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Physico-chemical characterization of coconut shell (*Cocos nucifera*)

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Abstract
Coconut shell (*Cocos nucifera*) is a widely available agricultural waste. However, their disposal poses environmental challenges and economic burdens. The study assesses the physical characteristics, proximate analysis, ultimate analysis, and higher heating value of coconut shell (*Cocos nucifera*). Physical measurements of randomly selected 25 samples revealed average weight, height, and thickness. Proximate analysis of samples indicated low moisture content (7.67%), making it suitable for thermal application process. Calorific value was found to be 4339.85 kcal kg^{-1}, indicating good combustion characteristics. Ultimate analysis using the multilinear regression technique (MLR model) equations showed high carbon content (56.43%), supporting its suitability as a combustion fuel. To explore their potential utilization, this study examines the physico-chemical properties of coconut shells, highlighting their suitability for various applications and underscoring the importance of implementing sustainable waste management approaches.

Keywords: Coconut shell (*Cocos nucifera*), physical properties; proximate analysis; ultimate analysis; calorific value, multilinear regression technique (MLR)

1. Introduction

Biomass is renewable in nature, plentily available, evenly distributed, carbon neutral and more economical than other renewable sources. It serves as a vital renewable energy resource that accounts for nearly 75 % of rural energy needs, and the rural population constitutes 70 % of the total population of India. Major agricultural crops of the Konkan region in Maharashtra are rice, millets, pulses, coconut, etc. Biomass can either be used directly or converted into other form of energy. The types of biomass usually the ones which are used for burning purposes viz: domestic cooking, heating in rural areas (Komala and Prasad, 2016) [10]. A few names are: Coconut shell, Rice husk, Maize stalks, Ground nut straw/shell, etc. are used for heating and cooking in rural areas. Coconut is cultivated in over 95 countries around the world, in the tropical belt of world over an area of about 12,196 million hectare with production of 69,836.36 million nuts and productivity is 49969 nuts per hectare (FAO, 2019) [6]. The coconut shell (*Cocos nucifera*) is a widely available agricultural waste renowned for its low ash content, high carbon, and volatiles, making it a cost-effective biomass source and and available in rural areas and during almost all seasons of the year. India, ranking third in coconut production globally, generates approximately 3.18-4.20 million tonnes of coconut shells annually. These shells, alongside fibrous husks, are by-products of coconut processing, contributing significantly to agricultural waste (Gunasekaran *et al*. 2012; Prakash *et al*. 2018) [7, 14]. On average each coconut tree yields 70-100 nuts per year which in turn will provide about 21-30 kg of coconut shells (Manjula *et al*. 1985) [12]. Konkan region of Maharashtra is a major coconut producing region in the Maharashtra. The average production of coconuts in the Konkan region is about 1,313.8 lakh nuts annually (Suhas *et al*. 2018) [16]. In Konkan region, the average production potential of coconut shell as a biomass is 17,737.64 tonnes annually. Coconut shells and husk are usually biomass or the waste products of coconut processing plants producing coconut oils and coconut flakes. The shell of the mature coconut is a uniformly dense material like hardwood that consists mainly of lignin and cellulose. The coconut shell stands as a significant contributor to global pollution issues, with approximately 3.19 million tonnes generated annually, representing over 60% of India's national waste volume (Ting *et al*. 2015) [17].

Originating largely from local coconut industries, it constitutes a readily available agricultural waste. With an energy content of 16.7 Giga Joules/ Tonne for husks and a calorific value of 20.81 MJ/kg for shells, they present substantial potential for various applications, including thermal processes (like heating, cooking, drying process), coconut shell powder production, handicrafts, and charcoal production (Dongardive *et al*. 2019; Raghavan, 2010) [5, 15]. However, their disposal poses environmental challenges and economic burdens Keeping all these points in view, the physico-chemical properties of coconut shell (*Cocos nucifera*) was studied.

2. Materials and Methods

The research study was carried out by using locally available coconut shell (*Cocos nucifera*) and these were collected from hotels, temples etc. The physical characteristics of coconut shells were measured by random selection of 25 samples of available coconut shells (half shells) in terms of weight, thickness and height. The proximate analysis, ultimate analysis, and gross heating value of coconut shell (*Cocos nucifera*) was found by selecting three samples from 25.

2.1 Characterization of biomass as feedstock

i. Physical characteristics of coconut shell

The physical characteristics of coconut shell were measured by random selection of 25 samples of available coconut shells (half shells) in terms of weight, thickness and height. The weight, thickness and height of 25 randomly selected coconut half shells were recorded by using electronic weighing balance, vernier caliper (L. C. 0.02 mm) and scale.

ii. Proximate analysis

The proximate analysis of sample was conducted using the analytical method ASTME-3173, 3174 and 3175. The analysis of moisture was determined as per ASTME-3173. The quantity of ash was determined according to ASTME-3174. The fraction of volatile was determined as per ASTME-3175 and the fixed carbon was determined by subtracting the summation of volatile matter, moisture content, and ash content from 100.

a. Moisture content

As per the ASTM D-3173, The moisture content of the raw biomass was assessed by measuring the weight loss of the material through the hot air oven drying method. Subsequently, the moisture content was computed by using formula:

$$\text{Moisture, \% (wet basis)} = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100 \qquad (1)$$

$$\text{Moisture, \% (dry basis)} = \frac{(W_2 - W_3)}{(W_3 - W_1)} \times 100 \qquad (2)$$

Where,
W_1 = Weight of crucible, g
W_2 = Weight of crucible + initial weight of sample, g
W_3 = Weight of crucible + weight of dried sample, g
b. Volatile matter

As per ASTM D- 3175, the volatile matter was assessed by placing the oven-dried sample, obtained after determining the moisture content, in a sealed crucible at a temperature of 950 ± 20 °C for seven minutes in a muffle furnace (Quality NSW-101, MF-1, Temperature range 0-1200 °C). The weight loss was then measured as the percentage of volatile matter present in the sample.

$$\text{Volatile Matter, \% (dry basis)} = \frac{(W_3 - W_4)}{(W_2 - W_1)} \times 100 \qquad (3)$$

Where,
W_1 = Weight of crucible, g
W_2 = Weight of crucible + sample, g
W_3 = Weight of crucible +weight of sample before keeping in muffle furnace, g
W_4 = Weight of crucible + weight of sample after keeping in muffle furnace, g

c. Ash content

As per ASTM D-3174, the residual samples underwent gradual heating in a muffle furnace to 750 °C for 30 minutes. After cooling, they were weighed repeatedly until a constant weight was achieved. The weight of the residue indicated the sample ash content as a percentage basis.

$$\text{Ash, \% (dry basis)} = \frac{(W_5 - W_1)}{(W_2 - W_1)} \times 100 \qquad (4)$$

Where,
W_1 = Weight of crucible, g
W_2 = Weight of crucible + sample, g
W_5 = Weight of crucible + Constant weight of sample after keeping in muffle furnace, g

d. Fixed carbon

The fixed carbon (FC) content in the sample gives a rough indication of the charcoal yield. The fixed carbon is estimated by using the following formula

$$\text{Fixed carbon (\%)} = 100 - \text{\% of (moisture content + volatile matter + ash)} \qquad (5)$$

iii. Heating value of coconut shell

The gross heating value of coconut shell (*Cocos nucifera*) was found using a bomb calorimeter (ASTME–711) under controlled conditions with 25 atmospheric pressure of oxygen to ensure complete combustion. The water equivalent of the apparatus was determined by burning a known weight (1.0 g) of pure and dry benzoic acid in powdered form in the bomb under identical conditions, with the rise in temperature noted for 5 minutes. The standard heating value of benzoic acid (6324 cal/g) was used to calculate the water equivalent. This allowed for the determination of the higher calorific value of coconut shell (*Cocos nucifera*) through the bomb calorimeter experiment was determined as

$$\text{Gross Calorific Value, } Q = \frac{[(W+w)(T_2 - T_1 + t_C)] - [t_A + t_F + t_T]}{m} \qquad (6)$$

Where,
W = Mass of water placed in the calorimeter, g
w = Water equivalent of the apparatus, g
T_1 = Initial temperature of water in the calorimeter, °C
T_2 = Final temperature of water in the calorimeter, °C
t_C = Cooling correction
t_A = Acid correction
t_F = Fuse wire correction
t_T = Cotton thread correction
m = Mass of fuel sample taken in the crucible, g

iv. Ultimate Analysis
The ultimate analysis includes determination of Carbon content, Hydrogen content, Oxygen content and Nitrogen content of the fuels. The ultimate analysis is helpful in calculating heat balances in any process in which biomass is used as fuel. Using the values of proximate analysis, ultimate analysis of the biomass was calculated by using the multilinear regression technique (MLR model) equations for predicting the elemental compositions of coconut shell (*Cocos nucifera*) (Lawal *et al*. 2021) [11].

i. Carbon Content, (%)
Carbon content (C) of the sample was calculated based on the following formula,

$$C = 348.4658 - 2.36909FC - 2.97122VM - 3.5354A - 3.67567M \quad (7)$$

ii. Hydrogen Content, (%)
The hydrogen (H) content of the sample was calculated theoretically based on following formula,

$$H = -6156.21 + 61.44348FC + 61.66506VM + 61.74225A + 61.65247M \quad (8)$$

iii. Oxygen Content, (%)
The oxygen (O) content of the sample was calculated theoretically by using the following formula,

$$O = 31071.47 - 309.621FC - 310.437VM - 312.201A - 310.789M \quad (9)$$

iv. Nitrogen content, (%)
Nitrogen content (N) of the sample was theoretically calculated by difference using the following formula,

$$N = 100 - \%\ of\ (C + H + O + Ash),\ \% \quad (10)$$

Where,
FC = Fixed Carbon, %
A = Ash content, %
VM = Volatile matter, %
M = Moisture content, %

3. Results and Discussion
The standard analytical procedures were used to determine the physical characteristics, proximate analysis, calorific value, and ultimate analysis of coconut shell (*Cocos nucifera*) as per methodology section. It was observed that, the average weight of individual coconut shell was found to be 0.081 kg with average height of 0.065 m and shell thickness was 0.0038 m.

The proximate analysis of coconut shell (*Cocos nucifera*) in terms of moisture content, volatile matter, fixed carbon content and ash content was determined as presented in Table 1 and Fig. 1 (a). The moisture content of coconut shell (*Cocos nucifera*) was found to be 7.67 % on dry basis, indicates that relatively low moisture content. The low moisture content of coconut shell makes suitable fuel for combustion applications, offering the potential for improved performance. The moisture content of coconut shell (*Cocos nucifera*) reported in the range of 7.40-11.00 % (dry basis) by various researches like Irawan *et al*. (2017) [9]; Iloabachie *et al*. 2018 [8]. From experimental data, it was observed that the volatile matter, ash content and fixed carbon of coconut shell (*Cocos nucifera*) were found as 66.1, 1.4 and 24.8 % respectively. The results showed the feasibility of coconut shell (*Cocos nucifera*) as a fuel for combustion because of low ash content and higher fixed carbon content. The similar types of work were reported by Parikh *et al*. (2007) [13]; Irawan *et al*. (2017) [9]; Iloabachie *et al*. (2018) [8].
The calorific value of coconut shell (*Cocos nucifera*) was determined with the help of bomb calorimeter and calorific value of coconut shell (*Cocos nucifera*) was found to be 4339.85 kcal kg^{-1}. The coconut shell has higher calorific value indicating good characteristics for combustion because higher heat generated during combustion leads to high temperature in various thermal applications. The similar results of calorific value for coconut shell (*Cocos nucifera*) was reported by Irawan *et al*. (2017) [9]; Iloabachie *et al*. (2018) [8].
The ultimate analysis of coconut shell (*Cocos nucifera*) in terms of carbon (C), hydrogen (H), oxygen and nitrogen content was estimated theoretically from the results obtained in proximate analysis using the multilinear regression technique (MLR model) equations (Lawal *et al*. 2021) [11]. The ultimate analysis findings for coconut shell (*Cocos nucifera*) is presented in Table 1 and figure 1 (b). The average carbon, hydrogen, oxygen and nitrogen content of coconut shell (*Cocos nucifera0*) were found to be 56.43, 4.16, 37.51, and 0.48 %, respectively. The elemental composition result of coconut shell (*Cocos nucifera*) in ultimate analysis correlates closely with the heat of combustion, containing high carbon content (C) which makes it suitable fuels for combustion process. The similar results of ultimate analysis for coconut shell (*Cocos nucifera*) was reported by Parikh *et al*. (2007) [13]; Irawan *et al*. (2017) [9]; Iloabachie *et al*. (2018) [8].

Table 1: Chemical properties of coconut shell (*Cocos nucifera*)

Sr. No.	Parameters	Coconut shell (*Cocos nucifera*)
1.	Proximate analysis	
	a. Moisture content, %	7.67
	b. Volatile matter, %	66.1
	c. Ash content, %	1.4
	d. Fixed carbon, %	24.8
2.	Calorific value (HHV), kcal/kg	4339.85
3.	Ultimate analysis	
	a. Carbon, %	56.43
	b. Hydrogen, %	4.16
	c. Oxygen, %	37.51
	d. Nitrogen, %	0.48

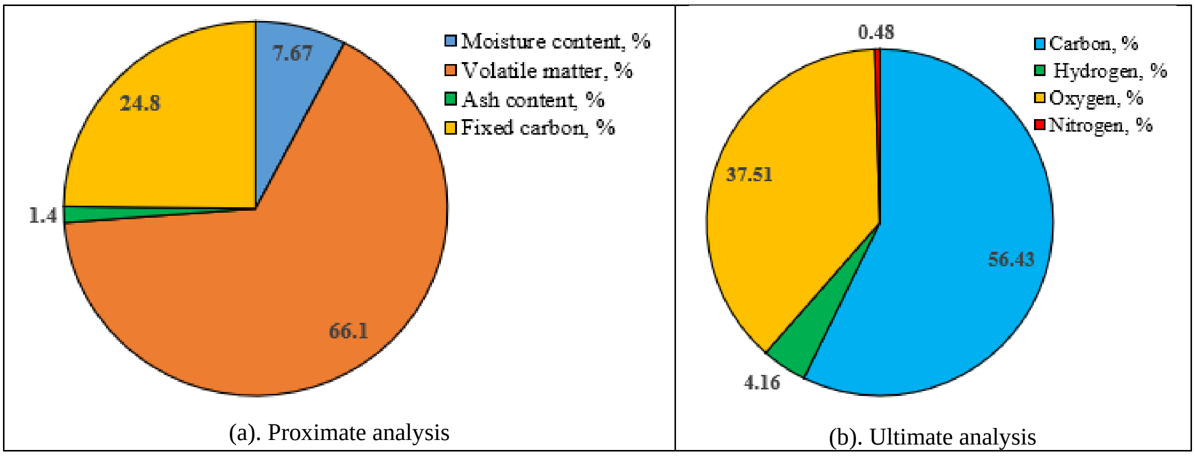

Fig 1: Proximate analysis and ultimate analysis of coconut shell (*Cocos nucifera*)

4. Conclusion

The coconut shell (*Cocos nucifera*) is recognized as agricultural residue, renowned for its low ash content, high carbon (C), and volatile content. It's readily available at lower costs in rural areas throughout almost every season of the year. The low moisture content (7.67 %) of coconut shell (*Cocos nucifera*) makes it a suitable fuel for combustion applications, offering the potential for improved performance. Furthermore, its higher calorific value indicates good characteristics for combustion, as higher heat generated during combustion leads to high temperatures in various thermal applications. The elemental composition of coconut shell (*Cocos nucifera*), as revealed in ultimate analysis using the multilinear regression technique (MLR model) equations, closely relates to the heat of combustion, containing high carbon (C) content which makes it suitable for combustion processes. This study investigates the physico-chemical characteristics of coconut shell (*Cocos nucifera*), shedding light on its potential as a sustainable and efficient biomass resource for various applications. Hence, the utilization of coconut shell (*Cocos nucifera*) presents a multitude of opportunities across various applications. Its renewability, environmental friendliness, and cost-effectiveness make it a valuable resource in the realm of biomass. By harnessing the coconut shell, we can significantly reduce reliance on finite resources while minimizing environmental impact. From energy production to agricultural uses and beyond, the versatility of coconut shell (*Cocos nucifera*), as a sustainable material offers a promising avenue for innovation and resource optimization.

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