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Effects of Coconut Flour and Milk Powder Supplementation on the Physicochemical Properties of Peanut Butter

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Abstract.
Peanut butter is a popular, versatile food spread globally known for its nutritional value and unique flavor. As consumer preferences evolve, there is an increasing demand for fortified products. Coconut flour and milk powder are potential fortification agents due to their nutritional benefits and compatibility with various food matrices.

We explored the effects of incorporating coconut flour and milk powder into peanut butter, analyzing its nutritional composition and sensory qualities. Various combinations (0, 5, 10, and 15% w/w) of coconut flour, milk powder, and their mixture were introduced into peanut butter followed by a thorough physicochemical and sensory analysis.

The results showed notable changes in both physical and chemical attributes. Coconut flour and its combination with milk powder increased the moisture content in peanut butter, while milk powder had the opposite effect. The protein content peaked in the peanut butter with 15% coconut flour, while the fat content diminished with higher concentrations of coconut flour and milk powder. Carbohydrate levels in the supplemented samples surpassed those of the control and commercial peanut butters. All the variants exhibited a pseudoplastic flow behavior, with coconut flour and milk powder concentrations affecting viscosity. The textural analysis revealed differences in oil separation, spreadability, and firmness, with 15% coconut flour yielding the highest firmness and oil separation. Noteworthy color changes were evident, particularly with the inclusion of 15% milk powder. Sensory assessments favored the peanut butter with a 15% blend of coconut flour and milk powder, while the color preference leaned towards the 15% milk powder variant. The consumers preferred the peanut butter fortified with a 15% blend of coconut flour and milk powder.

Our research can help food manufacturers create healthier, more appealing products that cater to evolving consumer preferences and dietary requirements.

Keywords. Butter, nuts, milk powder, fortification, rheology, texture, quality, sensory evaluation

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Физико-химические свойства арахисовой пасты с добавлением кокосовой муки и сухого молока

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Аннотация.
Арахисовая паста известна своей пищевой ценностью и уникальным вкусом. По мере развития потребительских предпочтений растет и спрос на обогащенные продукты. Кокосовая мука и сухое молоко имеют ряд преимуществ в этой области, т. к. хорошо сочетаются с различными пищевыми матрицами. Цель исследования заключалась в изучении влияния кокосовой муки и сухого молока на качество арахисовой пасты: ее питательный состав, органолептические свойства и т.д.

В ходе работы кокосовая мука, сухое молоко и их смеси (0, 5, 10 и 15 % по весу) добавлялись в арахисовую пасту. Физико-химические и органолептические показатели определяли с применением стандартных методов анализа. Полученные данные подвергались статистической обработке.

Результаты показали статистически значимые изменения как физических, так и химических свойств. Кокосовая мука и ее различные комбинации с сухим молоком увеличивали содержание влаги в арахисовой пасте. Влияние сухого молока оказалось прямо противоположным. Содержание белка достигло пика в образцах с 15 % кокосовой муки. При более высоких концентрациях кокосовой муки и сухого молока в образцах снижалось качество жира. Экспериментальные образцы содержали больше углеводов, чем контрольный образец и коммерческие образцы арахисовых масел. Для всех образцов было характерно псевдопластическое течение. Уровень вязкости зависел от концентрации кокосовой муки и сухого молока. Образцы различались по отделению жира, намазываемости и твердости. Самые высокие показатели твердости и отделения жира были зафиксированы в образцах с добавлением 15 % кокосовой муки. Наиболее заметные изменения цвета произошли в образцах с добавлением 15 % сухого молока. Наивысшую органолептическую оценку получил образец арахисовой пасты с 15 % смеси кокосовой муки и сухого молока, однако вариант с 15 % сухого молока имел оптимальные цветовые характеристики.

Применение результатов исследований при производстве обогащенной арахисовой пасты позволило расширить спектр функциональных продуктов, которые соответствуют меняющимся предпочтениям потребителей и современным диетическим требованиям.

Ключевые слова. Масло, орехи, сухое молоко, обогащение, реология, текстура, качество, сенсорная оценка

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Introduction

The quest for healthier and more sustainable food products has led to increased interest in the modification of traditional foods to improve their nutritional profile and functional properties. One of the challenges of modern food items is meeting consumers' expectations for both taste and health [1]. Peanut butter, a widely consumed food in various global cultures, is valued for its flavorful profile and substantial protein content. Over time, there have been different adaptations of peanut butter to improve its nutritional advantages and sensory qualities. High in protein and low in calories, peanut butter is a healthy alternative to dairy butter and is commonly used as a bread spread [2]. Although peanut butter is more prevalent in western countries than in Asian countries like India, its consumption is gradually increasing. Peanut butter has a range of advantages, such as aiding in weight loss and offering optimal nutritional value [3]. It is available in ready-to-eat forms and is also used in a range of applications such as breakfast food, savory sauces, and smoothies.

Peanuts (*Arachis hypogaea*) are classified as both a grain legume and an oil crop due to their high oil content. Peanut seeds are a valuable source of protein, lipids, and fatty acids, providing essential nutrients for human diet [4]. Roasted peanut kernels are an excellent source of folate, niacin, and vitamin E, although they are deficient in vitamins A and C, as well as calcium and iron [5]. Peanuts are rich in micronutrients, phytochemicals, tocopherols, and phenolic compounds, and the development of peanut butter can potentially increase the uses of peanuts in healthier, non-animal breakfast snack options [6]. The production of peanut butter involves important stages such as roasting and milling, which impact the product's texture, rheological characteristics, and overall quality [7]. Optimal amalgamation of components, such as nut paste, sugar, vegetable oil, and protein sources, is imperative to guarantee the steadfastness of peanut butter. Coconut flour and milk powder can augment the attributes of peanut butter, including its color, taste, flavor, and texture, thus increasing its attractiveness to customers.

Coconut flour is an excellent source of dietary fiber that may be effectively incorporated into food products to enhance their physical, chemical, and nutritional characteristics [8]. Coconut flour may contribute to the flavor, color, and mouth feel of peanut butter, as well as improve its spread quality. Milk powder also plays a significant role in enhancing the quality of peanut butter, including its color, flavor, taste, and overall acceptability. Peanut products supplemented with milk derivatives or comparable components have exhibited changes in sensory qualities. This implies that milk powder may modify the flavor, texture, and general consumer acceptability of peanut butter [9]. Coconut products, along with milk powder, are well-known for their nutritional advantages. They include a significant amount of dietary fiber, healthy fats, and a variety of essential vitamins and minerals. In this study, we aimed to fill the gap in existing literature by offering a thorough analysis of how these supplements impact the physicochemical characteristics of peanut butter.

Previous studies have touched upon the functional properties of coconut flour and its effects on the texture and sensory properties of baked and confectionery goods. For instance, a work on coconut flour's influence on dough and cookie texture revealed significant improvements in the product's quality and healthfulness [10]. Similarly, an investigation into the effects of coconut milk, tender coconut, and coconut sugar on ice cream highlighted their potential for improving sensory experiences through natural supplementation [11]. These findings underscore the versatility of coconut-derived ingredients in enhancing food products, providing a strong foundation for their application in peanut butter. However, the application of coconut flour and milk powder in peanut butter poses unique challenges and opportunities. These supplements may significantly alter the physicochemical properties of peanut butter, such as its phase behavior, moisture content, and oil binding capacity. They can affect everything in peanut butter, from its nutritional value to its storage stability and consumer acceptability. Therefore, we sought to systematically investigate these impacts, contributing valuable knowledge to the fields of food science and nutrition.

To sum up, the supplementation of peanut butter with coconut flour and milk powder presents a promising avenue for enhancing the nutritional profile and sensory qualities of this popular food product. By systematically exploring the effects of these supplements on the physicochemical properties of peanut butter, we aimed to provide valuable insights for food scientists, nutritionists, and the food industry at large, potentially paving the way for the development of healthier, more sustainable, and more appealing peanut butter products.

Study objects and methods

Preparation of coconut flour. Coconut flour was prepared according to the method of Ramya and Anitha with a slight modification [12]. Freshly purchased fully-grown coconuts were physically stripped of their shells, had their outer layer removed and the coconut water drained. The white coconut flesh was cleaned, mixed with heated water, and then filtered to extract the milk. The residual moist flour was dried in a cabinet dryer at 60°C for 4 hours. The dried substance was packaged and placed in the refrigerator to avoid the development of rancidity.

Preparation of peanut butter. Peanut butter was prepared according to the method described by Mohd. Rozalli *et al.* with few modifications [13]. Peanut butter was made by combining roasted peanuts, sugar, coconut flour, milk powder, and salt in varying amounts. After mixing and homogenizing peanut butter, it was placed in plastic containers and stored at room temperature.

Table 1. Formulations of peanut butter with coconut flour and milk powder

Таблица 1. Рецептуры арахисовой пасты с добавлением кокосовой муки и сухого молока

Sample	Peanut, %	Sugar, %	Coconut flour, %	Milk powder, %	Salt, %
S_1	94.5	5.0	–	–	0.5
S_2	89.5	5.0	5.0	–	0.5
S_3	84.5	5.0	10.0	–	0.5
S_4	79.5	5.0	15.0	–	0.5
S_5	89.5	5.0	–	5.0	0.5
S_6	84.5	5.0	–	10.0	0.5
S_7	79.5	5.0	–	15.0	0.5
S_8	89.5	5.0	2.5	2.5	0.5
S_9	84.5	5.0	5.0	5.0	0.5
S_{10}	79.5	5.0	7.5	7.5	0.5

Note: S_1 – Control sample; S_2 – Peanut butter with 5% coconut flour; S_3 – Peanut butter with 10% coconut flour; S_4 – Peanut butter with 15% coconut flour; S_5 – Peanut butter with 5% milk powder; S_6 – Peanut butter with 10% milk powder; S_7 – Peanut butter with 15% milk powder; S_8 – Peanut butter with 5% mixture; S_9 – Peanut butter with 10% mixture; and S_{10} – Peanut butter with 15% mixture.

Примечание: S_1 – контрольный образец; S_2 – арахисовая паста с 5 % кокосовой муки; S_3 – арахисовая паста с 10 % кокосовой муки; S_4 – арахисовая паста с 15 % кокосовой муки; S_5 – арахисовая паста с 5 % сухого молока; S_6 – арахисовая паста с 10 % сухого молока; S_7 – арахисовая паста с 15 % сухого молока; S_8 – арахисовая паста с 5 % смеси кокосовой муки и сухого молока; S_9 – арахисовая паста с 10 % смеси кокосовой муки и сухого молока; S_{10} – арахисовая паста с 15 % смеси кокосовой муки и сухого молока.

Table 1 shows the formulations of peanut butter with various ratios of coconut flour and milk powder.

The composition of the milk powder is presented in Table 2.

Proximate composition analysis. The coconut flour, peanut powder, and peanut butter samples were analyzed for moisture, protein, fat, ash, and carbohydrate contents according to the methods of AOAC and Momin *et al.* [14, 15].

Viscosity. Viscosity was measured with a digital rotational viscometer (NDJ-5S) to assess the flow behavior and consistency coefficient of the formulated peanut butter. The power law model was used to represent the viscosity of non-Newtonian fluids. The apparent viscosity was determined as a function of spindle speed using the following formula [16]:

$$\mu a = K\,(1/n)^n\,(4\pi N)^{(n-1)} \qquad (1)$$

where μa is the apparent viscosity, Pa·s; N is the spindle speed, RPS; K is the Consistency coefficient, Pa·sn; n is the Flow behavior index, dimensionless.

The procedure involved connecting the spindle, immersing it in the fluid, and recording dial readings at different speeds. The flow behavior index (n) and consistency coefficient (K) were calculated by analyzing the ln(μa) values plotted against ln(4πN).

Physical properties. The oil separation was observed following the method of Radočaj *et al.* with some modifications [17]. Pre-weighted filter paper (A) was put on top of each sample (B). After 24 hours, filter papers were collected and weighed (C) to measure the separated oil as a percentage.

Table 2. Composition of milk powder

Таблица 2. Химический состав сухого молока

Component/parameter	Amount
Protein, %	27
Milk fat (min), %	28
Lactose, %	38
Minerals, %	6
Moisture (max), %	3
Energy (per 100 g), kJ	2100

$$\text{Oil Separation} = \frac{C - A}{B} \times 100 \qquad (2)$$

Spreadability and firmness were measured according to the method of Mohd. Rozalli *et al.* with some modifications [13]. A TA.HD PLUS texture analyzer (Stable Microsystems, Surrey, UK) used a load cell of 5 kg with a conical TTC Spreadability Rig (HDP/SR) attachment (Stable Microsystems, Surrey, UK). The weight and height of the machine were calibrated for 5000 g and 25 mm, respectively. The measurement was carried out at a test speed of 1.0 mm/s and a penetration depth of 25 mm. Each operation was conducted in triplicate. The color of the peanut butter samples was evaluated with a Chroma Meter (CR-400/410, Konica Minolta, Japan). The measurements were taken under illuminants **C* and D65 using the LAB color space. The color system applied *L**, *a**, and *b** values, where *L** represents lightness (100: white, 0: black), *a** represents redness (+)/greenness (−), and *b** indicates blueness (−) or yellowness (+). The tests were conducted in tripli-

cate. The value of ΔE* was calculated using the following equation:

$$\text{Color change } (\Delta E) = (L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2] \quad (3)$$

Sensory analysis. All the peanut butter samples were analyzed according to the method of Huq *et al.* [18]. Consumer preference was determined on a 1-to-9-point hedonic scale from "Dislike extremely" to "Like extremely." Sensory properties such as color, flavor, and overall acceptability were evaluated by 15 semi-trained panelists.

Statistical analysis. The collected data on various parameters were statistically analyzed using IBM SPSS Statistics (IBM Corp., Armonk, N.Y., USA). The means for all the treatments were calculated and analysis of variance (ANOVA) for all the parameters was performed by F–test. The significance of difference between the pairs of means was compared by the least significant difference (LSD) test at 5% significance.

Results and discussion

Proximate composition of peanut powder and coconut flour. The proximate composition of peanut powder and coconut flour is shown in Table 3. The moisture, protein, fat, carbohydrate, ash, crude fiber, and dry matter contents for peanut powder were 7.5, 24.6, 45.4, 16.6, 2.4, 3.2, and 92.4%, respectively. These results are consistent with those previously published by Ayoola *et al.* [19]. Conversely, coconut flour included 4.2% moisture, 14.1% protein, 9.6% fat, 49.9% carbohydrates, 8.6% ash, 13.4% crude fiber, and 95.7% dry matter. The results are consistent with the findings reported by Sujirtha and Mahendran [20].

Proximate composition of peanut butter. The peanut butter samples, as well as commercial peanut butter, were examined for their moisture, fat, ash, protein, and total carbohydrate contents (Table 4).

Table 4 shows a progressive increase in the moisture content of peanut butter, the highest value recorded in the sample with 15% coconut flour. This rise in moisture

Table 3. Proximate composition of peanut and coconut flour

Таблица 3. Приблизительный химический состав арахисовой и кокосовой муки

Components, %	Peanut powder	Coconut flour
Moisture content	7.50 ± 0.12	4.20 ± 0.15
Protein	24.60 ± 0.11	14.10 ± 0.10
Fat	45.40 ± 0.24	9.60 ± 0.13
Carbohydrate	16.60 ± 0.10	49.90 ± 0.32
Ash	2.40 ± 0.06	8.60 ± 0.12
Crude fiber	3.20 ± 0.10	13.40 ± 0.10
Dry matter	92.40 ± 0.12	95.70 ± 0.15

Table 4. The effects of milk powder and coconut flour on the chemical composition of peanut butter

Таблица 4. Влияние сухого молока и кокосовой муки на химический состав арахисовой пасты

Sample	Moisture, %	Protein, %	Fat, %	Ash, %	Carbohydrate, %
C_1	1.30 ± 0.01^a	25.10 ± 0.30^a	51.10 ± 0.28^a	2.50 ± 0.30^a	20.10 ± 0.11^a
S_1	2.30 ± 0.02^b	25.50 ± 0.55^a	46.30 ± 0.19^b	2.60 ± 0.55^a	23.20 ± 0.24^b
S_2	2.80 ± 0.01^c	26.40 ± 0.47^a	45.40 ± 0.11^c	2.80 ± 0.47^a	23.30 ± 1.68^b
S_3	2.80 ± 0.01^c	26.70 ± 0.36^a	45.20 ± 0.23^c	3.10 ± 0.36^a	23.20 ± 1.80^b
S_4	2.90 ± 0.02^d	27.40 ± 0.60^a	44.40 ± 0.21^d	2.80 ± 0.60^a	23.40 ± 2.15^b
S_5	2.30 ± 0.01^e	26.10 ± 0.32^b	45.60 ± 0.26^e	3.50 ± 0.26^a	23.50 ± 1.84^b
S_6	2.30 ± 0.02^e	26.90 ± 0.30^c	45.20 ± 0.29^e	3.60 ± 0.30^a	23.50 ± 2.82^b
S_7	2.20 ± 0.02^f	27.60 ± 0.35^c	44.20 ± 0.22^f	3.90 ± 0.35^a	23.50 ± 3.07^b
S_8	2.60 ± 0.01^g	25.50 ± 0.31^d	46.90 ± 0.07^g	2.60 ± 0.18^b	22.90 ± 1.09^b
S_9	2.80 ± 0.01^h	26.23 ± 0.40^c	47.30 ± 0.18^h	2.80 ± 0.40^b	22.10 ± 2.29^b
S_{10}	3.10 ± 0.01^i	26.80 ± 0.32^c	47.90 ± 0.04^i	2.90 ± 0.32^b	21.60 ± 3.13^b

Note: Values are expressed as mean ± standard deviation of three replicates. Values with the same superscript within column indicates no significant difference ($p > 0.05$). C_1 – Commercial sample; S_1 – Control sample; S_2 – Peanut butter with 5% coconut flour; S_3 – Peanut butter with 10% coconut flour; S_4 – Peanut butter with 15% coconut flour; S_5 – Peanut butter with 5% milk powder; S_6 – Peanut butter with 10% milk powder; S_7 – Peanut butter with 15% milk powder; S_8 – Peanut butter with 5% mixture; S_9 – Peanut butter with 10% mixture; and S_{10} – Peanut butter with 15% mixture.

Примечание: Все значения представлены как среднее значение трех повторных экспериментов ± стандартное отклонение. Данные с одинаковым верхним индексом в одном столбце существенно не различаются ($p > 0{,}05$).
C_1 – коммерческий образец; S_1 – контрольный образец; S_2 – арахисовая паста с 5 % кокосовой муки; S_3 – арахисовая паста с 10 % кокосовой муки; S_4 – арахисовая паста с 15 % кокосовой муки; S_5 – арахисовая паста с 5 % сухого молока; S_6 – арахисовая паста с 10 % сухого молока; S_7 – арахисовая паста с 15 % сухого молока; S_8 – арахисовая паста с 5 % смеси кокосовой муки и сухого молока; S_9 – арахисовая паста с 10 % смеси кокосовой муки и сухого молока; S_{10} – арахисовая паста с 15 % смеси кокосовой муки и сухого молока.

can be ascribed to the elevated protein content, which augments the water retention ability of peanut butter with substantial amounts of coconut flour. The moisture content of peanut butter exhibited a progressive drop from 2.3 to 2.2% when the amount of milk powder added increased from 5 to 15%. The combination of coconut flour and milk powder in the peanut butter lead to a progressive increase in moisture. The moisture content in the commercial peanut butter (C_1) was 1.3%, which was lower than that in the control sample (2.3%).

As can be seen in Table 4, incorporating coconut flour into peanut butter (0 to 15%) enhanced the protein content from 25.1 to 26.7%, with the lysine content also increasing, thereby improving its nutritional profile. Adding milk powder (5 to 15%) to peanut butter incrementally raised the protein level from 26.1 to 27.6%. A mixture of coconut flour and milk powder in peanut butter yielded a protein content between 25.5 and 26.8%, similar to the control and commercial samples.

The fat content in peanut butter decreased as the substitution level of coconut flour increased, ranging from 46.3 to 44.4%. Similarly, the partial substitution of milk powder decreased the fat content in peanut butter from 45.6 to 44.2%. However, the mixture of milk powder and coconut flour added to peanut butter increased its fat content from 46.9 to 47.9%. According to our analysis, the commercial peanut butter (C_1) had the highest fat content at 51.1%, while the sample with 15% milk powder (S_7) had the lowest fat content at 44.2%.

The ash content, indicative of mineral content, increased from 2.6 to 2.8% with coconut flour additions and from 3.5 to 3.9% with milk powder supplementation. This upward trend may be attributed to a higher mineral content in coconut flour compared to peanut. The combination of coconut flour and milk powder raised the ash content from 2.6 to 2.9%. The commercial peanut butter (C_1) had the lowest ash content at 2.5%, while the sample with 15% milk powder (S_7) had the highest ash content at 3.9%. The control sample had an ash content of 2.5%.

The carbohydrate content varied with ingredient adjustments, increasing from 23.2 to 23.4% with coconut flour supplementation and rising slightly in the samples with milk powder. However, the combination of coconut flour and milk powder led to a decrease in total carbohydrates. The peanut butter with 15% milk powder had the highest carbohydrate content at 23.5%, whereas the commercial sample had the lowest at 20.1%. These results align with the research conducted by Mazaheri-Tehrani *et al.* on peanut butter fortified with soy-flour, Özcan and Seven on peanut varieties from seven cultivars, and Yeh *et al.* on peanut spread fortified with protein, vitamins, and minerals [21–23].

Physical analysis. Flow behavior. We investigated the flow behavior of the developed and commercial peanut butter samples, focusing on the effects of coconut flour and milk powder supplementation (Table 5).

Pseudoplasticity character was observed in all samples. Statistical analysis revealed significant differences ($p < 0.05$) in the flow-behavior index (n) and consistency coefficient (K) between treatments, control, and commercial samples. The control peanut butter had an n value of 0.11, while the commercial sample had an n value of 0.06. The increasing addition of coconut flour resulted in a rise in the flow-behavior index (n), indicating an increase in the pseudoplasticity of the peanut butter formulation. In contrast, the inclusion of milk powder resulted in a gradual reduction in the flow-behavior index, indicating a drop in pseudoplasticity. The inclusion of milk powder resulted in enhanced sensory qualities, as shown by

Table 5. The effects of coconut flour and milk powder supplementation on the flow behavior of peanut butter

Таблица 5. Влияние кокосовой муки и сухого молока на свойства текучести арахисовой пасты

Sample	Flow behavior index (n)	Consistency coefficient (K), Pa·s^n
C_1	0.06^{f}	112.93^{a}
S_1	0.11^{e}	101.33^{c}
S_2	0.17^{c}	88.88^{e}
S_3	0.19^{b}	83.78^{f}
S_4	0.24^{a}	77.43^{g}
S_5	0.13^{d}	98.35^{cd}
S_6	0.11^{e}	103.85^{c}
S_7	0.10^{e}	108.92^{b}
S_8	0.14^{d}	96.49^{d}
S_9	0.16^{c}	90.404^{e}
S_{10}	0.19^{b}	81.86^{f}

Note: The values are expressed as mean ± standard deviation of three replicates. The values with the same superscript within a column have no significant difference ($p > 0.05$). The same letters within the column for the behavior index and consistency coefficient indicate no significant difference ($p < 0.05$).

C_1 – Commercial sample; S1 – Control sample; S_2 – Peanut butter with 5% coconut flour; S_3 – Peanut butter with 10% coconut flour; S_4 – Peanut butter with 15% coconut flour; S_5 – Peanut butter with 5% milk powder; S_6 – Peanut butter with 10% milk powder; S_7 – Peanut butter with 15% milk powder; S_8 – Peanut butter with 5% mixture; S_9 – Peanut butter with 10% mixture; and S_{10} – Peanut butter with 15% mixture.

Примечание: Все значения представлены как среднее значение трех повторных экспериментов ± стандартное отклонение. Данные с одинаковым верхним индексом в одном столбце существенно не различаются ($p > 0{,}05$). Совпадение букв в столбце для индекса текучести и коэффициента согласованности указывают на отсутствие существенной разницы ($p < 0{,}05$).

C_1 – коммерческий образец; S_1 – контрольный образец; S_2 – арахисовая паста с 5 % кокосовой муки; S_3 – арахисовая паста с 10 % кокосовой муки; S_4 – арахисовая паста с 15 % кокосовой муки; S_5 – арахисовая паста с 5 % сухого молока; S_6 – арахисовая паста с 10 % сухого молока; S_7 – арахисовая паста с 15 % сухого молока; S_8 – арахисовая паста с 5 % смеси кокосовой муки и сухого молока; S_9 – арахисовая паста с 10 % смеси кокосовой муки и сухого молока; S_{10} – арахисовая паста с 15 % смеси кокосовой муки и сухого молока.

sensory evaluations. When a mixture of coconut flour and milk powder was incorporated, the flow behavior index values resembled those of the control sample. The consistency coefficient (K) ranged from 77.4 to 108.9 Pa·sn for the formulated peanut butters, compared to 101.3 Pa·sn for the control sample and 112.9 Pa·sn for the commercial sample. Addition of coconut flour decreased the consistency coefficient, while addition of milk powder increased it. The combination of coconut flour and milk powder resulted in gradually increasing consistency coefficients with incremental additions of the mixture. The data indicate that coconut flour intensifies pseudoplasticity, improving its propensity to spread, whereas milk powder reduces pseudoplasticity, which may affect sensory characteristics. Coconut flour and milk powder can be combined in an optimum manner to obtain the appropriate flow behavior and consistency in peanut butter compositions.

Texture and color. All the peanut butter samples were evaluated for their textural properties (oil separation, spreadability, and firmness), as well as color (Table 6).

As can be seen, the samples supplemented with coconut flour (5 to 15%) exhibited a significant increase in oil separation, from 2.1 to 2.3%. Conversely, the use of milk powder lessened the rate of oil separation. Adding a mixture of coconut and milk powder decreased oil separation (Table 6). The results demonstrate that milk powder has a superior ability to retain oil compared to coconut flour. Aryana *et al.* supplemented peanut butter with 0, 1.5, 2, and 2.5% palm oil and found oil separation at 4.95, 4.86, 3.98, and 5.51%, respectively [24]. The separated oil gets rancid and deteriorates the quality of peanut butter. Our findings are consistent with those reported by Ferdaus *et al.*, who assessed natural waxes as stabilizers for peanut butter, and those reported by Winkler-Moser *et al.*, who evaluated beeswax, candelilla wax, rice bran wax, and sunflower wax as alternative stabilizers for peanut butter [25, 26].

According to Table 6, the use of coconut powder (5 to 15%) resulted in increased spreadability and firmness of peanut butter. The addition of milk powder resulted in contrasting changes in spreadability and stiffness. The combination of coconut flour and milk powder improved the spreadability and firmness of the samples, with an increase ranging from 7.3 to 7.4% and from 13.7 to 13.9%, respectively. The spreadability of the experimental samples was greater than that of the control sample and the commercial peanut butter. These results align with the findings of Ferdaus *et al.* in their evaluation of natural waxes as stabilizers for peanut butter, as well as with the research conducted by Mohd. Rozalli *et al.* on the quality variations of stabilizer-free natural peanut butter during storage [13, 25].

Finally, there was a noticeable variation in color across the different samples. The ΔE color parameter was assessed in relation to the commercial peanut butter. The

Table 6. Textural properties of peanut butter

Таблица 6. Текстурные свойства арахисовой пасты

Sample	Oil separation, %	Spreadability, NS^{-1}	Firmness, N	Color ΔE
C_1	1.90 ± 0.13^{b}	7.10 ± 0.46^{bc}	12.90 ± 0.33^{bc}	–
S_1	2.10 ± 0.17^{ab}	7.20 ± 0.34^{bc}	13.60 ± 0.62^{bc}	2.70 ± 0.23^{f}
S_2	2.10 ± 0.22^{ab}	7.50 ± 0.13^{ab}	13.90 ± 0.95^{b}	4.30 ± 0.27^{cd}
S_3	2.20 ± 0.16^{ab}	7.70 ± 1.12^{ab}	14.40 ± 1.21^{ab}	5.80 ± 0.42^{c}
S_4	2.30 ± 0.25^{a}	7.90 ± 0.13^{a}	14.80 ± 0.71^{a}	7.50 ± 0.61^{b}
S_5	2.10 ± 0.17^{ab}	7.10 ± 0.78^{bc}	13.60 ± 0.62^{bc}	4.50 ± 0.85^{d}
S_6	2.10 ± 0.13^{ab}	$7.10 \pm 0.12b^{c}$	13.10 ± 0.33^{c}	7.40 ± 1.12^{bc}
S_7	2.10 ± 0.37^{b}	6.80 ± 0.46^{c}	12.90 ± 1.21^{c}	10.90 ± 0.85^{a}
S_8	2.10 ± 0.22^{ab}	7.30 ± 0.53^{b}	13.70 ± 0.95^{bc}	3.20 ± 0.61^{e}
S_9	2.10 ± 0.37^{ab}	7.40 ± 0.34^{ab}	13.70 ± 0.71^{bc}	5.20 ± 0.23^{bc}
S_{10}	2.10 ± 0.09^{ab}	7.40 ± 0.78^{ab}	13.90 ± 0.62^{bc}	7.20 ± 0.42^{bc}

Note: The values are expressed as mean ± standard deviation of three replicates. The values with the same superscript within a column have no significant difference ($p > 0.05$). C_1 – Commercial sample; S_1– Control sample; S_2 – Peanut butter with 5% coconut flour; S_3 – Peanut butter with 10% coconut flour; S_4 – Peanut butter with 15% coconut flour; S_5 – Peanut butter with 5% milk powder; S_6 – Peanut butter with 10% milk powder; S_7 – Peanut butter with 15% milk powder; S_8 – Peanut butter with 5% mixture; S_9 – Peanut butter with 10% mixture; and S_{10} – Peanut butter with 15% mixture.

Примечание: Все значения представлены как среднее значение трех повторных экспериментов ± стандартное отклонение. Данные с одинаковым верхним индексом в одном столбце существенно не различаются ($p > 0{,}05$).
C_1 – коммерческий образец; S_1 – контрольный образец; S_2 – арахисовая паста с 5 % кокосовой муки; S_3 – арахисовая паста с 10 % кокосовой муки; S_4 – арахисовая паста с 15 % кокосовой муки; S_5 – арахисовая паста с 5 % сухого молока; S_6 – арахисовая паста с 10 % сухого молока; S_7 – арахисовая паста с 15 % сухого молока; S_8 – арахисовая паста с 5 % смеси кокосовой муки и сухого молока; S_9 – арахисовая паста с 10 % смеси кокосовой муки и сухого молока; S_{10} – арахисовая паста с 15 % смеси кокосовой муки и сухого молока.

control sample (S_1) had a significantly lower ΔE value of 2.75, which increased as more coconut powder was added. Comparable patterns were observed for peanut butter that was enhanced with milk powder, as well as with a combination of coconut flour and milk powder. The increased ΔE signifies a greater degree of color variation against the reference, indicating changes in sensory properties. Larger quantities of coconut flour and milk powder in the samples enhanced both their lightness and whiteness. Conversely, smaller amounts of these supplements reduced the lightness and whiteness parameters. These findings emphasize the capacity of these components to improve the visual characteristics of peanut butter.

Sensory properties. The peanut butter samples showed significant differences in color (Table 7). Sample S had the highest mean score of 8.0, suggesting that it was 'liked very much'. There were no significant color differences among samples S_3, S_4, S_5, S_6, S_8, S_9, and S_{10}, with the scores ranging from 6.8 to 7.5 ('like moderately'). The control (S_1), commercial sample (C_1), and sample S_2 (5% coconut flour) earned the lowest scores of 6.6, 6.0, and 6.9, respectively, suggesting that they were 'liked slightly'.

Regarding flavor preference, significant differences were observed among the samples ($p < 0.05$). Sample S_{10} obtained the highest mean score of 8.0 ('like very much'). No significant differences in flavor were found among samples S_1, S_2, S_3, S_4, S_5, S_7, S_6 and S_9, with the scores ranging from 6.4 to 7.6 ('like moderately'). The commercial sample (C_1) obtained the lowest score of 5.7 ('like slightly'). Sample S_{10} (15% mixture) achieved the highest mean score of 8.0 ('like very much').

No significant differences in overall acceptability were found among samples S_5, S_6, S_7, S_8 and S_9, with the scores ranging from 6.7 to 7.5 ('like moderately'). Samples S_1, S_2, S_3, and S_4 obtained scores of 6.3, 6.4, 6.5, and 6.4, respectively ('like slightly'). The commercial sample (C_1) was given the lowest score of 5.6 ('neither like nor dislike').

Table 7. Sensory evaluation of peanut butter samples

Таблица 7. Органолептическая оценка образцов арахисовой пасты

Sample	Flavor	Color	Taste	Overall acceptability
C_1	5.7^{d}	6.0^{c}	5.6^{d}	5.6^{d}
S_1	6.9^{bc}	6.6^{bc}	7.2^{bc}	6.3^{cd}
S_2	6.9^{bc}	6.9^{bc}	6.4^{cd}	6.5^{c}
S_3	7.2^{abc}	7.1^{ab}	7.3^{abc}	6.6^{c}
S_4	7.2^{abc}	7.2^{ab}	7.2^{abc}	6.4^{cd}
S_5	6.4^{cd}	7.3^{ab}	7.7^{abc}	6.7^{bc}
S_6	6.8^{bc}	7.5^{ab}	6.9^{abc}	6.7^{bc}
S_7	7.2^{abc}	8.0^{a}	7.6^{ab}	7.0^{bc}
S_8	7.3^{ab}	6.8^{bc}	7^{abc}	7.5^{ab}
S_9	7.6^{ab}	7.1^{ab}	7^{abc}	7.1^{bc}
S_{10}	8.0^{a}	7.1^{ab}	8.0^{a}	8.0^{a}
LSD	0.42	0.46	0.51	0.41

Note: The values are expressed as mean ± standard deviation of three replicates. The values with the same superscript within a column have no significant difference ($p > 0.05$).
C_1 – Commercial sample; S_1 – Control sample; S_2 – Peanut butter with 5% coconut flour; S_3 – Peanut butter with 10% coconut flour; S_4 – Peanut butter with 15% coconut flour; S_5 – Peanut butter with 5% milk powder; S_6 – Peanut butter with 10% milk powder; S_7 – Peanut butter with 15% milk powder; S_8 – Peanut butter with 5% mixture; S_9 – Peanut butter with 10% mixture; and S_{10} – Peanut butter with 15% mixture.

Примечание: Все значения представлены как среднее значение трех повторных экспериментов ± стандартное отклонение. Данные с одинаковым верхним индексом в одном столбце существенно не различаются ($p > 0,05$).
C_1 – коммерческий образец; S_1 – контрольный образец; S_2 – арахисовая паста с 5 % кокосовой муки; S_3 – арахисовая паста с 10 % кокосовой муки; S_4 – арахисовая паста с 15 % кокосовой муки; S_5 – арахисовая паста с 5 % сухого молока; S_6 – арахисовая паста с 10 % сухого молока; S_7 – арахисовая паста с 15 % сухого молока; S_8 – арахисовая паста с 5 % смеси кокосовой муки и сухого молока; S_9 – арахисовая паста с 10 % смеси кокосовой муки и сухого молока; S_{10} – арахисовая паста с 15 % смеси кокосовой муки и сухого молока.

Conclusion

We analyzed the chemical compositions of peanuts and coconut flour, as well as the variations of peanut butter developed using these ingredients. In particular, we determined their moisture, protein, fat, carbohydrate, ash, and crude fiber contents. According to the results, the addition of coconut flour increased the moisture content in peanut butter, while the addition of milk powder decreased it. The protein content increased in the samples with a mixture of coconut flour and milk powder. The fat content decreased with increasing coconut flour supplementation but was unaffected by the mixture of coconut flour and milk powder. The carbohydrate content increased in all the treatments. The ash content increased in the peanut butter supplemented with coconut flour and a combination of coconut flour and milk powder. The sample with 15% mixture was the most highly acceptable, while the sample with 15% milk powder had the highest color preference score. The developed peanut butter variations had superior color, flavor, and taste compared to the commercial and control samples. Through systematic experimentation and analysis, our study provides valuable insights into the formulation of fortified peanut butter with improved nutritional quality and sensory appeal. Such knowledge can empower food manufacturers to develop healthier and more appealing products that cater to evolving consumer preferences and dietary requirements.

Ethics statement

The sensory evaluation was carried out in compliance with the established ethical rules. Each panelist was

required to give an informed written consent before proceeding with the process. Noteworthily, there are no strict requirements in Bangladesh for obtaining ethical approval for sensory tests [27].

Contribution

All authors have contributed equally to the study and are equally responsible for the information published in this article.

Conflict of interest

The authors declare that there is no conflict of interests regarding this publication.

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Заявление об этике

Процедура органолептической оценки проведена в соответствии с установленными этическими правилами, а также предусматривала предоставление информированного письменного согласия от каждого участника. В Бангладеш для проведения органолептической оценки не требуется одобрения комитета по этике [27].

Критерии авторства

Все авторы внесли равный вклад в исследование и несут равную ответственность за информацию, опубликованную в данной статье.

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Авторы заявили об отсутствии потенциальных конфликтов интересов в отношении исследования, авторства и / или публикации данной статьи.

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