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Effect of endosperm maturity on the physicochemical composition and sensory acceptability of coconut (*Coco nucifera*) milk and yoghurt

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The effect of endosperm maturity on the physicochemical compositions and sensory acceptability of coconut milk and yogurt was studied. The influence of fermentation time on the physicochemical characteristics and sensory acceptability of coconut yogurt was also determined. Varied coconut endosperm maturity (soft, medium and hard) and fermentation time (6, 12, 18 and 24 h) were used to produce milk and yogurt. The physicochemical compositions and sensory acceptability of the samples were evaluated using standard methods. The physicochemical characteristics of coconut milk and yogurt were influenced by both endosperm maturity and fermentation time. Coconut milk produced from hard coconut endosperm was the most preferred and recorded the highest brix (3.31°), fat (6.71%), total solid (16.02%), and acidity (1.26%) levels. Coconut yogurt fermented for 6 h was the most preferred. Optimization of both coconut milk and yogurt processes could produce a commercially viable product.

Key words: Coconut milk, coconut yoghurt, fermentation, physicochemical, sensory.

INTRODUCTION

Consumers are increasingly becoming aware of their health needs, as such there is a growing demand for plant-based milk and milk products, such as yogurt. People with dairy allergies and sensitivities, as well as those who have concerns about the use of animal products, including vegans, are turning to plant-based milk alternatives (Zandona et al., 2021).

In Ghana, where most adults are lactose intolerant, there is a rising demand for plant-based alternatives that are promised to be lactose-free, cholesterol-free, devoid of dairy proteins, trans fats, and low in calories (Storhaug et al., 2017). Plant-based milk and milk products are typically based on cereals or pseudocereals, legumes, seeds, or nuts, either produced individually or sometimes as composites (Sethi et al., 2016; Mäkinen et al., 2016). The main commodities used include soy, groundnut, tiger nut, almond, rice, and coconut milk (Vanga and Raghavan, 2018; Astolfi et al., 2020).

These plant-based milks are promoted as functional foods to health-conscious consumers due to their

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superior bioactive compounds such as phenolic compounds, antioxidants, dietary fiber, medium-chain fatty acids, phytosterols, and isoflavones (Zandona et al., 2021). Plant-based milks are produced using unit processes, such as the disruption of the plant milk source through size reduction processes, milk extraction, formulation, and packaging (Tangyu et al., 2019). The milk only requires inoculation with mono or mixed cultures at a suitable temperature and is allowed to ferment to produce curd or yogurt (Tangyu et al., 2019). Plant-based milk and milk products have been marketed based on claims of naturalness and sustainability (Schiano et al., 2020). However, research has indicated that most plant-based milk and milk products are classified as processed or ultra-processed foods according to the NOVA classification (Astolfi et al., 2020; Braesco et al., 2022). These processed and ultra-processed foods contain synthetic ingredients such as additives (Braesco et al., 2022). This categorization of plant-based milk and milk products may deter consumers seeking minimally processed food products with clean labels. Production of plant-based milk and yogurt using minimal processing technologies would not only meet consumers' needs but would also be vital for ease of technology transfer to the artisanal food industry.

Coconut milk is regarded as a functional food due to its high fiber and oil contents, as well as its nutritional benefits (Paul et al., 2020). The oil has been associated with a range of health advantages, including increased insulin secretion, the utilization of blood glucose, and anti-inflammatory effects (Dhanasekara et al., 2022). It is high in calcium, potassium, phosphorus, and the vitamins B6, C, and E (Tulashie et al., 2022). Although it has high saturated fat, it is considered a good plant milk source due to its good digestibility (Chetachukwu et al., 2019). Additional probiotic health benefits are gained when the milk is used to make yogurt. Yogurt is a nutrient-dense functional food created through lactic acid fermentation, and it has traditionally played an important role in the range of fermented food products that contribute to good health and well-being (Mostafai et al., 2019). The probiotic qualities of yogurt allow it to be used for a variety of medical purposes, including the treatment of gastrointestinal diseases, the prevention of antibiotic-induced diarrhea, and the alleviation of vitamin D insufficiency in hyperlipidemic individuals (Imele and Atemnkeng, 2001; Mostafai et al., 2019). Ghana is the top producer of coconuts in the West African sub-region, with an annual production of over 400,000 tons as of the year 2020 (FAOSTAT, 2023). However, the crop is largely underutilized, as its commercial use is primarily for oil production. There have been other food applications at the artisanal level, such as the production of toffees, cookies, and chips. It is important to take advantage of the use of coconut for milk and yogurt production as a means of diversifying the commodity and improving its utilization. Coconuts are harvested at different maturity levels in Ghana.

Consumers who are primarily interested in coconut water often discard the endosperm, which varies in maturity. These endosperms include soft coconut endosperm, medium coconut endosperm, and hard coconut endosperm (Angeles et al., 2021). Soft endosperms are typically found in young coconuts, usually about 6 months old, while medium endosperms are at the middle stage of coconut development, and hard endosperms are obtained from matured coconuts (Angeles et al., 2021). The aim of this study was to evaluate the effect of coconut maturity (thickness) on the physicochemical properties and sensory acceptability of coconut milk and coconut yogurt. The study also sought to determine the effect of fermentation time on the physicochemical properties and sensory acceptability of coconut yogurt.

MATERIALS AND METHODS

Sources of raw materials

Fresh coconut, starter culture, and sugar used for the study were all procured from a local market in Kumasi. The starter culture contained *Lactobacillus bulgaricus, Streptococcus thermophilus,* and *Lactobacillus acidophilus.*

Experimental design

The research employed a 3 × 4 factorial experimental design, with Factor I being coconut endosperm thickness at 3 levels (soft, medium and hard endosperm) and Factor II being fermentation time at 4 levels (6, 12, 18 and 24 h).

Vernier Caliper was used to measure the thickness of the pulp (soft endosperm with an average thickness of 4 mm, medium endosperm: an average thickness of 10.5 mm and hard endosperm: an average thickness of 15.3 mm).

Processing of coconut milk

The coconut was washed, de-husked, and gently cracked open into halves. The coconut endosperm was removed and carefully washed. The washed endosperms were cut into pieces and blended (using a Binatone Heavy Duty Commercial Blender BL-1505) with warm water (50°C) to dissolve the fat in the shredded coconut pulp. For 1 kg of coconut endosperm, 1 L of warm water was used. The slurry was sieved with a cheese cloth, bottled, and cooled for sensory and physicochemical analyses. Figure 1 shows the process flow diagram for coconut milk.

Preparation coconut yoghurt

Coconut milk samples were pasteurized at a temperature range of 85 to 90°C for 20 min and then cooled rapidly to 45°C for inoculation with a 2% starter culture (yogourmet). The mixture was incubated at 45°C for 6, 12, 18 and 24 h to obtain different coconut yoghurt samples. The set yogurt was quickly cooled for sensory evaluation and other physicochemical analyses. Figure 2 shows the process flow diagram for coconut yoghurt.

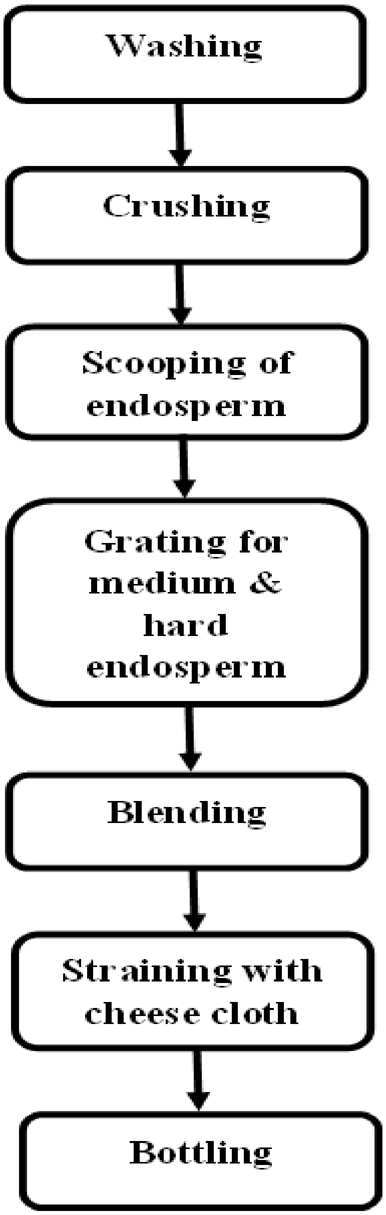

Figure 1. Process flow diagram for coconut milk.

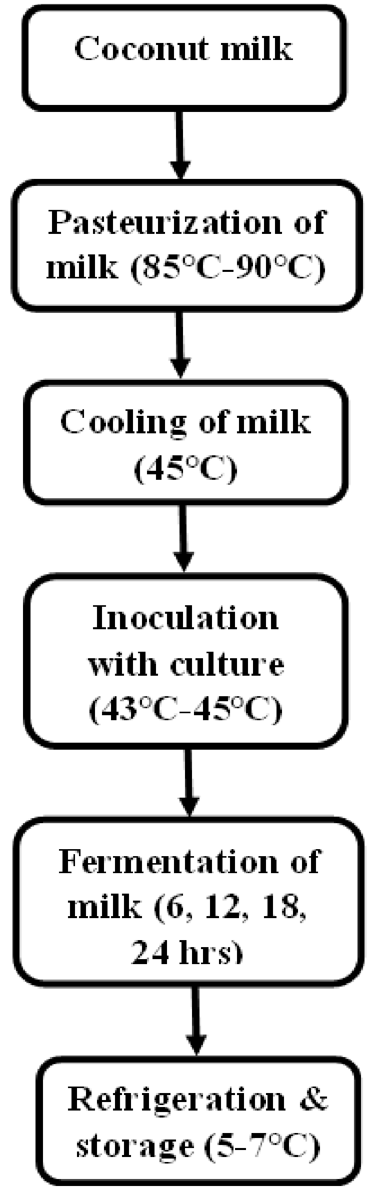

Figure 2. Process flow diagram for coconut yoghurt.

Physicochemical analysis of coconut milk and yoghurt

The titratable acidity of the samples was determined by using the method by AOAC (2000). A weighed amount of sample (5 g) was titrated against a standard 0.5 N NaOH to a pink endpoint using phenolphthalein as an indicator. The acid factor is 90.01 for lactic acid which is the dominant acid in milk (AOAC, 2000). The total titratable acidity value was calculated using the following formula:

$$Titratable\ acidity\ (\%) = \frac{Titre \times Normality\ of\ titrant \times 90.01 \times 100}{Weight\ of\ sample \times 1000} \quad (1)$$

The fat content of the coconut milk and yoghurt was determined by the Soxhlet extraction method with the aid of petroleum ether as extraction solvent (AOAC, 2000). The crude protein content of both the coconut milk and the yoghurt was determined using the Kjeldahl technique (AOAC, 2000).

The total ash was determined by the dry ashing method (AOAC, 2000), which involved weighing 2 g of the yoghurt samples into porcelain crucibles and incinerating the samples for 2 h in a muffle furnace (Thermolyne Benchtop Muffle furnace F48025-60, ThermoFisher Scientific) preheated at 600°C.

The moisture content of the sample was determined using a thermostatically controlled oven (Carbolite, PN 60 with 301 controller option) at 100 for 24 h based on the AOAC technique (AOAC, 2000). The following formula was used to derive the moisture percentage.

$$\%\ moisture = W_1 - \frac{W_2 \times 100}{W_1} \quad (2)$$

where W_1=initial weight of sample; W_2=weight of the dried sample. A digital pH meter (Jenway 3505, UK) was used to determine the pH of the samples and readings recorded. The total solids were determined using the AOAC technique (AOAC, 2000). The proportion of total solids in the residue was determined as the difference of 100% and the percentage moisture content of the samples.

Sensory evaluation of coconut milk and yoghurt samples

Coconut milk and coconut yogurt samples were refrigerated at temperatures between 4 and 7°C in plastic containers and labeled with three-digit identifiers. Fifty consumer panelists were asked to rate the samples on a 9-point Hedonic scale (1-dislike extremely to 9, like extremely) based on appearance, color, aroma, flavor, mouthfeel, taste (sourness), aftertaste, and overall acceptability (Obi et al., 2010). Water was used as palate cleansers between samples.

Data analysis

SPSS (version 21) was used to analyze the data. The influence of coconut maturity and fermentation on the samples was determined using analysis of variance (ANOVA), and significant differences were considered at $p < 0.05$.

RESULTS AND DISCUSSION

Effect of coconut maturity on the physicochemical compositions of coconut milk

There was a general increase in brix sugar content of the milk samples with the maturity of the endosperm used. The brix sugar content ranged between 2.4 and 3.34° brix for milk produced from the soft endosperm and medium endosperm, respectively (Table 1). These values were lower than the average value of 5.0 reported for skim coconut milk (Jermwongruttanachai et al., 2021). Possible causes for this difference include dissimilarities in formulation and the variety of coconuts used. The brix levels for all the coconut milk samples were below the Codex standard limits of 6.6 to 12.6 for light coconut milk (CODEX STAN 240-2003). This implies that these milk samples may require some form of sweetening to attain the required brix levels or concentration of solids. According to Raissa et al. (2007), the concentration of brix sugars in coconut milk continuously increases in the early months of development and then progressively diminishes at the stage of complete maturity of the nut, which is consistent with the results of this study. The fat content of the milk also increased with endosperm maturity, as observed by Angeles et al. (2021). Milk produced from hard coconut endosperm recorded the highest fat content of 6.71%, while milk produced from soft coconut endosperm recorded the lowest fat content of 2.33%. According to the Codex Standard, the fat content for light coconut milk and normal coconut milk is 5.0 and 10.0%, respectively. Therefore, the samples obtained from the study can be considered light coconut milk.

The protein content of the milk sample produced from soft coconut endosperm was the highest with a value of 3.48%. On the other hand, the moisture content decreased with increasing coconut maturity, ranging from 90.72% (for milk produced from soft endosperm) to 83.98% (for milk produced from hard endosperm). (Table 1). The moisture content of the milk was comparable to the Codex standard of 87.3 and 93.40% for normal and light coconut milk, respectively (CODEX STAN 240-2003). The titrable acidity for the milk sample produced from hard coconut endosperm was the highest with a value of 1.26%, while the soft coconut endosperm content was 0.44%. The predominant acids that may be present in coconut milk are lauric, myristic, and palmitic acids, which increase with coconut maturity (Lira et al., 2017).

The total solids of the coconut milk samples increased with the thickness of the endosperms, ranging from 9.28 to 16.02% for milk produced from coconut milk with soft and hard endosperm, respectively. There was no statistically significant difference ($p > 0.05$) in the pH of the milk samples, which ranged between 3.5 and 4.06, respectively. The pH of the milk samples indicates that it is slightly acidic compared to the required Codex standard of 5.95 (CODEX STAN 240-2003).

Effect of coconut maturity on the physicochemical composition of coconut yoghurt

Results indicate that there is a statistically significant difference ($p < 0.05$) in the brix levels of coconut yogurt samples. Yogurt produced from soft coconut endosperm recorded the highest brix of 2.52° brix, compared to the other two samples, which both recorded 2.18° brix. The fat contents of the yogurt samples ranged from 2.39 to 7.74% for yogurt samples produced from soft and hard endosperm, respectively (Table 2). The fat content of the coconut increased with endosperm maturity. According to Codex standards, the fat content of yogurt should be less than 15%, and the samples obtained were less than 15%, hence the result meets Codex's requirements. The fat content of the product will influence its body and mouthfeel.

The moisture content of the yogurt samples also decreased with the maturity of the coconut used, ranging between 82.90% for yogurt produced from hard coconut and 90.7% for yogurt produced from soft coconut, respectively. The protein content of the yogurt samples ranged between 2.0 and 2.6%. These values are slightly lower than the required value of 2.7% (CODEX STAN 240-2003). The titratable acidity content of the coconut yogurt sample produced from soft coconut yogurt recorded the highest value of 1.24%, while the hard

Table 1. Physicochemical compositions of coconut milk from varying endosperm thickness.

Parameter	Mean (± SEM) of type of coconut used			
	Hard coconut endosperm	**Medium coconut endosperm**	**Soft coconut endosperm**	**P-value**
Brix sugar	3.31 ± 0.28[a]	3.34 ± 0.11[a]	2.48 ± 0.23[b]	0.028
Fat (%)	6.71 ± 1.17[a]	4.88 ± 1.01[b]	2.33 ± 0.09[c]	0.014
Protein (%)	2.14 ± 0.52[b]	1.74 ± 0.41[c]	3.48 ± 0.51[a]	0.020
Moisture	83.98 ± 0.64[c]	85.85 ± 0.65[b]	90.72 ± 0.26[a]	<.001
Titratable acidity	1.26 ± 0.25[a]	1.17 ± 0.24[a]	0.44 ± 0.25[b]	0.017
Total solids	16.02 ± 0.90[b]	14.15 ± 0.82[b]	9.28 ± 0.60[a]	0.008
pH	4.06 ± 0.48	3.50 ± 0.23	3.98 ± 0.28	0.008

Means bearing different superscripts in the same row are significantly different (P<0.05). S.E.M = Standard error of means.

Table 2. Physicochemical compositions of coconut yogurt form varying endosperm thickness.

Parameter	Mean (± SEM) of type of coconut used			
	Hard coconut endosperm	**Medium coconut endosperm**	**Soft coconut endosperm**	**P-value**
Brix sugar	2.18 ± 0.01[b]	2.18 ± 0.02[b]	2.52 ± 0.11[a]	0.001
Fat (%)	7.74 ± 0.09[a]	4.64 ± 0.11[b]	2.39 ± 0.08[c]	0.001
Moisture (%)	82.99 ± 0.05[c]	85.60 ± 0.07[b]	90.77 ± 0.25[a]	0.001
Protein (%)	2.00 ± 0.01[a]	2.30 ± 0.11[a]	2.61 ± 0.23[a]	0.001
Titratable acidity (%)	1.07 ± 0.01[c]	1.15 ± 0.01[b]	1.24 ± 0.01[a]	0.001
Total solids	17.1 ± 0.08[c]	14.4 ± 0.09[b]	9.35 ± 0.09[a]	0.001
pH	4.08 ± 0.08[a]	4.03 ± 0.09[a]	3.94 ± 0.08[a]	0.539

Means bearing different superscripts in the same row are significantly different (P<0.05). S.E.M = Standard error of means.

coconut yogurt produced recorded the lowest value of 1.07%.

The titratable acidity level was marginally comparable to the Codex standard for yogurt (0.6%), but comparable to the total acidity of coconut yogurt reported by Peters et al. (2023), which ranged between 0.352 and 2.079%. This means that these yogurt samples may be slightly sour. However, a slight increase in the brix by sweetening could yield a brix-to-acidity ratio that offers favorable organoleptic properties.

There was a significant difference in the total solids content of the coconut yogurt samples. Yogurt samples produced from hard coconut endosperm recorded the highest total solids content (17.01%), while the soft coconut yogurt had the lowest (9.23%). The total solids content of the yogurt is indicative of its thickness, which is an important quality indicator.

The pH of the yogurt samples ranged between 3.94 (for yogurt produced from soft coconut endosperm) and 4.08 (for yogurt produced from hard coconut endosperm). Studies by Peters et al. (2023) also recorded slightly different values, ranging from 3.78 to 3.81, which may be due to the blend of cow milk and coconut milk used in their study.

Effect of fermentation time on physicochemical composition of coconut yoghurt

Results indicate that the fermentation time significantly affected the brix sugar, fat, total solid, protein, and titratable acidity ($p < 0.05$); however, changes in total solids and pH were not statistically significant ($p > 0.05$) (Table 3). The brix sugar decreased with increasing fermentation time, ranging from 2.55° brix for yogurt fermented for 6 h to 2.1° brix for coconut yogurt fermented for 24 h. The fat content of the yogurt samples also increased with fermentation time (Table 3).The increase in fat content of the samples during fermentation could be associated with an increasing microbial mass during fermentation. This increase in microbial mass results in increasing solids, which contributes to the decrease in moisture and an increase in protein contents of the samples during fermentation. As the sugar substrates are converted to acids over time during fermentation, it is expected that the acidity of the yogurt sample will increase with the time of fermentation. This phenomenon is consistent with the results obtained, where yogurt fermented for 6 h recorded a titratable acidity of 1.08%, which increased to 1.24% after 24 h of

Table 3. Physicochemical compositions of coconut yogurt at varying fermentation time.

Parameter	6 h	12 h	18 h	24 h	P-value
Brix sugar (%)	2.55±0.01[a]	2.33±0.01[b]	2.21±0.01[c]	2.10±0.01[d]	0.001
Fat (%)	4.53±0.01[b]	4.61±0.01[b]	5.22±0.01[a]	5.34±0.01[a]	0.001
Moisture	86.70±0.06[a]	86.70±0.06 [a]	86.20±0.06[a]	86.22±0.06[a]	0.100
Protein (%)	1.27±0.02[a]	1.27±0.02[a]	1.40±0.02[b]	1.28±0.02[a]	0.001
Titratable acidity (%)	1.08±0.01[c]	1.13±0.01[b]	1.14±0.01[b]	1.26±0.01[a]	0.001
Total solids	13.30±0.0[a]	13.30±0.01[a]	13.80±0.01[a]	13.78±0.01	0.101
pH	4.06±0.10[a]	4.04±0.10a	4.02±0.10 [a]	3.96±0.10 [a]	0.909

Means bearing different superscripts in the same row are significantly different (P<0.05);S.E.M = Standard error of means.

Table 4. Mean sensory score of coconut milk from different endosperm thickness.

Attributes	Soft coconut endosperm	Medium coconut endosperm	Hard coconut endosperm	P-value
Appearance	6.37±1.14[b]	6.05±1.07[b]	7.09±1.01[a]	0.003
Color	6.92±1.28[c]	6.52±1.30[a]	7.09±1.25[b]	0.000
Aroma	5.92±1.03[c]	5.37±1.20[a]	7.02±1.28[b]	0.000
Flavor	5.94±1.05[c]	5.31±1.01[a]	7.00±1.59[b]	0.000
Mouth feel (Body)	5.60±1.14[c]	4.72±1.28[a]	7.27±1.45[b]	0.000
Taste	5.27±1.04[c]	4.82±1.23[a]	6.64±1.07[b]	0.000
After taste	5.74±1.07[c]	4.64±1.20[a]	7.37±1.58[b]	0.000
Overall acceptability	5.92±1.25[c]	4.81±1.30[a]	7.56±1.54[b]	0.000

Scale 1- dislike extremely to 9- like extremely.

fermentation. The increase in acidity with an increase in fermentation time will have acceptability implications. A good balance of brix and acidity is required to produce an acceptable product.

Sensory acceptability of coconut milk samples

There was a statistically significant difference ($p<0.05$) in the sensory attributes of all the coconut milk samples evaluated. The sensory acceptability of the milk samples improved with increasing coconut maturity. Coconut milk produced from hard endosperm was most preferred for appearance (7.09), color (7.09), flavor (7.00), taste (6.64), aftertaste (7.37), mouthfeel (7.27), and overall acceptability (7.56) (Table 4). Poongodi and Rameshkumar (2022) found a mean value of 7.1 for the aroma of coconut milk and a value of 6.57 for the mean color of coconut milk, which is consistent with the results of this study. Products made from soft and medium coconut endosperm were barely acceptable. The acceptability of hard coconut milk was the best of the three samples. This means that the acceptability of the coconut milk will improve with increasing solid content, as improved solids will enhance the taste, a very important purchasing indicator. Thus, the best endosperm for coconut milk production is the hard coconut. However, further studies can be conducted on producing coconut milk from a combination of endosperms of various thicknesses to ascertain its sensory acceptability.

Sensory acceptability of coconut yoghurt samples

The preferences of the panelists significantly varied ($p < 0.05$) among all attributes evaluated in all the yogurt samples. The acceptability of coconut yogurt samples reduced with increasing fermentation time (Table 5). When compared with others fermented for 12, 18, and 24 h, coconut yogurt fermented for 6 h was the most preferred for all attributes (appearance, color, aroma, flavor, mouthfeel, taste, and aftertaste). This was reflected in the general acceptance of coconut yogurt, with coconut fermented for 6 h being the most preferred. The aroma, taste, and texture of yogurt are influenced by fermentation period and temperature. Prolonged fermentation increases the acidity of yogurt, which affects its sensory properties. Table 5 shows the mean sensory attributes of coconut yoghurt samples.

Conclusion

Coconut maturity influences parameters such as fat

Table 5. Mean sensory score of coconut yogurt at different fermentation times.

Attributes	Sample Codes				P-value
	100A	100B	100C	100D	
Appearance	7.52±1.20[c]	6.98±1.32[b]	6.38±1.25[b]	6.04±1.54[a]	0.000
Color	7.46±1.34[c]	7.14±1.55[c]	6.64±1.34[b]	6.22±1.42[a]	0.003
Aroma	7.54±1.28[c]	6.84±1.43[b]	6.40±1.22[b]	5.70±1.51[a]	0.005
Flavor	7.68±1.42[b]	7.16±1.54[b]	6.38±1.33[a]	5.68±1.23[a]	0.006
Mouth-feel	7.16±1.34[c]	6.92±1.04[c]	6.44±±1.36[b]	5.32±1.26[a]	0.000
Taste (sourness)	7.40±1.22[c]	6.86±1.38[bc]	6.26±1.52[b]	5.08±1.45[a]	0.005
After taste	7.80±1.44[c]	7.10±1.34[c]	6.28±1.41[b]	5.24±1.04[a]	0.001
Overall acceptability	7.98±1.33[d]	7.34±1.56[c]	6.70±1.46[b]	5.62±1.33[a]	0.000

100A = Coconut yoghurt for 6 h fermentation, 100B = Coconut yoghurt for 12 h fermentation, 100C = Coconut yoghurt for 18 h fermentation, 100D = Coconut yoghurt for 24 h fermentation.

content, total solids content, pH, and brix of both coconut milk and yogurt. The acceptability of coconut milk increases with endosperm maturity. Hence, coconut milk produced from mature coconuts with hard endosperm will be a commercially viable choice. However, a careful blend of endosperm from soft, medium, and hard coconuts could yield milk with desirable organoleptic characteristics. In the production of coconut yogurt, parameters such as brix, titratable acidity, fat, and protein are significantly influenced by fermentation time. Fermentation time also influences coconut yogurt acceptability. At an incubation temperature of 45°C, coconut milk should be incubated for a maximum of 6 hours to produce acceptable coconut yogurt.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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