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Quality Evaluation of Rice Crackers Fortified with Functional Plant Ingredients

Endah Puspitojati^{1*}, Siwitri Munambar¹, Kiki Juli Ambarwati¹, and Wildan Zacky Radithya²

¹ Agricultural Department, Politeknik Pembangunan Yogyakarta Magelang, Yogyakarta, Indonesia

² Biotechnology Department, Faculty of Agricultural Technology, Brawijaya University, Malang, Indonesia

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CORRESPONDING AUTHOR

*E-mail: endahpuspitojati@gmail.com

ABSTRACT

This study investigated the effects of fortification with functional plant ingredients—butterfly pea flower (*Clitoria ternatea*), roselle (*Hibiscus sabdariffa*), and ginger (*Zingiber officinale*)—on the physicochemical, antioxidant, textural, colour, and sensory properties of extruded rice crackers. A Completely Randomized Design consisting of four treatments (P1: control, P2: butterfly pea flower, P3: roselle, and P4: ginger addition) with triplicate experiments was applied. Results demonstrated that plant-based fortification significantly influenced proximate composition, bioactive compounds, and product quality attributes ($p < 0.05$). Roselle fortification produced the highest anthocyanin content and the strongest antioxidant activity, with values of 2.602 ppm and 16,059 ppm (IC₅₀), respectively. Butterfly pea flower enhanced flavonoid content to 0.010% and achieved the highest overall sensory acceptance (score 5.00). Ginger addition significantly improved textural characteristics, particularly hardness and crispiness, with values of 63.19 N and 1.96 N, respectively, contributing to a desirable snack structure. Colour parameters were strongly affected by natural pigments derived from functional plants, enabling clean-label visual differentiation of products. Overall, butterfly pea flower (P2) was identified as the optimal formulation, providing the best balance between functional enhancement and sensory acceptance. This study introduces functional rice crackers made from broken rice with improved antioxidant capabilities, diversifying the product from rice-based raw materials.

Contribution to Sustainable Development Goals (SDGs):

SDG 2: Zero Hunger

SDG 3: Good Health and Well-being

SDG 9: Industry, Innovation, and Infrastructure

SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

Indonesia is among the countries with the highest per capita rice consumption in the world, with 81.23 kg annually in 2023. Rice milling results in a significant amount of broken rice, accounting for 15–25% of the total milled rice, and this figure can vary depending on milling and postharvest handling efficiency, despite

the high demand. Although broken rice is nutritionally equivalent to head rice, it has a significantly lower market value. Therefore, developing value-added food products from broken rice represents an important strategy to increase its economic value, reduce postharvest losses, and promote sustainable food utilization.

Rice crackers represent a promising platform for such value addition. Extruded snack products are becoming more popular worldwide due to their convenience, affordability, and age-wide appeal. Rice crackers are popular gluten-free snacks with mild



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flavours, enabling diversification of formulations and functional fortification [1]. Rice crackers offer a technologically adaptable matrix for incorporating functional ingredients [2]. With growing consumer awareness of health and clean-label products, the development of naturally fortified snack foods has gained increasing attention.

Natural plant ingredients rich in bioactive compounds have been widely explored as functional additives. Butterfly pea flowers (*Clitoria ternatea*) are rich in anthocyanins, which are responsible for their intense natural blue hue and their high antioxidant activity [3]. Roselle (*Hibiscus sabdariffa*) possesses antioxidant and antimicrobial properties, as well as its distinctive red hue, which are attributed to its abundance of anthocyanins, phenolic compounds, and organic acids [4]. Ginger (*Zingiber officinale*) is a plant that provides a distinctive spicy aroma that may enhance sensory appeal [5]. It also contains phenolic compounds, including gingerol and shogaol, which are recognized for their antioxidant and anti-inflammatory properties [6].

Previous studies have reported that incorporating plant-based ingredients can enhance the antioxidant capacity of cereal-based snack products [2], [7]. However, comparative studies evaluating different functional plant sources with distinct bioactive profiles in rice-based snack formulations remain limited. In addition, the use of broken rice as a base material, combined with multiple functional plant ingredients, has received little attention.

1.2. Literature Review

1.2.1. Rice Crackers as a Functional Food Matrix

Rice crackers are rice-based snacks that are baked or extruded from rice. They are distinguished by their light, crispy texture and relatively low-fat content compared to fried snacks [1]. The formulation and processing conditions significantly affect their physical properties, including moisture content, texture, and expansion. Extrusion cooking is widely used in the production of modern snacks because it integrates mixing, cooking, shaping, and expansion into a single, continuous process. The process of extrusion involves inducing starch gelatinization, molecular transformation, and rapid moisture flashing through the application of high temperature, pressure, and mechanical shear [8]. This process results in the production of expanded structures with favorable crispness and low density.

The quality of extruded snacks is influenced by the development of their microstructure, which, in turn, determines their functional and sensory properties, according to a processing–structure–function relationship in food engineering. Rice crackers offer a versatile food matrix for incorporating functional ingredients without significantly compromising product acceptability, thanks to their neutral flavor profile and starch-rich composition. The inclusion of plant-based powders rich in phenolic compounds improves the nutritional value and antioxidant capacity of cereal-based snacks [2], [7]. Nevertheless, the inclusion of functional plant ingredients may alter melt rheology during extrusion, thereby affecting expansion ratio, hardness, and surface characteristics. Additionally, the stability of bioactive compounds, particularly anthocyanins and phenolics, can be affected by thermal and mechanical stresses during extrusion. As a result, incorporating ingredients not only improves functionality but also modifies sensory and

physicochemical properties. The development of fortified extruded rice crackers with optimal quality and consumer acceptance necessitates a comprehensive assessment of their physical, chemical, and organoleptic properties.

1.2.2. Functional Plant-Based Ingredients and Food Fortification in Rice Crackers

To improve the nutritional quality of food products and address public health concerns about nutrient deficiencies, food fortification is the intentional incorporation of essential nutrients or bioactive components [9]. Traditional food fortification has focused on enriching staple foods with micronutrients, particularly vitamins and minerals, to reach the population. Staple commodities, including rice, wheat flour, salt, milk, and sugar, are frequently used in conventional fortification strategies; their consistent consumption patterns make them effective delivery vehicles [10]. The previous study stated that industrial fortification guarantees consistent nutrient levels during large-scale processing. At the same time, biofortification directly increases nutrient content at the crop level through plant breeding or biotechnological methods [11], [12]. The concept of fortification has evolved in recent years to encompass food-to-food fortification, which employs naturally nutrient-rich foods or plant materials as functional ingredients, rather than micronutrient supplementation [11], [12]. In addition to enhancing nutrient bioavailability and product functionality, this method aligns with current consumer demand for clean-label products and natural functional foods [13]. An increasing number of cereal-based products are incorporating plant-based functional ingredients, such as phenolic compounds, pigments, and phytochemicals, to enhance their antioxidant activity and health-promoting properties.

The neutral flavour, high consumer acceptance, and starch-based composition of rice crackers render them an appropriate carrier for food-to-food fortification. Functional plant ingredients derived from butterfly pea flower (*Clitoria ternatea*), roselle (*Hibiscus sabdariffa*), and ginger (*Zingiber officinale*) are incorporated to provide both nutritional and technological benefits. Butterfly pea flowers are abundant in anthocyanins, particularly tematins, which are responsible for their natural blue hue and potent antioxidant properties [14]. In addition to its attractive red colour, roselle is a rich source of anthocyanins, phenolic compounds, and organic acids, which contribute to its antioxidant and antimicrobial properties [4]. Ginger contains bioactive phenolics, including shogaol and gingerol, which exhibit antioxidant and anti-inflammatory properties and enhance the aroma and flavour of food [6]. Incorporating plant powders into cereal-based snacks has been shown to enhance their functional properties in previous studies. However, these additions may also affect their sensory and physical attributes. Starch gelatinization behavior, expansion characteristics, colour development, and texture formation can be modified by functional plant ingredients, particularly in baked or extruded snack systems.

1.3. Research Objective

This study aimed to evaluate the impact of incorporating butterfly pea flower, roselle, and ginger powder on the quality attributes of rice crackers. The study specifically investigates their impact on the physical properties, functional characteristics, and nutritional

composition of the final product. In addition, consumer acceptance of rice crackers was also evaluated.

2. MATERIALS AND METHODS

The study was conducted from May to December 2025 at the Postharvest Laboratory, Politeknik Pembangunan Pertanian Yogyakarta–Magelang, Indonesia. White broken rice was used as the main raw material. Butterfly pea flower, roselle, and ginger powders were used as fortifying agents. All chemicals used for analysis were of analytical grade. The main equipment included an extruder, oven, microwave, UV–Vis spectrophotometer, centrifuge, chromameter, pH meter, analytical balance, and standard laboratory glassware.

This study employed a Completely Randomized Design (CRD) with one factor, namely the type of herbal powder added to rice crackers:

P1 = control (without herbal powder)

P2 = addition of 10 g butterfly pea powder

P3 = addition of 10 g roselle powder

P4 = addition of 10 g ginger powder

Each treatment was conducted in triplicate, resulting in 12 experimental units (4 treatments $\times$ 3 replications).

2.1. Rice Cracker Production

Rice (500 g) was mixed with salt (5 g), mushroom broth powder (2 g), and 10 g of herbal powder according to treatment. The mixture was homogenized and extruded. The extrusion process was carried out using a small-scale single-screw extruder. The heat was generated from mechanical shear and friction during the extrusion process. The feed moisture content of the mixture was adjusted to 15% before extrusion, and the screw speed was approximately 150 rpm. Extrudates were cut into 3–5 cm pieces, cooled at room temperature, and further dried using a microwave for 3 minutes to achieve crispness. Products were packaged in polyethylene (PE) plastic before analysis.

2.2. Analytical Methods

2.2.1 Colour measurement

Colour analysis of samples using a colourimeter (NH319, 3NH Technology Co., Ltd, China) to get CIE a^* , b^* , and L^* values. The L^* value refers to dark (0) vs. bright (100); the a^* value refers to red (+) vs green (–); the b^* value refers to yellow (+) vs. blue (–); Each treatment had three replicates [15].

2.2.2 Texture analysis

The textural properties of rice crackers were determined using a Texture Analyzer. Texture profile analysis (TPA) was performed by compressing the samples twice to 50% deformation. From the force–time curve, the following parameters were obtained: hardness, cohesiveness, fracture force, gumminess, chewiness, and adhesiveness. Each measurement was conducted in three replicates, and the mean values were reported [16].

2.2.3 Proximate analysis

The proximate (moisture, ash, protein, carbohydrate, and fat) contents were determined according to the official AOAC procedures [17].

2.2.4 Antioxidant activity

Antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. Absorbance was measured at 517 nm using a UV–Vis spectrophotometer, and the results were expressed as percentage inhibition of DPPH radicals [18]. Total anthocyanin content was quantified using the pH-differential method, based on absorbance measurements at two pH values [19]. Total flavonoid content was determined using the aluminium chloride ($AlCl_3$) colourimetric assay and expressed as quercetin equivalents [20].

2.2.5. Sensory Evaluation

Sensory evaluation was conducted to assess consumer acceptance of the rice cracker samples. Four treatments of rice crackers were evaluated using 100 untrained panelists. The sensory test was performed using a 7-point hedonic scale, where 1 = strongly dislike and 7 = strongly like. Panelists evaluated several sensory attributes, including colour, aroma, taste, crispness, shape, aftertaste, and overall acceptance. Each sample was coded with random three-digit numbers and presented to the panelists in a randomized order to minimize bias. The sensory scores were recorded based on the panelists' level of preference. A score of 4 was considered the minimum acceptable level of product acceptance. All evaluations were conducted under controlled conditions, and panelists were provided with drinking water to cleanse their palate between samples.

2.3. Statistical Analysis

Data were analyzed using a one-way ANOVA at the 5% significance level. Significant differences among treatments were further tested using Duncan's Multiple Range Test (DMRT).

3. RESULT AND DISCUSSION

3.1. Proximate Composition and Energy Value of Rice Crackers

Table 1 shows that the proximate composition of rice crackers differed significantly among treatments ($P < 0.05$), indicating that the addition of functional plant ingredients affected the products' nutritional characteristics. The lowest moisture was observed in P4 (ginger addition), suggesting improved drying efficiency or reduced water retention resulting from the incorporation of ginger powder. Lower moisture content is desirable because it improves the shelf stability of crackers. The reduced moisture content in the ginger-fortified crackers may be attributed to structural alterations in the starch matrix during heat processing. Fibrous plant particles can interfere with starch gelatinization and expansion, leading to increased moisture loss during drying. Comparable findings have been reported in cereal-based extruded snacks, wherein the addition of plant powders affected water binding and decreased total moisture levels due to altered starch–fiber interactions [21].

P1: control, P2: rice crackers with butterfly pea flower (*Clitoria ternatea*) addition, P3: rice crackers with roselle (*Hibiscus sabdariffa*) addition, P4: rice crackers with ginger (*Zingiber officinale*) addition. Values are presented as mean $\pm$ standard deviation. Different superscript letters indicate significant differences among treatments ($P < 0.05$).

The fat content significantly decreased in P4 (0.117%), while P2 and P3 exhibited higher fat levels. This difference may be related to lipid contributions from plant materials and interactions between added ingredients and starch matrices during processing. A substantial increase in ash content was observed in fortified samples compared with the control. P4 showed the highest ash value (3.330%), indicating higher mineral content derived from ginger, followed by butterfly pea flower and roselle treatments. This phenomenon confirms the potential of botanical additions to enhance mineral availability in snack products [22].

Table 1. Proximate Composition and Energy Value of Rice Crackers

Treatments	P1	P2	P3	P4
Moisture content (%)	5.94±0.05 ^c	5.90±0.04 ^c	5.66±0.04 ^b	4.87±0.02 ^a
Fat (%)	1.13±0.01 ^b	1.42±0.07 ^c	1.44±0.06 ^c	0.12±0.01 ^a
Ash (%)	0.31±0.04 ^a	2.82±0.01 ^b	2.85±0.05 ^b	3.33 ±0.04 ^c
Crude fibers (%)	6.19±0.07 ^d	4.76±0.11 ^b	4.91±0.08 ^b	3.21±0.05 ^a
Protein (%)	5.17±0.09 ^a	6.56±0.02 ^c	5.68±0.12 ^b	6.10±0.03 ^d
Carbohydrate by diff (%)	81.28±0.04 ^c	78.54±0.01 ^a	79.43±0.34 ^b	82.37±0.03 ^d
Total sugar (%)	0.77±0.00 ^a	1.27±0.00 ^c	0.89±0.00 ^b	1.52±0.00 ^d
Energy (Kcal/100g)	345.19±0.09 ^d	343.01±0.64 ^a	343.32±0.39 ^b	344.24±0.13 ^c

In contrast, crude fibre content decreased from P1 to P4, with the control showing the highest fibre content (6.191%). The reduction may be associated with dilution effects and structural changes during the formulation and expansion of rice crackers. The protein content improved in all fortified treatments. P2 demonstrated the highest protein level (6.559%), followed by P4 and P3. The increase suggests that plant-based fortification provides additional nitrogenous compounds, improving the nutritional quality of rice crackers [16].

The carbohydrate content (by difference) varied significantly, with P4 showing the highest value (82.367%). This increase is consistent with the lower fat and moisture contents observed in the ginger-added formulation. Regarding sweetness attributes, total sugar content increased markedly in fortified samples, particularly in P4 (1.522%), which may be due to natural sugars present in ginger. The calculated energy value ranged from 343.011 to 345.190 kcal/100 g. Although statistically different, the energy variation among treatments was relatively small, indicating that fortification improved nutritional composition without substantially altering caloric density. Overall, incorporating butterfly pea flowers, roselle, and ginger successfully enhanced the nutritional profile of rice crackers, particularly protein and mineral content, while maintaining acceptable energy levels.

3.2. Antioxidant Content of Rice Crackers

Table 2 presents the antioxidant content of the functional plants used as additional ingredients in rice crackers. The bioactive compound analysis demonstrated clear differences among butterfly pea flower, roselle, and ginger, which subsequently influenced the phytochemical properties and antioxidant capacity of the fortified rice crackers.

Butterfly pea flower exhibited the highest anthocyanin content (260.61±0.00 ppm), followed by roselle (182.13 ± 0.79 ppm). This result confirms that butterfly pea flowers are a rich natural source of anthocyanin pigments, particularly ternatin

compounds, which contribute to strong antioxidant activity and characteristic blue colouration. In contrast, ginger did not contain measurable amounts of anthocyanins, as its antioxidant properties primarily derive from phenolic constituents such as gingerol, shogaol, and zingerone rather than from anthocyanin pigments.

The total flavonoid content was slightly higher in butterfly pea flower (0.328 ± 0.274 %) compared to roselle (0.260 ± 0.059%), indicating that both plants provide important flavonoid compounds contributing to free radical scavenging activity. Regarding antioxidant activity (IC₅₀), butterfly pea flower showed stronger antioxidant capacity (296.77 ± 1.64 ppm) than roselle (329.57 ± 1.19 ppm), since lower IC₅₀ values indicate higher antioxidant effectiveness.

Table 2. Antioxidant of functional plants

Content	Butterfly pea flower	Roselle	Ginger
Anthocyanin (ppm)	260.61±0.00	182.13±0.79	10.30± 0.15
Flavonoid (%)	0.33±0.27	0.26±0.06	0.19±0.00
Antioxidant (IC ₅₀ , ppm)	296.77±1.64	329.57±1.19	5,714.82± 8.38

The incorporation of functional ingredients significantly affected flavonoid content, anthocyanin concentration, and antioxidant activity of rice crackers (Table 3). The flavonoid content increased in all fortified treatments compared with the control (P1). The highest flavonoid level was observed in P2 (0.010%), followed by P3 (0.008%) and P4 (0.005%). This condition indicates that supplementation with butterfly pea flower and roselle effectively enriched the final product with flavonoid compounds, while ginger contributed moderate levels of phenolic compounds.

Similarly, anthocyanin content significantly increased in fortified rice crackers. P3 (roselle addition) produced the highest anthocyanin content (2.60 ppm), followed by P2 (2.05 ppm), whereas P4 showed only a slight improvement over the control. The presence of anthocyanins in P2 and P3 confirms successful transfer of pigment antioxidants from plant materials into the cracker matrix during processing. The relatively lower anthocyanin level in P2 compared with raw butterfly pea flower material may be attributed to thermal degradation during extrusion. Thermal processing conditions may promote partial degradation of anthocyanin molecules through oxidation, polymerization, or structural transformations of the flavylum cation. These reactions reduce measurable anthocyanin levels but may still contribute to antioxidant activity by forming secondary phenolic derivatives [23].

The most notable improvement was observed in antioxidant activity. The control sample (P1) showed the weakest antioxidant capacity with an IC₅₀ value of 36,970.44 ppm. Fortification markedly reduced IC₅₀ values, indicating enhanced antioxidant potential. P3 demonstrated the strongest antioxidant activity (IC₅₀ = 16,059.17 ppm), followed by P2 and P4. The superior antioxidant performance of roselle-fortified crackers may be due to synergistic interactions among the anthocyanins, organic acids, and phenolic compounds present in roselle. Although ginger does not contain anthocyanins, P4 still exhibited improved antioxidant activity compared with the control, confirming that non-anthocyanin phenolics, such as gingerols, also play an important role in free radical scavenging.

Table 3. Antioxidant of Rice Crackers

Treatments	Flavonoid (%)	Anthocyanin (ppm)	Total antioxidant (IC ₅₀ , ppm)
P1	0.003±0.000	1.027±0.033 ^a	36,970.436±114.671 ^d
P2	0.010±0.000	2.051±0.033 ^c	17,673.111±69.731 ^b
P3	0.008±0.000	2.602±0.082 ^d	16,059.172±18.933 ^a
P4	0.005±0.000	1.149±0.017 ^b	24,809.298±78.459 ^c

P1: control, P2: rice crackers with butterfly pea flower (*Clitoria ternatea*) addition, P3: rice crackers with roselle (*Hibiscus sabdariffa*) addition, P4: rice crackers with ginger (*Zingiber officinale*) addition. Values are presented as mean ± standard deviation. Different superscript letters indicate significant differences among treatments ($P < 0.05$).

Overall, the addition of functional plant ingredients successfully enhanced the phytochemical quality and antioxidant properties of rice crackers. Butterfly pea flower and roselle primarily contributed anthocyanins and flavonoids, while ginger improved antioxidant activity through phenolic compounds. Among treatments, roselle fortification (P3) produced the most effective antioxidant enhancement, indicating its strong potential as a functional ingredient for developing antioxidant-rich snack products.

3.3. Texture Profile Analysis of Rice Crackers

Texture characteristics are important quality attributes influencing consumer acceptance of rice crackers. The addition of functional ingredients significantly affected several texture parameters, including hardness, fracture force, gumminess, chewiness, and adhesiveness, while cohesiveness showed relatively minor variation among treatments. The hardness value ranged from 33.886 to 63.191 N. The highest hardness was observed in P4 (ginger addition), indicating a firmer, denser structure compared with the other treatments. Ginger powder may interact with starch components, reducing expansion during processing and resulting in a compact texture. Conversely, P3 (roselle addition) exhibited the lowest hardness, suggesting improved crispness and a lighter structure. The control sample (P1) showed moderate hardness, while butterfly pea flowers (P2) increased hardness compared to the control.

Table 4. Texture profile of rice crackers

Parameter	P1	P2	P3	P4
Hardness (N)	36.48±0.97 ^b	43.96±1.35 ^c	33.88±0.40 ^a	63.19±0.57 ^d
Cohesiveness (N)	0.45±0.00	0.46±0.03	0.44±0.01	0.46±0.00
Fracture (N)	2.51±0.55 ^b	1.88±0.16 ^a	1.86±0.19 ^a	1.96±0.00 ^a
Gumminess (N)	16.25±0.26 ^a	20.30±1.79 ^b	14.93±0.61 ^a	28.88±0.30 ^c
Chewiness (N)	12.41±0.16 ^b	15.55±1.51 ^c	10.74±0.80 ^b	21.48±0.03 ^d
Adhesiveness (N)	0.12±0.021 ^a	0.25±0.05 ^a	0.37±0.05 ^b	0.26±0.14

P1: control, P2: rice crackers with butterfly pea flower (*Clitoria ternatea*) addition, P3: rice crackers with roselle (*Hibiscus sabdariffa*) addition, P4: rice crackers with ginger (*Zingiber officinale*) addition. Values are presented as mean ± standard deviation. Different superscript letters indicate significant differences among treatments ($P < 0.05$).

The cohesiveness values were relatively similar among treatments (0.440–0.461), indicating that ingredient fortification did not substantially alter the internal bonding strength of the

cracker matrix. This suggests that the structural integrity of starch gelatinization and retrogradation remained relatively stable despite ingredient substitution. The fracture force, which represents crispness, decreased significantly in fortified samples compared with the control. P1 showed the highest fracture value (2.507 N), while P2, P3, and P4 presented lower values. Lower fracture force indicates easier breakability and improved crisp texture, which is generally preferred for snack products. The addition of plant powders likely created microstructural discontinuities that facilitated cracking. This is in line with a study on corn extruded snacks supplemented with bilberry pomace extract, which resulted in a decrease in fracturability, as a result of the weakening of the internal structure and the formation of a less compact matrix, caused by the reduced amount of starch available for gelatinization and the increased fiber content [24]

A similar trend was observed for gumminess, where P4 recorded the highest value (28.885 N), followed by P2, while P1 and P3 showed lower values. Higher gumminess in the ginger-fortified sample is associated with increased hardness and stable cohesiveness, resulting in a more compact, less brittle texture. The chewiness parameter also increased significantly in P4 (21.477 N), indicating that the addition of ginger required greater masticatory energy. In contrast, roselle addition (P3) resulted in the lowest chewiness, suggesting the formation of a lighter, crispier product structure.

For adhesiveness, P3 showed the highest value (0.366 N), suggesting a slightly stickier surface compared with other treatments. This may be attributed to the organic acids and soluble compounds present in roselle, which influence surface moisture interactions. The other treatments showed relatively similar, lower adhesiveness values. Overall, the incorporation of functional ingredients modified the textural properties of rice crackers. Ginger addition produced the hardest and most chewy texture, butterfly pea flower increased firmness moderately, while roselle contributed to a softer and crispier product. During the thermal expansion of cereal-based products, starch gelatinization and vapor pressure contribute to the formation of porous structures. The addition of plant powders can modify this expansion behaviour by altering melt viscosity and starch availability, thereby affecting fracture characteristics and crispness of the final product [25]

3.4. Colour Characteristics of Rice Crackers

Colour is an important sensory attribute that influences consumer perception and acceptance of snack products. The results showed that adding different functional ingredients significantly affected the colour parameters of rice crackers.

Table 5. Colour of Rice Crackers

Treatments	L	a	b
P1	71.80±1.43 ^c	4.10±1.47 ^b	9.81±0.29 ^b
P2	63.12±0.36 ^a	2.17±0.07 ^a	8.46±0.22 ^a
P3	64.72±0.19 ^a	4.21±0.15 ^b	10.96±0.18 ^c
P4	85.40±1.21 ^b	4.73±0.02 ^b	15.04±0.55 ^d

P1: control, P2: rice crackers with butterfly pea flower (*Clitoria ternatea*) addition, P3: rice crackers with roselle (*Hibiscus sabdariffa*) addition, P4: rice crackers with ginger (*Zingiber officinale*) addition. Values are presented as mean ± standard deviation. Different superscript letters indicate significant differences among treatments ($P < 0.05$).

The lightness value (L^*), representing brightness, ranged from 63.12 to 85.40. The highest L^* value was observed in P4 (ginger addition), indicating a brighter product appearance. This may be related to ginger's natural yellowish colour and its lower pigment intensity compared to anthocyanin-rich ingredients. In contrast, P2 and P3 exhibited significantly lower L^* values, indicating darker products resulting from the incorporation of coloured plant materials [26]. The decrease in lightness in these treatments may also result from pigment degradation and Maillard reactions occurring during thermal processing [27].

The a^* value, which indicates redness–greenness, ranged from 2.17 to 4.73. P2 showed the lowest a^* value, indicating reduced red intensity, while P4 presented the highest a^* value, reflecting increased reddish tones. The higher redness in ginger-fortified crackers may originate from browning reactions during heating as well as the inherent pigment characteristics of ginger compounds.

The b^* value (yellowness–blueness) increased markedly across treatments, with P4 showing the highest value (15.043). This confirms that the addition significantly enhanced the yellow colour of the crackers. Meanwhile, P2 displayed the lowest b^* value, indicating reduced yellowness due to the bluish pigments contributed by butterfly pea flower anthocyanins. P3 showed intermediate values, reflecting the influence of roselle pigments that tend to produce reddish colouration.

Overall, the incorporation of functional ingredients clearly modified the visual appearance of rice crackers. Butterfly pea flower and roselle reduced product brightness due to natural pigments, whereas ginger enhanced lightness and yellowness, producing a more visually bright product. These findings demonstrate that plant-based fortification not only improves nutritional quality but also significantly influences product colour, potentially affecting consumer preferences and marketability.

3.5. Sensory Evaluation of Rice Crackers

The sensory evaluation results demonstrated that incorporating different functional ingredients influenced consumer acceptance of rice crackers across all evaluated attributes, including colour, aroma, taste, crispiness, shape, aftertaste, and overall acceptability (Fig 1)

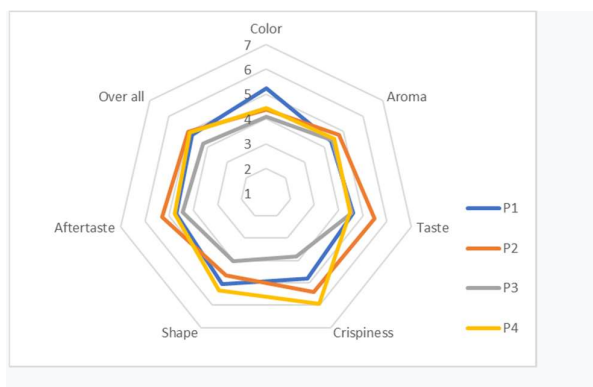


Fig 1. Radar chart of sensory evaluation scores of rice crackers under different treatments.

P1: control, P2: rice crackers with butterfly pea flower (*Clitoria ternatea*) addition, P3: rice crackers with roselle (*Hibiscus sabdariffa*), P4: rice crackers with ginger (*Zingiber officinale*) addition.

The colour attribute received the highest score in the control sample (P1), indicating that panellists were more familiar with the conventional appearance of rice crackers. The addition of

butterfly pea flower (P2) and roselle (P3) reduced colour preference slightly, likely because of the unusual bluish or reddish hues produced by the natural pigments. Although functional colouring enhances nutritional value, unfamiliar colours may initially affect consumer perceptions. For aroma, P2 received the highest score, suggesting that the butterfly pea flower contributed a more acceptable, neutral aroma than the other treatments. The relatively similar aroma scores among treatments indicate that fortification did not negatively influence aromatic acceptability. The taste attribute was most preferred in P2, indicating that the addition of butterfly pea flowers produced a favourable flavour balance. The improved taste acceptance may be related to mild flavor characteristics that do not dominate the base rice cracker taste. In contrast, roselle (P3) showed slightly lower taste scores, possibly due to its natural acidity, while ginger (P4) provided a distinctive spicy note that was acceptable but not superior to P2.

A notable difference was observed in crispiness, where P4 achieved the highest score (5.94). This result aligns with the texture profile analysis, which showed higher hardness and chewiness values for the ginger-fortified crackers. The higher crispiness perception in the ginger-fortified crackers corresponds well with the instrumental texture results, indicating that structural modifications in the starch matrix directly influenced sensory texture perception. Similar relationships between expansion structure and crispness perception have been reported in cereal-based snack products [28]. The shape attribute was also highest in P4, indicating that ginger addition improved product integrity and physical appearance during processing. Structural stability may be associated with improved dough binding properties. In terms of aftertaste, P2 showed the highest acceptance, suggesting that butterfly pea flower produced a cleaner and more pleasant residual flavour compared to roselle and ginger, which may leave slightly sour or spicy after-notes. The overall acceptability results showed that P2 had the highest panellist preference, followed by P4, P1, and P3. This indicates that butterfly pea flower fortification provided the best balance between functional enhancement and sensory quality. Although roselle improved antioxidant properties, its influence on taste and texture slightly reduced consumer acceptance. Overall, the findings demonstrate that incorporating functional ingredients can successfully enhance rice crackers without compromising sensory quality. Butterfly pea flower improved overall consumer preference, while ginger significantly enhanced crispiness, highlighting the importance of selecting functional ingredients that balance nutritional benefits with desirable sensory attributes.

4. CONCLUSION

The incorporation of functional plant ingredients significantly influenced the physicochemical properties, bioactive compounds, texture characteristics, color attributes, antioxidant activity, and sensory acceptance of rice crackers. Fortification with butterfly pea flower, roselle, and ginger successfully enhanced the nutritional and functional value of the products compared with the control. Butterfly pea flower addition (P2) improved flavonoid content, sensory taste preference, aftertaste, and overall acceptability, indicating good consumer acceptance while providing functional benefits. Roselle fortification (P3) contributed the highest anthocyanin content and strongest antioxidant activity, demonstrating its potential as a natural

antioxidant source, although sensory acceptance was slightly lower due to its acidic characteristics. Ginger addition (P4) significantly improved textural properties, particularly hardness and crispiness, resulting in the highest crispiness score among treatments. Overall, functional rice crackers enriched with plant-based ingredients can be developed as innovative snack products with enhanced antioxidant potential and acceptable sensory quality. Among the treatments, butterfly pea flower showed the best balance between functional properties and consumer preference. At the same time, roselle and ginger offered specific advantages related to antioxidant capacity and texture improvement, respectively.

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