

Research Article

Effects of Flour Type and Longan Addition on the Quality of Longan-Fortified Baked Crackers

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ABSTRACT

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Khao Griab, a popular fried snack in Thailand, is typically made from deep-fried crackers. However, deep-fried foods are known for their high oil content, which is linked to metabolic disorders. This research aimed to develop a baked version of '*Khao Griab*' as a healthier alternative by modifying the traditional production process, substituting baking for frying. Three types of commercial flour/starch were compared: tapioca starch (TS), glutinous rice flour (GRF), and non-glutinous rice flour (NGRF). The moisture content of the crackers ranged from 0.80% to 2.36%, with water activity values between 0.133 and 0.287. The expansion ratios of the three cracker samples ranged from 21.67% to 56.67%, with NGRF-based crackers showing the lowest expansion, followed by GRF and TS. Crackers made from NGRF were the least hard, while those made from TS were slightly harder, and GRF-based crackers exhibited the highest hardness. The TS-based crackers had the highest L^* value and the lowest b^* value, whereas NGRF-based crackers had the lowest L^* value and the highest redness ($+a^*$) and yellowness ($+b^*$). Sensory evaluation indicated that TS-based crackers achieved higher scores across all attributes, establishing TS as the preferred base for fortification with 5–15% longan. Hardness increased with higher longan levels, and the 10% longan-fortified TS cracker was identified as the optimal formulation based on both sensory acceptance and nutritional improvement. A 30 g serving of longan-fortified baked crackers provides 120 kcal, with percent Daily Values (%DV) of 1% for fat and 2% for sodium—both lower than those of commercial products.

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1. Introduction

Snacks are enjoyed worldwide and play an important role in providing sustenance between main meals, helping to influence feelings of satiety. In Thailand, the snack retail sector was valued at 105,200.7 million baht in 2023, with savory snacks accounting for the largest share over 47,206.8 million baht, or 44.9% of total snack consumption, according to the Trade Policy and Strategy Office, Ministry of Commerce. However, like other energy-dense foods such as cakes, biscuits, and sugary drinks, many snacks are high in calories. Unhealthy snacks, often high

in sugar, fat, and salt, contribute to poor oral health, hypertension, obesity, and diabetes (Almoraie *et al.*, 2021).

Various technologies are used in snack production, including extrusion, frying, roasting, and baking. In Thailand, the traditional frying method, where food is cooked in hot oil, remains the most popular due to its low cost and quick preparation time, making it more accessible to consumers. Frying also imparts a distinctive flavor, taste, color, and crispness that consumers enjoy. However, a key concern with deep-fried foods is their high oil content, which is linked to metabolic disorders such as heart disease, obesity, and high

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cholesterol (Rani *et al.*, 2023). To address these concerns, healthier alternatives such as drying and baking are gaining popularity, as these methods do not require added fats and can result in lower calorie content (Chobot, 2024).

Local fried crackers, known as *Khao Griab* in Thailand, are a beloved snack, and their production process is relatively simple. It begins with mixing flour, ingredients like pepper, garlic, and coriander root, along with hot water in the right proportions. The dough is then molded, steamed, cooled, cut into thin pieces, and dried either through air drying or sun drying before being fried until fluffy. This straightforward process, using readily available materials and equipment, allows manufacturers to create a variety of products with distinct characteristics. However, shifting consumer preferences are pushing producers to innovate, seeking products that are not only ready for immediate consumption but also healthier.

The growing demand for healthier snacks, driven by consumer trends and government initiatives to reduce sugar, fat, and salt intake, has led manufacturers to develop alternatives such as gluten-free, sugar-free, vegan, high-fiber, and low-fat snacks. This trend is evident in the expanding healthy snack market, valued at over 28,314.8 million baht, representing 26.9% of the total snack market and growing at a rate of 11.3% (Trade Policy and Strategy Office, 2024). This shift presents an opportunity for local producers to tap into the health-conscious food market.

In response to these changing demands, this research aimed to develop a healthier version of the local cracker by using a baking method instead of frying, while keeping the other production steps the same. Deep fat frying, with its high rate of heat transfer from hot oil, is more efficient than baking, producing expanded, crispy textures, whereas the lower heat transfer rate in baking results in slower cooking and longer processing times (Tuta and Palazoglu, 2017). In this study, three types of flour were selected for comparison based on their potential to improve product quality in the baking process: tapioca starch (TS), the traditional flour for fried crackers (Akonor *et al.*, 2016); glutinous rice flour (GRF); and non-glutinous rice flour (NGRF). The choice of flour is a key determinant of both the physicochemical and sensory characteristics of crackers. TS, which is low in protein and lipids, is particularly suitable for fried cracker production (Noranizan *et al.*, 2010), as it promotes greater porosity through complete starch granule expansion, resulting in lower product density (Cheow *et al.*, 2004). In contrast, GRF and NGRF are commonly used in roasted rice snacks such as *arare* and *senbei* (Kim and Koh, 2019). During production, the chilling step facilitates slicing but also induces hardening, which varies with the rice cultivar and ripening stage. GRF, characterized by very low amylose and high amylopectin content, produces a sticky and elastic texture, whereas NGRF generally yields crackers with a harder, rougher texture (Pichetnawin, 2004). These flours were selected

for their potential to enhance product quality and consumer acceptance, thereby providing guidance for the development of healthier cracker alternatives.

Longan (*Dimocarpus longan* Lour.), widely cultivated in Northern Thailand, is prized for its sweet flavor and bioactive compounds, with total phenolic content (22.09–132.47 mg GAE/100 g) and flavonoids contributing to strong antioxidant activity (Zhang *et al.*, 2020; Silva and Sirasa, 2018). Although longan is rich in bioactive compounds, market instability causes price fluctuations, highlighting the need for product diversification. Incorporating longan into baked crackers may increase its value and provide consumers with novel, healthier snack options, but fruit and vegetable enrichment in crackers has been associated with increased hardness due to higher dietary fiber (Thi *et al.*, 2024; Yayah *et al.*, 2017). In this context, the present study aimed to formulate baked crackers with three types of flour-tapioca starch (TS), glutinous rice flour (GRF), and non-glutinous rice flour (NGRF)-and to incorporate longan at varying levels, in order to evaluate their effects on product quality and nutritional value according to Thai standards.

2. Materials and Methods

Tapioca starch (TS; Five stars fish brand, Thailand), glutinous rice flour (GRF; Erawan brand, Thailand), and non-glutinous rice flour (NGRF; Erawan brand, Thailand) were purchased from a local supermarket. Granulated sugar (Mitr Phol brand, Thailand), pepper (Rai Thip brand, Thailand), and salt (Prung Thip brand, Thailand) were used according to the traditional '*Khao Griab*' recipe. Dried longan (*Dimocarpus longan* Lour. cv. E-Daw) was obtained from a local agricultural farm in Northern Thailand.

2.1 Comparison of starch/flour types for crackers ('*Khao Griab*') by baking process

Three formulations of crackers were produced, each composed of a different type of flour TS, GRF, and NGRF. The proportions were as follows: 96% of each type of flour, 2.5% sugar, 0.6% garlic, 0.6% pepper, and 0.3% salt. Hot water was added to the solid ingredients in a ratio of 1:2.5. The mixture was kneaded by hand until a smooth dough was formed. The dough was then accurately weighed and placed into a mold (4.5 x 7.5 x 5 cm, W x L x H), and steamed for 40 minutes. After steaming, the cooked dough was allowed to cool at room temperature before being stored in the refrigerator for 12 hours. Once set, the dough was sliced into thin pieces (1 mm thick) and baked at 160°C for 15 minutes.

2.2 Assessment and characterization

2.2.1 Moisture content

The moisture content of crackers before and after baking was determined using the standard AOAC method 925.10 (AOAC, 2019).

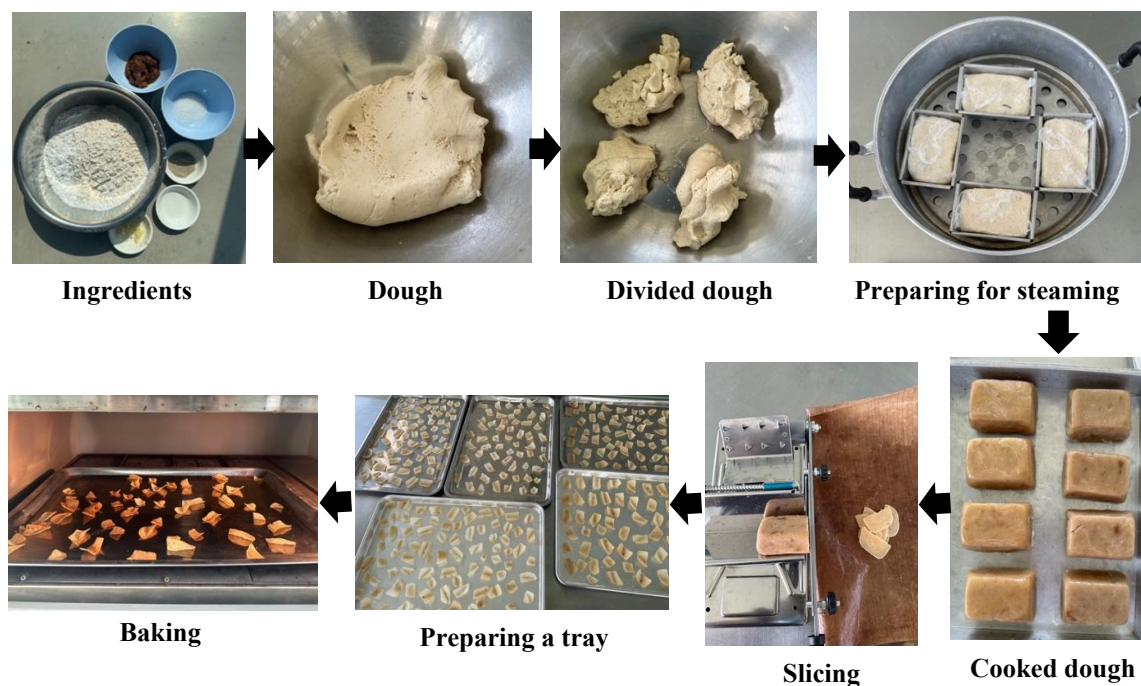


Figure 1 The processing of baked crackers ('Khao Griab').

2.2.2 Texture characteristic

The textural properties of 10 crackers from each treatment were determined using a texture analyzer (TA-XT Plus model; Stable Micro Systems Ltd., UK), following the method of Say *et al.* (2022). The data acquisition rate was 500 points per sec. Pre-test, test, and post-test speeds were set at 10, 1, and 10 mm/s, respectively. The cracker samples were placed on an aluminum cylinder (HDP/CFS crisp fracture support rig) to allow the sphere probe (ball P/0.25s) to pass through after penetrating the sample. The maximum force (kg), number of force peaks, and peak area (kg·mm) were recorded.

2.2.3 Expansion ratio

The expansion ratio of the crackers was determined using the method of Say *et al.* (2022) to measure the thickness of the crackers before and after baking with a vernier caliper. The expansion ratio was calculated according to Equation (1).

$$\text{Expansion ratio} = \left(\frac{\text{thickness after baking} - \text{thickness before baking}}{\text{thickness before baking}} \right) \times 100 \quad (1)$$

2.2.4 Color evaluation

Color values of powders were measured using a hand-held Chroma Meter (Konica Minolta, CR-400, Japan.) in terms of L^* , a^* , and b^* values.

2.2.5 Sensory evaluation

The sensory evaluations were conducted by 30 untrained panelists (aged 15-55 years) to evaluate product acceptability using a 5-point hedonic scale (1= dislike extremely to 5=like extremely). Each formulation was served to the panelists in a clear plastic cup labeled with a three-digit

random code. A cup of drinking water was served to the panelists to clean their palates before and after the sensory test of each sample. The panelists evaluated acceptability on color, aroma, crispiness, taste and overall liking.

2.3 Development of longan crackers using the baking method

The suitable type of flour for producing baked crackers was selected prior to incorporating longan. Dried longan (initial moisture 11.8%) was rehydrated with water at a 1:10 ratio, boiled for 30 min, and then blended for 3 min. Longan was added at 5%, 10%, and 15% of the total ingredients and mixed with the other dry components before adding hot water. The subsequent steps for cracker preparation followed the procedure described above. Each treatment of longan-fortified crackers was prepared in two replicates and assessed as outlined in Section 2.2.

2.4 Nutritional content of developed longan crackers

The nutritional content of the developed longan crackers was analyzed to determine calories, total fat, saturated fat, cholesterol, protein, total carbohydrates, sugar, sodium, and potassium, according to the AOAC method. (AOAC, 2023).

2.5 Statistical analysis

The experimental data were evaluated using analysis of variance (ANOVA). Duncan's new multiple range test was employed to determine the differences between means, with significance defined at $p < 0.05$.

3. Results and Discussion

3.1 Characteristics of crispy crackers ('Khao Griab') by baking process

The moisture content and water activity of the three cracker treatments are shown in Table 1. The moisture content of the sliced dough gel produced from the three types of flour ranged from 39.24% to 44.90%. The dough gel from NGRF exhibited the highest moisture content, followed by TS and GRF. A similar finding by Pereira *et al.* (2020) reported that the moisture content of emulsion-type cooked sausage with added rice flour, tapioca starch, and glutinous rice flour was 65.72%, 65.36%, and 65.17%, respectively. This suggests that the functional properties of amylopectin in glutinous rice starch could enhance moisture absorption during the gelatinization process. Additionally, higher amylose content also influences the moisture content of foods. Widjajaseputra (2012) showed that levels of amylose contributed to the homogeneity of moisture distribution. An increase in amylose content resulted in higher moisture content in rice flour-based spring roll wrappers. This effect is related to the function of amylose as a gel former, where amylose molecules align through hydrogen bonds and release water molecules (Dogan, 2004). Since the amylose content is highest in rice flour, followed by cassava flour, and lowest in waxy rice flour (Saeleaw and Schleining, 2010), this variation may affect the moisture content of the dough gel.

After baking, the moisture content of the crackers decreased to between 0.80% and 2.36%. The results indicated that the trend of moisture content after baking was consistent with that before baking, with NGRF maintaining the highest moisture content, followed by TS and GRF. All moisture content levels of the finished products complied with the Thai Community Product Standard for 'Crispy Snack' (107/2554), which specifies that moisture should not exceed 4%.

The trend in water activity of baked products mirrored that of moisture content, with NGRF showing the highest values, followed by TS and GRF. The water activity of all dough gels was similar, at 0.998, and decreased to values between 0.133 and 0.287 after baking. From a microbiological perspective, water activity below 0.6 is considered safe (Saha, 2020). Additionally, both water activity and moisture content serve as indicators of crispness. Findings from Kulchan *et al.* (2010) reported that specific values of water activity and moisture content 0.54 and 6%, respectively could be regarded as critical points for the loss of crispness.

The expansion ratios of the three cracker samples varied between 21.67% and 56.67%, with NGRF-based crackers exhibiting the lowest expansion, followed by those made from GRF and TS. Saeleaw and Schleining (2010) found a negative correlation between expansion and protein content. They reported that, regarding protein content, rice flour had the

highest value (6.55%), followed by waxy rice flour (5.79%) and cassava starch (0.13%). These results are consistent with the expansion findings from this study. The textural properties of three different crackers are presented in Table 2. The number of peak counts relates to porosity. The crust of porous structures resists the compressed force, resulting in a peak force, and then collapses with further compression applied (Say *et al.*, 2022). Thus, peak count indicates a crispy texture, while peak area suggests the hardness of the cracker. As shown in Table 2, the hardness (or peak area) of crackers made from NGRF was significantly the lowest, followed by those made from TS, while the highest hardness was observed in those made from GRF. The correlation analysis between cracker hardness and amylose content revealed a negative relationship (Kim and Koh, 2019). According to Saeleaw and Schleining (2010), rice flour had a higher amylose content (35.43% on a dry basis), followed by cassava starch (27.10% on a dry basis) and waxy rice flour (7.10% on a dry basis), conforming to the hardness properties observed in this study. Similarly, crispiness mirrored hardness, with NGRF crackers being least crispy, TS-based crackers moderate, and GRF-based crackers the crispiest. This agrees with Nammakuna *et al.* (2009) reported that rice-flour crackers are crumbly, have low expansion, and tend to crack easily.

As shown in Table 3, there were significant differences ($p < 0.05$) in L^* , a^* , and b^* values. All three crackers were white, with L^* values greater than 50. The TS-based cracker exhibited the highest L^* value but the lowest b^* value, indicating a light yellow color, along with a negative trend in a^* , suggesting proximity to the green axis of the color space. The NGRF-based cracker had the lowest L^* values and the highest levels of redness ($+a^*$) and yellowness ($+b^*$) compared to the others, indicating that it was slightly dark brown. The brown color of the crackers resulted from a chemical reaction between reducing sugars and a primary amino group, known as the Maillard reaction. Rice flour, as mentioned by Saeleaw and Schleining (2010), had a high protein content, and thus the resulting crackers exhibited the lowest lightness. The cracker samples made from three types of flour/starch were showed in Figure 2.

Mean sensory property scores of three cracker samples are shown in Table 4. No significant differences were observed between TS-based samples and the GRF-based sample for color, aroma, texture, taste, and overall liking ($p > 0.05$). Sensory scores indicated that the TS-based cracker exhibited higher scores for all attributes compared to the GRF-based cracker; thus, TS was selected as the appropriate base for fortifying with longan.

Table 5 presents the moisture content, water activity, and color values of longan-fortified crackers after baking. Both parameters increased with higher levels of longan incorporation, but moisture content at all levels remained within the limit specified by the Thai Community Product Standard for "Crispy Snacks" (107/2554), not exceeding 4%. Increasing longan

content also decreased the L^* value while increasing the a^* and b^* values, indicating a darker and more intensely colored product. Similar results were reported by Changso and Sanon (2024)

found that steamed cupcake containing 15% dried longan juice exhibited the darkest color compared with those containing 0, 5, or 10%, likely due to the inherent color of dried longan.

Table 1 Moisture content and water activity of crackers before and after baking.

Flour type	Before baking		After baking	
	Moisture content (%)	Water activity ^{ns}	Moisture content (%)	Water activity
Tapioca starch (TS)	42.38±1.89a	0.998±0.000	1.10±0.23b	0.199±0.000b
Glutinous rice flour (GRF)	39.24±0.73b	0.998±0.000	0.80±0.19b	0.133±0.001c
Non glutinous rice flour (NGRF)	44.90±2.36a	0.998±0.000	2.36±0.03a	0.287±0.000a

Values are means ± SD.

Means value ± SD with different superscript letters in the same column are significantly different ($p < 0.05$).

Table 2 Expansion ratio and texture properties of three baked crackers.

Flour type	Expansion ratio (%)	Texture properties		
		Peak count	Max. Force (kg)	Peak area (kg.mm)
Tapioca starch (TS)	56.67±5.77a	13.00±1.98a	1.65±0.69b	1.70±0.42a
Glutinous rice flour (GRF)	31.67±2.89b	16.58±2.35a	3.12±0.91a	2.64±1.12a
Non glutinous rice flour (NGRF)	21.67±2.89c	7.68±0.75b	0.67±0.21b	0.21±0.09b

Values are means ± SD.

Means value ± SD with different superscript letters in the same column are significantly different ($p < 0.05$).

Table 3 Color values in terms of L^* a^* and b^* of three baked crackers.

Flour type	Color		
	L^*	a^*	b^*
Tapioca starch (TS)	71.56±0.55a	-2.19±0.01c	13.43±0.12c
Glutinous rice flour (GRF)	66.05±0.79b	1.86±0.08b	21.84±0.94b
Non glutinous rice flour (NGRF)	62.18±0.41c	4.40±0.00a	24.33±0.06a

Values are means ± SD.

Means value ± SD with different superscript letters in the same column are significantly different ($p < 0.05$).

Table 4 Sensory scores (5-point hedonic scale) of three baked crackers.

Flour type	Color	Aroma ^{ns}	Crispiness	Taste	Overall liking
Tapioca starch (TS)	4.00±0.76a	3.60±0.83	4.00±0.53a	3.93±0.70a	4.07±0.80a
Glutinous rice flour (GRF)	3.93±0.88ab	3.47±0.83	3.63±0.63ab	3.73±0.70a	3.73±0.46a
Non glutinous rice flour (NGRF)	3.30±0.98b	3.27±0.70	3.00±1.13b	2.93±0.88b	2.93±0.80b

Values are means ± SD.

Means value ± SD with different superscript letters in the same column are significantly different ($p < 0.05$).

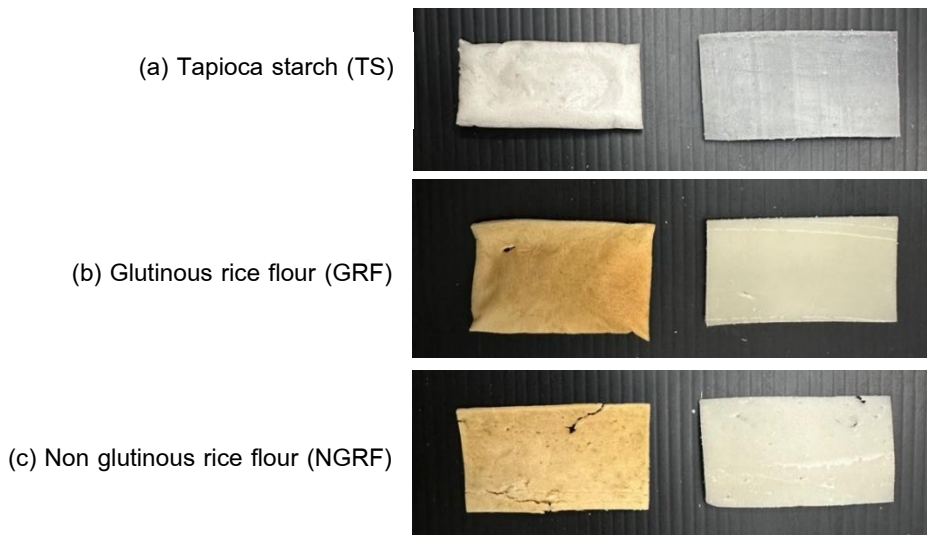


Figure 2 The cracker samples made from three types of flour/starch.

As shown in Table 6, the addition of longan negatively affected the expansion ratio of the crackers, likely due to a reduction in amylopectin content in the starch. Increasing amounts of longan also increased crispiness and hardness. This effect occurs because added ingredients can interfere with

starch expansion by interacting with starch granules. Similarly, Mahmoud *et al.* (2023) reported that the inclusion of freeze-dried banana peel and pulp increased cracker hardness. Such ingredients may inhibit starch expansion, resulting in denser and thicker filaments, which ultimately increase hardness.

Table 5 Moisture content, water activity and color values of longan crackers.

Longan (%)	Moisture content after baking (%)	Water activity after baking	Color		
			L^*	a^*	b^*
0	1.10±0.23c	0.199±0.000b	71.56±0.55a	-2.19±0.01d	13.43±0.12d
5	2.15±0.22b	0.217±0.010b	75.48±0.65b	2.19±0.02c	10.46±0.13c
10	3.17±0.31a	0.286±0.006a	68.06±0.17c	2.79±0.00b	15.87±0.02b
15	3.84±0.51a	0.300±0.002a	50.02±0.37d	7.86±0.03a	21.73±0.93a

Values are means ± SD.

Means value ± SD with different superscript letters in the same column are significantly different ($p < 0.05$).

Table 6 Expansion ratio and texture properties of longan crackers.

Longan (%)	Expansion ratio (%)	Texture properties		
		Peak count	Max. Force (kg)	Peak area ^{ns} (kg.mm)
0	56.67±5.77a	13.07±1.31a	1.65±0.69a	1.70±0.42
5	43.33±5.77b	20.97±3.35b	2.56±1.29ab	3.52±2.29
10	33.33±5.77b	26.04±4.54c	4.60±1.37b	3.97±1.94
15	15.00±5.00c	30.94±3.64d	7.78±1.24a	5.39±1.65

Values are means ± SD.

Means value ± SD with different superscript letters in the same column are significantly different ($p < 0.05$).

Mean sensory property scores for three baked longan cracker samples and the control (without longan) are shown in Figure 3. No significant differences were observed between the control and the samples fortified with 5% and 10% longan for any of the attributes ($p > 0.05$), except for the longan aroma attribute. Sensory scores indicated that the 10% longan-fortified cracker exhibited the highest aroma score, while the cracker with the highest amount of longan (15%) exhibited the lowest scores for all attributes ($p < 0.05$). This may be due to the

darker color, harder texture, and burnt taste from the longan during baking. Incorporation of 10% longan produced high overall liking, color, longan aroma, texture, and taste, with scores ranging from 4.00 to 4.20 on a 5-point hedonic scale, which corresponds to a liking level between "slightly liked" and "extremely liked." This proportion was chosen as the optimal amount of longan to fortify the baked TS-based cracker. The 10% longan-fortified baked TS-based cracker prototype is shown in Figure 4.

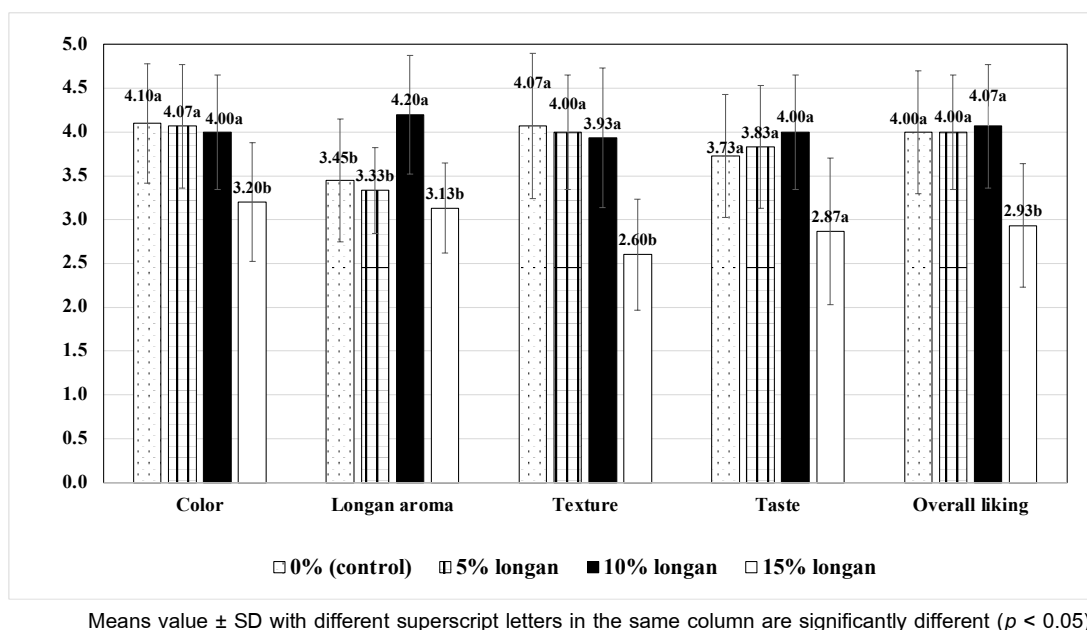


Figure 3 Sensory scores (5-point hedonic scale) of longan crackers.



Nutrition facts

Servings per container: 2

Amount per serving ½ bag (30 g)

Calories 120

% Daily value*

Total fat 0.5 g 1%

Saturated fat 0 g 0%

Cholesterol 0 mg 0%

Protein 2 g

Total carbohydrate 26 g 9%

Sugar 2 g

Sodium 30 mg 2%

Potassium 40 mg 1%

*Percent daily values based on a 2,000 calories diet.

Daily values may be higher or lower depending on individual calories needs.

Figure 4 The 10% longan-fortified baked TS-based cracker prototype (60 gram) and the nutritional composition.

3.2 Nutritional value of baked longan cracker

The nutritional composition of the baked longan cracker (Figure 4) indicates that one serving (30 g) provides 120 kcal, 2 g of protein, 0.5 g of total fat, and 30 mg of sodium, corresponding to 1% of the daily value (%DV) for fat and 2% for sodium. By comparison, commercially available fried crackers deliver 180 kcal, 12 g of total fat, and 280 mg of sodium per serving. Similarly, baked crackers enriched with vegetables have been reported to contain 137–141 kcal per 30 g (Galal *et al.*, 2023), while baked products on average provide about 780 mg of sodium per 30 g serving (Timic *et al.*, 2020). Excessive intake of fat-particularly saturated and trans fatty acids-and sodium is associated with an increased risk of cardiovascular disease in adults (Glassner, 2018; Wang *et al.*, 2020). Accordingly, the relatively low fat and sodium contents of the baked longan cracker position it as a healthier alternative. Beyond its nutritional advantages, this product enhances the utilization of Thailand's agricultural raw materials, responds to growing consumer demand for healthier options, and offers a practical production process suited for small-scale local producers.

4. Conclusion

Baked crackers were developed by adapting the traditional method for local fried crackers, using affordable materials and equipment. Among the flours tested, TS-based crackers showed the highest expansion, lightness, and sensory scores, while NGRF and GRF produced harder, less preferred crackers. Incorporation of longan at 5%, 10%, and 15% in TS-based crackers increased moisture, water activity, redness, yellowness, crispiness, and hardness, but higher levels reduced sensory acceptance. The 10% longan-fortified TS cracker achieved the highest overall liking, color, longan aroma, texture, and taste, and was therefore selected as the optimal formulation. Nutritionally, this product is classified as low-fat (less than 3 g per serving) according to Thai regulations, combining both improved sensory quality and health benefits.

5. Suggestions

Future studies should investigate protein fortification as a strategy to enhance the nutritional quality and health benefits of crackers.

6. Acknowledgments

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