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Bioactive Compounds and Nutritional Properties of Crispy Puffed Rice Products Made from Organic Rice

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ABSTRACT

Rice is a fundamental dietary essential with substantial nutritional value, especially brown and pigmented varieties, which are abundant in bioactive compounds such as anthocyanins, oryzanol, and tocotrienols that promote anti-inflammatory, antioxidant, and cardiovascular health advantages. The formulation of value-added rice products incorporating black sesame offers a strategy to improve both nutritional content and functional attributes. This study sought to examine the bioactive compounds present in organic rice and processed organic crispy rice products, evaluate their physical and chemical quality, assess their nutritional value, and compare the product quality to the Thai Community Product Standard TIS 36/2554. Antioxidant activity was assessed utilizing the DPPH assay, total phenolic content was quantified via the Folin–Ciocalteu method, and anthocyanin content was evaluated employing the pH differential technique. Physical quality parameters encompassed color, moisture content, water activity, and dietary fiber, whereas nutritional analysis evaluated energy, protein, fat, and vitamin levels. Additionally, product quality and safety assessments were conducted in accordance with community product standards. The findings indicated that fresh organic rice possessed the highest total phenolic content, measuring 124.78 mg GAE/100 mL, and demonstrated an antioxidant activity of 35.69%. Following processing into a crispy product, total phenolics decreased to 23.26 mg GAE/100 mL, and antioxidant activity declined to 17.23%. However, fortification with black sesame elevated the total phenolic content to 35.68 mg GAE/100 mL and increased antioxidant activity to 36.75%. The anthocyanin content in the black sesame formulation increased to 0.88 mg/100 g, compared to 0.07 mg/100 g in the original product. Physical quality assessment revealed a moisture content of 5.30%, aligning with the standard maximum of 6%, water activity values ranging from 0.01 to 0.12 conducive to inhibiting microbial growth, and dietary fiber content between 11.21% and 12.59%, which are comparatively high relative to conventional snack products. Nutritional analysis demonstrated that black sesame fortification elevated the energy content from 3,256 to 4,306 calories per gram, increased protein from 6.55 to 15 g/100 g, raised fat from 1.05 to 4.52 g/100 g, and enhanced dietary fiber from 11.21 to 13.59 g/100 g.

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1. Introduction

Rice (Oryza sativa L.) constitutes a dietary staple for the Thai populace and for populations globally. This food source offers fundamental nutritional elements, encompassing energy, protein, vitamins, and antioxidant substances. Brown and pigmented rice varieties, which preserve significant quantities of cereal and germ, are especially noteworthy for their elevated nutritional value. Consequently, these rice varieties are abundant in nutrients that are advantageous to human health (Goufo & Trindade, 2014; Mohan et al., 2018). Furthermore, rice is gaining recognition as a functional food owing to its substantial levels of bioactive compounds, including anthocyanins, oryzanol, and tocotrienols, which demonstrate anti-inflammatory and antioxidant characteristics, thereby contributing to the promotion of cardiovascular health (Prasertsri, 2022; Rao, 2016).

Table 1: Major Nutrients of Rice

Category	Nutrients	Average Content in Brown Rice (per 100 g)	Benefits
Carbohydrates	Starch, dietary fiber	75–80 Grams	Provides energy; dietary fiber supports digestive function
Protein	Glutelin, albumin	7–9 Grams	Supports tissue repair and the synthesis of enzymes and hormones
Fats	Unsaturated fatty acids, rice bran oil	1–3 Grams	Aids in the absorption of fat-soluble vitamins and helps prevent arterial blockage

Table 2: Key Phytochemicals

Compound Groups	Examples	Health Benefits
Anthocyanins	Found in black rice and Riceberry rice	Exhibits antioxidant and anti-inflammatory properties
Polyphenols (Phenolic acids)	Found in rice bran and rice bran oil	Reduces cholesterol levels and chronic inflammation
Gamma-oryzanol (γ-oryzanol)	Found in rice bran and rice bran oil	Reduces cholesterol levels and chronic inflammation
Tocotrienols	Found in rice bran oil	Delays cellular and skin aging
Phytosterols	Found in rice bran	Helps reduce the absorption of dietary cholesterol

Currently, rice is processed through various methods that necessitate essential knowledge and equipment in food processing. Examples of rice processing techniques include drying, which decreases moisture content and consequently slows chemical reactions and microbial proliferation; fermentation, which entails the removal of water from the food and the activity of microorganisms to decompose nutrients, thereby converting perishable substances into more stable forms, as exemplified by fermented rice products; and heat treatment, which serves to eliminate pathogenic microorganisms and naturally occurring enzymes responsible for food spoilage, as well as to cook rice, such as in grilled, fried, and steamed rice preparations. In this study, organic rice was transformed into a processed fried sheet product to augment its value-added potential and to function as a health-conscious food item, notably through the inclusion of black sesame to improve its nutritional content.

The fundamental principle in the production of organic crispy rice products involves dehydrating, particularly baking, which decreases the moisture content of the food to prolong shelf life by preventing chemical alterations. Hot air oven drying entails circulating heated air over foods with high moisture content, facilitating heat transfer to the food surface and promoting the evaporation and removal of internal moisture. This study concentrated on analyzing the bioactive compounds present in rice utilized for production, assessing the physical quality of the processed organic crispy rice product, and evaluating the nutritional value of the organic crispy rice following the dehydrating process.

Black sesame offers numerous health advantages, notably supporting bone and dental health owing to its calcium content, which is reported to be up to six times greater than that of milk. Additionally, it contributes to the enhancement of brain and cardiovascular functions through its omega-3, omega-6, and omega-9 fatty acids. A principal bioactive compound in black sesame is sesamin, which demonstrates several significant physiological effects. Sesamin exhibits potent antioxidant and anti-inflammatory properties that aid in safeguarding bodily cells from oxidative harm and in mitigating persistent inflammation. It also promotes bone and joint health by facilitating the maintenance of bone density, aiding in the prevention of osteoporosis, and potentially reducing discomfort related to joint inflammation or osteoarthritis. In relation to cardiovascular health, sesamin has demonstrated the ability to lower blood cholesterol levels, especially low-density lipoprotein cholesterol, reduce blood pressure, and mitigate the risk of cardiovascular diseases and atherosclerosis. Furthermore, sesamin facilitates blood glucose regulation by enhancing insulin activity and lowering blood glucose levels, providing advantages for individuals with diabetes or those at risk. Preliminary research has also indicated that sesamin may possess anticancer properties by suppressing the proliferation or promoting the apoptosis of specific cancer cells, including those of the breast and liver. Sesamin is an important bioactive compound that the human body is unable to synthesize and must therefore be acquired through the

ingestion of sesame seeds or dietary supplements containing sesamin extracts.

2. Experimental Procedure

2.1 Study of bioactive compound content

2.1.1 Antioxidant activity was assessed employing the DPPH method, as detailed by Jirasatid and Nopharatana (2018). The antioxidant capacity was assessed through the 2,2-diphenyl-1-picrylhydrazyl scavenging assay. Rice extract samples were obtained through a 24-hour extraction using 95% methanol. One milliliter of the clear extract was combined with 3 mL of DPPH standard solution in an amber vial and vigorously agitated. The mixture was permitted to react in darkness at ambient temperature for 30 minutes, during which the solution's color transitioned from blue to light yellow. Absorbance was subsequently measured at a wavelength of 515 nm (A_{515}) utilizing a spectrophotometer (Shimadzu UV-1601, Japan), and the antioxidant activity was determined in accordance with Equation (1).

$$\%\ \text{DPPH Radical Scavenging Activity} = \left(\frac{A_0 - A_1}{A_0}\right) \times 100$$

2.1.2 Total phenolic content was assessed employing the Folin–Ciocalteu method as outlined by Srisuk et al. (2021). Rice extract samples were obtained through a 24-hour extraction using 95% methanol. An aliquot of 0.30 mL of the extracted sample was combined with 1.50 mL of 10% (v/v) Folin–Ciocalteu reagent, followed by the addition of 3 mL of 7.5% (v/v) Na_2CO_3 solution in distilled water. The mixture was subsequently adjusted to a final volume of 10 mL with distilled water, vigorously agitated, and permitted to react in the dark for 30 minutes. Absorbance was recorded at a wavelength of 765 nm (A_{865}) utilizing a spectrophotometer (Shimadzu UV-1601, Japan). Total phenolic content was determined using a gallic acid standard curve within the concentration range of 50–200 mg/mL.

2.1.3 Anthocyanin content was determined employing the pH differential technique, adapted from AOAC (2019). The rice extract sample was diluted tenfold using distilled water. Two test tubes were prepared: in tube 1, 0.2 mL of the extract was adjusted to pH 1.0 with a 0.025 M potassium chloride buffer; in tube 2, 0.2 mL of the extract was adjusted to pH 4.5 with a 0.4 M sodium acetate buffer. Following thorough mixing, absorbance was measured at 520 and 700 nm, and anthocyanin content was determined as cyanidin-3-glucoside equivalents using Equation (2) and Equation (3), where A = (A520 − A700)pH 1.0 − (A520 − A700)pH 4.5 (2).

(2) $$A = (A_{520} - A_{700})\ \text{pH 1.0} - (A_{520} - A_{700})\ \text{pH 4.5}$$

(3) $$\text{Anthocyanin Content} = (A \times 449.2 \times \text{Dilution Factor} \times 103)/26{,}900\ \text{mg/L}$$

2.2 Results of Physical and Chemical Quality Evaluation of the Product

Color values L*, a*, and b* were measured utilizing a Chroma Meter CR-400 (Konica Minolta, Japan). Moisture content was determined by AOAC (2000) standards. Water activity (aw) was determined utilizing a water activity meter (AquaLab Model 3TE, USA). The dietary fiber content was assessed employing AACC Method 32-10 (Crude Fiber). β-Carotene was quantified employing the in-house technique IM-CH-098, which is based on AOAC (2023) Methods 2011.07 and 2001.13. Vitamin B1 was quantified using in-house TM-CH-005, which is based on AOAC (2023) technique 986.27. Vitamin E (alpha-tocopherol) was quantified utilizing an in-house method derived from the guidelines outlined in the Official Journal of the European Communities (13 July 2000). Anthocyanin content was quantified utilizing the in-house protocol WI-TMC-86, in accordance with AOAC (2023) Method 2005.02. Sesamin content was determined utilizing an in-house method based on the HPLC-DAD technique. Vitamin B12 was determined using the in-house method STM No. 01-016, which is based on AOAC (2023) Method 952.20. Protein content was quantified following the procedures outlined in AOAC International (2019), Official Method 978.04 (Kjeldahl method). Fat content was determined in accordance with AOAC International (2019), Official Methods of Analysis (21st ed.), Method 920.39 (Crude Fat or Ether Extract).

Section 1: Results of Bioactive Compound Analysis of Rice Used for Production and the Processed Organic Crispy Rice Product with Black Sesame Topping

Bioactive Compounds	Organic Rice	Organic Crispy Rice Product	Black Sesame
Phenolic Compounds (mg GAE/100 mL)	124.78	23.26	35.68
DPPH (%)	35.69	17.23	36.75
Anthocyanins	1.26	0.07	0.88
Vitamin E	0.45	ND	ND
Vitamin B1	0.32	0.28	0.45
Vitamin 12	0.78	1.05	0.01
Beta-carotene	ND	ND	0.02

The analysis of bioactive compounds in organic rice used as source material, the processed organic crispy rice product, and the formulated product with black sesame reveals that the processing procedure significantly influenced the bioactive compound content. Both decreases in certain compounds and increases in particular bioactive groups were observed. These findings align with prior studies indicating that food processing, especially thermal treatment, can modify the chemical composition of bioactive compounds in cereal grains (Zieliński & Kozłowska, 2000; Fardet et al., 2019).

2.2.1 Total Phenolic Content and Antioxidant Activity (DPPH)

Raw organic rice displayed the highest total phenolic content at 124.78 mg GAE/100 mL and exhibited robust antioxidant activity, with a DPPH value of 35.69%, suggesting that organic rice is a significant natural source of antioxidants. This finding aligns with earlier research indicating that cereals and rice are primary sources of phenolic compounds possessing antioxidant properties (Zieliński & Kozłowska, 2000; Fardet, 2010). However, following processing into an organic crispy rice product, a significant reduction in bioactive compounds was observed, with total phenolic content decreasing to 23.26 mg GAE/100 mL and DPPH antioxidant activity diminishing to 17.23%. These findings are consistent with food science principles indicating that thermal treatment and processing may cause the degradation or reduction of specific phenolic compounds (Zieliński & Kozłowska, 2000; Fardet et al., 2019).

In the case of the black sesame formulation, the total phenolic content rose to 35.68 mg GAE/100 mL, demonstrating that the addition of phenolic-rich constituents can partially offset losses incurred during processing and augment the product's antioxidant capacity. This observation aligns with reports indicating that dark-colored rice and cereals possess higher concentrations of phenolic compounds and demonstrate enhanced antioxidant activity compared to light-colored cereals (Zhang et al., 2010; Zhu, 2018).

Anthocyanins

The results indicated that the anthocyanin content in the organic crispy rice product was comparatively low at 0.07 mg/100 g, while the black sesame formulation demonstrated a significant increase to 0.88 mg/100 g. This finding suggests that utilizing dark-colored raw materials and selecting rice or ingredients with natural pigmentation can effectively augment flavonoid-based antioxidant compounds. This observation aligns with reports that recognize dark-colored cereals as significant sources of anthocyanins (Zhu, 2018). Anthocyanins serve an essential function in antioxidant activity and in mitigating oxidative stress within the human body. Although the anthocyanin concentrations in the product are still lower than those present in some intensely pigmented plant sources, the notable increase observed in the black sesame formulation underscores the potential for developing functional, health-oriented food products, consistent with findings from nutritional science literature (Gonçalves et al., 2021).

Vitamin B1

Vitamin B1 was found in the organic crispy rice product at a concentration of 0.28 mg/100 g, rising to 0.45 mg/100 g in the black sesame formulation, suggesting that the added ingredient contributed to an elevated vitamin B1 content, which is essential for energy metabolism and nervous system function (Fitzpatrick et al., 2012). Conversely, vitamin B12 was detected in the organic crispy rice product at 1.05 µg/100 g, but it declined significantly to 0.01 µg/100 g in the black sesame formulation. This decrease may be ascribed to ingredient dilution and the instability of vitamin B12 when subjected to thermal processing, as prior research has indicated that B-group vitamins can be degraded during food processing (Lešková et al., 2006).

Beta-Carotene (β-Carotene)

Beta-carotene was not detected in the basic organic crispy rice product; however, it was identified in the black sesame formulation at a concentration of 0.02 mg/100 g. Although the measured quantity was comparatively modest, the detection of this provitamin A compound in the black sesame formulation suggests that incorporating pigmented ingredients can augment the variety of bioactive compounds present in the product. This observation aligns with reports indicating that carotenoids are frequently present in unprocessed materials exhibiting dark pigmentation (Rodriguez-Amaya, 2016).

Section 2: Results of Physical and Chemical Quality Evaluation of Organic Rice and the Processed Crispy Rice Products

Physical Quality	Organic Rice	Organic Crispy Rice Product	Organic Crispy Rice Product with Added Black Sesame
Moisture Content	3.90	5.30	5.12
Color L	85.69	75.54	47.30
a	1.23	2.67	10.65
b	3.45	5.42	28.36
Aw	0.11	0.01	0.12
Dietary Fiber (%)	11.02	11.21	12.59

The assessment of the physical and chemical quality of organic rice used as raw material, the organic crispy rice product, and the organic crispy rice product enriched with black sesame demonstrated that processing and formulation adjustments affected product quality in various aspects, notably moisture content, water activity, and dietary fiber. These factors are essential determinants of food safety, textural integrity, and expiration stability in crispy food products. The results align with prior research suggesting that the precise regulation of physical and chemical characteristics is essential for the development of high-quality processed cereal-based products (Rahman, 2009; Fellows, 2017).

Moisture Content

Raw organic rice demonstrated a moisture content of 3.90%, whereas the organic crispy rice product exhibited an elevated moisture content of 5.30%, and the black sesame-fortified formulation recorded a moisture content of 5.12%. The rise in moisture content after processing may be ascribed to environmental moisture absorption subsequent to drying, and the contribution of supplementary ingredients incorporated into the formulation. This observation aligns with reports suggesting that desiccated food products are capable of absorbing moisture from the ambient air during storage (Rahman, 2009).

Nonetheless, these moisture levels stayed below the threshold established by the Thai Community Product Standard (TIS 36/2554), which prescribes a maximum moisture content of 6%. This demonstrates that the dehydrating process effectively regulates moisture content while preserving the intended crispness of the product. This observation aligns with Fellows (2017), who documented that desiccated foods with moisture levels below 6–8% demonstrate excellent physical stability, diminished quality decline, and prolonged shelf life.

Water Activity (Aw)

The water activity (Aw) of unprocessed organic rice was 0.11, whereas the organic crispy rice product demonstrated a significantly lower Aw value of 0.01, and the black sesame–fortified formulation exhibited an Aw of 0.12. Water activity values below 0.60 are regarded as unfavorable for the proliferation of pathogenic and spoilage microorganisms, signifying that the products are within a range conducive to microbiological stability.

These findings demonstrate that both organic crispy rice formulations exhibit acceptable microbiological safety and are appropriate for storage without the addition of preservatives. This finding aligns with the reports by Rahman (2009) and Jay et al. (2005), which indicate that foods with water activity levels below 0.60 pose a minimal risk of microbial contamination and constitute a significant quality attribute of commercially manufactured crispy foods.

Color Values (L, a, b*)**

Raw organic rice demonstrated a L* value of 85.69, reflecting a high level of luminosity prior to processing. The a* value (1.23) and b* value (3.45) indicated subdued red and yellow hues, which are characteristic of unprocessed rice and suggest high quality of the raw material.

The L*, a*, and b* values of the crispy rice products demonstrate that both dehydrating and black sesame fortification generally resulted in decreased L* values and a shift of a* values toward darker coloration. These modifications can be ascribed to Maillard reactions involving reducing carbohydrates and amino acids, along with the contribution of natural pigments derived from black sesame. This interpretation aligns with the findings of Zhang et al. (2018), who indicated that thermal treatment in cereal-based products markedly influences color brightness and intensity.

Dietary Fiber

The organic crispy rice product contained 11.21% dietary fiber, whereas the black sesame-fortified formulation demonstrated an elevated fiber content of 12.59%. This finding suggests that processing and the integration of oilseed-derived plant components, such as black sesame, can effectively increase the dietary fiber content in the product. This observation aligns with reports indicating that incorporating seeds and plant-derived ingredients can enhance the dietary fiber content of refined cereal products (Slavin, 2013).

Dietary fiber at this level is regarded as comparatively high relative to traditional snack products and is linked to significant health advantages, such as enhanced gastrointestinal function, better blood glucose regulation, and a decreased risk of non-communicable chronic diseases, in accordance with findings by Slavin (2013) and Fardet (2010). Overall, the findings of the physical and chemical quality assessment demonstrate that both the fundamental organic crispy rice product and the black sesame-enriched formulation are appropriate for consumption and storage, as evidenced by low moisture levels, minimal water activity, acceptable microbiological safety, and elevated dietary fiber content. The addition of black sesame did not negatively impact the physical quality; instead, it improved the nutritional value and increased the potential for the product to be developed as a health-focused snack, consistent with principles of whole-grain cereal and healthy crispy food product development (Fellows, 2017; Fardet, 2010).

Section 3: Results of Nutritional Value Analysis of the Organic Crispy Rice Product Before and After Formulation Improvement

Nutritional Value	Organic Crispy Rice Product	Organic Crispy Rice Product with Black Sesame
Total Energy (cal/1 g)	3,256	4,306
Total Fat (per 100 g)	1.05	4.52
Protein (per 100 g)	6.55	15
Dietary Fiber (per 100 g)	11.21	13.59

The nutritional assessment of the organic crispy rice product demonstrated that enhancing the formulation with black sesame fortification significantly influenced its nutritional profile, encompassing energy, fat, protein, and dietary fiber content. These modifications demonstrate the potential to transform the product from a standard nibble into a health-focused food with improved nutritional content. This finding aligns with methodologies for convenience food development that utilize cereal-based products fortified with oilseeds and functional ingredients (Rathod & Annapure, 2016; Singh et al., 2020).

Total Energy

The fundamental organic crispy rice product delivered 3.256 kcal/g of energy, whereas the black sesame formulation exhibited an elevated energy content of 4.306 kcal/g. This augmentation in energy content is directly attributable to elevated levels of fat and protein in the black sesame formulation, as these nutrients deliver greater energy per gram compared to carbohydrates. This observation aligns with established nutritional principles, which demonstrate that lipids and proteins possess greater energy densities than carbohydrates (FAO/WHO, 2010; Fardet et al., 2019).

However, the observed energy levels remain within a suitable range for snack products and are lower than those of fried rice products or high-fat snack items. Therefore, the product corresponds with the concept of a "healthier alternative snack," as prior research has indicated that baked or dried crispy rice products deliver substantially lower energy content compared to fried snack options (Singh et al., 2020).

Total Fat

The overall fat content of the fundamental formulation was merely 1.05 g per 100 g, highlighting the typical low-fat nature of crispy rice products. Conversely, the black sesame formulation exhibited a higher fat content of 4.52 g/100 g, which can be directly ascribed to the inherent fat content of black sesame.

Although the fat content increased, it remained low relative to fried refreshment products, which generally contain more than 15–30 g/100 g of fat (Singh et al., 2020). Furthermore, the fat extracted from black sesame is primarily unsaturated and encompasses bioactive compounds such as sesamin, which have been documented to promote cardiovascular health and lipid metabolism (Majdalawieh et al., 2020; Sun et al., 2022). Therefore, the rise in fat content within the black sesame formulation can be understood as an increase in "beneficial fats" rather than fats linked to negative health consequences.

Protein

Protein content significantly increased from 6.55 g/100 g in the basic formulation to 15 g/100 g in the black sesame formulation, demonstrating that black sesame fortification substantially improved the product's protein nutritional value. This finding aligns with research on the development of crispy rice products, which has demonstrated that the addition of seeds or oilseed-derived plant ingredients effectively enhances protein content (Rathod & Annapure, 2016).

This protein level lies within a moderate to high range for cereal-based snack products and conforms to contemporary trends in snack development that prioritize enhanced satiety and weight control. Previous research has indicated that higher-protein diets increase feelings of fullness and may decrease total energy consumption in subsequent meals (Slavin, 2013; Fardet, 2010).

Dietary Fiber

The dietary fiber content increased from 11.21 g/100 g to 13.59 g/100 g following formulation enhancement. This amount of dietary fiber is regarded as elevated relative to traditional snack products and aligns with the results presented in Section 2, which confirmed the product's suitable physical and chemical quality attributes.

Increased dietary fiber intake yields significant health consequences, specifically concerning gastrointestinal performance, glycemic control, and the sensation of fullness. This observation aligns with the findings of Slavin (2013) and Fardet (2010), which suggest that diets abundant in dietary fiber derived from whole cereals and seeds are correlated with a decreased incidence of non-communicable chronic diseases and promote the formulation of functional health foods. The enhancement of the organic crispy rice product's formulation through black sesame fortification demonstrably improved its nutritional profile, specifically with respect to protein, dietary fiber, and the quality of its fats. While the overall energy content exhibited an increase, it remained within an acceptable threshold for consumption as a health-conscious nibble option.

Section 4: Results of Product Quality Comparison According to the Fried Rice Product Standard (TIS 36/2554)

General Characteristics	Specified Standards	Standards
General Appearance	The product should be vibrant and may display minor breakage. For flavored rice cracker products, the garnish must be securely affixed to the rice cracker sheet and uniformly distributed.	Crispy; product breakage observed
Texture	Must be crispy, not sticky or excessively hard	Crispy, not sticky or excessively hard
Color	Must exhibit natural color characteristic of rice crackers, with uniform appearance and no burning or scorching	Exhibited natural color characteristic of rice crackers, uniform in appearance, with no burning or scorching
Flavor and Aroma	Must have a pleasant natural flavor and aroma characteristic of rice crackers, with no off-flavors or undesirable odors	Exhibited a pleasant natural flavor and aroma characteristic of rice crackers, with no off-flavors or undesirable odors
Moisture Content	Must not exceed 6% by weight	5.30
Food Additives	No preservatives of any kind are permitted, except those naturally present in raw materials,	No preservatives were detected

General Characteristics	Specified Standards	Standards
	provided that their types and amounts comply with legally specified regulations	
Microorganisms		
Total Microbial Count	Must not exceed 1 × 10^6 colonies per gram of sample	**5.90**× 10^1
Salmonella	Must not be detected in 25 g of sample	Not detected in the sample
Staphylococcus aureus	Must be less than 10 colonies per gram of sample	Not detected in the sample
Escherichia coli	By the MPN method, must be less than 3 per gram of sample	Must be less than 3 MPN
Yeasts and Molds	Must not exceed 100 colonies per gram of sample	9 colonies per gram of sample

The comparison of the developed organic crispy rice product against the Thai Community Product Standard TIS 36/2554 (rice crackers) revealed full compliance with all stipulated requirements. The product fulfilled the specified criteria pertaining to physical attributes, sensory properties, microbiological safety, and food chemical composition.

General Appearance and Texture

The product demonstrated a crisp texture, exhibited durability without breaking readily, and displayed uniform adhesion of its components, aligning with the standard requirements that specify the product must be crispy and neither sticky nor excessively firm. These findings align with research on crispy rice products, suggesting that crispness is strongly correlated with low moisture content and the starch structure developed through optimal roasting procedures (Singh et al., 2020). Furthermore, sustaining low water activity (Aw) levels is essential for preserving the product's texture throughout its shelf life, which is a vital consideration in the commercial development of crispy rice products (Rahman, 2009).

Color, Aroma, and Flavor

The product displayed a consistent coloration without any indications of searing or scorching, indicative of pigmentation obtained from natural raw materials. This observation aligns with the Thai Community Product Standard, which mandates that products exhibit appropriate color characteristics and lack any aberrant appearance. The aroma and flavor of the product were indicative of rice and its components, with no discernible off-odors or objectionable tastes. These findings are consistent with research on the sensory attributes of baked rice products, indicating that employing high-quality raw materials and maintaining appropriate baking procedures can reduce the formation of off-flavors linked to lipid oxidation.

Moisture Content and Food Chemical Safety

The moisture content of the product was 5.30%, which is below the maximum limit of 6% specified in the Thai Community Product Standard, thereby enhancing product stability and reducing the risk of quality deterioration and microbial proliferation. No restricted preservatives were identified in the product, demonstrating adherence to food additive regulations and supporting the principles of health-conscious and organic food production. Previous research on desiccated food products has demonstrated that proper regulation of moisture content and water activity can diminish the necessity for preservatives (Fellows, 2017) and prevent excessive Maillard reactions that could negatively impact product quality (Zhang et al., 2018).

Microbiological Quality

Microbiological analysis indicated that the total plate count was within the prescribed standard limits, and no significant pathogenic microorganisms, including Salmonella spp., Staphylococcus aureus, or Escherichia coli, were identified. Yeast and mold concentrations were also observed to be significantly low. These findings align with research on crispy food products, demonstrating that foods with water activity below 0.60 and subjected to proper thermal treatment possess high microbiological safety (Jay et al., 2005). The findings illustrate the potential of the developed product for commercial deployment at the community level and indicate that it may serve as a model for future enhancements to higher quality and safety standards.

3. Summary of Experimental Results

This study effectively demonstrated that an organic crispy rice product enriched with black sesame can function as a nutritious, secure, and high-quality snack alternative, integrating traditional rice-based foods with functional ingredients. The addition of black sesame significantly improved the levels of bioactive compounds, protein, dietary fiber, and health-promoting lipids, while remaining compliant with Thai Community Product Standards and ensuring microbiological safety. The developed product demonstrates attributes of a functional food appropriate for health-conscious consumers in search of nutritionally enhanced refreshment options. The processing method utilized, specifically hot air oven drying, efficiently regulated moisture content and water activity to levels that guaranteed product stability, a firm texture, and an extended shelf life without reliance on synthetic preservatives. These findings corroborate the commercial viability of the product and establish a basis for additional development and scale-up toward industrial manufacturing, with the potential to further enhance nutritional attributes, optimize the retention of bioactive compounds, increase the value of organic rice, and provide healthier snack alternatives with superior nutritional quality for consumers.

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