

Comparison of engineering properties of organic and inorganic coconut: Implications on the design of coir fiber extraction machine

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Abstract

Coconut husk is widely used as a source of natural fibers in the tropics. Dehusking and fiber extraction are some of the important unit operations in coir manufacturing. For the development of an efficient and economically viable fiber extraction machine, the engineering properties of conventional and organically grown coconuts were evaluated. Selected engineering properties of whole coconut were investigated. The average true density and bulk density were in the range of 414.63 ± 111.85 to 529.28 ± 123.02 and 161.66 ± 24.41 to 212.23 ± 18.96 kg/m³, respectively. Along with whole coconuts, engineering properties of husk (weight, moisture content, and husk thickness), shell (weight, thickness, bulk density, and moisture content), and kernel parameters (weight, thickness, and moisture content) were also evaluated. The application of organic treatment (T4) exhibited substantial impacts, leading to a higher coconut weight (1.354 kg) as compared to conventional practices (T5), and increased dimensions (158.599 mm diameter and 205.000 mm height) and improved bulk density (190.97 kg/m³) in comparison to other organic treatments. In deshelled coconuts, T4 showcased a higher shell weight (175.667 g) and shell thickness (4.767 mm). The kernel parameters of T4 displayed enhancements, featuring a kernel weight of 314.334 g and a thickness of 11.774 mm. Although the study could not find any correlation between the farming practices and engineering characteristics of coconut fruit, the data presented herein could be utilized for the design and improvisation of efficient fiber extraction machines.

Practical Applications

Developing countries are exploring the possibilities of implementation of organic farming for the production of agro products. Implementation of organic farming not only affects yield but may also change the engineering properties and nutritional characteristics of products. Understanding the engineering properties of food products grown under organic conditions is important for the modification of the design in the existing machineries and/or development of new food processing equipments.

KEYWORDS

bulk density, coir, machine design, natural fibers, true density

1 | INTRODUCTION

Coconut is a versatile plantation crop cultivated in more than 90 countries around the world with its major production concentrated in Asia and Pacific. The major world production share of coconut is accounted by countries such as India, Philippines, Indonesia, Malaysia, Thailand, Sri Lanka, and Papua New Guinea. Coconut influences the rural economy of our country providing livelihoods for many farm households either directly or indirectly. As per Coconut Development Board (CDB, 2020), India has produced 20,308 million nuts from an area of 2173 ha with a productivity of 9345 nuts per hectare in the year 2019–2020. Most of its production comes from small and marginal farmers utilizing an array of inorganic fertilizers, pesticides, herbicides, and fungicides. Continuous use of these chemical alternatives has caused increased soil acidity, major and micronutrient imbalances, and decrease in soil biological properties (Djokoto et al., 2016). Hence, the current scenario warrants the application of low-cost organic and sustainable nutrient sources, which will help in improving and replenishing soil resources. It opens up enormous potential for practising organic farming in coconut-based production systems. With underlying input, technical, economic, and institutional concerns, one of the major issues related to organic products is the lack of sizeable markets and matching productivity. Lower yield ratios were considered a major constraint by 46.7% of farmers and there exists a common fear of lower yield with the adoption of organic methodologies (Jaganathan et al., 2013). The benefits of organic production methods over conventional production systems are still debatable (Reddy, 2010). Besides, there are economic, social, ethical, and market limitations on the acceptance of organic products. In addition, the lack of a solid and common standard agency or institutional mechanism is one of the major limiting factors in the recognition of the products. However, it is of no doubt that this arena is still lacking some relevant and major studies.

Coir, also known as coconut fiber, is a lignocellulosic fiber derived from the outer husk (exocarp layers) of the coconut fruit. Today, the demand for more biodegradable, sustainable, renewable, and recyclable materials is driving an increase in the use of coir fiber made from coconut husk. The extracted coir fibers often have a golden or brown-reddish color with a length and diameter ranging between 0.01 and 0.04 in. and from 12 to 24 μm , respectively (Rajan & Abraham, 2007a). Coconut husk contains between 20% and 30% fibers of varying lengths (Hasan et al., 2021). Additionally, the thick and coarse coir fibers made from coconut husks have qualities such as superior acoustic resistance, greater hardness quality, non-toxicity, resistance to microbial degradation, and the fibers do not exhibit combustible properties (Hasan et al., 2021; Rajan & Abraham, 2007a, 2007b).

India produces more than 80% of the world's coir fiber, making it the largest coir producer in the world (Prashant et al., 2014). The major unit operations involved in coir processing includes dehusking, soaking (for 3–6 months), composting, washing, de-fibered, drying, and so on. Chopping knives and crowbars were the traditional equipments in India for dehusking coconuts. When constructing an

ergonomically superior dehusking machine, the physical characteristics of the coconut fruits such as their weight, size, husk thickness, density, and moisture content are crucial (Pandiselvam et al., 2018). Traditional fiber manufacturing from husks is a time-consuming and labor-intensive procedure. Alternatively, mechanical defibered process is performed after 5 days of immersion of husk in water. Crushing, separation, washing, and drying are the major unit operations involved in the mechanical process of coir fiber extraction. The design and development of an efficient coconut fiber extraction machine could offer an effective solution to existing process challenges including time, labor costs, transportation cost, and dependency on skilled labor. For the right design and efficient operation of coconut fiber processing equipment, knowledge of the physical and morphological properties of the coconut husk is necessary. Designing and developing a coconut dehusking and fiber extraction machine requires extensive knowledge of the coconut's structure, density, porosity, moisture content, and weight. The cultivation practices adopted play a major role in defining the engineering properties of coconut. Hence, the effect of different cultivation practices on the properties of resultant fruit and its implications on the design and development of coir fiber extraction machine was investigated. Moreover, coconuts exhibit non-uniformity in both size and shape. Even slight alterations in the shape and size of these fruits can significantly impact the effectiveness of diverse processes and associated equipment. The design of machinery for processing, sorting, grading, transporting, and packaging fruits heavily relies on the physical characteristics of coconuts, which encompass bulk density, true density, and porosity (Sonawane et al., 2020). A deep understanding of coconut morphology and the distribution of morphological characteristics forms the foundation for all post-harvest processes related to coconuts such as dehusking, deshelling, testa removal, milk extraction, slicing, and drying (Pandiselvam et al., 2018). Understanding parameters such as testa thickness, sphericity, diameter, height, husk thickness, husk moisture content, shell diameter, shell height, and shell thickness is invaluable when designing testa removal machinery (Pandiselvam et al., 2019). Coconut kernel attributes, including weight, thickness, density, and moisture content, play a pivotal role in the design of machines used for grating, pulverizing, slicing, and milk extraction (Pandiselvam et al., 2021). This study investigates the engineering properties of coconut fruit and its derived products, focusing on the influence of organic and inorganic cultivation practices. Various parameters including weight, height, circumference, diameter, bulk density, true density, porosity, husk thickness, and moisture content were analyzed. The aim is to provide valuable scientific insights that may help in the design and development of efficient processing equipment for coir, dehusked coconut, and coconut kernel.

2 | MATERIALS AND METHODS

2.1 | Sample

The WCT cultivar (51-years-old tree) of coconut was grown under different treatments at the agricultural farm of ICAR-Central Plantation

Crops Research Institute (ICAR-CPCRI), Kasaragod, India. The details of treatments are presented in Table 1. Treatment involves amalgamation and assessment between different organic method permutations and delineating the combinations from the typical chemical fertilizer application method. The present treatment conditions were imposed from 2014 onwards. Coconuts of uniform sizes (30 from each treatment) were harvested and transported to the Agro Processing Complex, ICAR-CPCRI, Kasaragod (12.528 N latitude and 74.969 E longitude), for the measurement of different physical properties of nut and husk. Images of the fruits of coconut trees under different treatments are shown in Figure 1.

2.2 | Determination of coconut properties

2.2.1 | Weight

The weight of whole coconut, husk and coconut weight after dehusking, and shell and kernel weight were measured using the electronic weighing balance (M/s. Atlas Weighing, Chennai, India) having the sensitivity ± 0.5 g. Figure 2 depicts the different forms of coconut fruits used to measure the weight.

2.2.2 | Circumference, diameter, and height

The circumference (middle section) of the matured coconut was measured manually with the help of a measuring tape which has the least

count of 1 mm. The shape of the coconut was ellipsoid; therefore, the horizontal circumference was measured. The diameter of the coconut was derived from the circumference. The height was measured with the help of a digital vernier caliper which has the least count of ± 0.01 mm.

2.2.3 | Densities and porosity

The bulk density of coconut was calculated by measuring the mass of coconut and the volume including the pore space. The volume was measured by placing the coconut inside a container which has a volume of 0.0342 m^3 . The same procedure was followed for bulk density measurements of dehusked and deshelled coconut. The true density was calculated by the water displacement method. The porosity was calculated using the relationship between bulk density, true density, and porosity (Mohsenin, 2020; Pandiselvam et al., 2018).

2.2.4 | Husk thickness

The coconut was dehusked using a dehusking machine developed by ICAR-CPCRI, Kasaragod, India (Manikantan et al., 2018). The thickness of the husk at different orientations (H1, H2, H3, and H4) was measured using digital vernier calipers which has the least count of ± 0.01 mm. H1 and H2 represent the vertical distances between the perianth and shell and the shell and fruit base, respectively, whereas, H3 and H4 are the horizontal distances between the fruit skin and the shell on the right and left sides, respectively.

2.2.5 | Moisture content

The moisture content of husk, shell, and kernel was measured by keeping 30 g sample in a hot air oven at $106 \pm 1^\circ\text{C}$ for 24 h (Varghese et al., 2016) and then the moisture content was expressed in % d.b.

2.3 | Statistical analysis

The data of 30 coconuts from each treatment was collected, recorded, and subjected to analysis of variance and mean separation according

TABLE 1 Details of the organic farming technique followed in coconuts.

Details of the treatment	
T1	In situ organic matter (frond, inflorescence waste, and husk) recycling in trenches made in the inter space of 6 coconut palms (15 m length, 1.2 m width, and 60 cm depth) + in situ green manuring in the basin (100 g cowpea seeds shown in the basin of 1.8 m radius area and ploughing the same in the basin when it attained 50% flowering) + bioinoculants (100 g each of <i>Azospirillum</i> and phosphobacterium). Plant growth-promoting rhizobacteria (PGPR) consortia in the basin
T2	In situ organic matter (frond, leaf, inflorescence waste, and husk) recycling in trenches made in the interspace of 6 coconut palms (15 m length, 1.2 m width, and 0.60 m depth) + in situ green manuring in the basin + bioinoculants (100 g each of <i>Azospirillum</i> and phosphobacterium) + cow dung (50% or 25 kg of recommended dose of organic manure of all crops)
T3	Combination of T1 + 50% recommended K_2O using sulphate of potash (sulphate of potash is certified under organic)
T4	Combination of T2 + 50% recommended K_2O using sulphate of potash
T5	Chemical fertilizer application (500 g N, 320 g P_2O_5 , 1200 g K_2O applied in two splits) + coconut mulching in the basin (30 kg coconut leaves applied for mulching)

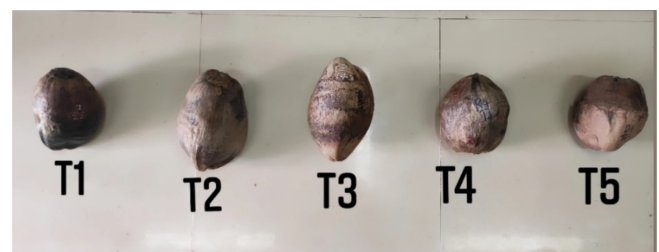


FIGURE 1 Different treatments of coconuts taken under this study.

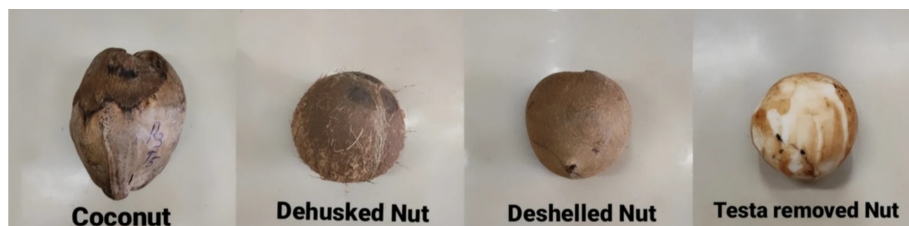


FIGURE 2 Different forms of the coconut fruits used to measure the engineering properties.

to Duncan's multiple range test with 5% level of significance using SAS software (SAS Institute, Cary, NC, USA).

3 | RESULTS AND DISCUSSION

3.1 | Coconut fruit properties

3.1.1 | Weight

The weight of the coconuts, undertaken from five different cultivation practices, was found to be ranging between 0.687 and 1.354 kg (Table 2). It is evident that the weight was high in the organic treatment T4 compared to the conventional approach of chemical fertilizer applications (T5). Among the organic treatments, higher values of weight of the sample were observed in T4 followed by T5 which shows that treatment had a significant effect ($p < .05$) on the weight of coconut. Even though there are not enough studies, the results suggest the possibility of production of good-quality coconut based on the proper selection of organic combinations. In spite of the treatment differences, studies have shown that there are considerable changes in the weight of the coconut depending on cultivation practices, species, maturity stage, and so on (Varghese et al., 2016). The combined application of the muriate of potash and borax recorded the increase in the nut weight up to 7 months of age (Sathi Babu et al., 2021). Continuous nutrient availability ensures increase in nut weight may be due to an increase in cell division and expansion of cell, involvement in hormonal metabolism, and also known to stimulate rapid mobilization of water and sugars in the nut (Singh et al., 2012).

Pandiselvam et al. (2018) examined the engineering properties of five different varieties of coconuts, namely Kera Shankara, Malayan Yellow Dwarf, Malayan Orange Dwarf, Chowghat Orange Dwarf, and Chowghat Green Dwarf, and reported that the average weight of the individual fruits varied significantly from 0.30 to 1.02 kg depending on the cultivar. Another study by Pandiselvam et al. (2019) reported that the weights of different tender coconut varieties (6–7 months old) vary between 1.32 and 2.34 kg. Hence, maturity stage of coconut is also an important factor affecting the weight of the coconut. The study also established that weight is one of the important physical parameters necessary for the design of tender coconut trimming machine and dehusking machine. The knowledge about husk weight and fiber dimension is essential for an effective design of the feed hopper and fiber extraction and/or crushing unit in coir machine.

3.1.2 | Height, circumference, and diameter

Similar to the other parameters, dimensional fractions of coconut were better in organic sample T4 than the conventional sample. Contrary to these results, the height of coconut was higher in samples obtained from T3, followed by T2. Organic manures having the property of releasing nutrients in a slow manner helps in continuous supply of essential nutrients to the palms for a longer period which in turn helps in the improved growth and development of the palm. The superior performance of T2 to T4 treatments may be attributed to higher availability of potassium along with other major and micro nutrients and their higher uptake through an efficient root system in the plants as potassium is the limiting factor for coconut production (Hameed Khan et al., 2001). The synergistic effect of *Azospirillum* and *Phosphobacterium* contributed to higher availability and uptake of nutrients, resulting in a higher yield (Latha et al., 2009). Besides the proven nutritional qualities, superior visual and physical properties of organic produce are reported widely in several studies (Menezes Ayres et al., 2019; Zhao et al., 2007). Moreover, the height and diameter of the coconuts are also reported to vary depending on the cultivars and maturity. The height of *Namhom* coconut—a variety of Thai young coconut—was reported to be 179.7 ± 5.3 mm by Jarimopas et al. (2009), whereas the height of mature Nigerian coconuts were reported to be 184.93 mm (Alonge & Adetunji, 2011). The physical attributes of coconuts determine the fruit's shape and size, and these properties are vital in the development of machinery and equipment employed in post-harvest operations like grading, sorting, dehusking, and so on. Knowledge about these dimensional parameters is crucial in the design of a coconut dehusking machine, as these dimensions are essential in designing an effective fruit holder for dehusking. These parameters can also be used to calculate the sphericity of the coconut fruits, which in turn determines the design of an extraction unit. To separate the husk from coconuts, commercially available coconut dehusking machines have two spike teeth rollers. The machine's capacity and effectiveness depend on the distance between the rollers and spike design used to dehusk coconuts. Therefore, measuring the diameter and circumference of coconuts is crucial in determining the clearance between the dehusking rollers and spike tooth length and diameter. If the size of the coconut is smaller than the space between the rollers, then not enough shearing and impact force is applied on the surface of the coconut husk. As a result, it is possible that coconuts will rotate between the rollers, resulting in either no dehusking or only partial dehusking, ultimately decreasing the machine's capacity and efficiency (Deo et al., 2020). The parameters crucial for the design of machinery are foundational when it comes to creating equipment for the grading, sorting, packaging, and handling of diverse horticultural products, such as coconuts. Given the non-

TABLE 2 Consolidated data of various parameters of mature coconut.

Treatment	Coconut weight (kg)	Diameter (mm)	Height (mm)	Bulk density (kg/m ³)	True density (kg/m ³)	Porosity (%)
T1	0.687 ± 0.10 ^b	147.086139.784 ± 22.936.19 ^a	170.334 ± 13.05 ^b	185.97 ± 38.12 ^{ab}	475.17 ± 85.11 ^a	64.305 ± 7.32 ^a
T2	0.785 ± 0.29 ^b	144.707 ± 17.03 ^a	205.000 ± 32.917 ^{ab}	161.66 ± 24.41 ^b	414.63 ± 111.85 ^a	59.176 ± 6.16 ^a
T3	0.85 ± 0.34 ^b	139.784 ± 6.19 ^a	209.334198.334 ± 13.209.8 ^{ab}	169.15 ± 22.02 ^{ab}	486.19 ± 45.17 ^a	60.222 ± 5.18 ^a
T4	1.354 ± 0.16 ^a	158.599 ± 15.06 ^a	185.334 ± 7.02 ^a	190.97 ± 4.77 ^{ab}	529.28 ± 123.02 ^a	62.210 ± 0.94 ^a
T5	1.198 ± 0.09 ^a	157.14 ± 8.73 ^a	198.334 ± 9.87 ^a	212.23 ± 18.96 ^a	504.17 ± 94.5 ^a	60.093 ± 3.56 ^a

Note: Values with the same letters are not significantly different at 5% level.

uniformity in the size and shape of these products, even slight variations in their dimensions can lead to reduced operational efficiency in various processes and related equipment. Utilizing different models, it becomes possible to achieve more precise separation of fruits based on minor variations in shape and size, which holds great potential for automating the grading system of fruits on an industrial scale. The above data can be used for such predictive modeling in future studies.

3.1.3 | Density and porosity of coconut samples

Coconut samples from organic treatments were found to have substantial density and porosity elements. There were no significant differences between the treatments in true density which ranged between 414.634 and 529.277 kg/m³. The bulk density of the samples ranged from 161.657 to 212.227 kg/m³ with no significant variance between treatments T2, T4, and T5 (Table 2). Higher true and bulk densities of coconut could be ascribed to treatment T4 and T5. It implies the magnitude of synergy and combinations of organic inputs in modulating this parameter under study. True density values of these organically grown samples were comparable with certain other important dwarf varieties of coconut including Chowghat Green Dwarf (CGD) (Pandiselvam et al., 2018). Importance and likelihood of treatment combinations could elucidate the disparity in the values. However, maximum porosity was observed in T1 treatment with no remarkable variances between the different treatments. The porosity and density of the coconuts are reported to vary depending on the maturity, variety, and moisture content of the coconuts (Alonge & Adetunji, 2011; Pandiselvam et al., 2018; Pandiselvam et al., 2019). The bulk densities of mature coconut from Malayan Yellow Dwarf, Kera Shankara, Malayan Orange Dwarf, Chowghat Orange Dwarf, and Chowghat Green Dwarf varieties (Pandiselvam et al., 2018) were higher than the WCT cultivar and varied from 273.42 ± 62.94 to 375.77 ± 114.84 kg/m³. The bulk densities also tend to decrease with decrease in moisture content and varied from 222.58 ± 62.66 to 348.83 ± 106.28 kg/m³ and a similar trend was also observed with the porosity values. The porosity of mature coconut varied from 27.6% ± 9.1% to 62.6% ± 4.6% (Pandiselvam et al., 2018). The density and porosity of the sample plays an important role in determining the power of the equipment as higher density could yield higher weight per unit volume on the dehusking roller or knife, thereby affecting the shearing efficiency. The physical properties of coconuts, including bulk density, true density, and porosity, are instrumental parameters in the design of equipment for processing, sorting, grading, transportation, and packaging of fruits. Notably, porosity is a key attribute that influences the management of storage temperatures for fruits (Sonawane et al., 2020).

3.2 | Properties of husk

3.2.1 | Weight and moisture content

Weight of the husk of coconut grown under different conditions varied very little due to the treatment environments. Amid higher values

of weight in treatment T3, the weight of the husk ranged between 0.346 and 0.660 kg (Table 3) and was within the range of previous reports (Pandiselvam et al., 2018). Alongside, there were no significant differences in the parameters within the treatment. Possibility of positive and negative deviations within the similar combinations of treatments necessitates more detailed study. Moisture values of the husk declined to trail a prefigure with higher values of 43.894% observed in treatment T5. No significant differences were reported between organic treatments. In the husk parameters, no significant variance was observed between the inorganically and organically grown coconut samples. The moisture content of the husk can in turn affect the mechanical properties of the coconut fibers. Studies have reported that green coconut fiber has low tensile properties (Lomeli-Ramírez et al., 2018). Moreover, Terdwongworakul et al. (2009) reported a high rupture force for green coconuts compared to the brown fibers. Hence, dehusking and defibering of young coconut is easy than mature coconut. This is because the presence of high moisture in the fiber tissue causes its easy deformation and thereby rupture. The values of tensile strength and rigidity could be useful to determine the shear and cutting force needed for dehusking and extraction of fiber from coconut husk.

3.2.2 | Husk thickness

The effect of treatments on the husk thickness varied depending on the position of evaluation. Compared to bottom (H2), right (H3), and left sides (H4), a significant difference between the treatments was observed in the thickness at the top portion (H1) (Table 3). With the higher value of 59.00 mm recorded for T1 treatment, the thickness at the top portion varied between 34.81 and 59.00 mm. Thickness values of coconut husk samples varied between 24.804 and 33.947 mm at bottom (H2), 17.564 and 22.844 mm at right side (H3), and 15.48 and 21.25 mm at left side (H4). Our findings were in accordance with the results of Jarimopas et al. (2009), Pandiselvam et al. (2018), and Pandiselvam et al. (2019), where the dimensions of mature and young tender coconuts were evaluated. In comparison with the individual treatments, the synergy of various treatments modified the overall thickness of the husk. Knowledge about the husk thickness is important as it can help determine the length and distance between the spike tooth rollers and crushing/extraction unit (distance

between the crushing unit and sieve) of the dehusker and fiber extraction machine.

3.3 | Properties of dehusked coconut

3.3.1 | Weight, diameter, and bulk density of samples

The diameter of dehusked coconut also followed a similar trend as observed in tender coconut (Table 4). The diameter of dehusked samples ranged from 92.88 to 108.79 mm suggesting coconut from organic methods had more diameter (T4 > T2 > T3) than that of inorganic treatment (T5). The effectiveness of a combination of different natural techniques is evident in the results. Combination treatments had a better parameter value and the highest diameter of 108.79 mm was observed in treatment T4 (Table 4). The observed diameter of the dehusked coconut was in accordance with the results of Asha Monicka et al. (2017), who investigated the attributes of dehusked West Coast tall variety of coconuts. It reported a diameter for the dehusked coconut in the range of 70–120 mm. Comparable drift followed after dehusking of coconut samples suggests the effectiveness of the treatment. Organic treatment was found to be effective in maintaining the sensory properties of the produce than the product of the conventional management (Rembiałkowska, 2007). However, with the bulk density of the samples, superiority was there in T1 than conventional treatments. Treatments were found to have a significant effect on these samples with values ranging from 360.81 to 442.31 kg/m³. Contrary to other findings, coconut obtained from organic treatment exhibited higher values of bulk density than the inorganic ones. It also implied the likelihood of organic treatment methods in enhancing the edible portion of the produce. The weight of the dehusked coconut ranged between 0.346 and 0.660 kg with the maximum value observed in treatment T4 followed by T5. Weight of the sample was on par with inorganic method denoting the effect of organic treatment in maintaining the quantitative parameter of the samples. The increase in the availability of potassium, nitrogen, and phosphorus in the soil under the integrated nutrient management system might have induced the weight of dehusked coconut (Bhalerao et al., 2021; Karna et al., 2022). A similar observation was reported by Asha Monicka et al. (2017) on the weight of dehusked coconuts where the weights

TABLE 3 Coconut husk parameters evaluated.

Treatment	Husk weight (kg)	Moisture content, % d.b.	Husk thickness (mm)			
			H1 (top), mm	H2 (bottom), mm	H3 (right), mm	H4 (left), mm
T1	0.346 ± 0.152 ^a	33.367 ± 20.214 ^{ab}	59.00 ± 8.688 ^a	28.69 ± 7.245 ^a	18.374 ± 7.296 ^a	15.48 ± 2.629 ^a
T2	0.411 ± 0.099 ^a	18.681 ± 13.153 ^b	34.807 ± 20.362 ^b	24.804 ± 3.302 ^a	21.524 ± 3.248 ^a	19.16 ± 5.263 ^a
T3	0.660 ± 0.266 ^a	34.491 ± 3.776 ^{ab}	37.124 ± 3.83 ^{ab}	26.13 ± 0.715 ^a	22.844 ± 1.317 ^a	21.25 ± 6.786 ^a
T4	0.421 ± 0.304 ^a	28.371 ± 21.542 ^b	39.174 ± 8.956 ^{ab}	29.557 ± 4.049 ^a	17.564 ± 5.765 ^a	18.45 ± 4.572 ^a
T5	0.529 ± 0.087 ^a	43.894 ± 22.528 ^a	43.36 ± 11.466 ^{ab}	33.947 ± 5.635 ^a	17.84 ± 2.511 ^a	17.63 ± 2.617 ^a

Note: Values with the same letters are not significantly different at 5% level.

of the nut ranged from 0.180 to 0.725 kg. The study was conducted using 100 West Coast Tall variety coconuts grown under inorganic conditions, where the weights of the nuts showed a normal distribution and followed Gaussian model with the maximum number of nuts falling in range of 400–600 g.

3.4 | Properties of deshelled coconut

3.4.1 | Shell parameters

Unlike other parameters evaluated, a significant difference between the inorganic and organic treatment methods was observed in shell weight. Parameter values ranged between 93.33 and 175.667 kg showing variations due to treatments (Table 5). Shell weight was higher in treatment T4, followed by T5, correlating with the weight parameter of tender coconuts. The results are in accordance with the report of Pandiselvam et al. (2018) which depicted the relation of higher shell weight to heavier and intact coconut. The shell thickness of the deshelled coconut samples exhibited higher values toward

organic treatment T4. The value ranged between 4.207 and 4.767 mm. The shell thickness observed in our study was higher than the earlier values reported by Varghese et al. (2016), where the authors reported an average shell thickness of 3 mm. There was no significant difference between the treatments in case of bulk density values with the maximum density shown by treatment T4 and the minimum value by treatment T2. The information on shell moisture content, weight, and thickness are of paramount importance for the design and development of cutting wheel in deshelling equipment.

3.4.2 | Kernel parameters

The weight of the kernel ranged between 187.33 and 314.33 g suggesting the effect of the type of treatment on the parameter. Lower weight values were detected in organic treatment T1 and higher values were found in treatments T4 (Table 6). There was no significant difference between T2 and T3 treatments. Kernel weight if correlated with the overall weight showed a similar trend and emphasized the fact that the organic treatment had an impact on the quality aspect of

TABLE 4 Consolidated data on parameters of dehusked coconut.

Treatment	Weight after dehusking (kg)	Diameter after dehusking (mm)	Bulk density (kg/m ³)
T1	0.346 ± 0.152 ^a	92.88 ± 13.68 ^b	442.31 ± 53.66 ^b
T2	0.421 ± 0.304 ^a	107.34 ± 5.75 ^{ab}	360.81 ± 8.33 ^{ab}
T3	0.411 ± 0.099 ^a	102.48 ± 13.16 ^{ab}	395.75 ± 45.27 ^a
T4	0.660 ± 0.266 ^a	108.79 ± 5.68 ^b	380.25 ± 24.12 ^{ab}
T5	0.529 ± 0.087 ^a	98.00 ± 33.72 ^a	395.28 ± 25.03 ^{ab}

Note: Values with the same letters are not significantly different at 5% level.

TABLE 5 Consolidated data on shell parameters.

Treatment	Shell weight (g)	Shell thickness (mm)	Bulk density of deshelled coconut (kg/m ³)	Moisture content of shell, % d.b.
T1	93.334 ± 11.931 ^c	4.207 ± 1.26 ^b	304.594 ± 4.841 ^b	9.129 ± 17.869 ^a
T2	133.334 ± 38.084 ^b	4.406 ± 0.808 ^a	240.499 ± 23.7 ^c	8.394 ± 0.525 ^b
T3	144 ± 12.125 ^{ab}	4.151 ± 0.776 ^b	281.98 ± 39.41 ^{bc}	7.502 ± 2.595 ^b
T4	175.667 ± 15.568 ^a	4.767 ± 0.352 ^{ab}	332.80 ± 35.2 ^a	10.334 ± 8.82 ^{ab}
T5	162.334 ± 6.028 ^{ab}	4.492 ± 0.967 ^a	304.787 ± 11.085 ^b	7.403 ± 2.388 ^b

Note: Values with the same letters are not significantly different at 5% level.

TABLE 6 Consolidated data on kernel parameters.

Treatment	Kernel weight (g)	Kernel thickness (mm)	Volume of water (mL)
T1	187.334 ± 61.809 ^c	6.920 ± 5.774 ^a	47.35 ± 33.95
T2	218.667 ± 24.007 ^b	9.156 ± 2.205 ^a	41.538 ± 36.71
T3	230.334 ± 24.007 ^{ab}	8.820 ± 0.491 ^a	72.73 ± 72.24
T4	314.334 ± 77.359 ^a	11.774 ± 0.758 ^a	92.96 ± 53.52
T5	285 ± 13.077 ^{ab}	10.305 ± 1.254 ^a	107.88 ± 62.07

Note: Values with the same letters are not significantly different at 5% level.

the produce. Application of potassium and boron not only increased nut size and nut weight but also facilitated the faster translocation of starch and sugar from leaves to nuts, higher sweetness of the coconut water, kernel development, and softness of the biomass of the copra (Sathi Babu et al., 2021). Karna et al. (2022) also reported that the application of green manuring + bio fertilizers + organic recycling + soil test based nutrients NPK (chemical fertilizers) application significantly increased the weight of the kernel and copra. Comparably, thickness value was higher in case of treatments T4 and T5 and lower in case of T1. Analyzing the volume of water obtained from these treated samples, higher volume of water was obtained in the case of T5 and T4 coconut samples. Added to that is the lowest volume of water obtained from organic treatment T2. A slightly higher kernel thickness in the range of 7.98 ± 0.58 (for the cultivar Chowghat Orange Dwarf) to 12.57 ± 0.38 mm (for Malayan Orange Dwarf) was reported by Pandiselvam et al. (2018). This increased thickness may be due to the difference in coconut maturity as maturity of the coconut is reported to affect the kernel thickness (Pandiselvam et al., 2021). Kernel weight of the samples were in range with that of previous reported values by Pandiselvam et al. (2018) and varied from 96.42 ± 19 (Chowghat Green Dwarf) to 316.32 ± 28 g (Malayan Orange Dwarf). Coconut meat is a rich source of natural fibers. For the efficient extraction of coconut meat, it is necessary to know about the kernel parameters (Pandiselvam et al., 2021). For the design and development of effective post-harvest equipment, knowledge of these engineering characteristics of coconut meat and their interactions is required. The design and improvement of effective dietary fiber extraction machinery can be aided by the data and interpretation discussed in this study.

4 | CONCLUSION

The present study revolves around the suitability and effect of different methods of cultivation on the engineering parameters of coconut. In comparison, each engineering parameter was showing higher values in organic treatment method, with the superiority of treatment T4. In the production of coir, dehusking and extraction are a crucial unit operation. Identification of the engineering characteristics of coconut is essential for designing innovative, ergonomically superior coconut dehusking and fiber extraction equipment. The design and improvement of effective fiber extraction machinery can be aided by the data and interpretation discussed here. Additionally, these findings can be applied in the development of machinery to remove coconut testa, a desheller, and a machine to extract coconut meat, among others. Due to lack of component analysis of edible portion and nutritional evaluation, it is not appropriate to establish the advantage of organic method. Hence, the possibility of further studies of the nutritional and component aspects of these samples is necessary.

AUTHOR CONTRIBUTIONS

Ravi Pandiselvam: Conceptualization; methodology; investigation; original draft. **M. R. Manikantan:** Conceptualization; methodology;

investigation. **P. Subramanian:** Methodology; investigation. **M. Anjaly Shanker:** Methodology; investigation; writing original draft. **Anandu Chandra Khanashyam:** Methodology; investigation; writing original draft. **R. Surekha:** Investigation; resources; original draft. **Alka Gupta:** Investigation; writing original draft; review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

- Alonge, A. F., & Adetunji, W. B. (2011). Properties of coconut (*Cocos nucifera* L.) relevant to its dehusking. *Journal of Agricultural Science and Technology A*, 1(11), 1089–1094. <https://doi.org/10.17265/2161-6256/2011.11a.020>
- Asha Monicka, A., Pandiarajan, T., Ganapath, S., Indu Rani, C., & Sathy, R. (2017). Characterization of attributes in dehusked coconut. *Journal of Agricultural Engineering*, 54(4), 1–10.
- Bhalerao, P. P., Maheswarappa, H. P., & Sumitha, S. (2021). Effect of integrated nutrient management on coconut (*Cocos nucifera*) based cropping systems in south Gujarat. *Current Horticulture*, 9(2), 52–55.
- CDB. (2020). *All India final estimates of area and production of coconut*. Retrieved from <http://www.coconutboard.gov.in/Statistics.aspx>
- Deo, M. M., Mathew, A. C., Manikantan, M. R., & Hebbar, K. B. (2020). Performance evaluation of semi-automatic coconut de-husking machine for west coast tall variety of coconut. *International Journal of Current Microbiology and Applied Sciences*, 9(6), 3187–3194. <https://doi.org/10.20546/ijcmas.2020.906.381>
- Djokoto, J. G., Owusu, V., Awunyo-Vitor, D., & Yildiz, F. (2016). Adoption of organic agriculture: Evidence from cocoa farming in Ghana. *Cogent Food & Agriculture*, 2(1), 1242181. <https://doi.org/10.1080/23311932.2016.1242181>
- Hameed Khan, A., Upadhyay, A. K., & Palaniswami, C. (2001). Potassium in plantation crops. In: *Proc. Intl. Symp. on K in nutrient management for sustainable crop production in India*. New Delhi, India (pp. 467–497).
- Hasan, K. M. F., Horvath, P. G., Bak, M., & Alpar, T. (2021). A state-of-the-art review on coir fiber-reinforced biocomposites. *RSC Advances*, 11(18), 10548–10571. <https://doi.org/10.1039/d1ra00231g>
- Jaganathan, D., Thamban, C., Jose, C., Jayasekhar, S., & Anithakumari, P. (2013). Analysis of organic farming practices in coconut in South India. *Journal of Plantation Crops*, 41(1), 71–79.
- Jarimopas, B., Ruttanadat, N., & Terdwongworakul, A. (2009). An automatic trimming machine for young coconut fruit. *Biosystems Engineering*, 103(2), 167–175. <https://doi.org/10.1016/j.biosystemseng.2008.10.004>
- Karna, A. K., Mishra, G., Nayak, P. K., Sahoo, S. C., Nayak, R. K., & Panda, R. K. (2022). Effect of cropping systems and integrated nutrient management on growth and yield of coconut in littoral sand. *International Journal of Plant & Soil Science*, 34(23), 1502–1509.
- Latha, A., Radhakrishnan, V. V., & Mini, S. (2009). Effect of organic manures and biofertilisers on nutrient uptake, yield and quality of *Plumbago rosea* grown as intercrop with coconut. *Journal of Plantation Crops*, 37(2), 157–159.

- Lomeli-Ramírez, M. G., Anda, R. R., Satyanarayana, K. G., de Muniz, G. I. B., & Iwakiri, S. (2018). Comparative study of the characteristics of green and brown coconut fibers for the development of green composites. *BioResources*, 13(1), 1637–1660.
- Manikantan, M. R., Pandiselvam, R., Beegum, S., & Mathew, A. C. (2018). Harvest and postharvest technology. In *The coconut palm (Cocos nucifera L.) – Research and development perspectives* (pp. 635–722). Springer.
- Menezes Ayres, E. M., Lee, S. M., Boyden, L., & Guinard, J. X. (2019). Sensory properties and consumer acceptance of cantaloupe melon cultivars. *Journal of Food Science*, 84(8), 2278–2288. <https://doi.org/10.1111/1750-3841.14724>
- Mohsenin, N. N. (2020). *Physical properties of plant and animal materials: v. 1: Physical characteristics and mechanical properties*. Routledge.
- Pandiselvam, R., Khanashyam, A. C., Manikantan, M. R., Balasubramanian, D., Beegum, P. P. S., Ramesh, S. V., Kothakota, A., Niral, V., & Shil, S. (2021). Textural properties of coconut meat: Implication on the design of fiber extraction and coconut processing equipment. *Journal of Natural Fibers*, 1–13, 11092–11104. <https://doi.org/10.1080/15440478.2021.2009401>
- Pandiselvam, R., Manikantan, M. R., Kothakota, A., Rajesh, G. K., Beegum, S., Ramesh, S. V., Niral, V., & Hebbar, K. B. (2018). Engineering properties of five varieties of coconuts (*Cocos nucifera* L.) for efficient husk separation. *Journal of Natural Fibers*, 17, 1–9. <https://doi.org/10.1080/15440478.2018.1507863>
- Pandiselvam, R., Manikantan, M. R., Subhashree, N., Mathew, A. C., Balasubramanian, D., Beegum, P. P. S., Ramesh, S. V., Niral, V., Ranjini, T. N., & Hebbar, K. B. (2019). Correlation and principal component analysis of physical properties of tender coconut (*Cocos nucifera* L.) in relation to the development of trimming machine. *Journal of Food Process Engineering*, 42, 1–9. <https://doi.org/10.1111/jfpe.13217>
- Prashant, Y., Gopinath, C., & Ravichandran, V. (2014). Design and development of coconut fiber extraction machine. *SAS Tech Journal*, 13(1), 64–72.
- Rajan, A., & Abraham, T. E. (2007a). Coir fiber–process and opportunities. *Journal of Natural Fibers*, 3(4), 29–41. https://doi.org/10.1300/J395v03n04_03
- Rajan, A., & Abraham, T. E. (2007b). Coir fiber process and opportunities. *Journal of Natural Fibers*, 4(1), 1–11. https://doi.org/10.1300/J395v04n01_01
- Reddy, B. S. (2010). Organic farming: Status, issues and prospects – A review. *Agricultural Economics Research Review*, 23(347–2016-16927), 343–358.
- Rembiałkowska, E. (2007). Quality of plant products from organic agriculture. *Journal of the Science of Food and Agriculture*, 87(15), 2757–2762.
- Sathi Babu, N., Medda, P. S., Bhattacharjee, H., Kumar Sinha, A., & Ghosh, A. (2021). Leaf boron and potassium and nut weight in coconut (*Cocos nucifera* L.) as affected by their individual and combined applications in Terai region of West Bengal. *International Journal of Current Microbiology and Applied Sciences*, 10(2), 919–927.
- Singh, P. C., Gangwar, R. S., & Singh, V. K. (2012). Effect of micronutrients spray on fruit drop, fruit quality and yield of Aonla cv. Banarasi. *Hort-Flora Research Spectrum*, 1(1), 73–76.
- Sonawane, D., Pathak, S. S., & Pradhan, R. C. (2020). Physical, thermal, and mechanical properties of bael fruit. *Journal of Food Process Engineering*, 43(February), e13393. <https://doi.org/10.1111/jfpe.13393>
- Terdwongworakul, A., Chaiyapong, S., Jarimopas, B., & Meeklangsaen, W. (2009). Physical properties of fresh young Thai coconut for maturity sorting. *Biosystems Engineering*, 103(2), 208–216. <https://doi.org/10.1016/j.biosystemseng.2009.03.006>
- Varghese, A., Francis, K., & Jacob, J. (2016). A study of physical and mechanical properties of the Indian coconut for efficient dehusking. *Journal of Natural Fibers*, 14(3), 390–399. <https://doi.org/10.1080/15440478.2016.1212760>
- Zhao, X., Chambers, E., IV, Matta, Z., Loughin, T. M., & Carey, E. E. (2007). Consumer sensory analysis of organically and conventionally grown vegetables. *Journal of Food Science*, 72(2), S87–S91.

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