Asia-Pacific Journal of Science and Technology :Volume :30 Issue :05 Article ID: APST-30-05-14 Research Article

APST

Asia-Pacific Journal of Science and Technology

https//:www.tci-thaijo.org/index.php/APST/index

Published by Research and Innovation Department,
Khon Kaen University, Thailand

Impact of popped sangyod rice on the Physicochemical and Sensory qualities of dried Krayasart bars

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Received 28 May 2024
Revised 30 October 2024
Accepted 28 May 2025

Abstract

This study aimed to enhance the nutritional profile and sensory acceptability of dried Krayasart bars by incorporating popped Sangyod rice and stevia, and to evaluate their physicochemical and sensory characteristics. Three formulations were developed using 10.5 g, 12.5 g, and 14.5 g of popped Sangyod rice per 100 g of Krayasart mixture, with other ingredients kept constant. The optimal recipe was subsequently dried in compressed forms (2 × 2 × 2 cm and 2 × 4 × 2 cm; width × length × height) at 60, 80, and 100°C. As the amount of popped Sangyod rice increased, the L* value increased, whereas the a*, b*, and hardness values tended to decrease. Final moisture content decreased as the amount of popped rice increased. The formulation containing 10.5 g of popped Sangyod rice per 100 g of Krayasart received the highest customer satisfaction score. Consequently, formulation 1 (with 10.5 g of popped Sangyod rice per 100 g) was selected for testing in the drying process at 60°C, 80°C, and 100°C. The results indicated that the initial moisture content was 11.51% wb; after drying, it decreased to 7.36-9.34% wb for the 2 x 2 x 2 cm and 8.02-9.52% wb for the 2 x 4 x 2 cm samples. The water activity values in each sample were less than 0.65. Higher drying temperatures increased the a*, b*, and hardness values but decreased the L* value. The highest sensory test scores for both sizes of Krayasart were achieved at a drying temperature of 80°C.

Keywords: Popped rice, Khao Sangyod, Krayasart bars, Drying, Physicochemical

1. Introduction

Krayasart is an ancient Thai dessert that reflects the traditional wisdom of the Thai people. It is typically made from popped rice, young rice flakes, peanuts, and toasted sesame seeds, blended with sugarcane juice or palm sugar to produce a sticky, crisp, and cohesive texture. Studies have found that Krayasart is a high-energy product, rich in protein essential for the body, and a source of both soluble and insoluble dietary fiber [1, 2]. It has been suggested that individuals who consume foods containing a variety of grains receive adequate and balanced nutrients to meet the body's needs. However, certain ingredients in Krayasart may pose health risks when consumed in excess. For example, high intake of palm sugar has been associated with diabetes, coronary artery disease, and other health problems [3, 4]. To support the development of a healthier Krayasart product, stevia extract was incorporated as a low-calorie sweetener. Stevia provides minimal energy, does not accumulate in the body, and is therefore suitable for individuals with diabetes or those managing their weight. Effective blood sugar control is particularly important for these populations [5]. Another key ingredient in Krayasart is rice flakes, traditionally made by roasting rice husks until they split open, creating white, flower-like grains, usually from jasmine rice. However, with the development of various rice varieties to enhance nutritional value, Sangyod rice has emerged as a particularly promising option due to its superior nutritional profile. Therefore, incorporating Sangyod rice into Krayasart production represents a significant opportunity for improving the product's nutritional quality.

Sangyod rice is a native variety from Phatthalung Province, originally cultivated in the agricultural area of Phatthalung City. The grains exhibit distinctive characteristics, including a crimson seed coat and a notably high nutritional value. A 100 g sample of Sangyod brown rice contains 6.46 mg. of niacin, 4.81 mg. of dietary fiber, and 0.52 mg. of iron [6]. Sangyod rice is reported to nourish the blood and slow the aging process. Its iron content may help prevent dementia, while its phosphorus content is higher than that of many other rice varieties. The high fiber content supports digestive and intestinal health. In addition, it contains antioxidants such as gamma-oryzanol, which may reduce the risk of cancer. It also helps lower levels of low-density lipoprotein (LDL) cholesterol and triglycerides while increasing high-density lipoprotein (HDL) levels. These health-promoting properties help reduce the risk of heart disease and stroke by enhancing blood circulation and reducing arterial narrowing [6]. Sangyod rice has also been reported to alleviate stress and relieve menopausal symptoms. As a result, it is regarded as a native rice variety with excellent nutritional value and potential health benefits [7]. Moreover, the red coloration of Sangyod rice is attributed to flavonoid pigment, particularly anthocyanins. These compounds possess antioxidant properties, which help slow the aging process and lower the risk of chronic diseases such as cardiovascular disease, cancer, and immune disorders. In addition, anthocyanins contribute to the grain's distinctive color and aroma [8, 9].

Sangyod rice holds significant potential for the development of healthy foods and has gained increasing popularity among health-conscious consumers. However, no studies to date have specifically addressed the optimal amount of rice to be used in Krayasart production. In addition, transforming Krayasart into a compressed form, commonly referred to as cereal bars, offers an attractive alternative for improving convenience and promoting consumption. To ensure product stability, enhance crispiness, and improve sensory appeal, the bars must undergo an appropriate drying process after molding. Therefore, this study aims to determine the optimal ratio of popped Sangyod rice, identify the suitable size of Krayasart sticks, and establish the appropriate drying temperature for producing appealing dried Krayasart bars.

2. Materials and methods

2.1 Preparation of popped Sangyod rice

High-quality Sangyod rice with clean, unbroken grains was purchased from a neighborhood store. The initial moisture content was adjusted to 10–12% wet basis (wb). To ensure uniform heat exposure, each 100 g batch of rice was roasted in a temperature-adjustable electric frying pan over medium heat at 150–160°C, with continuous stirring to promote even heating and prevent burning. Roasting continued until the grains popped and expanded, resembling white blossoms, with the sound of popping used as an indicator of proper expansion. The roasted rice was then transferred to a bamboo winnowing tray in a thin, even layer. This arrangement facilitated husk separation, as the lighter husks could be blown away or shaken off more efficiently, resulting in clean, popped Sangyod rice.

2.2 Ingredients for making Krayasart product

Krayasart was made using popped Sangyod rice, peanuts, black and white sesame seeds, coconut milk, glucose syrup, and stevia sugar. Table 1 shows the proportion of ingredients used in each formulation.

Table 1 The proportion of ingredients used to make Krayasart products.

Treatments	popped Sangyod rice (g)	Peanuts (g)	Black sesame (g)	White sesame (g)	Coconut (g)	Glucose Syrup (g)	Stevia Sugar (g)	Total (g)
Test 1 (10.5)	10.5	25	7	7	25	25	0.5	100
Test 2 (12.5)	12.5	23	7	7	25	25	0.5	100
Test 3 (14.5)	14.5	21	7	7	25	25	0.5	100

2.3 Preparation of Krayasart

Coconut milk was simmered in a temperature-controlled electric pan at 100–110°C until oil separation occurred. Stevia sugar was then added, and the mixture was stirred continuously until it became homogeneous. Glucose syrup was subsequently incorporated, followed by peanuts, black sesame, and white sesame seeds. The final ingredient added was popped Sangyod rice, which varied among treatments. For Formula 1 (Test 1), 10.5 g of popped Sangyod rice was added per 100 g of total product. In Formulas 2 and 3, the same preparation procedure was followed, but the amount of popped Sangyod rice was adjusted to 12.5 g (Test 2) and 14.5 g (Test 3), respectively. The complete proportions of all ingredients used in each treatment are presented in Table 1. All Krayasart samples were prepared in triplicate and subsequently evaluated for physicochemical properties and sensory characteristics.

2.4 Drying process

The optimal sample was selected based on the highest overall acceptability score from the sensory evaluation (see Section 2.5). This selected formulation was prepared according to the procedure described in Section 2.3. Ten grams were weighed and compressed into 2x2x2 cm (width x length x height) superlene blocks, and 17 g were compressed into 2x4x2 cm blocks. The samples were dried in a hot air oven (Model WTB Binder, Germany) at 60, 80, and 100°C. Weight and moisture content variations were recorded every 20 minutes until equilibrium was reached. After drying, the samples were sealed in zip-lock bags and stored in a desiccator to prevent moisture absorption. The physicochemical properties were then evaluated, including the determination of the moisture ratio (using Equation 1) and drying rate (Equation 2) [10].

$$Moisture\ ratio\ (MR) = \frac{(M_t - M_{eq})}{M_i - M_{eq}} \quad (1)$$

$$Drying\ rate = \frac{(M_i - M_f)}{t} x w_d \quad (2)$$

where the moisture ratio (MR) is defined as: M_i: initial moisture content of the sample (%wb); M_t: moisture content of the sample at any given time (%wb); M_{eq}: equilibrium moisture content of the sample (%wb); M_f: final moisture content of the sample (%wb); W_d: mass of the dry substance (g); t: drying time (hours)

2.5 Examination of the physicochemical and sensory evaluations

2.5.1 Moisture content

Two grams of the sample were weighed according to AOAC [11] guidelines and dried in a hot-air oven (Model WTB Binder, Germany) at 105°C for 16 h. After drying, the sample and its container were placed in a desiccator for 30 min before being weighed. The moisture content was calculated using Equation (3) and expressed as a percentage on a wet basis. Each sample was analyzed in triplicate.

$$\%wb = \frac{(W_i - W_f)}{W_i} x100 \quad (3)$$

where: W_i is the weight of the sample before baking (g); W_f is the weight of the sample after baking (g)

2.5.2 Water activity

Each sample was measured in triplicate using a water activity machine (Model Aqualab Model 3 TE, USA).

2.5.3 Color value

Color measurement was performed using a color difference meter (Model JC801, Tokyo, Japan), and results were expressed in terms of L*, a*, and b* values. L* ranges from 0 (black) to 100 (white), a* represents the red-green axis (positive values indicate redness, negative values indicate greenness), and b* represents the yellow-blue axis (positive values indicate yellowness, negative values indicate blueness). Prior to measurement, the instrument was calibrated using a standard calibration plate. The standard values for L*, a*, and b* were 98.11, -0.11, and -0.08, respectively. Each sample was analyzed in triplicate.

2.5.4 Hardness value

Texture measurements were performed using an Instron Universal Tester Machine equipped with a Warner-Bratzler blade at a crosshead speed of 50 mm/min. Krayasart samples, both before and after drying (sized 2 × 2 × 2 cm and 2 × 4 × 2 cm, respectively), were cut at the center. The maximum force (maximum load) required to cut through each sample was recorded in Newtons (N). Each measurement was conducted in triplicate.

2.5.5 Sensory evaluation

Krayasart samples, sized 2x2x2 cm and 2x4x2 cm and dried at 60, 80, and 100°C, respectively, were subjected to sensory evaluation. All six samples were served to each of the thirty panelists in a randomized order. To minimize bias, each sample was labeled with a three-digit code. Consumer acceptance of the Krayasart bars made from popped Sangyod rice was assessed using the 9-point Hedonic scaling, ratings from 1 (dislike extremely) to

9 (like extremely), following the method of Mahattanatawee et al. [12]. The attributes evaluated included color, aroma, texture, taste, and overall acceptability.

2.5.6 Statistical analysis

Each physical and chemical property was measured in triplicate. Data are presented as mean ± standard deviation (SD) values. One-way analysis of variance (ANOVA) was performed to assess differences among experimental conditions, and Duncan's multiple range test was applied to identify significant differences at $p < 0.05$.

3. Results and discussion

After evaluating three ratios of popped Sangyod rice incorporation into Krayasart, the formulations were as follows: Formula 1 (Test 1) contained 10.5 g of popped rice per 100 g of Krayasart; Formula 2 (Test 2), 2.5 g; and Formula 3 (Test 3), 14.5 g. Changes in physicochemical properties, including moisture content, water activity, color value, hardness, and sensory attributes, were measured. The results are summarized in Tables 2 and 3.

Table 2 Physicochemical properties of Krayasart as affected by the ratio of popped Sangyod rice (g per 100 g of product).

Treatments	Color value			Water activity	Moisture content	Hardness
	L*	a*	b*	(a_w)	(%wb)	(N)
Test 1 (10.5)	36.84±0.21^{c}	2.54±0.20^{a}	13.42±0.12^{b}	0.64±0.02^{a}	10.32±0.43^{a}	18.31±3.67^{a}
Test 2 (12.5)	46.21±0.11^{b}	2.51±0.01^{a}	15.73±0.05^{a}	0.62±0.01^{a}	9.90±0.22^{a}	18.99±3.21^{a}
Test 3 (14.5)	51.56±0.06^{a}	2.20±0.01^{b}	7.95±0.01^{c}	0.55±0.01^{b}	7.53±0.57^{b}	14.92±2.26^{b}

*Values are mean +/- standard deviation determinations.
^{abc}: The means with the same superscripts within each column are insignificantly different at $p \leq 0.05$ by Duncan multiple range test.

Table 3 Sensory evaluation of Krayasart samples formulated with different ratios of popped Sangyod rice.

Treatments	Color	Flavor	Texture	Taste	Over acceptability
Test 1 (10.5)	6.60±1.25^{a}	7.13±1.28^{a}	6.13±1.33^{a}	7.30±1.26^{a}	7.23±0.94^{a}
Test 2 (12.5)	6.73±1.82^{a}	6.10±1.47^{b}	6.73±1.72^{a}	5.90±1.60^{b}	6.43±1.48^{a}
Test 3 (14.5)	5.20±1.69^{b}	6.10±1.71^{b}	4.93±1.76^{b}	5.37±1.34^{b}	5.07±1.33^{b}

*Values are mean +/- standard deviation determinations.
$^{abc:}$ The means with the same superscripts within each column are insignificantly different at $p \leq 0.05$ by Duncan multiple range test.

3.1 Effect of popped Sangyod rice ratio on the physicochemical properties of Krayasart

3.1.1 Color

Color is a critical factor influencing consumer acceptance of food products. Table 2 compares the L*, a*, and b* color values of the three Krayasart formulas. An increase in the amount of popped Sangyod rice resulted in a statistically significant ($p \leq 0.05$) increase in the L* value. Test 1 (10.5), Test 2 (12.5), and Test 3 (14.5) resulted in L* values of 36.84±0.21, 46.21±0.11, and 51.56±0.06, respectively. On the other hand, when the content of popped Sangyod rice in Formula 1 was increased, the a* values dropped from 2.54 ± 0.02 to 2.20 ± 0.01. The yellowness value (b*) significantly decreased ($p \leq 0.05$) in Formulas 1, 2, and 3, with values of 13.42±0.12, 15.73±0.05, and 7.95±0.01, respectively. The observed increase in the L* value, along with decreases in a* and b* values, can be attributed to the dilution and thermal degradation of anthocyanin pigments during processing. These pigments, primarily anthocyanins, are naturally found in the bran layer of Sangyod rice, a pigmented rice variety known for its high anthocyanin content concentrated in the outer layers [13]. As the proportion of popped Sangyod rice increased, the product developed a more porous structure compared to whole-grain rice. This porous structure may have facilitated greater heat and oxygen penetration, which can accelerate the degradation of anthocyanins [14], resulting in a lighter (higher L*) and less red (lower a*) appearance. Furthermore, the increase in surface area due to popping could have reduced the concentration of pigments per unit volume, contributing to the overall color change observed in the final products. Similar trends have been reported by Mazza and Miniati [15], Abdel-Aal and Hucl [16], and Suppavorasatit et al. [17].

3.1.2 Water activity and moisture content

After adjusting the proportion of popped Sangyod rice as shown in Table 2, the moisture contents of Test 1 (10.5%) and Test 2 (12.5%) were 10.32±0.43% wb and 9.90±0.22% wb, respectively. Although a numerical difference was observed, the variation in moisture content between the two formulations was not statistically significant ($p > 0.05$). However, in Test 3 (14.5), when more popped Sangyod rice was added, the moisture value was 7.53±0.57% wb, representing a statistically significant decrease ($p \leq 0.05$). All three product formulas fell into the dry food category or had comparatively low moisture ratings. The water activity levels for all three Krayasart formulations ranged between 0.55 and 0.64. There was no statistically significant difference ($p > 0.05$) in water activity between Formulas 1 and 2, indicating that the slight variation in popped Sangyod rice content between these two formulations was not sufficient to produce measurable changes in water activity. In contrast, Formula 3 exhibited a significantly lower water activity ($p \leq 0.05$), with a value of 0.55. This reduction can be attributed to the higher proportion of popped Sangyod rice, which likely decreased the bulk density and increased the porosity of the matrix. The enhanced porosity may have facilitated greater moisture loss during processing, thereby reducing both moisture content and water activity.

In Krayasart, low moisture content leads to a distinctly crispy texture, while elevated moisture levels hinder proper clumping and diminish the desired stickiness of the final product. Adjusting the ratio of popped Sangyod rice resulted in low moisture levels across all three product formulas, classifying them as dry foods. These values comply with the community product standards for Krayasart (MPC.709/2004), which specify a maximum moisture content of 12% wb. Water activity reflects the availability of water in food, which can accelerate degradation. Water that is structurally bound or associated with other food molecules plays a critical role in this process. Higher water activity supports bacterial growth, leading to faster deterioration. The testing showed that all three Krayasart formulations had water activity values between 0.55 and 0.64, classifying them as dry food products with levels below 0.6 [18].

3.1.3 Hardness

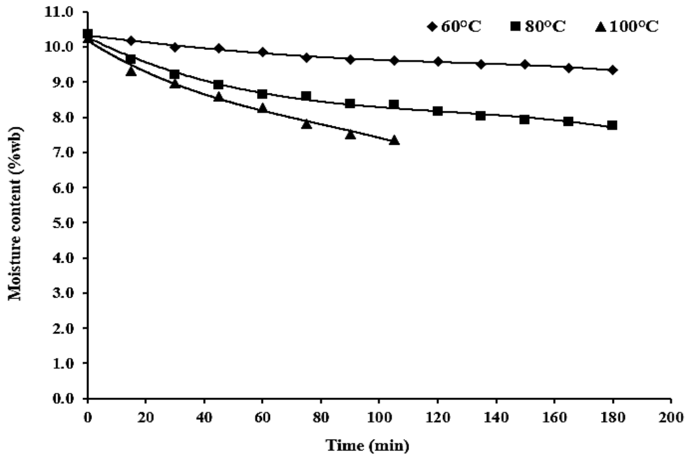
Table 2 shows that using 10.5 g of popped Sangyod rice per 100 g of Krayasart resulted in a hardness value of 18.31±3.67 N. Increasing the amount to 12.5 g yielded a statistically similar value of 18.99±3.21 N ($p > 0.05$). However, a further increase to 14.5 g significantly reduced the hardness to 14.92 ± 2.26 N ($p \leq 0.05$). These results suggest that the hardness of Krayasart is influenced by the quantity of popped Sangyod rice. The increased amount of popped rice likely introduced more air into the product matrix, thereby reducing structural density and weakening its internal binding and compression resistance. This decrease in structural integrity corresponds with the lower hardness values observed. This finding aligns with the study by Lekjing et al. [19], who reported that the inclusion of Sangyod brown rice flour in snack formulations reduced both swelling and hardness.

3.1.4 Sensory evaluation

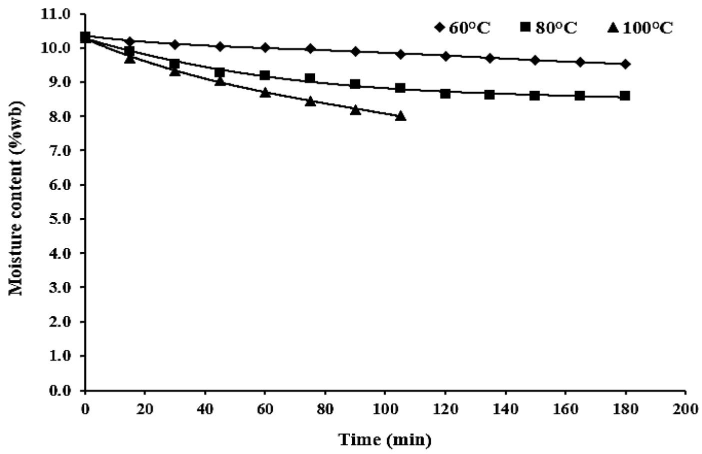
Table 3 presents consumer satisfaction with the three Krayasart formulas. Consumers preferred the flavor and taste of Krayasart made with 10.5 g of popped Sangyod rice per 100 g (Test 1) over those made with 12.5 g (Test 2) and 14.5 g (Test 3). Using 12.5 g of popped Sangyod rice per 100 g resulted in higher ratings for color and texture compared to the other formulas. However, in terms of overall acceptability, Krayasart made with 10.5 g of popped Sangyod rice per 100 g (Test 1) received the highest rating.

3.2 Effect of drying temperature on Krayasart bar characteristics

Initial experiments revealed that using popped Sangyod rice at a maximum ratio of 10.5 g per 100 g of Krayasart improved the product's chemical and physical properties, as well as consumer satisfaction. Based on these results, subsequent tests were conducted to investigate the effects of drying at three different temperatures: 60°C, 80°C, and 100°C. According to the community product standard for Krayasart (MPC.709/2004), the moisture content should not exceed 12% wet basis (wb). The initial moisture content of the Krayasart mixture before drying was 11.51% wb, which met the standard. However, the resulting texture was chewy, lumpy, and lacked crispness. Since this study aimed to product Krayasart in bar and crisp forms, the product was dried at three temperature levels: 60°C, 80°C, and 100°C. Two sizes of the Krayasart bars were used in the experiments: 2 × 2 × 2 cm and 2 × 4 × 2 cm (width × length × height).

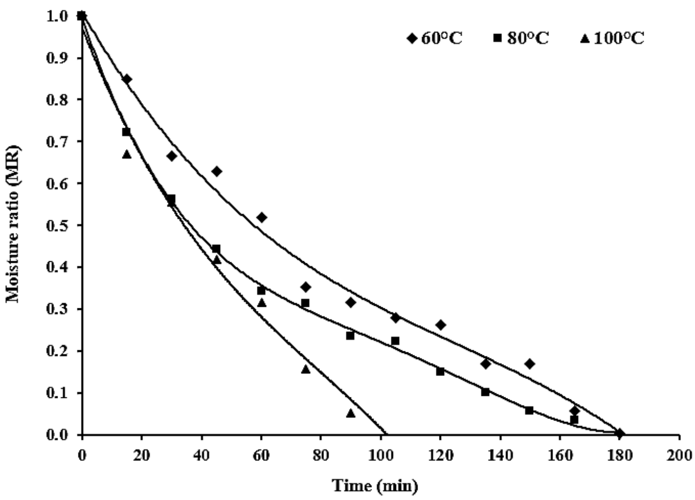


Size 2x2x2



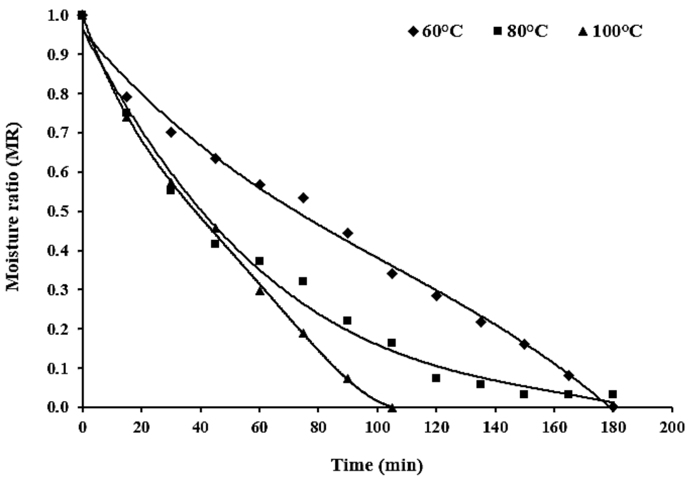
Size 2x4x2

Figure 1 Changes in moisture content of Krayasart bar products over time during drying at 60, 80, and 100°C.



Size 2x2x2

Figure 2 Changes in the moisture ratio of Krayasart bar products over time during drying at 60, 80, and 100°C.



Size 2x4x2

Figure 2 (cont.) Changes in the moisture ratio of Krayasart bar products over time during drying at 60, 80, and 100°C.

As shown in Figure 1, the moisture content of the Krayasart bar decreased significantly from an initial value of 10.34% (wb) when dried at 60°C, 80°C, and 100°C. For bars sized 2x4x2 cm, the final moisture contents were 9.52%, 8.53%, and 8.02%wb, respectively. For 2x2x2 cm bars, the final values were relatively consistent at 9.34%, 7.76%, and 7.36%wb. Moisture left the product more rapidly at higher temperatures, as the increased heat energy accelerated evaporation. Compared to lower temperatures, this resulted in a quicker reduction in final moisture content. However, as drying progressed, the remaining tightly bound moisture became more difficult to remove. Consequently, extending the drying time did not significantly reduce the moisture content in the product, as the product had already reached a plateau. When moisture could no longer migrate to the surface, drying was considered complete [20, 21].

Figure 2 illustrates the moisture ratio of dried Krayasart over time at 60, 80, and 100 °C for both sample sizes (2×2×2 cm and 2×4×2 cm). The rate of moisture reduction was non-linear and followed an exponential trend at all three temperatures. During the drying process, surface moisture evaporated from the heated Krayasart pieces, resulting in a sharp decline in the moisture ratio during the initial phase. In this period, free water unbound to food molecules was removed. Following this initial phase, the drying rate remained relatively constant as the moisture ratio declined linearly, with internal moisture continuously migrating to the surface. This drying behavior was influenced by several factors, including drying temperature, air humidity, and food structure, which affected the overall moisture ratio reduction pattern [22, 23].

Table 4 Drying rate of Krayasart bar products at different drying temperatures (60, 80, and 100°C) for two sample sizes (2×2×2 and 2×4×2 cm).

Sample size (cm)	Drying temperature (°C)	Drying time (min)	Initial (Final) moisture content (%wb)	Drying rate (g/hr)
2x2x2	60°C	180	10.34 (9.34)	2.48
	80°C	180	10.34 (7.76)	6.50
	100°C	150	10.34 (7.36)	8.84
2x4x2	60°C	180	10.34 (9.52)	3.91
	80°C	180	10.34 (8.53)	9.10
	100°C	150	10.34 (8.02)	14.21

Table 4 shows that the drying rate of Krayasart bars increased with both sample size and drying temperature. All samples were prepared from a single, well-mixed batch to ensure a uniform initial moisture content of 10.34% (wb) before being molded into different sizes. This allowed for a fair comparison of drying behavior between the two sample sizes. Larger pieces (2x4x2 cm) generally exhibited higher drying rates than smaller ones (2x2x2 cm), particularly at elevated temperatures. At 100°C, the larger pieces had a drying rate of 14.21 g/hr. compared to 8.84 g/hr. for the smaller pieces. At 80°C, the rates were 9.10 g/hr. and 6.50 g/hr. for the larger and smaller samples, respectively. However, at the lower temperature of 60°C, the difference in drying rates between sizes was less pronounced, with values of 3.91 g/hr. and 2.48 g/hr. for the larger and smaller samples, respectively. These results, while not derived from a two-way statistical analysis, reflect descriptive observations that indicate how increasing temperature may amplify the influence of sample size on drying efficiency.

Table 5 Color (L, a, b*), water activity, and moisture content of Krayasart bar products dried at 60, 80, and 100°C.

Sample size	Drying Temperature	Color value			Water activity	Moisture content
		L*	a*	b*	a_w	(%wb)
2x2x2 cm	Control	36.84±0.11^a	2.54±0.59^d	13.42±0.02^d	0.66±0.01^a	10.33±0.02^a
	60°C	36.45±0.04^a	3.30±0.02^c	16.18±0.03^{bc}	0.65±0.02^a	8.89±0.31^c
	80°C	33.70±0.02^b	4.44±0.03^b	16.66±0.11^b	0.59±0.04^b	7.65±0.16^e
	100°C	31.94±0.53^d	5.88±0.02^a	17.51±0.99^a	0.52±0.02^c	7.11±0.47^e
2x4x2 cm	Control	36.84±0.11^a	2.54±0.59^d	13.42±0.02^d	0.66±0.01^a	10.33±0.02^a
	60°C	36.46±0.03^a	3.32±0.02^c	16.18±0.03^{bc}	0.64±0.02^a	9.23±0.29^b
	80°C	33.69±0.06^b	2.44±0.02^d	15.67±0.02^c	0.58±0.03^b	8.31±0.44^d
	100°C	32.92±0.49^c	5.88±0.05^a	17.51±0.11^a	0.53±0.01^c	7.68±0.43^e

*Values are mean +/- standard deviation determinations.

$^{abc:}$ The means with the same superscripts within each column are insignificantly different at $p \leq 0.05$ by Duncan multiple range test.

3.3 Physicochemical properties of Krayasart bars dried at various temperatures

3.3.1 Color

According to Table 5, the lightness (L*), redness (a*), and yellowness (b*) values of Krayasart prior to drying (control) were 36.84, 2.54, and 13.42, respectively. Subsequent drying at 60, 80, and 100°C led to a decrease in L* to 31.94, while a* and b* increased to 5.88 and 17.51, respectively. The pattern of color changes during drying was similar for both sample sizes (2×2×2 cm and 2×4×2 cm). Across the tested temperatures range, lightness (L*) decreased, whereas redness (a*) and yellowness (b*) increased, indicating a tendency for color darkening with increasing temperature, likely due to a non-enzymatic browning reaction, specifically the Maillard reaction. Enzymatic browning is unlikely under the drying conditions used, as the high temperatures (60–100°C) would have denatured enzymes such as polyphenol oxidase. Moreover, enzymatic activity is generally inactivated early during thermal processing at temperatures above 60°C [24, 25]. The Maillard reaction involved the formation of glycosylamine through the reaction between the amine group in protein and the carbonyl group in reducing sugar. This reaction progresses through a series of complex steps, ultimately forming brown pigments known as melanoidins, with reaction rates increasing at elevated temperatures [26, 27].

3.3.2 Water activity and moisture content

According to Table 5, the water activity and moisture content of Krayasart bars before drying were 0.66 and 10.33%wb, respectively. Drying at 60, 80, and 100°C significantly reduced the water activity values from 0.65 to 0.52 (p <0.05). The moisture content also significantly decreased (p <0.05) from 8.89%wb to 7.11%wb for Krayasart bars of size 2x2x2 cm, and from 9.23%wb to 7.68%wb for those of size 2x4x2 cm. Additionally, the water activity of the 2x4x2 cm Krayasart bars significantly decreased (p ≤0.05) from 0.64 to 0.53. Maintaining water activity and moisture content below the thresholds at which microbes, bacteria, yeast, and mold can thrive is crucial for extending product shelf life and preventing food spoilage. Water activity values below 0.6 have been shown to inhibit almost all microbial activities [28, 29]. The dried Krayasart bars, processed at 60-100°C, exhibited water activity values below 0.6 and moisture content below 10.33%wb. These conditions indicate minimal risk of microbial growth and are therefore likely to contribute to extended shelf life. Moreover, sample size influenced the final moisture content, with larger Krayasart bars (2×4×2 cm) retaining higher moisture levels than smaller ones (2×2×2 cm) at each drying temperature. This trend can be attributed to the lower surface area-to-volume ratio of larger samples, which slows the rate of heat and moisture transfer. As a result, moisture escapes less readily from the interior of larger samples, leading to slower drying rates and higher residual moisture despite exposure to the same thermal conditions [30].

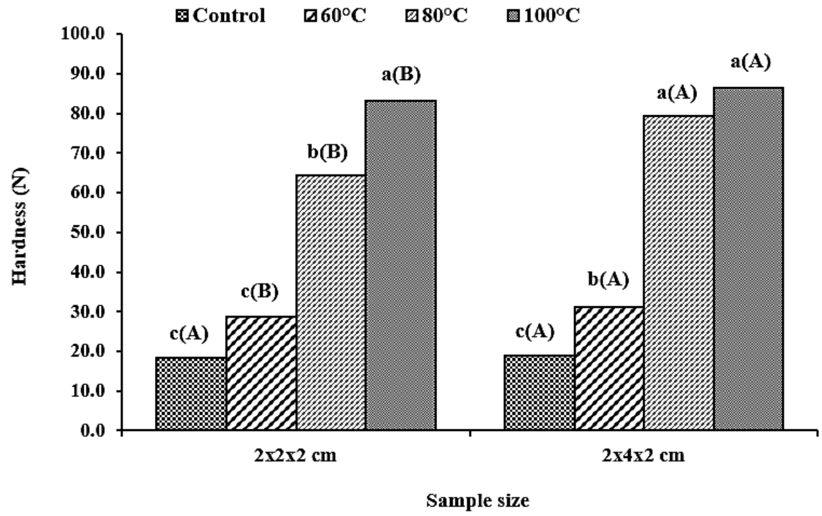


Figure 3 Hardness comparison of dried Krayasart bars at different temperatures and sample sizes.
Different lowercase letters (a–c) indicate significant differences ($p < 0.05$) among temperatures within the same sample size.
Different uppercase letters (A, B) indicate significant differences ($p < 0.05$) between sample sizes at the same temperature.
(Duncan New's Multiple Range Test (DMRT), $p \leq 0.05$, n=3).

3.3.3 Hardness

Figure 3 presents the hardness values of dried Krayasart bars in sizes 2x2x2 cm and 2x4x2 cm dried at 60°C, 80°C, and 100°C. For both sample sizes, hardness significantly increased ($p \leq 0.05$) with rising drying temperatures. Specifically, the 2x2x2 cm bars exhibited hardness values of 28.81 N, 64.33 N, and 83.28 N at 60°C, 80°C, and 100°C, respectively. Similarly, the 2×4×2 cm bars showed increased hardness values of 31.21 N, 79.48 N, and 86.56 N across the same temperatures. These differences are indicated by different lowercase superscript letters (a–c), representing statistically significant differences among drying temperatures within the same sample size. Moreover, at each temperature, the larger-sized bars (2×4×2 cm) exhibited significantly higher hardness values than the smaller ones (2×2×2 cm), as denoted by different uppercase superscript letters (A, B). This suggests that sample size has a clear effect on hardness, potentially due to slower internal moisture removal and greater matrix densification in the larger samples during drying. The overall increase in hardness with temperature is attributed to rapid surface water evaporation at higher drying temperatures, resulting in a harder and more brittle texture. This is also associated with increased browning, as observed in the color measurements discussed earlier. The drier and crunchier structure at higher temperatures likely require greater shear force during texture analysis.

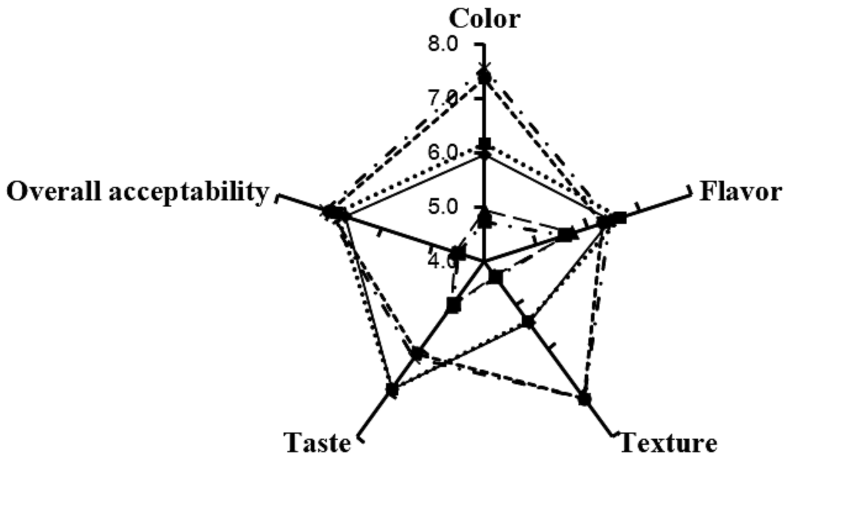


Figure 4 Sensory evaluation of dried Krayasart bar products at 60, 80 and 100 °C.

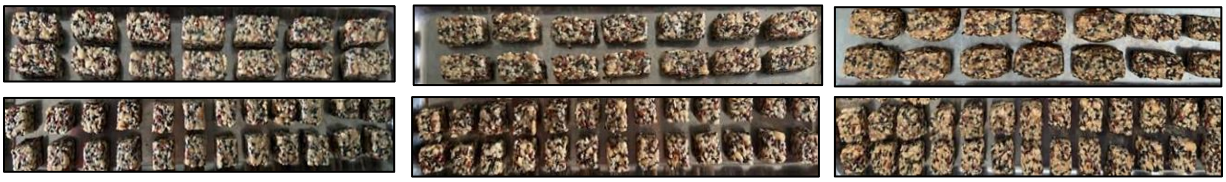
3.3.4 Sensory evaluation

Figure 4 presents the results of consumer satisfaction testing for Krayasart bars. At 80°C, both configurations showed the highest color scores: 7.37 for 2x2x2 and 7.57 for 2x4x2, indicating optimal color development, likely due to controlled Maillard reactions and mild caramelization. In contrast, samples dried at 100°C exhibited significantly lower scores (4.93 and 4.73), reflecting excessive browning and color degradation. The texture was acceptable at 60°C, with scores of 5.37 (2x2x2) and 5.40 (2x4x2), but improved markedly at 80°C, where both reached 7.13. This suggests that moderate drying temperatures enhanced moisture retention and structural properties. At 100°C, texture deteriorated, with scores dropping to 4.33 and 4.37, likely due to over-drying and hardening.

Flavor and taste were rated highest at 60°C, with flavor scores of 6.63 (2x2x2) and 6.43 (2x4x2) and identical taste scores of 6.90. These results suggest that lower temperatures preserved volatile compounds and flavor intensity. However, scores declined at 100°C, possibly due to flavor degradation and off-flavor formation. At 80°C, scores remained acceptable, indicating a balance between sensory quality and structural improvements.

Despite higher flavor and taste ratings at 60°C, overall acceptability was greatest at 80°C, with scores of 7.00 for 2x2x2 and 7.07 for 2x4x2. This highlights the favorable combination of color, texture, and flavor at this temperature. The lowest acceptability was observed at 100°C (4.57 and 4.50), underscoring the negative sensory impact of excessive heat. Figure 5 illustrates representative samples from each drying condition. These findings emphasize the importance of precise temperature control. Drying at 80°C, particularly the 2x4x2 configuration, emerged as optimal for sensory quality and consumer satisfaction.

(A) (B) (C)



60°C 80°C 100°C

Figure 5 Krayasart bars after being dried at (A) 60°C, (B) 80°C, and (C) 100°C.

4. Conclusions

Traditional Krayasart faces challenges in modern markets due to high palm sugar content, limited variety, and short shelf life. Despite growing demand for healthier snacks, little research has explored functional ingredient integration in dried Krayasart bars. This study developed bars using popped Sangyod rice, a high-fiber, antioxidant-rich local rice, and stevia to improve nutrition and acceptability. A two-phase experiment tested three rice levels (10.5, 12.5, and 14.5 g/100 g) for physicochemical and sensory properties, then dried the optimal formula (10.5 g) at 60°C, 80°C, and 100°C in two bar sizes. The 10.5 g formulation dried at 80°C in the larger size showed the best texture, moisture, and sensory scores. Higher rice levels weakened texture, and 100°C drying caused over-drying and discoloration. These results offer practical guidance for modernizing traditional Thai snacks by using local functional ingredients and optimized drying. The developed bar is shelf-stable, health-oriented, and culturally relevant. Future studies should examine drying microstructure, shelf life under various packaging, and wider consumer acceptance. Enhancing formulations with bioactive compounds and advanced drying methods may further improve quality and market potential.

5. Acknowledgements

Financial support was provided by Rajamangala University of Technology Thanyaburi (RMUTT), Faculty of Engineering, Agricultural Engineering, Thanyaburi, Pathum Thani, Thailand.

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