for MOD cultivar of 11 months maturity, at the bottom section.

### 摘要

椰子肉的纹理特性(如冲孔力,切割力,冲孔能量和切割能量)是高效,符合人体工程学设计的纤维提取机和加工设备(如椰子切片机和光栅机)的重要参数。由于有关椰子肉这些质地特性的文献有限,我们的研究在三个不同位置分析了这些质地特性,即:9个月龄,10个月龄和11个月龄的马来黄矮星(MYD),马来橙矮星(MOD)和Chowghat橙矮星(COD)品种的眼睛,中间和底部位置。统计分析表明,品种,成熟度和装载位置是显著影响椰子肉质特性的主要因素。据报道,MOD是最坚韧的品种,其次是MYD和COD。研究发现,戳切椰子肉所需的力和能量分别随着成熟度(11个月>10个月>9个月)和加载位置(底部>中间部分>眼睛部分)的增加而增加。11个月熟的MOD品种的肉的冲击力最高,眼睛,中间和底部分别为 $18.41 \pm 1.53$  n,  $36.70 \pm 5.72$ n和 $39.12 \pm 6.65$  n。11个月成熟的MOD品种在底部的最高冲孔和切割能量分别为 $168.89 \pm 7.37$  J和 $254.21 \pm 28.14$  J。

### KEYWORDS

Mechanical properties; fiber extraction; coconut chips slicing machine; cutting and punching force; cutting and punching energy

### 关键词

关键词: 机械性能; 纤维提取; 椰子切片机; 切割和冲孔力; 切割和冲压能量

## Introduction

India is one of the largest producers of coconut in the world. It is estimated that in India almost 12 million people depend on the coconut sector in diverse areas such as processing, cultivation, or trading activities (Raghavi et al. 2019). The export values of coconut products from India have seen a drastic increase in the last few years. During the year 2016–2017, India has witnessed a 42% increase in export revenue (20167 million rupees) from coconut products than 2015–2016 (2706 million rupees) (Jayasekhar et al. 2019). Nevertheless, India's contribution of processed coconut products such as copra meal and desiccated coconut stands only at 0.004% and 1% of the global export share (Jayasekhar et al. 2019). It was also reported that the low production rate of value-added products and lack of skilled labor are the major challenges encountered in the Indian coconut industry (Jayasekhar et al. 2019). However, these inherent problems could be addressed by the adoption of appropriate mechanization operations.

Coconut meat or kernel (botanically endosperm) is consumed by humans since ancient times. In India, out of the total production of coconuts, 5% is consumed as tender coconut for drinking purposes and almost 70% of the coconut is used for edible purposes (Raghavi et al. 2019). Coconut meat of 7–8 months maturity is soft in texture and is a rich source of protein and sugar. At this stage, the meat is either consumed as such or with the sweet tender coconut water. As the nuts mature, the protein, moisture and ash content of the fresh coconut meat gradually decreases, whereas the fat content progressively increases (Manikantan et al. 2018). The coconut meat is also high in dietary fiber (60.9 g/ 100 g), which is significantly higher than other local fiber sources such as banana, cassava, or wheat (Trinidad et al. 2001). An increase in fiber content of coconut meat with respect to maturity were also reported by many researchers (Chuntarat, Na Jom, and Tongchitpakdee 2013; Santoso et al. 1996). Coconut kernel is also a rich source of vitamins and minerals. The coconut meat protein also has a digestibility of 86–94% and a biological value of 71–77% (Banzon et al. 1990). It contains about 7% sugar and is rich in carbohydrates such as sucrose, glucose, fructose, pentose, raffinose, galactose, etc. (Manikantan et al. 2018). Coconut products are also reported to have therapeutic values such as cardioprotective, hepato-protective, anti-obesity, anti-cancer, anti-diabetic, anti-inflammatory effects, and neuroprotective effects (Ramesh et al. 2021).

Today the major commercially available coconut products are coconut chips, desiccated coconut, shredded coconut, coconut juice, and coconut milk-based products (frozen delicacy and milk powder). For the preparation of the aforementioned products, the coconut meat has to be sliced or grated either by mechanical or manual means (Pandiselvam et al. 2019a). Cutting and slicing of coconut kernels into uniform thickness and shape is a very crucial unit operation in coconut processing industries (Pandiselvam et al. 2019b). Conventionally followed manual method is a cumbersome and time-consuming process. Moreover, the production rate and uniformity of the final sliced product depend on the skill of the operator. Therefore, to ensure the process faster and simpler, designing of an economical and efficient machinery is imperative (Pandiselvam et al. 2018).

Our previous study (Pandiselvam et al. 2018) investigated the effect of engineering properties of whole coconut on design and development of dehusking machine. The present study explores the textural features of different maturity of coconut meat. For the designing of coconut meat processing and fiber extraction equipment with improved efficiency, it is indispensable to investigate the engineering properties of coconut meat. Also, the basic engineering and textural properties greatly aid the optimal designing of machine components. It confers the machine operators with ergonomic comfort in terms of appropriate heart rate, oxygen consumption, and energy expenditure (Aware and Mehta 2021). As the major unit operation involved in coconut meat processing is slicing and shredding and/or grating, this study evaluated the force, deformation, and energy related to these unit operations. Improvements in the field of plant breeding have given rise to new breeds with higher yield and kernel weight and hence, this study was carried out in the popular Indian coconut cultivars

such as Malayan Yellow Dwarf (MYD), Malayan Orange Dwarf (MOD), and Chowghat Orange Dwarf (COD). This research work has also attempted to establish a correlation between the textural properties of coconut meat with the cultivar and maturity by using Principal component analysis (PCA).

## Materials and methods

### Raw materials

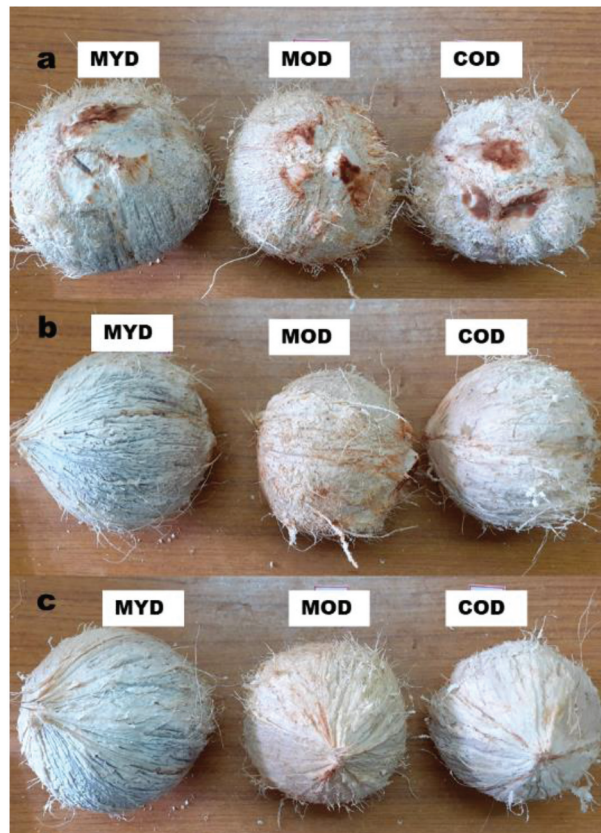
Coconut cultivars such as Malayan Yellow Dwarf (MYD), Malayan Orange Dwarf (MOD), and Chowghat Orange Dwarf (COD) of appropriate maturity stage (9–11 months) were harvested from the ICAR-Central Plantation Crops Research Institute (ICAR-CPCRI) Farm, India ([Figure 1](#)). The maturity of the coconuts was ascertained based on the suitable information already recorded in the label or tag placed during pollination. These dwarf cultivars are most common in India due to their high economic yielding potential. Also, 9–11 months old, matured nuts are generally used for the production of snowball tender coconut, coconut chips, coconut milk extraction, and the production of grated coconuts for culinary purposes. Hence, it is pertinent to study the textural characteristics of the nuts with 9–11 months of maturity to design the coconut processing equipment. The harvested nuts were dehusked ([Figure 2](#)) and deshelled using in-house developed equipments (Manikantan et al. 2018). The eye, middle, and bottom sections of the coconut meat was separated and placed for texture studies.

### Texture analysis

The textural properties of coconut meats were determined with a Stable Micro Systems Texture Analyzer (model TA. HD Plus). Customized cutting and punching probes [dimensions of the punching tool used in this study are 5 mm (diameter) × 68 mm (length) and that of the cutting tool is 70 mm (width) × 66 mm (length) × 3 mm (thickness)] were developed and employed in this study considering the hard texture of coconut meat. The specifications of the probes utilized were presented elsewhere (Pandiselvam et al. 2019a). The bevel angle of the cutting tool was fixed at 30 and 45°. Punching and cutting tests were performed at three different loading positions as eye (top), middle, and bottom section (near to fruit base). The sample size of 20 mm × 20 mm was selected to perform the cutting and punching test. Texture analyzer settings were as already enumerated (Pandiselvam et al. 2019a). The peak force was considered as the maximum cutting/punching force and the area under this curve is known as cutting/punching energy.



**Figure 1.** Figure showing the various cultivars (maturity 9 months) used in the study.



**Figure 2.** Figure showing the eye (a), middle (b) and the bottom (c) section of the dehusked coconut.

### **Statistical analysis**

Each experiment was replicated with 10 nuts for the given factors such as variety and maturity stage. Analysis of variance (ANOVA) was computed by assuming RBD (Randomized block design) layout style data arrangement using R software Version 4.0.3 (R-CoreTeam 2013). The summary statistics and the effect of significance of differences between cultivar, maturity, and their interaction means (Fisher-LSD test) were determined using the Agricolae package (De Mendiburu and Simon 2015). The relationship among parameters was further explored using the principal component analysis (PCA) technique. Results of PCA were visualized using Biplot constructed between first two principal components (Dim 1 and Dim 2) by “factoextra” packages in R.

## **Results and discussion**

### **Punching force**

Coconut is a popular fruit in tropical countries and is used for meat, juice, oil, and milk. Determination of textural properties such as punching force is very crucial in developing energy-efficient machines such as coconut meat grating, chips slicing machine, and milk extraction units (Pandiselvam et al. 2019a, 2019b). The effect of different cultivars with respect to various punching positions and maturity is shown in Table 1. Maturity of the fruit was one of the major factors that affected the firmness of the coconut meat. The punching force of the sample tends to increase with the increase in maturity of the fruits. An increase in punching force from  $7.2 \pm 0.44$  N to  $13.41 \pm 2.82$  N

**Table 1.** Effect of cultivar, maturity, and punching position on punching force of coconut meat.

Cultivar	Maturity (months)	Punching Force (N)		
		Eye section	Middle Section	Bottom section
MYD	11	13.41 ± 2.82	25.67 ± 6.29	39.68 ± 4.91
MYD	10	9.21 ± 1.53	13.23 ± 1.51	23.32 ± 1.94
MYD	9	7.2 ± 0.44	7.64 ± 0.26	9.55 ± 0.54
MOD	11	18.41 ± 1.53	36.70 ± 5.72	39.12 ± 6.65
MOD	10	10.6 ± 0.35	4.17 ± 0.21	11.01 ± 1.30
MOD	9	3.47 ± 0.75	3.9 ± 0.50	7.72 ± 2.35
COD	11	12.066 ± 0.58	14.90 ± 1.62	32.05 ± 5.18
COD	10	10.65 ± 0.37	11.04 ± 1.35	12.58 ± 2.39
COD	9	3.33 ± 0.14	8.95 ± 1.65	9.85 ± 0.86

MYD-Malayan Yellow Dwarf, MOD-Malayan Orange Dwarf, COD-Chowghat Orange Dwarf

was reported for the MYD cultivar during 9–11 month maturity for the eye section. A similar increase in punching force from  $3.47 \pm 0.75$  N to  $18.41 \pm 1.53$  N and from  $3.33 \pm 0.14$  N to  $12.066 \pm 0.58$  N were found for the cultivars MOD and COD, respectively. The genotype of the samples was another factor that influenced the textural parameters. In this study, the highest punching force for the eye section was reported for the MOD cultivar with  $18.41 \pm 1.53$  N followed by MYD and COD with  $13.41 \pm 2.82$  N and  $12.066 \pm 0.58$  N respectively, at 11 month maturity.

Punching force also varied according to the loading position, with the bottom section of the kernel recording a higher punching force followed by the middle section and eye section. The highest punching force was reported for the bottom section of MYD and MOD exhibiting  $39.68 \pm 4.91$  N and  $39.12 \pm 6.65$  N force, respectively, whereas the lowest punching force were reported for the eye section of COD variety. It was observed that the eye section is softer than the middle and bottom section. Coconut has three eyes one on each carpel (Figure 2). Among them, two eyes are harder because of lignifications whereas one eye is soft through which the germinating embryo emerges (Child 1974; Harries 2012).

The maturity stage of the nut is another important parameter that determines the quality of coconut meat. Maturity determines the amount of meat and fiber content and the tenderness of coconut meat. The meat of immature coconuts of 6–7 months old exhibit very soft and jelly-like texture (Pandiselvam et al. 2019b). For coconut fruits of 7–8 months maturity, the volume of liquid in the fruits decreases and the meat turns from a jelly-like appearance to a firm opaque solid mass. Snowball tender coconut is a popular coconut product that is developed from 8 to 9 month matured coconut. In this context, the textural properties of 8–9 month matured coconut are essential for the design and development of snowball machine. Beyond this maturity stage, the meat turns thick and soft and then to leathery coconut meat (Pascua 2017; Pascua, Pascua, and Peralta 2020). These changes in textural properties can be due to the change in water and crude fiber content of the coconut fruit during maturity. The proximate analysis of coconut fruit at various maturity stages (6–9 months) have shown a significant increase in the crude fiber (22.4–34.7%) and a decrease in moisture content (58.5–46.6%) with respect to its maturity (Chuntarat, Na Jom, and Tongchitpakdee 2013). An increase in dietary fiber contents such as lignin and hemicellulose from 0.97% to 3.50% and 3.09% to 17.38% were also reported during 6–12 month maturation period of coconut fruits (Santoso et al. 1996). These changes in meat with respect to maturity, in turn, increase the force necessary to punch the meat. Hence, the textural feature of 11 month matured coconut meat is also essential for design and development of fiber extraction machine. Mitchell et al. (2010) reported an increase in the flesh penetration force for coconut based on its maturity. Coconuts were classified into immature (170–180 days), mature (180–195 days) and over mature (195 days and above) based on their maturity and was assessed for their textural properties. The study reported the lowest penetration force for the immature coconuts with  $1.83 \pm 0.59$  N followed by mature nuts with  $6.51 \pm 3.73$  N and over matured fruits,  $16.97 \pm 6.22$  N. An increase in hardness of coconut kernel from  $67.4 \pm 18.7$  N to  $126.9 \pm 21.7$  N over 6–9 month of maturity were also reported by Chuntarat, Na Jom, and Tongchitpakdee (2013).

Jamal Ayour et al. (2017) have also reported maturity and variety as major factors influencing the firmness of apricot fruits. Khodabakhshian et al. (2019) reported that the textural properties of pomegranate fruit and arils exhibit a strong correlation with the fruit maturity and loading position.

### Cutting force

Knowledge regarding the cutting force of coconut meat is necessary for the efficient design of cutting/dicing/shredding equipment. Particularly cutting blade design (bevel angle, thickness, contact area, and rotational speed) and prime mover selection depend on the cutting force. The cutting force with respect to the sharpness of the blades, maturity, and punching position of various cultivars is given in Table 2. The cutting force was significantly affected by the degree of bevel angle of the cutting tool. The cutting blade with a bevel angle of 45 degrees showed a comparatively less force to cut the tender coconut meat than 30-degree angle, indicating an increased sharpness. The highest cutting force was recorded for MOD cultivar of 11 months maturity followed by COD and MYD. The MOD cultivar of 9 and 11 months maturity showed a cutting force of  $5.55 \pm 2.77$  N and  $38.48 \pm 17.34$  N, respectively, when cutting was performed with 45 degree bevel tool, whereas with 30 degree bevel angle the cutting force increased to  $8.28 \pm 2.68$  N and  $62.53 \pm 9.05$  N, respectively, at the eye section. A similar pattern of increase in cutting force was observed for the middle and bottom sections of the meat. This increase in fruit firmness is due to the increase in flesh firmness of coconut fruit. Mitchell et al. (2010) studied the firmness of coconut meat at different maturity stages and have reported that the flesh inside gets thicker and firmer with respect to its maturity stage. The cutting force was also found to vary according to the loading position. For the MOD cultivar of 9 months maturity  $5.55 \pm 2.77$  N,  $6.69 \pm 0.90$  N, and  $13.56 \pm 2.62$  N was reported for the eye, middle, and bottom sections, respectively, when cutting with a 45 degree beveled tool, but when cutting was performed with a 30 degree bevel tool the force significantly increased to  $8.28 \pm 2.68$  N,  $16.04 \pm 4.44$  N, and  $14.44 \pm 2.07$  N, respectively. This is because when the kernel or solid endosperm starts to form, it begins from the stylar end and develops toward the stem end (Siriphanich et al. 2011). Hence, the mature fibers (lignin and hemicellulose) located to the bottom section tend to be firmest. Similar results on the influence of orientation of applied load on fruit texture were reported in oranges (Singh and Reddy, 2006). This study also reported significantly higher firmness in stem-calyx axis in vertical position than that in horizontal position. Due to the presence of spongy white tissue on top and the presence of mature fiber at the bottom orientation, a significantly higher cutting force was reported at the bottom section of the tender coconut followed by the middle and top sections (Pandiselvam et al. 2019a). It is also evident from the results that the cutting force was always higher than punching force. This difference in the cutting and punching force can be attributed to the dimensions of the probe. The force required for cutting and punching is directly proportional to the contact area. As the probe used for cutting has

**Table 2.** Effect of cultivar, maturity, and loading position on cutting force of coconut meat.

Cultivar	Maturity (months)	Cutting Force (N) –45 degree bevel angle			Cutting Force (N) –30 degree bevel angle		
		Eye section	Middle Section	Bottom section	Eye section	Middle Section	Bottom section
MYD	11	24.09 ± 3.69	42.63 ± 12.54	81.47 ± 11.96	50.87 ± 3.69	60.13 ± 4.72	93.54 ± 7.68
MYD	10	22.25 ± 2.51	23.17 ± 3.17	49.94 ± 5.79	27.78 ± 5.05	29.53 ± 3.34	47.75 ± 8.29
MYD	9	12.80 ± 0.81	16.69 ± 1.65	34.05 ± 5.99	11.82 ± 1.45	16.87 ± 2.71	20.64 ± 5.02
MOD	11	38.48 ± 17.34	79.22 ± 28.21	119.02 ± 17.51	62.53 ± 9.05	83.22 ± 5.95	89.16 ± 9.12
MOD	10	13.82 ± 5.68	29.40 ± 8.11	36.40 ± 5.97	10.44 ± 0.36	13.92 ± 3.61	33.12 ± 5.17
MOD	9	5.55 ± 2.77	6.69 ± 0.90	13.56 ± 2.62	8.28 ± 2.68	16.04 ± 4.44	14.44 ± 2.07
COD	11	32.78 ± 3.07	36.89 ± 9.32	46.37 ± 4.38	23.18 ± 4.40	27.13 ± 6.12	39.50 ± 7.06
COD	10	34.72 ± 5.64	32.63 ± 2.44	46.77 ± 6.64	16.72 ± 0.66	22.86 ± 4.40	24.68 ± 2.67
COD	9	22.21 ± 7.65	32.29 ± 6.28	32.16 ± 7.27	12.87 ± 0.73	13.83 ± 1.13	17.66 ± 2.45

MYD-Malayan Yellow Dwarf, MOD-Malayan Orange Dwarf, COD-Chowghat Orange Dwarf

**Table 3.** Effect of cultivar, maturity, and loading positions on punching energy.

Cultivar	Maturity (months)	Punching energy (J)		
		Eye section	Middle section	Bottom section
MYD	11	20.42 ± 3.04	41.4 ± 2.42	74.13 ± 8.53
MYD	10	19.27 ± 3.30	32.63 ± 0.83	51.96 ± 11.01
MYD	9	12.03 ± 4.29	11.09 ± 5.06	24.75 ± 2.65
MOD	11	28.34 ± 1.47	35.17 ± 3.83	168.89 ± 7.37
MOD	10	8.77 ± 2.22	15.79 ± 3.98	18.55 ± 2.39
MOD	9	8.18 ± 1.44	7.30 ± 0.81	24.07 ± 3.53
COD	11	31.40 ± 2.99	21.14 ± 5.97	64.94 ± 18.32
COD	10	14.65 ± 2.01	20.03 ± 1.24	37.26 ± 5.23
COD	9	5.57 ± 1.30	12.52 ± 3.89	17.82 ± 2.09

MYD-Malayan Yellow Dwarf, MOD-Malayan Orange Dwarf, COD-Chowghat Orange Dwarf

a higher dimension area compared to the punching tool, the cutting tool covered more unit area while performing the test; hence, cutting force always showed higher values than the punching. These data are very useful while designing knife tools for removing or scrapping coconut meat.

### Punching energy

The experimental data of punching energy with respect to cultivar, maturity, and punching position is given in Table 3. The maximum punching energy required to puncture the tender coconut meat was found to depend on the cultivar. The cultivar MOD showed the highest punching energy of  $168.89 \pm 7.37$  J, followed by MYD and COD with  $74.13 \pm 8.53$  J and  $64.94 \pm 18.32$  J of energy, respectively, at the bottom section. This can be due to the difference in the coconut meat firmness. Pandiselvam et al. (2018) studied the engineering properties of diverse coconut varieties, namely Malayan Orange Dwarf (MOD), Malayan Yellow Dwarf (MYD), Kera Shankara (KS), Chowghat Green Dwarf (CGD), and Chowghat Orange Dwarf (COD). The study reported that the volume of the liquid endosperm, the kernel thickness, and kernel weight depended on the coconut cultivar tested, with MOD showing significantly higher values followed by MYD and COD cultivar. An apparent relationship between flesh thickness to genotype was also established by Pandiselvam et al. (2019b). The punching energy of the coconut meat was also influenced by its maturity. The 11 month old coconut meat required higher punching energy followed by 10 and 9 months matured coconut meat irrespective of the position. For the cultivar MYD, the punching energy in the eye section increased from  $12.03 \pm 4.29$  J and  $20.42 \pm 3.04$  J (9 and 11 months) depending upon its maturity. A similar increase was also reported for MOD and COD cultivar with a respective increase of  $8.18 \pm 1.44$  J to  $28.34 \pm 1.47$  J and  $5.57 \pm 1.30$  J to  $31.40 \pm 2.99$  J. A significant difference in punching energy was also observed for punching positions. The least punching energy was reported for the eye section, followed by middle and bottom positions.

**Table 4.** Effect of cultivar, maturity, and loading positions on cutting energy of coconut meat.

Cultivar	Maturity (months)	Cutting Energy (J) –45 degree bevel angle			Cutting Energy (J)–30 degree bevel angle		
		Eye section	Middle Section	Bottom section	Eye section	Middle section	Bottom section
MYD	11	39.23 ± 13.78	46.45 ± 7.79	142.33 ± 22.30	32.10 ± 1.92	48.30 ± 7.99	270.98 ± 44.14
MYD	10	27.06 ± 2.86	32.52 ± 3.77	107.84 ± 18.91	31.82 ± 6.19	39.04 ± 8.83	180.66 ± 13.35
MYD	9	13.36 ± 3.95	19.94 ± 2.46	57.78 ± 5.80	13.11 ± 2.69	34.26 ± 0.72	76.50 ± 13.21
MOD	11	106.64 ± 5.86	230.27 ± 123.55	274.49 ± 115.67	176.57 ± 16.60	226.34 ± 9.85	254.21 ± 28.14
MOD	10	30.52 ± 8.17	71.83 ± 20.13	50.62 ± 3.92	13.40 ± 3.10	21.08 ± 4.82	31.47 ± 13.72
MOD	9	10.75 ± 3.38	19.74 ± 2.08	30.00 ± 3.90	9.28 ± 1.04	15.83 ± 11.52	28.16 ± 1.46
COD	11	70.83 ± 12.97	115.77 ± 9.18	215.40 ± 10.10	73.27 ± 11.29	73.25 ± 7.07	78.81 ± 11.96
COD	10	56.43 ± 15.13	74.33 ± 7.21	167.82 ± 32.32	19.09 ± 7.67	50.09 ± 7.59	52.24 ± 6.57
COD	9	38.51 ± 16.43	69.97 ± 7.99	133.02 ± 28.59	13.62 ± 2.16	20.62 ± 7.55	40.97 ± 11.10

MYD-Malayan Yellow Dwarf, MOD-Malayan Orange Dwarf, COD-Chowghat Orange Dwarf

**Table 5.** Effect of cultivar, maturity, and loading positions on cutting and punching deformation in coconut meat.

Cultivar	Maturity (months)	Cutting Deformation											
		Deformation (mm)-45 degree bevel angle						Deformation (mm)-30 degree bevel angle					
		Eye section	Middle Section	Bottom section	Eye section	Middle Section	Bottom section	Eye section	Middle Section	Bottom section	Eye section	Middle Section	Bottom section
MYD	11	7.79 ± 0.28	7.82 ± 0.18	7.99 ± 0.01	3.9 ± 0.27	6.31 ± 1.47	5.55 ± 1.88	7.44 ± 0.90	7.86 ± 0.22	7.94 ± 0.06	7.95 ± 0.03	7.98 ± 0.02	7.91 ± 0.07
MYD	10	7.97 ± 0.03	7.95 ± 0.07	7.98 ± 0.02	7.03 ± 1.31	6.63 ± 1.84	7.35 ± 0.34	7.95 ± 0.03	7.98 ± 0.02	7.91 ± 0.07	7.99 ± 0.09	7.93 ± 0.05	7.99 ± 0.00
MYD	9	7.98 ± 0.02	7.99 ± 0.01	7.47 ± 0.82	6.68 ± 0.36	7.43 ± 0.87	7.96 ± 0.03	7.9 ± 0.09	7.93 ± 0.05	7.99 ± 0.00	7.9 ± 0.09	7.93 ± 0.05	7.99 ± 0.00
MOD	11	6.09 ± 1.09	6.63 ± 0.36	7.85 ± 0.16	4.07 ± 1.31	7.81 ± 0.33	7.25 ± 0.71	7.93 ± 0.06	7.99 ± 0.01	7.99 ± 0.01	7.93 ± 0.06	7.99 ± 0.01	7.99 ± 0.01
MOD	10	7.14 ± 0.73	7.74 ± 0.37	7.60 ± 0.70	7.98 ± 0.01	7.99 ± 0.01	7.96 ± 0.05	7.84 ± 0.15	7.99 ± 0.02	7.99 ± 0.01	7.84 ± 0.15	7.99 ± 0.02	7.99 ± 0.01
MOD	9	7.60 ± 0.67	6.93 ± 0.29	8.00 ± 0.00	6.62 ± 0.17	7.99 ± 0.01	7.83 ± 0.30	7.98 ± 0.00	7.88 ± 0.17	7.99 ± 0.00	7.98 ± 0.00	7.88 ± 0.17	7.99 ± 0.00
COD	11	6.22 ± 0.77	6.57 ± 0.81	6.72 ± 2.14	7.92 ± 0.14	7.69 ± 0.34	6.93 ± 1.05	7.95 ± 0.04	7.36 ± 1.09	7.99 ± 0.00	7.95 ± 0.04	7.36 ± 1.09	7.99 ± 0.00
COD	10	7.52 ± 0.42	7.15 ± 0.71	7.52 ± 0.42	7.16 ± 0.69	7.08 ± 0.59	7.1 ± 1.53	7.99 ± 0.02	7.95 ± 0.03	7.98 ± 0.01	7.99 ± 0.02	7.95 ± 0.03	7.98 ± 0.01
COD	9	7.76 ± 0.24	7.35 ± 0.39	7.97 ± 0.01	7.97 ± 0.06	6.35 ± 0.15	7.55 ± 0.61	7.99 ± 0.01	7.99 ± 0.01	7.73 ± 0.26	7.99 ± 0.01	7.99 ± 0.01	7.73 ± 0.26

MYD-Malayan Yellow Dwarf, MOD-Malayan Orange Dwarf, COD-Chowghat Orange Dwarf

**Table 6.** ANOVA of different textural properties of coconut meat (F values are mentioned in the table).

Factors	df	Punching force (N)			Punching deformation (mm)			Punching energy (J)		
		Eye	Middle	Bottom	Eye	Middle	Bottom	Eye	Middle	Bottom
Cultivar (V)	2	11.82**	38.3*	92.3**	0.10771	0.09116	0.017359	22.4	357.8**	1410**
Maturity (M)	2	217.44**	954.9**	1915.0**	0.13091	0.22163	0.025404	757.0*	1087.1**	18339**
V x M	4	18.38**	204.9**	50.3*	0.05921	0.08596	0.024304	62.6**	141.9**	4799**
Error	16	1.67	9.3	12.5	0.0907	0.14152	0.00888	8.2	13.7	79
CV (in %)		13.1	21.76	17.19	3.82	4.77	1.19	15.19	17.29	17.22
CD		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
V		1.29	3.04	3.53	0.3	0.38	0.09	2.86	3.7	8.9
M		1.29	3.04	3.53	0.3	0.38	0.09	2.86	3.7	8.9
V x M		2.24	5.26	6.11	0.52	0.65	0.16	4.96	6.4	15.42

Cutting Parameters at 30° bevel angle										
Factors	df	Cutting force (N)			Cutting Deformation (mm)			Cutting Energy (J)		
		Eye	Middle	Bottom	Eye	Middle	Bottom	Eye	Middle	Bottom
Cultivar (V)	2	386.4**	717**	1676**	8.295**	2.4034*	2.107	4080**	5798**	32144**
Maturity (M)	2	2980.3**	4424**	7518**	6.856**	1.8858 *	3.26	18103**	22484**	56593**
V x M	4	543.9**	929**	732**	2.192*	0.3413	0.92	6412**	11498**	11659**
Error	16	18.3	13	39	0.505	0.4452	1.02	51	78	435
CV (in %)		17.15	11.38	14.83	10.78	9.1	14.04	16.77	15.08	18.52
CD		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
V		4.28	3.58	6.27	0.71	0.67	1.01	7.12	8.85	20.85
M		4.28	3.58	6.27	0.71	0.67	1.01	7.12	8.85	20.85
V x M		7.41	6.2	10.86	1.23	1.15	1.75	12.32	15.33	36.11

Cutting Parameters at 45° bevel angle										
Factors	df	Cutting force (N)			Cutting Deformation (mm)			Cutting Energy (J)		
		Eye	Middle	Bottom	Eye	Middle	Bottom	Eye	Middle	Bottom
Cultivar (V)	2	283.1**	277.7	589**	2.3330**	2.2006**	0.5002	2066 **	11386**	11271*
Maturity (M)	2	750.8**	2788	7285**	2.7876**	0.8720*	0.1969	6155 **	22920**	44395
V x M	4	174.9*	951.5**	1953**	0.5538	0.3181	0.6989	1412 **	9150**	8727*
Error	16	43.4	136.6**	61	0.2762	0.1527	0.6652	114	1802	2034
CV (in %)		28.98	34.87	15.26	7.16	5.32	10.62	24.48	57.92	33.81
CD		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
V		6.58	11.68	7.79	0.53	0.39	0.82	10.69	42.42	45.07
M		6.58	11.68	7.79	0.53	0.39	0.82	10.69	42.42	45.07
V x M		11.41	20.23	13.5	0.91	0.68	1.41	18.52	73.48	78.06

\*\*Significant at 1% level; \*Significance at 5% level

### Cutting energy

Cutting energy is another important parameter that warrants adequate consideration while designing a cutting or shredding equipment and is a critical factor for deciding the motor horsepower. The experimental data of cutting energy with respect to cultivar, maturity, and punching position is presented in Table 4. The cutting energy was estimated by utilizing 45- and 30-degree bevel angle probes. Blades designed at a 45-degree angle was comparatively sharp than 30 degree beveled blades. The highest cutting energy with 45 degree beveled probe was observed for MOD cultivar of 11 months maturity and showed a progressive increase in the cutting energy for the eye ( $106.64 \pm 5.86$  J), middle ( $230.27 \pm 123.55$  J), and bottom ( $274.49 \pm 115.67$  J) sections. The required cutting energy also depends on fruit maturity. For MYD and COD cultivars, the cutting energy of 9, 10, and 11 month fruits increased from  $13.36 \pm 3.95$  J to  $27.06 \pm 2.86$  J and to  $39.23 \pm 13.78$  J and  $38.51 \pm 16.43$  J to  $56.43 \pm 15.13$  J and to  $70.83 \pm 12.97$  J respectively, for the eye section. For 30 degree bevel probes, the highest cutting energy was observed at the bottom section of 11 months matured MOD

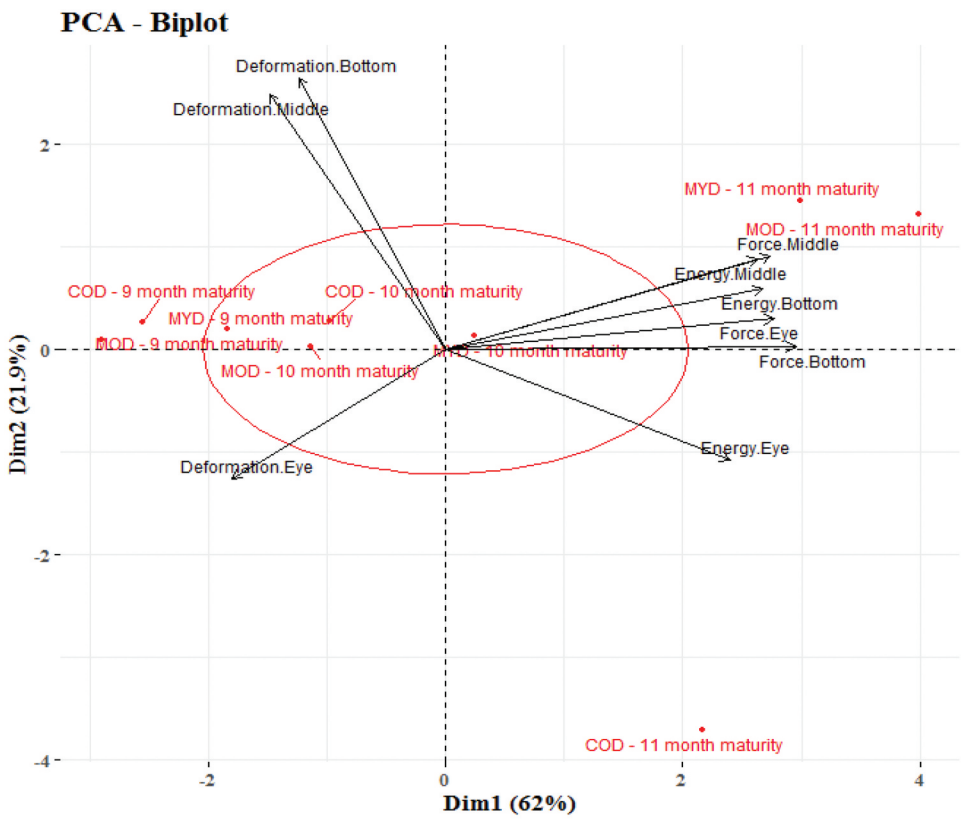


Figure 3. PCA-biplot of punching experiment.

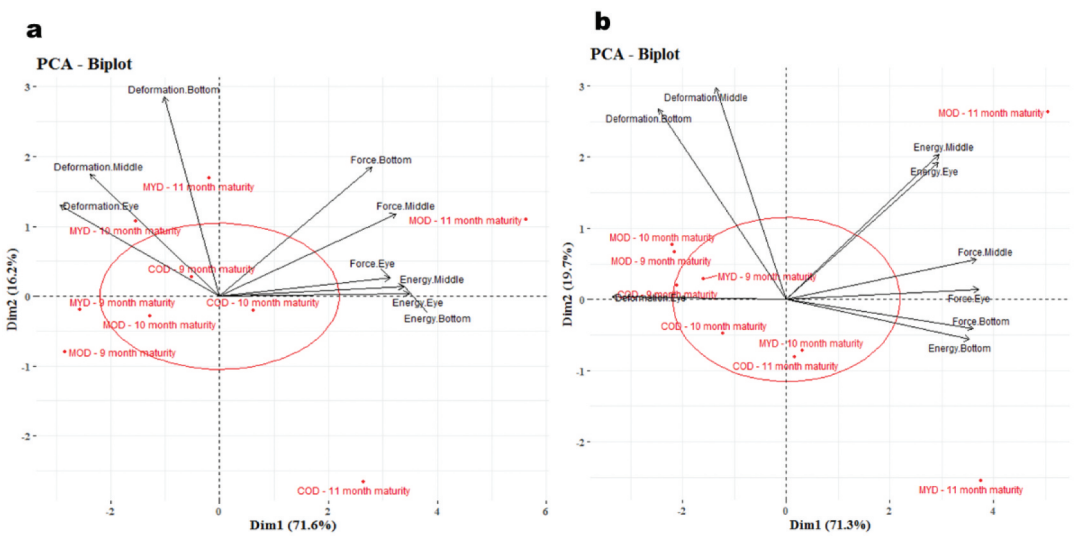


Figure 4. PCA-biplot of cutting experiments with (a) 45 degree and (b) 30 degree bevel angle.

(254.21 ± 28.14 J) cultivar followed by MYD (270.98 ± 44.14 J) and COD (78.81 ± 11.96 J). The cutting energy showed an increasing trend for the eye (176.57 ± 16.60 J), middle (226.34 ± 9.85 J), and bottom (254.21 ± 28.14 J) sections for MOD.

### **Cutting and punching deformation**

Cutting and punching deformation values are important parameter that determines the sharpness and shape of the tool. Knowledge about this mechanical property is vital for developing tools such as tender coconut cutting/trimming knife, coconut meat slicing knife, pulverizing tools, and punching tools, etc. The variation of punching and cutting force with respect to cultivar, maturity, and loading position is given in Table 5. Interestingly, the punching deformation does not have a significant difference between cultivar, maturity, and the loading position (Table 6). However, a significant difference was observed for cutting deformation in the eye and middle section. Coconut meat is a non-homogeneous biological material, which has non-uniformity in deformation. A similar observation was reported by Khodabakhshian et al. (2019).

### **Principal Component Analysis (PCA)**

Principal component analysis (PCA) was performed to further differentiate the coconut fruits according to maturity, cultivar, and mechanical properties (Figures 3 and 4). Figure 3 shows the PCA-Biplot of the punching experiments. By the cross-validation technique, it was established that 2 principal component is necessary for explaining the total variability on cultivar, maturity, and mechanical properties. By the first principal component (Dim1), 62% variation was explained and it correlates the variables such as energy and force, whereas for second principal component (Dim2) which explained 21.9% variation correlated well with deformation. The coconut meat samples of 11 months old maturity were found to be grouped in dimension 1, whereas samples of 9 and 10 month old maturity were grouped under dimension 2. In cutting experiment, the PCA-Biplots for cutting experiment with 45 degree and 30 degree bevel angle tools, 2 principal components were established (Figure 4). For 45 degree bevel angle tools, the first principal component explained 71.6% variance and correlated well with force and energy. The second principal component represented 16.2% variance and corresponded well with deformation. In the case of cutting experiments with the 30 degree beveled cutting tool, the first principal component explained 71.3% of the total variation whereas the second principal component explained 19.7% of the total variation.

### **Conclusion**

The mechanical properties of coconut meat were found to greatly depend on the cultivar, maturity, and loading position. The punching and cutting energy varied between 5.57 ± 1.30 J to 168.89 ± 7.37 J and 9.28 ± 1.04 J to 254.21 ± 28.14 J, respectively, for all three cultivars. Whereas the punching force of coconut meat varied between 3.33 ± 0.14 N and 39.12 ± 6.65 N and cutting force between 12.87 ± 0.73 N and 119.02 ± 17.51 N. In the case of cutting and punching deformation, our study found no significant difference between cultivars, load position, and the bevel angle of the cutting tools. The results suggest that as the coconut mature, the meat gets harder and thicker causing an increase in force and energy that is required to perform the major unit operations. Another significant variation observed was with respect to the loading position. The meat taken from bottom section of the mature coconut were more hard than middle or eye section supposedly due to the presence of more mature fiber as solidification of the liquid endosperm starts from the bottom part of the fruit. Knowledge about these engineering properties of coconut meat and their relationships are necessary for the design and development of efficient post-harvest machinery. Coconut meat is a rich source of natural fiber and are used today to increase the dietary fiber content in many food products. The data and interpretation described herein can be used for design and development of an efficient fiber

extraction equipment. Moreover, the results can also be used for developing mechaneries such as coconut milk extractor, coconut scraping, grating and grinding machine, and coconut meat removal knife tools.

## Acknowledgments

We would like to thank PC Unit, AICRP on Post-Harvest Engineering and Technology, Ludhiana for the financial support. We express our sincere gratitude to the Director, ICAR-CPCRI, Kerala for providing the necessary facilities.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This work was supported by the Indian Council of Agricultural Research (ICAR)-All India Coordinated Research Project on Post-Harvest Engineering & Technology (AICRP on PHET), Ludhiana, India [1000767022].

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