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Puffing techniques for chinese flowering cabbage rice crackers using an air fryer

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ABSTRACT

Khao Kreab Wow (KKW) is a traditional Thai snack that has long been favored for its crisp texture and pleasant taste. However, conventional production methods often lack proper hygienic controls. This study aims to determine the conditions for puffing KKW enriched with Chinese flowering cabbage powder using air fryer technology. The study was divided into two main phases: (1) determining the drying time at 70°C for 30, 60, 90, and 120 minutes. The results showed that drying for 60 minutes yielded a moisture content of 10.54%, the lowest bulk density ($p \leq 0.05$), and the highest expansion ratio ($p \leq 0.05$), making it suitable for both storage and puffing; and (2) identifying the puffing conditions using an air fryer at 180, 190, and 200°C for 3, 2.50 and 2 minutes respectively. The temperature of 200°C resulted in the highest expansion ratio ($p \leq 0.05$), the lowest puffing yield ($P \leq 0.05$), and the highest sensory acceptance ($p \leq 0.05$). Therefore, drying at 70°C for 60 minutes followed by puffing at 200°C using an air fryer is the most suitable method for producing a commercially viable healthy snack. This approach also adds value to local agricultural products by incorporating indigenous vegetables into traditional snack foods.

Keywords: puffing techniques, rice crackers, air fryer

INTRODUCTION

Khao Kreab Wow, a traditional Thai crispy rice snack, has a long history of local consumption and is characterized by its thin, flat, and crisp texture reminiscent of a kite. In recent years, consumer interest in healthier variations of traditional snacks has increased significantly. Reflecting this trend, the global rice crackers market is projected to grow from USD 2,238.09 million in 2024 to USD 3,096.1 million by 2032, with a compound annual growth rate (CAGR) of 4.14% (Credence Research Inc., 2025; Research and Markets, 2025). The development of nutritionally enhanced, health-conscious snack products is therefore aligned with current market demands.

Previous studies have explored the incorporation of functional ingredients into traditional snacks to enhance their nutritional profile. For instance, Settapramote et al. (2023) successfully enriched KKW with Chinese flowering cabbage powder, significantly increasing its protein, fiber, and micronutrient content. However, traditional production methods—such as sun drying and charcoal grilling—often pose challenges in terms of quality control and hygiene, leading to inconsistent product quality and limiting scalability, especially at the household and community levels (Provincial Cultural Office, 2017).

Air fryer technology, which utilizes high-speed hot air circulation to heat food, offers a promising alternative to traditional frying. This method allows for rapid and uniform heat distribution without the need for added oil. The hot air induces the Maillard reaction, producing desirable color, crispness, and aroma (Téllez-Morales et al., 2024). When applied to starch-based products such as KKW, this process facilitates rapid moisture evaporation and internal steam generation, leading to puffing and structural expansion. The result is a light, crisp product similar in texture to deep-fried snacks but with significantly reduced fat content. Air fryer systems also allow for precise control of temperature and time, contributing to consistent product quality and reducing the formation of harmful compounds such as acrylamide, which are commonly associated with conventional oil frying (Kahlon et al., 2025).

Furthermore, studies by Kahlon et al. (2025) demonstrated that puffed snacks made from garbanzo beans and Bengal gram using air fryer technology retained high protein levels (21–22%) and exhibited

significant expansion ratios (136–173%) without compromising nutritional quality. Similarly, Téllez-Morales et al. (2024) confirmed that hot air frying preserves desirable textural properties, moisture content, and minimizes harmful by-products compared to traditional frying methods.

This study aims to determine the conditions for puffing KKW enriched with Chinese flowering cabbage powder using air fryer technology. The goal is to develop a product with improved physical characteristics, and commercial potential, while also providing a practical and hygienic production method suited for household and community-level applications.

MATERIALS AND METHODS

1. Drying Time of Chinese Flowering Cabbage Rice Crackers.

The preparation of Chinese flowering cabbage powder and the rice cracker product was adapted from the method described by Settapramote et al. (2023) as well as the ingredients were showed in Table 1. Glutinous rice flour was mixed with hot water and kneaded using a high-speed mixer for 10 minutes. After kneading, the dough was shaped into cylindrical forms and steamed at high heat for 20 minutes. The steamed dough was then remixed using a mixer for an additional 20 minutes. The dough was subsequently rolled into flat sheets and cut using a 4 cm diameter mold. The formed pieces were placed on a wire rack and dried in a hot air oven at 70 °C for 2 hours. Samples were collected at 30, 60, 90, and 120 minutes during the drying process. Each collected sample was fried using an air fryer at 160 °C for 4 minutes. The final products were analyzed for the following parameters: color values, percentage of puffing yield, expansion ratio, bulk density, percentage expansion, texture characteristics, water activity, and moisture content.

Table 1. Basic formulation of Chinese flowering cabbage rice crackers product

Ingredients	Gram	Percent
Glutinous rice flour	450	50
Boiling water	300	33
Palm sugar	100	11
Vegetable oil	40	4
Chinese flowering cabbage powder	22.5	2

Source : Settapramote et al. (2023)

2. Frying Conditions for Expansion of Chinese Flowering Cabbage Rice Crackers

2.1 Determination of Puffing Time Using an Air Fryer

To identify the puffing time, the rice cracker samples were subjected to puffing in an air fryer at three temperature settings: 180 °C, 190 °C, and 200 °C for a total duration of 3.5 minutes. Samples were collected every 0.5 minutes and evaluated through sensory analysis to determine the most appropriate puffing time for each temperature condition.

2.2 Determination of Puffing Temperature

The samples showing the highest sensory scores from temperature and time conditions in section 2.1 were selected for further quality analysis. Parameters evaluated included moisture content, percentage of puffing yield, bulk density, water activity, texture profile, color values, percentage expansion, and puffing ratio. These results were used to determine the puffing temperature for the product.

3. Analysis of Physical and Sensory Properties

3.1 Moisture Content

Moisture content was determined using 3 grams of the dried Chinese flowering cabbage rice cracker. The sample was analyzed using a food moisture analyzer (Moisture Balance Model MA50R, Radwag, Poland).

3.2 Percentage of Puffing Yield

The percentage of puffing yield was calculated by initially weighing the raw rice cracker sheet. The same sample was then subjected to puffing in the drying process, after which it was weighed again. The percentage of Puffing yield was calculated using the following formula:

$$\text{Puffing yield (\%)} = (\text{Initial weight} - \text{Final weight}) \times 100/\text{Initial weight}$$

3.3 Bulk Density

The bulk density of the puffed rice crackers was determined using three randomly selected pieces. The samples were first weighed, and their volume was then measured using a volume displacement method with sesame seeds. Bulk density was calculated using the following equation:

$$\text{Bulk Density (g/cm}^3\text{)} = \text{Weight of rice crackers (g)} / \text{Volume of rice crackers (cm}^3\text{)}$$

3.4 Water Activity (aw)

Water activity was measured using a water activity meter (LABSWIFT-aw, NOVASINA Novasina AG, Switzerland).

3.5 Texture Profile Analysis

The texture of sample was measured using a Texture Analyzer (TA.XTplus, Stable Micro Systems Ltd., Surrey, UK) with a cylindrical probe (P/36, 36 mm). Samples (3 × 3 cm) were conditioned at 25 ± 2 °C for 30 min prior to testing. A two-cycle compression test was performed at a pre-test speed of 1.0 mm/s, test speed of 1.0 mm/s, post-test speed of 5.0 mm/s, 50% compression distance, and a trigger force of 5 g. Each sample was subjected to ten measurements, with the method adapted from Settapramote et al. (2023). Hardness was determined as the maximum force during the first compression, while crispness (fracturability) was identified as the force at the first major break in the curve.

3.6 Color Measurement

Color values of the samples were evaluated using a colorimeter (CQXE/SAV-2, HunterLab, Reston, USA). The results were reported with CIE L*a*b* colour system in terms of L* (lightness), a* (red-green), and b* (yellow-blue) values, defined as follows:

L*: ranging from 0 (black) to 100 (white)
a*: a+ indicate redness, a- indicate greenness
b*: b+ indicate yellowness, b- indicate blueness

3.7 Percentage of Expansion

The percentage of expansion was evaluated by measuring both the diameter and thickness of the rice crackers before and after puffing. Measurements were taken at four equidistant points along the equatorial zone of each piece, as adapted from Shavandi et al. (2023). The expansion percentage was calculated using the following formula:

$$\text{Expansion (\%)} = ((\text{Dimension after puffing} - \text{Dimension before puffing}) / \text{Dimension before puffing}) \times 100$$

3.8 Puffing ratio

The puffing ratio was determined using the seed displacement method, adapted from Bunthawong & Khamkruea, 2021), with sesame seeds as the medium. The volume of raw and puffed rice cracker samples (n = 3) was measured by the difference in seed level before and after sample insertion in a 100 mL graduated cylinder. The puffing ratio was calculated as Volume of Puffed Sample / Volume of Raw Sample.

3.9 Sensory Evaluation

Sensory quality of the Chinese flowering cabbage rice crackers was evaluated in terms of appearance, color, crispness, aroma, flavor, and overall acceptability. The evaluation was conducted with 30 untrained panelists using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely), adapted from García-Gómez et al. (2022). Each participant received one piece of each sample, presented simultaneously in transparent zip-lock bags labeled with three-digit random codes. The sample with the highest overall acceptability score was selected for further consideration.

This sensory test protocol was reviewed and approved by the Institutional Review Board of Rajamangala University of Technology Lanna, approval number RMUTL-IRB 064/2023.

4. Statistical Analysis

The results of physical analyses were expressed as means with standard deviation (SD). One-way analysis of variance (ANOVA) was used to determine significant differences among treatment groups based on a Completely Randomized Design (CRD). Sensory evaluation data were analyzed using a Randomized Complete Block Design (RCBD). Duncan's Multiple Range Test (DMRT) was employed to identify significant differences between mean values. All statistical analyses were performed using SPSS software version 22.0.

RESULTS AND DISCUSSION

1. Drying Time of Chinese Flowering Cabbage Rice Crackers

The drying process of the Chinese flowering cabbage rice crackers, based on the basic formulation shown in Table 1, was conducted at a constant temperature of 70 °C using a hot air oven. The drying durations examined were 30, 60, 90, and 120 minutes. Samples were collected at 30-minute intervals and subsequently puffed using an air fryer at 160 °C for 4 minutes. The puffed products were then analyzed for physical qualities, including moisture content, puffing yield, bulk density, percentage of expansion, and puffing ratio. The results are presented in Table 2.

The physical analysis revealed statistically significant differences ($p \leq 0.05$) among the drying times in all measured parameters. Moisture content decreased progressively with increased drying time. At 30 minutes, the moisture content was 11.42%, which decreased to 7.45% at 120 minutes. These values are within the acceptable limits set by the

Thai Community Product Standard (2005), which stipulates that moisture in raw crackers should not exceed 15% by weight.

Moisture plays a crucial role in determining the puffing behavior of rice crackers. Moisture levels within the range of 10–11% are generally optimal for steam generation during puffing, which builds internal pressure leading to expansion. During the drying process, a thin surface layer is formed that can retain this pressure during rapid water vaporization, contributing to effective puffing. Thus, drying not only removes moisture but also affects the formation of this pressure-retaining surface, which is essential for optimal expansion (Nguyen et al., 2013).

The highest puffing yield was measured at 30 minutes (17.46%), while the lowest was at 120 minutes (14.58%). This behavior can be explained by the moisture content of partially dried samples. Shorter drying times (30-60 minutes) resulted in more puffing during air frying. When exposed to quick heating, the water evaporated abruptly, resulting in internal steam pressure and porous structures, which improved puffing yield. However, for longer drying times (90-120 minutes), excessive moisture removal resulted in a solid surface crust, reducing the internal vapor pressure available for expansion and hence decreasing puffing efficiency (Ding et al., 2006; Shavandi et al., 2023).The bulk density values varied with drying time, measuring 0.09, 0.08, 0.13, and 0.16 g/cm³ for 30, 60, 90, and 120 minutes. Shorter drying intervals resulted in decreased bulk density because the product matrix expanded and formed a porous structure, whereas longer drying reduced puffing capacity and increased bulk density due to constrained expansion. This is similar with prior research, which found that residual moisture is important for the expansion, crispness, and density of puffed snacks (Ding et al., 2006; Shavandi et al., 2023).

The highest puffing ratio was observed at 30 minutes (25.33) and 60 minutes (23.66), while lower values were recorded at longer drying times. The percentage of expansion followed a similar trend, with the maximum observed at 30 minutes (750.04%). In contrast, longer drying times, particularly at 90 and 120 minutes, led to significant reductions in both expansion (513.50% and 253.76%), and puffing ratio (18.00% and 11.00%).

The decrease in expansion with extended drying times may be attributed to over-drying, which can cause the product to char or shrink rather than expand. This observation aligns with prior findings that suggest drying times beyond 60 minutes may negatively affect the structural integrity and puffing behavior of the crackers (Panomwan, 2009; Wongrat et al., 2024).

Table 2. Moisture content, puffing yield, bulk density, expansion ratio, and puffing ratio of mustard green powder rice crackers dried at different times

Time (minutes)	Quality analysis				
	Moisture (%)	Puffing Yield (%)	Bulk Density (g/cm³)	Expansion (%)	Puffing ratio
30	11.42 ± 0.58[a]	17.46 ± 0.26[a]	0.09 ± 0.01[a]	750.04 ± 79.12[a]	25.33 ± 2.51[a]
60	10.54 ± 0.46[a]	16.26 ± 0.43[a]	0.08 ± 0.00[b]	676.21 ± 19.24[a]	23.66 ± 2.30[a]
90	8.70 ± 0.24[b]	15.81 ± 0.11[b]	0.13 ± 0.01[c]	513.50 ± 53.76[b]	18.00 ± 1.00[b]
120	7.45 ± 0.25[c]	14.58 ± 0.42[b]	0.16 ± 0.01[c]	253.76 ± 28.07[c]	11.00 ± 1.73[c]

Note: Values are presented as mean ± standard deviation.
[a,b,c] Different superscript letters in the same column indicate statistically significant differences ($p \leq 0.05$)

The results of the study indicated that the drying durations of 30, 60, 90, and 120 minutes had a statistically significant effect ($P \leq 0.05$) on the physical properties of Chinese flowering cabbage rice crackers, specifically in terms of moisture content, puffing yield, expansion percentage, and puffing ratio. Among these, the samples dried for 30 and 60 minutes exhibited superior physical qualities compared to those dried for 90 and 120 minutes, particularly with respect to bulk density, expansion, and puffing capacity, which varied markedly with increasing drying time.

Based on these findings, the drying durations of 30 and 60 minutes were identified as the most suitable options, offering optimal quality across multiple physical parameters.

To further evaluate product stability, the raw crackers dried at 30 and 60 minutes were subjected to a shelf-life study under ambient storage conditions (20–25 °C) for one week. Results showed no observable differences in quality between the two groups on Day 1. However, by Day 5, the crackers dried for 30 minutes exhibited visible white filamentous growth on their surface, indicating the onset of spoilage. In contrast, the crackers dried for 60 minutes remained unchanged throughout the storage period (Data not shown).

This suggests that the 60-minute drying duration not only enhances immediate product quality but also contributes to better shelf stability when stored at room temperature for up to one week.

2. Frying Conditions for Puffing Chinese Flowering Cabbage Rice Crackers

2.1 Puffing Time Using an Air Fryer

The puffing behavior of Chinese flowering cabbage rice crackers was studied using an air fryer

at three different temperatures: 180 °C, 190 °C, and 200 °C. Samples were collected every 0.5 minutes up to a maximum duration of 4.5 minutes to determine the optimal puffing time for each temperature condition.

As puffing time increased, the color of the crackers gradually changed from dark green to brown. Based on these observations, the time range between 1.5 and 3.5 minutes —where the product exhibited light green coloration prior to browning— was selected for further sensory evaluation (Data not shown).The following time-temperature combinations were chosen based on preliminary observations:

180 °C for 3 minutes
190 °C for 2.5 minutes
200 °C for 2 minutes

Sensory evaluation results, summarized in Table 3, revealed that crackers puffed at 190 °C for 2.5 minutes received the highest overall acceptability score of 8.10 on a 9-point hedonic scale. This condition yielded products with optimal visual and structural characteristics, including uniform expansion in both width and thickness, absence of flat or unevenly puffed areas, and no signs of burning, cracking, or folding caused by excessive or uneven heating.

These desirable traits significantly influenced the sensory perception and overall consumer acceptance of the product. The results indicate that the condition of 190 °C for 2.5 minutes is the most suitable for achieving high product quality and consumer appeal.

Table 3. Sensory on overall liking of Chinese flowering cabbage rice crackers using an air fryer at different conditions.

Temperature	Time (Sec.)				
(ºC)	90	120	150	180	210
180	5.40 ±0.52^{c}	5.50 ±0.53^{c}	6.40 ±0.52^{b}	8.1 ±0.57^{a}	6.90 ±0.74^{b}
190	7.00 ± 0.82^{b}	7.10 ±0.74^{b}	8.10 ±0.74^{a}	6.30 ±1.06^{c}	6.00 ±1.05^{c}
200	7.00 ±0.67^{b}	8.00 ±0.94^{a}	6.40 ±0.52^{bc}	6.68 ±0.57^{cd}	5.70 ±0.67^{d}

Note: Mean ± standard deviation.
^{a,b} Different letters in row indicate statistically significant differences (p≤0.05).
^{ns} Data is not significantly different (p>0.05).

2.2 Puffing Temperature Using an Air Fryer

To determine the optimal puffing temperature, the physical properties of Chinese flowering cabbage rice crackers were analyzed after being puffed at three different air fryer temperatures: 180 °C, 190 °C, and 200 °C. Quality parameters evaluated included water activity (aw), moisture content, texture (hardness and crispness), color values (L*, a*, b*), puffing yield, bulk density, and puffing ratio.

The results revealed that water activity (aw) and moisture content did not significantly differ among the temperature groups ($p > 0.05$). The aw values ranged from 0.25 to 0.27. Although not statistically significant, there was a decreasing trend in moisture content with increasing puffing temperature, from 3.59% at 180 °C for 3 minutes to 3.25% at 190 °C for 2.50 minutes and 200 °C for 2 minutes (Table 4).

Texture analysis of puffed crackers at the three temperatures showed significant differences in both hardness and crispness ($P \leq 0.05$). A slight reduction in hardness was observed when temperature increased from 180 °C to 190 °C, dropping from 85.25 N to 84.41 N. At 200 °C, the product exhibited the highest crispness value of 52.39 gf/s. The crispness increased consistently with rising temperature (Table 4).

These results may be attributed to starch gelatinization and expansion at higher temperatures, which promote the formation of a more porous matrix. Such porous structures lower product density and hardness while enhancing crispness (Chedoloh & Suhaimin, 2019).

Table 4. water activity (a_w), moisture content, Hardness, and Crispness of Chinese cabbage rice crackers puffed using an air fryer at different temperatures.

Temperature (ºC)	Quality analysis			
	a_w^{ns}	Moisture content (%)^{ns}	Hardness (N)	Crispness (gf/s)
180	0.25 ± 0.01	3.59 ± 0.02	85.25 ± 0.05^{a}	45.29 ± 0.05^{c}
190	0.26 ± 0.01	3.25 ± 0.16	84.41 ± 0.10^{c}	51.27 ± 0.05^{b}
200	0.27 ± 0.01	3.44 ± 0.15	84.92 ± 0.05^{b}	52.39 ± 0.06^{a}

Note: Mean ± standard deviation.
^{a,b} Different letters in row indicate statistically significant differences (p≤0.05).
^{ns} Data is not significantly different (p>0.05).

In contrast, color parameters and texture characteristics differed significantly with temperature ($P \leq 0.05$). The lightness (L*) was highest at 180 °C (49.40), indicating a brighter appearance. As the puffing temperature increased, the L* value decreased, suggesting a darker product color due to browning. The green color value (a*) decreased with increasing temperature, showing reduced green intensity; the highest (i.e., most negative) value of a* was -15.46 at 200 °C. Similarly, yellow color values (b*) declined as puffing temperature increased, with

the highest b* value of 6.37 recorded at 180 °C (Table 5).

These color changes were likely the result of non-enzymatic browning, as starches containing proteins and reducing sugars facilitated rapid Maillard reactions during heating, which are more prominent at higher temperatures. (Kanokmedhakul et al., 2021)

Table 5. Color values of Chinese cabbage rice crackers puffed using an air fryer at different temperatures.

Temperature (ºC)	Quality analysis		
	L*	a*	b*
180	49.40 ± 0.05[a]	-13.43 ± 0.10[a]	6.37 ± 0.14[a]
190	48.47 ± 0.32[c]	-14.32 ± 0.09[b]	5.32 ± 0.09[b]
200	48.93 ± 0.7[b]	-15.46 ± 0.34[c]	5.46 ± 0.34[b]

Note: Mean ± standard deviation.
[a,b] Different letters in row indicate statistically significant differences (p≤0.05).
[ns] Data is not significantly different (p>0.05).

The effect of different puffing temperatures (180 °C, 190 °C, and 200 °C) on the quality of Chinese flowering cabbage rice crackers was investigated (Table 6). The results showed that puffing temperature had no statistically significant effect (p > 0.05) on bulk density and puffing ratio. The bulk density of the products ranged narrowly between 0.37–0.38 g/cm³, while the puffing ratio ranged from 15.66 to 18.66.

In contrast, puffing yield differed significantly among the temperature conditions (p≤0.05). The highest puffing yield was observed at 180 °C, reaching 21.52%, while lower values were found at higher puffing temperatures: 17.64% at 190 °C and 16.33% at 200 °C

The observed reduction in puffing yield with increasing puffing temperature may be attributed to the formation of a crust on the cracker, which could limit internal moisture evaporation. This phenomenon aligns with findings reported by Mariotti (2006), who explained that higher frying temperatures can cause the surface of food products to harden more rapidly and even char slightly, thus reducing the rate of moisture loss from the interior.

Table 6. Puffing yield, density and puffing ratio of Chinese flowering cabbage rice crackers puffed using different air-free frying temperatures.

Temperature (ºC)	Quality analysis		
	puffing yield (%)	Bulk density (g/cm³)[ns]	Puffing ratio [ns]
180	21.52 ± 2.65[a]	0.38 ± 0.04	18.66 ± 1.52
190	17.64 ± 1.05[b]	0.37 ± 0.04	15.66 ± 0.57
200	16.33 ± 0.79[b]	0.38 ± 0.04	17.33 ± 2.08

Note: Mean ± standard deviation.
[a,b] Different letters in row indicate statistically significant differences (p≤0.05).
[ns] Data is not significantly different (p>0.05).

As presented in Table 7, puffing temperature had a statistically significant effect (p≤0.05) on the percentage expansion of Chinese flowering cabbage rice crackers, both in terms of width and thickness. The crackers puffed at 180 °C exhibited a width expansion of 21.22% and a thickness expansion of 526.69%. At 190 °C, the width and thickness expansion increased slightly to 21.93% and 527.66%, respectively. The highest expansion values were observed at 200 °C, with width expansion reaching 23.10% and thickness expansion at 576.65%.

These results indicate a clear trend where higher puffing temperatures lead to greater expansion of the crackers. This can be attributed to the rapid vaporization of internal moisture at elevated temperatures, which generates sufficient internal pressure to expand the product matrix. The accelerated water evaporation likely enhances the puffing process, resulting in increased volume and reduced product density.

Table 7. Expansion values of Chinese flowering cabbage rice crackers puffed using air fryer at different temperatures.

Temperature (ºC)	Percentage of rice cracker expansion	
	Width (cm)	Thickness (cm)
180	21.22 ± 0.10[b]	526.69 ± 3.39[b]
190	21.93 ± 0.61[b]	527.66 ± 7.31[b]
200	23.10 ± 0.92[a]	576.65 ± 2.74[a]

Note: Mean ± standard deviation.
[a,b] Different letters in column indicate statistically significant differences (p≤0.05).

The sensory evaluation of Chinese flowering cabbage rice crackers puffed using an air fryer at 180 °C, 190 °C, and 200 °C revealed that aroma scores did not differ significantly among temperature treatments (p > 0.05), with values ranging between 7.30–7.66, indicating a moderate level of liking. However, significant differences (p≤0.05) were observed in appearance, color, taste, crispiness, and overall acceptability (Table 8). The crackers puffed at 200 °C received the highest sensory scores in all aforementioned categories, with values of 7.83 for appearance, 7.86 for color, 7.66 for taste, 7.83 for crispiness, and 8.03 for overall acceptability. These scores reflect a moderate to high level of liking.

The results suggest that 200 °C is the most suitable puffing temperature, as it yielded the highest consumer acceptability across all sensory attribute, particularly in terms of visual appeal, crispiness, and color. The superior product characteristics at this temperature may be attributed to the optimal moisture evaporation rate, which enhances expansion and puffing. This leads to a more desirable texture

(crispness) while better preserving the natural color of the raw materials, as noted in previous findings (Panomwan, 2009; Wongrat et al., 2024).

Furthermore, the physical properties of the crackers including water activity (a_w), moisture content, bulk density, and puffing ratio were not significantly affected by puffing temperature ($p > 0.05$). However, lightness (L*), green color (a*), yellow color (b*), crispiness, puffing yield, and expansion showed significant differences ($p \leq 0.05$). These changes support the finding that higher temperatures contribute to favorable structural and visual transformations in the product.

Overall, considering both instrumental quality parameters and sensory acceptability, 200 °C was identified as the most suitable puffing temperature for producing Chinese flowering cabbage rice crackers with enhanced appearance, texture, and consumer preference.

Table 8. Sensory of rice Chinese flowering cabbage Rice Crackers by puffing in an air-free fryer.

Temperature (°C)	Appearance	Color	Crispness	Flavor^{ns}	Taste	Overall liking
180	7.10 ±1.15^{b}	7.06 ± 1.08^{b}	6.90 ±0.80^{b}	7.30 ±1.11	7.10 ±1.15^{b}	7.16 ±0.98^{b}
190	7.60 ±1.03^{ab}	7.56 ±1.00^{ab}	7.30 ±1.23^{b}	7.53 ±1.07	7.46 ±1.07^{b}	7.73 ±0.90^{a}
200	7.83 ±1.11^{a}	7.86 ±0.97^{a}	8.53 ±0.50^{a}	7.66 ±0.99	8.06 ±0.82^{a}	8.03 ±0.80^{a}

Note: Mean ± standard deviation.

^{a,b} Different letters in row indicate statistically significant differences ($p \leq 0.05$).

^{ns} Data is not significantly different ($p > 0.05$).

CONCLUSION

The Chinese flowering cabbage rice crackers dried at 70 °C for 60 minutes demonstrated the most favorable quality characteristics, including a moisture content of 10.54%, the lowest bulk density (0.08 g/cm³), and the highest expansion ratio (676.21%). In terms of puffing, the use of an air fryer at 200 °C for 2 minutes resulted in the best product quality regarding color, crispness, and sensory acceptability, with average sensory scores ranging from 7.66 to 8.53, indicating moderate to high levels of consumer preference. These findings suggest the potential for utilizing this processing method in practical household and community-level applications and for future studies.

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