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RESEARCH ARTICLE

Coconut reinvented: Development of a high-value functional product from the 'tree of life'

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Abstract

This study focuses on developing and characterizing a tender coconut kernel bar as a value-added product. Coconut (*Cocos nucifera* L.), known as "Kalpavriksha" or "tree of a thousand uses," is a significant crop in tropical regions, with India ranking as the third-largest producer worldwide after Indonesia and Philippines, producing approximately 11.4 million tons annually. The research aimed to standardize technology for converting tender coconut kernel, which often goes to waste after the consumption of tender coconut water, into a nutritious bar, addressing economic risks faced by coconut growers due to price fluctuations. The production methodology involved extracting and processing coconut pulp from 8-9 months maturity coconuts sourced from Tamil Nadu Agricultural University, incorporating ingredients including sugar (50 %), corn flour (25 g), rice flour (25 g) and citric acid (10 g). The mixture was cooked to 50 °Brix, poured into aluminium trays and dried at 60 °C for 12 hrs before cutting and packaging in silver-laminated aluminium packaging. Nutritional analysis revealed that the fresh kernel contained 50 % moisture, 4 % protein, 10 % carbohydrates and 2 % crude fiber. The finished product contained 19.67 % moisture, 2.45 % protein, 0.96 % crude fiber and 1.23 % ash, with a pH of 5.21. Mineral analysis using ICP-OES revealed significant amounts of potassium (2672.19 ppm), calcium (316.03 ppm), magnesium (298.97 ppm) and iron (162.68 ppm). Sensory evaluation using a 9-point hedonic scale showed high consumer acceptability with an overall score of 7.9. The product maintained stable sensory characteristics during three months of refrigerated storage. This innovation provides an effective solution for tender coconut kernel utilization while creating a nutritious snack alternative with functional health benefits, contributing to the economic sustainability of coconut cultivation through value addition.

Keywords: nutritional composition; sensory evaluation; shelf stability; sustainable agriculture; tender coconut; value addition

Introduction

Coconut (*Cocos nucifera* L.) is an important nut-bearing palm of the Arecaceae family. It is an important and versatile tree crop with diverse end-uses, supporting the livelihood of many farm households in the primary sector, grown in many states of India (1). It is commonly referred to as the tree of heaven - "Kalpavriksha" or the "tree of a thousand uses". Often referred to as nature's gift to mankind, the coconut serves as a source of food, beverages, oilseeds, fibers, timber and various health products (2). Coconut is cultivated globally, with intensive farming practices in tropical regions. According to the data from the Food and Agriculture Organization, the total world production of coconuts is approximately 60.7 million tons (MT). Among coconut-producing countries, India ranks as the third largest producer after Indonesia and Philippines, with a total production of 11.4 million tons (MT) of nuts per year (3). South Indian states, namely Kerala, Tamil Nadu, Karnataka and Andhra Pradesh, account for approximately 80-90 % of the total production of Indian coconut (4). Coconut cultivation in India is predominantly concentrated in the Southern Peninsular Plateau, with Andhra Pradesh, Karnataka, Kerala and Tamil Nadu together accounting for 89 % of the total area and 91 % of the total production. During the period 2011–2020, the growth rate of coconut production declined in all major states except Kerala. Andhra Pradesh, Karnataka and Tamil Nadu showed negative trends in area and/or yield but maintained relatively lower instability indices. Yield improvements were identified as the primary contributors to production changes, emphasizing the importance of adopting strategies aimed at enhancing productivity to sustain future coconut cultivation (5). Currently, coconut growers face increased economic risks and uncertainties due to significant price fluctuations. To secure a sustainable future for the coconut sector, it is essential to reduce reliance on coconut oil and promote the production of diversified value-added products (6). Coconut products are widely used in various culinary and nutritional applications due to their rich nutritive metabolites and distinct flavors. For instance, tender coconut water is a nutrient-rich and refreshing beverage packed with minerals and other beneficial compounds. The mature coconut kernel, abundant in fat and protein, offers coconut milk, serving as a key ingredient in virgin coconut oil (VCO) extraction (7). Additionally, ensuring the livelihood security of those dependent on the sector requires a value chain approach in Kasaragod, Kerala, to empower coconut farmers through better coordination and improved practices. Ten farmer groups adopted technologies that increased net returns from Rs. 44981 to Rs. 200201 per hectare. Four Women SHGs produced value-added products with profit potential up to Rs. 200000 per hectare. The project showcases the impact of value chain strategies in enhancing coconut sector productivity. Strengthening the coconut value chain through effective forward and backward integration (8). The analysis revealed that 100 g of dried coconut haustorium contained 1.05 ± 0.2 % ash, 44.2 ± 4.6 % soluble sugar, 24.5 ± 3.2 % starch, 5.50 ± 0.3 % protein, 1.99 ± 0.9 % fat, 5.72 ± 0.4 % soluble dietary fiber, 20.3 ± 1.9 % insoluble dietary fiber and 146 ± 14.3 mg of phenolic compounds. Mineral profiling indicated the presence of 145 ± 8.6 mg potassium, 104 ± 9.6 mg magnesium, 33.9 ± 8.2 mg calcium, 30.9 ± 1.9 mg phosphorus, 9.45 ± 2.1 mg manganese, 0.292 ± 0.1 mg copper, 2.53 ± 0.2 mg iron and 1.20 ± 0.1 mg zinc. Coconut by-products can be effectively incorporated into a variety of food products, including baked goods, extruded snacks and sweets. Coconut has been a vital food source for centuries in tropical regions, especially in Indian cuisine, notably in Kerala. The nutrient-rich kernel provides calories, vitamins and minerals such as potassium, calcium, magnesium and iron. It also contains dietary fiber (7 %), protein (5 %) and coconut oil (9). Key compounds like tocopherol, phenolics and phytohormones contribute to its health benefits. Studies suggest that consuming the whole coconut kernel with its oil is more beneficial for blood cholesterol levels than coconut oil alone (9). It provides numerous health benefits, including antidiabetic and anticancer properties. It also helps to improve the immune system and promote cardiovascular health. It is particularly appropriate for people with celiac disease or gluten intolerance because it is naturally gluten-free. It is a healthy alternative because its nutritional profile is like that of wheat flour. All in all, it is a wholesome and nourishing food choice (10). Several processing methods are used to produce snack foods, with extrusion cooking gaining popularity due to its versatility, high productivity, energy efficiency, reduced cooking time, improved product quality and low operational costs (11). This is an attempt at value addition in the coconut crop. Based on the scientific information collected, it was observed that tender coconuts are consumed mainly for water and the kernel often goes to waste uneaten. This could be converted into a bar, which can be an industrial product from the by-product of the tender coconut water processing industry. Value addition to all the stages of coconut processing will further benefit the growers. Hence, this study was proposed to standardize the technology to produce tender coconut kernel bars. The fruit bar contains fewer calories, less than 100 kcal per serving, compared to many other snacks. Consuming fruit bars is an economic and convenient value-added substitute for natural fruits as a source of various nutritional elements. The tender coconut kernel bar was prepared based on the FSSAI specifications of the mango fruit bar. Among the three sugar concentrations tested (30 %, 40 % and 50 %), the formulation with 50 % sugar content emerged as the most acceptable, receiving the highest preference from the testers. This formulation was evaluated based on several factors, including taste, texture and overall sensory appeal. The 50 % sugar content provided the optimal balance of sweetness, ensuring the fruit bar was flavorful while not overly sugary. In comparison, the 30 % and 40 % sugar formulations were considered less satisfying, as they lacked the desired sweetness and depth of flavor. Overall, the 50 % sugar formulation was deemed to deliver the best sensory experience, making it the most suitable choice for the tender coconut kernel bar.

Materials and Methods

Procurement of raw materials

Tender coconuts at 8-9 months of maturity were sourced from the Coconut Nursery Farm, Tamil Nadu Agricultural University (TNAU), Coimbatore. The selection of high-quality coconuts was ensured to maintain uniformity in processing and product quality.

Collection and processing of coconut pulp

The outer shell of the coconut was carefully removed, ensuring minimal damage to the kernel. The kernel was thoroughly washed with clean water to remove any residual impurities. The cleaned coconut kernel was then shredded and ground using a pulper or mixer to obtain a smooth and uniform pulp.

Cooking and ingredient incorporation

A measured quantity of 1000 g of coconut pulp was transferred into a stainless-steel vessel.

To enhance sweetness and texture, 500 g of sugar was added and mixed well. Additional ingredients, including 25 g of corn flour and 25 g of rice flour, were incorporated to improve the consistency and binding properties. To maintain the desired acidity and improve shelf life, 10 g of citric acid was added. The mixture was continuously stirred and cooked until it reached a Total Soluble Solids (TSS) value of 50 °Brix, ensuring proper caramelization and flavor development. Once the desired consistency was achieved, the hot coconut puree was carefully poured into aluminium trays coated with a thin layer of butter to prevent sticking.

Drying process

The coconut mixture trays were placed in a cabinet dryer at 60 °C. The dehydration process was carried out for 12 hrs to achieve optimal moisture reduction, ensuring a chewy yet firm texture for the final product. Proper monitoring was conducted during the drying process to prevent over-dehydration and preserve the natural coconut flavor.

Cutting and packaging

After drying, the coconut bar was removed from the trays and cut into uniform, desirable sizes for standardization. Each piece was carefully packed in silver-laminated aluminium packaging, providing an effective barrier against moisture, light and oxygen exposure. The packages were sealed using a heat-sealing machine to maintain product integrity and freshness.

Storage and shelf life

The packed coconut bars were stored in an airtight container to prevent moisture absorption and protect against external contaminants. The storage conditions were maintained under refrigeration, ensuring the temperature did not exceed the recommended limit for a shelf life of 90 days. Periodic quality assessments were conducted to monitor any changes in texture, flavor and microbial safety during storage (Fig. 1).

Deshelling

↓

Cutting

↓

Scooping out the kernel from the shell

↓

Pulping

↓

Heating (Until reaching TSS of 50° Brix)

↓

Mixing of ingredients

↓

Smearing trays with butter

↓

Pouring pulp mixture into trays

↓

Cabinet dryer dehydration at 60 °C

↓

Tender coconut kernel bar

Fig. 1. Preparation of tender coconut kernel bar.

Quality analyses

Moisture (%)

Moisture content is determined by measuring the weight loss of a sample during heating. A standard method (ISO 1442: 1997) involves drying a 5-8 g sample, mixed with pre-dried sand, in an oven at 103 ± 2 °C for 2 hr intervals until a constant weight is reached. The AOAC approved methods such as air drying a 2 g sample at 100-102 °C for 16-18 hrs, drying at 125 ° C to constant weight or drying under vacuum at 95-100 °C. An alternative method uses microwave drying, providing results in 3-5 min with integrated systems. Moisture is determined by measuring the weight loss due to evaporation under controlled conditions. However, non-water components may evaporate, or water removal may be incomplete due to the formation of a 'skin' on the sample surface. Thus, precise conditions and consistency are essential for accurate moisture determination (13).

Total soluble protein (%)

The total soluble protein content in the flesh of the coconut kernel at the maturity stage and in the coconut bar was estimated and expressed as a percentage. Protein reacts with the Folin-Ciocalteau reagent (FCR), forming a blue-colored complex. This color is a result of the alkaline copper reacting with the protein and the reduction of phosphomolybdic and phosphotungstic components in the FCR by the amino acids tyrosine and tryptophan present in the protein. The intensity of the blue color is measured calorimetrically at 660 nm. To perform the assay, pipetted out 0.2, 0.4, 0.6, 0.8 and 1.0 mL of the working standard solution into separate test tubes. Added 0.1 mL and 0.2 mL of the sample extract to two additional test tubes. Brought the volume in all tubes to 1 mL with water. A test tube containing 1 mL of water taken as the blank. Added 5 mL of solution C, mix well and incubated at room temperature for 10 min. Added 0.5 mL of FCR, mixed immediately and incubated the tubes at room temperature in the dark for 30 min. Measured the absorbance at 660 nm, using the blank for calibration. If the sample contains high phenolic compounds or pigments, prepare the extract using a reducing agent, such as cysteine and NaCl, to precipitate the protein and reduce interference (14).

Crude fiber (%)

The crude fibre content of the coconut kernel bar sample was determined and expressed as a percentage (15). During acid and alkali treatment, oxidative hydrolytic degradation of native cellulose and significant lignin degradation occur. After final filtration, the residue is weighed, incinerated, cooled and weighed again. The weight loss is used to calculate the crude fibre content. To begin, extracted 2 g of the ground sample with ether or petroleum ether (initial boiling temperature 35-38 °C, final temperature 52 °C) to remove fat. This extraction step may be omitted if the fat content is less than 1 %. Boiled 2 g of the dried sample with 200 mL of H_2SO_4 for 30 min, using bumping chips. Filtered the mixture through muslin cloth and wash with boiling water until the washings are acid-free. Boiled the residue with 200 mL of NaOH for 30 min, then filtered through muslin cloth again, washed with 25 mL of boiling H_2SO_4, three 50 mL portions of water and 25 mL of alcohol. Transferred the residue to a pre-weighed ashing dish (W1 g), then dried it for 2 hrs at 130 ± 2 °C. Cooled the dish in a desiccator and weighed it (W2 g). Ignited the residue for 30 min at 600 ± 15 °C, cooled in a desiccator and reweigh (W3 g). The crude fibre content is then calculated based on the weight loss.

Calculation

$$\% \text{ Crude fiber content} = \frac{\text{Reference loss in weight on ignition x } (W_2 - W_1) - (W_3 - W_1)}{\text{Weight of sample (g) x 100}}$$

Fat (%)

Weighed 2-3 g of dried sample in a thimble and place it in the Soxhlet apparatus. Added the required solvent (petroleum ether, ethyl ether or hexane) and extracted for 16 hrs. Removed the thimble, evaporated residual solvent using a hot water bath and dried the flask at 105 °C for 30 min. Finally, cooled in a desiccator and weigh ('b' g) (16).

$$\text{Crude fat or oil content in the sample (\%)} = \frac{\text{Dry weight basis (b-1)}}{\text{Weight of sample (g)}} \text{ x 100}$$

Total ash content (%)

The ash content of the samples was determined gravimetrically by using Ranganna's method (14). Noted the tare weight of three silica dishes. Accurately weighed 5 g of the sample into each. Charred the material carefully on a burner or hot plate and transfered the dishes to a muffle furnace and ashed at a temperature of around 525 °C until awhite ash is obtained. Moisten the ash in dishes with water. Dried in the steam bath and on a hot plate and re-ashed at 525 °C. Cooled in a desiccator and weighed. Reserved the ash in one dish for the determination of water-soluble and water-insoluble ash, in the second dish for acid-insoluble ash and the ash in the third dish for determining the alkalinity of ash.

$$\text{Total ash (\%) in the sample} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \text{ X 100} \quad \frac{(W_3 - W_1)}{(W_2 - W_1)}$$

pH

The pH measurement of coconut water and kernel is important for assessing their acidity, stability and quality in food applications. The sample is prepared by extracting fresh coconut water and filtering it to remove suspended particles. The kernel is ground into a fine paste and mixed with distilled water in a 1:5 ratio to form a slurry. Before measurement, the pH meter is calibrated using standard buffer solutions of pH 4.0, 7.0 and 10.0 to ensure accuracy. The electrode is then inserted directly into the coconut water or kernel slurry and the reading is recorded once stabilized. Typically, coconut water exhibits a mildly acidic pH (4.5-5.2), while the pH of the kernel varies based on its maturity. This method provides accurate pH assessment, crucial for coconut-based food product development and quality control.

Carbohydrate (%)

To estimate the carbohydrate content in a sample, 100 mg of the sample is weighed into a boiling tube. It is hydrolysed by heating in a boiling water bath for 3 hrs with 5 mL of 2.5 N hydrochloric acid (HCl), then allowed to cool to room temperature. The hydrolyzed solution is neutralized using solid sodium carbonate until effervescence stops. The volume is then made up to 100 mL with distilled water and centrifuged. The supernatant is collected and 0.5 mL and 1 mL aliquots are taken for analysis. Standard solutions are prepared by taking 0, 0.2, 0.4, 0.6, 0.8 and 1 mL of the working standard, with '0' serving as the blank. The volume in each tube, including the sample tubes, is adjusted to 1 mL using distilled water. Next, 4 mL of anthrone reagent is added to each tube. The tubes are heated in a boiling water bath for 8 min, then rapidly cooled. The resulting green to dark green color is measured at 630 nm using a colorimeter or spectrophotometer. A standard curve is plotted with the concentration of the standard on the X-axis and absorbance on the Y-axis. The carbohydrate content in the sample is then calculated by comparing its absorbance to the standard graph (17).

Calculation

Amount of carbohydrate present in sample (% mg)=

$$\frac{\text{Sugar value from graph (mg)}}{\text{Aliquot sample used (0.5 or 1 ml)}} \times \frac{\text{Total vol. of extract (ml)}}{\text{Wt. of sample (mg)}} \times 100$$

Estimation of mineral composition (ICP-OES)

The Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) method is a widely used technique for determining the mineral composition of food samples with high sensitivity and accuracy. The procedure begins with the sample preparation, where a known quantity of the sample is dried, ground into a fine powder and subjected to acid digestion using a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) or hydrochloric acid (HCl) to dissolve the minerals. The digested sample is then filtered and diluted with deionized water to obtain a clear solution suitable for analysis. Next, the sample solution is introduced into the ICP-OES instrument, where it is nebulized into an argon plasma at an extremely high temperature (6000–10000 K). In the plasma, the elements present in the sample are excited to higher energy states and as they return to their ground state, they emit characteristic wavelengths of light. The emitted light is then detected by a spectrometer, which separates the wavelengths and measures the intensity corresponding to each element. The instrument software compares the measured intensities with a calibration curve prepared using standard solutions of known mineral concentrations, allowing precise quantification of elements like zinc, iron, calcium, potassium, sodium, magnesium and manganese. Finally, the results were analyzed and the mineral concentrations in the sample are expressed in parts per million (ppm) or milligrams per kilogram (mg/ kg). This method is highly efficient, providing rapid, multi-element analysis with high sensitivity, accuracy and reproducibility, making it an ideal choice for determining mineral content in food products.

Results

Nutritional composition of fresh coconut kernel

The fresh tender coconut kernel meat was analyzed for its nutritional composition, revealing a well-balanced profile of essential nutrients mentioned in Table 1. The analysis showed that the moisture content was 50 %, indicating its high-water content, which contributes to its soft texture and refreshing taste. The fat content was relatively low at 0.2 %, making it a light and healthy food option. The protein content was recorded as 4 %, suggesting its potential role in muscle repair and body functions. The carbohydrate content was found to be 10 %, providing a source of energy, mainly in the form of natural sugars. The mineral content was 1 %, highlighting the presence of essential micronutrients important for various physiological functions. Additionally, the crude fiber content was 2 %, which aids in digestion and promotes gut health. This nutritional composition makes fresh tender coconut kernel meat a valuable functional food with hydrating, energy-providing and digestive benefits.

Table 1. Nutritional composition of fresh coconut kernel

Product	Moisture (%)	Fat (%)	Protein (%)	Carbohydrate (%)	Mineral (%)	Fibre (%)
Tender coconut kernel	50	0.2	4	10	1	2

Physico-chemical properties of the tender coconut kernel bar

The physico-chemical properties of the tender coconut kernel bar were analyzed and the results are presented in Table 2. The proximate analysis provided detailed insights into its nutritional and compositional characteristics. The pH of the product was recorded at 5.21, indicating a slightly acidic nature, which may influence its shelf stability and microbial safety. The protein content was found to be 2.45 %, contributing to its nutritional value as a source of essential amino acids. The crude fiber content was 0.96 %, which supports digestive health by promoting gut motility. The ash content, representing the total mineral composition was recorded as 1.23 %, signifying the presence of essential micronutrients. The moisture content was measured as 19.67 %, which plays a crucial role in determining the texture, shelf life and microbial stability of the product. These findings suggest that the tender coconut kernel bar is a nutrient-rich product with a balanced composition, suitable for consumption as a healthy and functional snack.

Table 2. Physico-chemical properties of the tender coconut kernel bar

S. No	Parameters	Average value
1	pH	5.21
2	Protein (%)	2.45
3	Moisture (%)	19.67
4	Ash (%)	1.23
5	Crude fiber (%)	0.96

Mineral composition of the tender coconut kernel bar

The mineral composition of the tender coconut kernel bar was analyzed using the ICP-OES method and the results are presented in Table 3. The analysis revealed that the product contains 0.44 mg/100 g of zinc, which plays a crucial role in immune function and enzyme activity. The iron content was recorded as 16.26 mg/100 g, essential for hemoglobin formation and oxygen transport. A significant amount of calcium (31.60 mg/100 g) was present, contributing to bone health and muscle contraction. The potassium content was found to be 267.21 mg/100 g, making it a rich source of this essential electrolyte that aids in muscle function and blood pressure regulation. The sodium concentration was 16.28 mg/100 g, playing a key role in fluid balance and nerve signaling. Magnesium, an important mineral for energy production and nerve transmission was measured at 29.90 mg/100 g. Additionally, manganese was present at 0.78 mg/100 g, supporting antioxidant functions and metabolic processes. These results indicate that the tender coconut kernel bar is a nutritionally valuable product, rich in essential minerals that contribute to overall health, bone strength, muscle function and metabolic activities.

Table 3. Mineral composition of the tender coconut kernel bar

S. No.	Parameters	Values in mg/100 g
1	Zinc	0.44
2	Iron	16.26
3	Calcium	31.602
4	Potassium	267.21
5	Sodium	16.28
6	Magnesium	29.89
7	Manganese	0.78

Organoleptic evaluation

The organoleptic evaluation of the tender coconut kernel bar was conducted using a 9-point hedonic scale to assess its sensory attributes, including appearance, color, texture, flavor, taste and overall acceptability. A panel of untrained judges was selected to evaluate the product under standardized conditions. Each judge was provided with coded samples of the tender coconut kernel bar and asked to rate their sensory perception based on the hedonic scale, where 1 represents "dislike extremely" and 9 represents "like extremely." The scores were then compiled and statistically analyzed to determine the overall acceptability of the product. The evaluation revealed that the tender coconut kernel bar achieved an overall acceptability score of 7.9, indicating that the product was well-received by the panelists. Additionally, the study assessed the storage stability of the product under refrigerated conditions (4 °C) for three months. The results showed that the sensory characteristics remained stable without significant deterioration in texture, flavor or appearance, confirming that the tender coconut kernel bar can be stored under refrigeration while maintaining its quality and consumer appeal Fig. 2.

Discussion

Coconut-based products offer diverse health and culinary benefits, including virgin coconut oil, coconut milk, neera and coconut sugar. Rich in medium-chain triglycerides (MCTs), coconut milk and cream enhance both sweet and savory dishes. Coconut water acts as a natural isotonic drink, while coconut chips and desiccated coconut add flavor and nutrition. Neera and coconut sugar serve as healthier sweeteners with a low glycemic index. Overall, coconut innovations provide flavorful, nutritious and versatile food options (18).

The fresh coconut kernel primarily consists of water (41.7 ± 0.5 %) and fat (40.2 ± 1.2 %), along with protein (4.1 ± 0.3 %), sugar (5.6 ± 0.2%) and crude fiber (3.5 ± 0.1 %). In contrast, the dehydrated kernel has a higher fat content (65.5 ± 2.0 %) and contains protein (6.8 ± 0.4 %), sugar (6.5 ± 0.3 %), crude fiber (9.2 ± 0.2 %) and carbohydrates (6.0 ± 0.2 %). The composition of coconut milk residue (MR) differs significantly from fresh coconut kernel, with fat as its major component (42.6 ± 1.2 %), concentrated 1.06 times more than in fresh kernel due to incomplete fat removal during extraction. However, MR has a lower fat content than the dehydrated kernel. The crude fiber content in MR (23.2 %) shows a 6.62 fold increase from the fresh kernel and a 2.52 fold rise compared to the dehydrated kernel, primarily due to coconut milk extraction and dehydration. Coconut water and kernel are nutrient-rich edible parts of the coconut (19, 20).

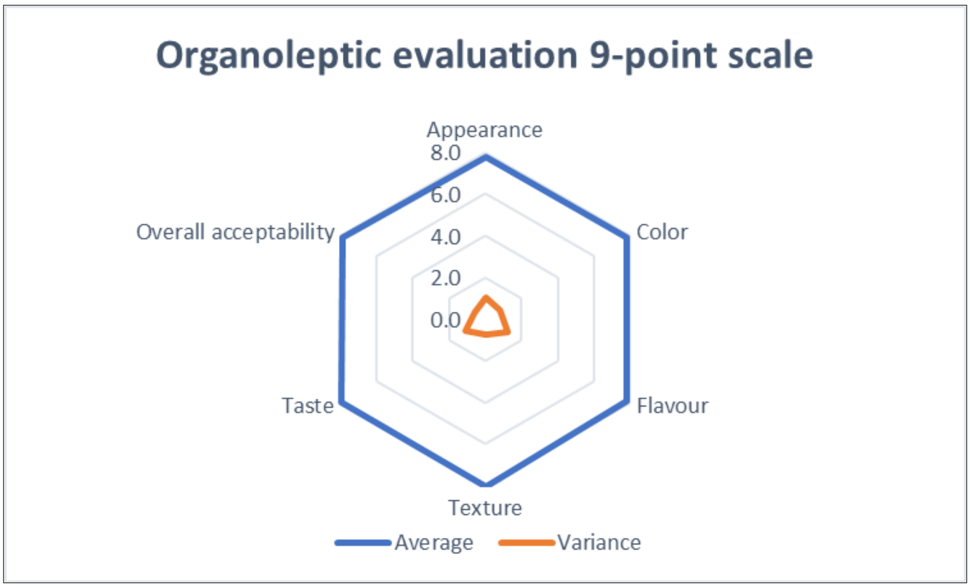

Fig. 2. Organoleptic evaluation of the coconut kernel bar.

This study evaluated their physico-chemical properties, phytonutrient composition and stability at different maturity stages. Coconut water, with its high moisture and mild acidity, serves as a natural hydrating beverage, while the kernel loses moisture and becomes firmer as it matures. The fat content is low in coconut water but high in the kernel, highlighting its lipid-rich nature. Mineral content remains stable in coconut water but decreases in the kernel. The study also found that phenolic compounds and medium-chain fatty acids (MCFAs) increased with maturity, enhancing their antioxidant and metabolic benefits. Coconut kernel oil contained more saturated fats, especially lauric acid (C12:0), while monounsaturated fats declined. The tocopherol (Vitamin E) content in the kernel was higher than in commercial coconut products, reinforcing its functional food potential. Overall, coconut water and kernel are valuable raw materials for developing health-promoting food products (21).

The coconut palm has different parts: leaves, buds, flowers, fruit and germinating nuts. Some of these parts are protein-rich, providing benefits for human health. For example, the protein content in the edible white kernel of the coconut is about 4.3 %, mostly consisting of globulin (22). Coconut cake, a by-product of milk and oil extractions, contains a high amount of protein (23). In recent years, the demand for protein has shifted from moderate intake to a focus on high-quality, nutritious and functional sources, driven by rising consumption and improved living standards (24).

Carbohydrates, including sugar and starch, are organic compounds made of carbon, hydrogen and oxygen. According to the Coconut Development Board, sugar concentration in coconut water increases from 1.5 % in early maturation to 5–5.5 %, then declines to about 2 % at full maturity. In the early stages, sugars are mainly glucose and fructose (reducing sugars), while sucrose (non-reducing sugar) appears later and increases with maturity. At full maturity, sucrose makes up about 90 % of the total sugars, while reducing sugars decrease (25). Coconut water contains a small amount of protein, with higher levels of arginine, alanine, cystine and serine compared to cow’s milk. As it lacks complex proteins, the risk of causing allergic reactions or shock in patients is minimized (26).

Coconut kernel residue from coconut milk and virgin oil is a rich source of dietary fiber, though coconut milk residue has a high fat content. Cell wall polysaccharides extracted from virgin oil residue vary based on the solvent used. The chemical, functional and metal ion properties of these residues are comparable to other food by-products but they have higher metal ion concentrations. Utilizing these residues as dietary fiber offers health benefits and economic potential for the coconut industry (27). Young coconut mesocarp (YCM) is rich in phenolic compounds with high antioxidant activity but remains underutilized in the food industry. This study explored YCM-based cookies by substituting regular flour with 8 % (C8) and 16 % (C16) YCM powder. The addition of YCM increased crude fiber and moisture while reducing fat content. Antioxidant activity significantly improved due to the retained catechin and caffeic acid derivatives. YCM darkened the cookies, reduced hardness and enhanced oxidative stability, thus prolonging shelf life. These findings highlight YCM powder as a valuable ingredient for enhancing the nutritional and functional properties of baked goods (28). Coconut kernel contains zinc, iron, potassium, sodium, copper, manganese, magnesium and calcium, with no detectable lead, ensuring its safety. Despite sodium and potassium being the most abundant minerals, their low levels make the oil unsuitable as a dietary supplement but beneficial for hypertensive individuals. It is a good source of manganese, essential for enzyme activity, bone health and nervous function. Zinc is present in moderate amounts, supporting biological functions, while iron and copper are found in lower concentrations. Magnesium levels are minimal, limiting its nutritional value, but overall, the oil offers selective health benefits through its mineral composition. Incorporating macauba kernel cake increased the fat, ash and fiber content in food bars while enhancing lauric, stearic and oleic acid levels. Up to 20 % incorporation improved hardness and cohesiveness but reduced brittleness, while higher concentrations darkened the bars. Sensory analysis showed an 82.5 % acceptance for the 10 % incorporation, which was softer and more brittle. The study highlights the nutritional and sensory benefits of macauba kernel cake, promoting its use in food products while reducing waste (29).

The present study demonstrated the successful development of tender coconut kernel bar as a novel, value-added product with promising nutritional and sensory attributes. The significant reduction in moisture content from 50 % in fresh kernel to 19.67 % in the barbar contributes to the product's extended shelf life by inhibiting microbial growth and enzymatic reactions (30). The moderate pH of 5.21 further enhances the product's stability against bacterial contamination (31).

The protein content (2.45 %) in the bar, though lower than in the fresh kernel (4 %), remains nutritionally significant. The retention of crude fiber (0.96 %) contributes to the product's potential health benefits, including improved digestion (32). The mineral content analysis revealed that the bar is particularly rich in potassium, calcium and magnesium, which are essential for various physiological functions, including muscle contraction, nerve transmission and bone health (33).

The high overall acceptability score (7.9 on a 9-point hedonic scale) indicated that the tender coconut kernel bar possessed desirable sensory attributes. The favorable scores for appearance, color, flavor, texture and taste suggested that the product could have good market potential as a nutritious snack (34). The formulation used in this study, with 50 % sugar content, was found to be optimal for sensory acceptability. This aligns with the findings of a study which reported that fruit bars typically require 40-50 % sugar for acceptable taste and texture (35). The addition of corn flour and rice flour improved the binding properties and texture of the bar, consistent with observations on the mango bar (36).

The stability of the product under refrigerated conditions for three months indicates its potential for commercial distribution with appropriate packaging and storage recommendations. This extended shelf life is particularly advantageous compared to the fresh kernel, which has limited stability (37). The development of tender coconut kernel bar represents an efficient utilization of a by-product from the tender coconut water industry, potentially increasing the economic returns from coconut cultivation and processing. This aligns with the growing interest in sustainable food production systems that minimize waste and maximize resource utilization.

Conclusion

The development of the tender coconut kernel bar demonstrates an effective solution to coconut processing challenges. This research successfully converts the typically discarded tender coconut kernel into a nutritious, shelf-stable product with significant mineral content and excellent consumer acceptance. The standardized production process yielded a product with a well-balanced, nutrient-rich product with a high sensory score (7.9/9) and a refrigerated shelf life of three months. Rich in essential minerals including potassium (2672.19 ppm), calcium (316.03 ppm) and magnesium (298.97 ppm), the kernel bar provides considerable nutritional benefits. This innovation strengthens the coconut value chain through forward integration while reducing dependence on volatile coconut oil markets. For coconut farmers facing economic uncertainties and price fluctuations, this value-added product offers diversification opportunities and alternative income streams. The research aligns with sustainability goals by reducing waste and enhancing resource utilization efficiency. Ultimately, the tender coconut kernel bar represents a promising pathway for securing livelihoods in the coconut sector while meeting consumer demand for nutritious, convenient food products.

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Authors' contributions

All authors made equal contribution in this research.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

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