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Impact of Temperature and Frying Time on Colour, Texture, and Physicochemical Properties of Wheat-Taro Snack

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Abstract

Taro root is indeed a valuable food crop, rich in nutrients like starch, sugar, minerals, vitamins, and fiber. Especially, mucilage in taro root is a thickening, binding, emulsifying, swelling capacities, or foaming agent in food. The frying process develops the desirable colour, texture and physicochemical properties. This study aimed to evaluate the impacts of deep frying of different temperatures (130, 135, and 140 °C) and duration (7.0, 7.5, and 8.0 minutes) on the wheat-taro snack in industry. The wheat-taro snack was evaluated for quality properties (moisture content, expansion ratio, weight loss, oil absorption, hardness, fracturability, and colour values (L, a*, and *b*) snack from taro flour. The research findings indicated that frying temperature exhibited a robust positive correlation with the expansion ratio, weight loss, and texture properties of wheat-snacks. Frying time had a predominantly negative effect on moisture content but was positively associated with the oil absorption, fracturability, and the colour values (L, a**, and *b*). The correlations between moisture content and weight loss, and texture of the wheat-snack were strong and negative. It can be inferred that a frying temperature of 135 °C for 8 minutes was identified as suitable for producing wheat-taro snacks that exhibited the most desirable attributes in terms of colour and texture.*

Keywords: Expansion ratio, frying, oil absorption, wheat-taro snack, texture.

1. Introduction

Taro (*Colocasia esculenta*), a plant of the Araceae family, is a very important staple crop in the human diet and is mainly grown in the humid tropical regions of the world. It has been reported that taro is a potential source of about 3.0 to 19% mucilage and 70 to 80% starch. The unique feature of this starch lies in its small grain size, contributing to its ease of digestion. The mucilage has excellent viscosity, water-holding capacity, oil-holding capacity, and antimicrobial activity. Thus, these remarkable functional properties make mucilage a promising ingredient with possible applications as a fat replacer, gel former, thickener, foaming agent, and emulsifier [1]. Taro mucilage was as a stabilizing or thickening agent, resulting in reduced fat levels in high-quality bread. Moreover, taro plays an effective protective role against cancer and cancer-related risk factors, including carcinogens and biological agents, and various pathophysiological conditions, such as inflammation and oxidative stress, while controlling metabolic dysfunctions and boosting the immune system [1]. Besides, taro is also a source of compounds with antioxidant activity such as DPPH (2,2 Diphenyl-1- picrylhydrazyl), phenolic, carotenoid, and ascorbic acid. However, viscous mucilage of fresh or steamed taro mash lead to difficult blending. Therefore, taro flour has the benefits of long-term storage, low transportation cost, and easy mixing.

Snack foods encompass an extensive array of products, such as potato chips, crackers, nuts, and extruded snacks, among others. Snack food extrusion involves subjecting specific grains to a range of intricate physical processes to produce snacks with diverse shapes and textures [2]. In addition to traditional snacks, quickly processed snacks such as extruded snack foods, are increasingly popular because they meet requirements such as taste, nutritional value, and reasonable price. The snack is crispy, spongy, diverse in processing, easy to store, and has many flavours. Consequently, taro has become an excellent choice for consumption by children and young adults.

Snacks are made from the main ingredients of wheat, baking powder, combined with spices and additives, and then fried in cooking oil. Wheat flour has many components such as starch, protein, lipids, and enzymes. The gluten protein forms the principal network of dough, endowing it with elastic, cohesive, and viscous properties. It has been reported that gluten quality is highly correlated with noodle texture such as springiness [3]. Gluten easily forms a network with constituents of taro flour for rolling, cutting, and

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shaping dough as noodles or snacks. Wheat and taro flour are blended and rapidly rolled to form sheets, which are then cut to produce snack dough in an industrial scale.

In the deep-frying process, heat is transferred from the hot oil to the surface of the food material, simultaneously drawing moisture from the interior to the surface. This leads to the development of high-temperature and low-moisture conditions as the frying continues, which in turn contributes to the desired characteristics of texture and flavour in the food [4].

Among the various classes of physical properties of foods and foodstuffs, texture is widely recognized as the most crucial attribute in assessing product quality. Hardness, in particular, is a significant physical property employed to assess food structure and is closely linked to the act of chewing [5].

Numerous researchers have dedicated their efforts to studying the physical properties of foods, including aspects such as colour appearance, the presence of oily areas on the surface, and the texture of potato chips [6].

However, a significant research gap exists in exploring the influence of deep frying on the physicochemical properties of wheat-taro snacks. Therefore, this study was initiated with the primary objective of investigating the impact of frying temperature and duration on several key quality values. These properties encompassed aspects such as moisture content, expansion ratio, weight loss, oil absorption, and textural properties (specifically hardness, and fracturability), and colour values (L, a^*, and b^*) of snack from wheat and taro flour.

2. Materials and Methods

2.1. Materials

Taro roots had a weight of 700 to 800 g and a diameter of 9.0 to 12 cm. They were peeled and sliced with the thickness of 2-3 mm. The taro slices were blanched at the temperature of 90 ºC for 2 minutes. The blanched slices were dried at 60 ºC until the moisture of 8%. After grinding, flour was sifted through the sieve size of 0,105 mm. The taro flour contained protein of 5.6%, lipid of 0.6%, the starch of 71.0%, and mucilage of 2.9%. The dried taro flour was kept in glass jars with tin lids for the experiment.

The other ingredients included wheat flour (11% protein content, and gluten content 32% Baker's choice brand), modified starch (E1412, sourced from Vietnam), and extra refined sugar (sourced from Bien Hoa, Vietnam).

2.2. Methods

2.2.1. Preparation of snack

The snack preparation was illustrated as in industry. The flour mixture was composed of 80 g of taro flour, 20 g of modified starch, and 100g of wheat flour. The flour mixture was added with sugar (2.0%), salt (1.0%), MSG (1.2%), baking powder (1.0%), and citric acid (1.0%). Water was added to the flour mixture to achieve a dough with a moisture content of 36%. The dough was kneaded and rolled six times to achieve a smooth texture. Noodling was done with a noodle maker (AKS YTD220 from Taiwan) to produce noodles with a thickness of 0.2 cm and a width of 0.6 cm. The noodle strands were cut into 5 cm lengths to shape the snack. Portions of the snack weighing 30 g each were deep-fried at different temperatures (130, 135, and 140 °C) for varying times (7.0, 7.5, and 8.0 minutes). After frying, the snacks were placed on tissue paper to absorb excess oil from the surface. The fried snacks were spread over the plate to cool at the room temperature for 10 minutes.

2.2.2. Physicochemical properties

The moisture content, or water content, was assessed by subjecting the ground sample (5 g) to heat in an oven set at 105 °C for 24 hours, employing the specified method AOAC [7]. The oil of snack was extracted and determined according to Smith *et al.*, (1985) [8]. Oil absorption was estimated by the increase of oil of the snack before and after frying. Weight loss was determined by mass difference before and after frying [9]. The expansion ratio was determined by the ratio of volume change before and after frying according to the analytical method of Yu (1991) [10].

2.2.3. Texture profile analysis

Texture analysis was conducted using a TA-XT2 Texture analyser connected to a computer, equipped with a ‘‘share blade’’, rectangular attachment for cutting (70 mm · 3 mm). The velocity of the head with the attachment was 25 mm/ minute with a 50 kg load cell. The measurements were taken to determine the maximum force (hardness) necessary to cut one slice of wheat-taro snack [11]. Each measurement was conducted on 10 wheat-taro snack samples The distance at break was an indication of fracturability of the product.

2.2.4. Colour measurement

Colour values (L, a^*, and b^*) were evaluated using a Hunterlab SAV colourimeter. Before each measurement session, the instrument was standardized using both a white and a black ceramic plate as references. To ensure precision in the data, samples were scanned at four different locations, and the colour values (L, a^*, and b^*) were derived as the average of five measurements.

2.2.5. Data analysis

The average data was calcuated from the three replicates. The data were subjected to statistical analysis, which involved performing an Analysis of Variance (ANOVA), calculating Pearson correlation coefficients, and determining means using Duncan's multiple range tests at a significance level of p less than 0.05. Significant differences were represented by varying letters. These statistical analyses were carried out using Statgraphic Centurion 15.

3. Results and Discussion

3.1. Evaluation of the Impact of Temperature Factors and Frying Time on the Properties

After frying and cooling, the wheat-snack samples were determined for moisture content, colour values, expansion ratio, weight loss, oil absorption, and texture (hardness and fracturability).

The wheat-snack samples were crispy if they were fried at those temperatures (130, 135, and 140 °C) for varying times (7.0, 7.5, and 8.0 minutes). In the case of crispy products, the force-deformation pattern is distinguished by a sequence of distinct force peaks, each corresponding to the rupture or breakage of individual products [12].

The Fig. 1 shows that frying temperature strongly influenced on weight loss, ratio expansion and hardness, Meanwhile, the frying duration sharply affected on moisture content, the L and a^* values, and fracturability

However, these effects on hardness were determined to be of moderate magnitude. Notably, frying time exhibited a strong impact on oil absorption, and fracturability, while frying temperature displayed a more pronounced influence on weight loss compared to frying time.

Fig. 1. shows that frying temperature greatly affected the variance of snacks for expansion ratio (50.62%), weight loss (47.41%), and hardness (34.50%), but it relatively influenced moisture content (5.50%) and fracturability (32.41%). Frying time had strong effects on the variance for moisture (93.03%), oil absorption (46.27%), fracturability (57.19%), but it had fewer impacts on expansion ratio (14.43%), weight loss (38.97%), and hardness (31.87%).

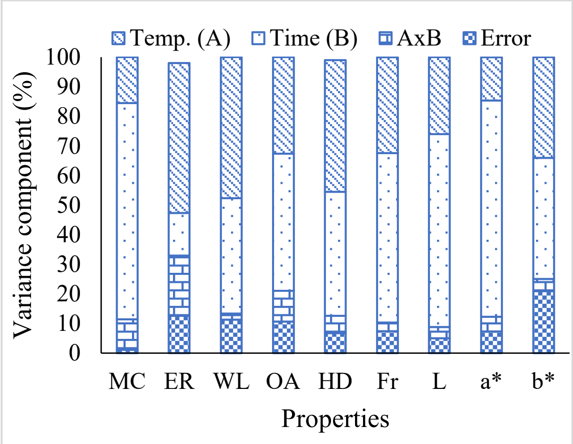

Fig. 1: Components of variance for colour, texture, and physicochemical properties of wheat-taro snack fried at different temperatures and times.

Abbreviations: Temp, temperature, MC, moisture content; ER, expansion ratio; WL, weight loss; OA, oil absorption; HD, hardness; Fr, fracturability

The statistically significant findings in Table 1 ($p < 0.001$) reveal a substantial influence of frying temperature and time on most properties such as moisture content, weight loss, oil absorption, expansion ratio, the colour values, and fracturability.

Table 1. Mean square value from ANOVA for colour, texture, physicochemical properties, and of wheat-taro snack fried at different temperatures and time

Factor	Mean square								
	MC	ER	WL	OA	HD	Fr	L	a^*	b^*
Temp. (A)	0.44^{***}	5.78^{***}	3.17^{***}	2.68^{**}	4.69^{**}	0.12^{***}	21.92^{***}	1.68^{***}	2.04^{***}
Time (B)	7.40^{***}	1.65^{*}	2.59^{***}	5.48^{***}	4.34^{**}	0.30^{***}	54.85^{***}	8.34^{***}	2.45^{***}
AxB	0.01	2.13^{**}	1.07	1.03	0.06	0.02	1.59^{*}	0.28^{*}	0.12
Error	0.01	0.41	0.08	0.40	0.50	0.01	0.47	0.09	0.14

Note: The values designated with *, **, and *** indicate significant difference at p less than 0.05, 0.01, and 0.001, respectively. Abbreviations: Temp, temperature, MC, moisture content; ER, expansion ratio; WL, weight loss; OA, oil absorption; HD, hardness; and Fr, fracturability.

Table 2. Colour, texture, physicochemical properties of wheat-taro snack fried at different temperatures and times

Paramters	Time	Temperature 130 °C	135 °C	140 °C	Average
Moisture content (%)	7.0 minutes	$3.46^{1} \pm 0.08$	3.38 ± 0.07	3.14 ± 0.09	$3.33^{3A} \pm 0.08$
	7.5 minutes	2.62 ± 0.16	2.34 ± 0.12	2.11 ± 0.10	$2.35^{B} \pm 0.13$
	8.0 minutes	1.74 ± 0.10	1.57 ± 0.08	1.25 ± 0.10	$1.52^{C} \pm 0.09$
	Average	$2.60^{2a} \pm 0.11$	$2.43^{b} \pm 0.07$	$2.17^{c} \pm 0.08$	
Expansion ratio (%)	7.0 minutes	55.07 ± 0.95	55.49 ± 0.57	56.49 ± 0.57	$55.68^{B} \pm 0.60$
	7.5 minutes	55.86 ± 0.28	56.53 ± 0.35	57.20 ± 0.91	$56.53^{A} \pm 0.51$
	8.0 minutes	55.33 ± 0.42	56.00 ± 0.89	57.00 ± 0.42	$56.11^{AB} \pm 0.52$
	Average	$55.42^{b} \pm 0.51$	$56.01^{b} \pm 0.45$	$56.90^{a} \pm 0.54$	
Weight loss (%)	7.0 minutes	7.87 ± 0.48	8.23 ± 0.43	9.27 ± 0.13	$8.45^{B} \pm 0.36$
	7.5 minutes	8.10 ± 0.16	8.66 ± 0.29	9.13 ± 0.15	$8.63^{B} \pm 0.12$
	8.0 minutes	8.94 ± 0.36	9.38 ± 0.14	10.05 ± 0.22	$9.46^{A} \pm 0.21$
	Average	$8.30^{c} \pm 0.37$	$8.76^{b} \pm 0.21$	$9.48^{a} \pm 0.16$	
Oil absorption (%)	7.0 minutes	$26.06 \pm 0{,}32$	$25.39 \pm 0{,}21$	$24.92 \pm 0{,}22$	$25.46^{C} \pm 0.58$
	7.5 minutes	$26.80 \pm 0{,}25$	$26.50 \pm 0{,}24$	$25{,}80 \pm 0{,}15$	$26.37^{B} \pm 0.45$
	8.0 minutes	$27.58 \pm 0{,}15$	27.01 ± 0.17	$26.44 \pm 0{,}36$	$27.01^{A} \pm 0.62$
	Average	$26.81^{a} \pm 0{,}25$	$26.30^{ab} \pm 0{,}22$	$25.72^{b} \pm 0{,}27$	
Hardness (N)	7.0 minutes	10.05 ± 0.86	11.08 ± 0.73	11.67 ± 0.34	$10.93^{A} \pm 0.61$
	7.5 minutes	10.99 ± 0.45	11.93 ± 0.57	12.17 ± 0.63	$11.70^{B} \pm 0.27$
	8.0 minutes	11.56 ± 1.13	12.36 ± 0.85	13.04 ± 0.42	$12.32^{C} \pm 0.56$
	Average	$10.87^{c} \pm 0.65$	$11.79^{b} \pm 0.56$	$12.29^{a} \pm 0.45$	
Fracturability (mm)	7.0 minutes	0.72 ± 0.07	0.84 ± 0.05	0.90 ± 0.07	$0.82^{C} \pm 0.05$
	7.5 minutes	0.89 ± 0.03	1.13 ± 0.07	1.06 ± 0.05	$1.03^{B} \pm 0.04$
	8.0 minutes	0.97 ± 0.05	1.21 ± 0.05	1.17 ± 0.03	$1.12^{A} \pm 0.02$
	Average	$0.90^{c} \pm 0.05$	$1.11^{a} \pm 0.06$	$1.10^{a} \pm 0.05$	
L^*	7.0 minutes	53.25 ± 0.94	56.01 ± 0.45	56.96 ± 0.24	$55.41^{C} \pm 0.45$
	7.5 minutes	56.23 ± 0.96	56.94 ± 0.64	57.88 ± 0.35	$57.02^{B} \pm 0.51$
	8.0 minutes	58.32 ± 0.29	60.15 ± 1.01	62.30 ± 0.77	$60.25^{A} \pm 0.38$
	Average	$55.93^{c} \pm 0.63$	$57.70^{b} \pm 0.52$	$59.04^{a} \pm 0.16$	
a^*	7.0 minutes	5.53 ± 0.46	6.44 ± 0.22	7.10 ± 0.37	$6.35^{C} \pm 0.34$
	7.5 minutes	6.65 ± 0.14	6.90 ± 0.30	7.20 ± 0.41	$6.91^{B} \pm 0.26$
	8.0 minutes	8.00 ± 0.30	8.21 ± 0.22	8.48 ± 0.15	$8.23^{C} \pm 0.23$
	Average	$6.73^{c} \pm 0.26$	$7.18^{b} \pm 0.23$	$7.59^{a} \pm 0.37$	
b^*	7.0 minutes	20.30 ± 0.46	20.96 ± 0.34	21.24 ± 0.39	$20.84^{B} \pm 0.38$
	7.5 minutes	20.81 ± 0.28	21.15 ± 0.42	21.45 ± 0.28	$21.13^{B} \pm 0.42$
	8.0 minutes	21.29 ± 0.22	21.70 ± 0.22	22.56 ± 0.59	$21.85^{A} \pm 0.34$
	Average	$20.80^{c} \pm 0.31$	$21.27^{b} \pm 0.36$	$21.75^{a} \pm 0.39$	

Note: The average data were aggregated over [1]the frying temperature according to the column or [2]the frying time according to the row, respectively. Different letters in the same column (A, B or C) or row (a, b or c) indicate significant difference at p less than 0.05 between the average data in the same colume or in the same row, respectively. MC, moisture content; ER, expansion ratio; WL, weight loss; OB, oil absorption; HD, hardness; Fr, fracturability.

3.2. Effect of Temperature and Frying Time on Moisture, Expansion, Weight Loss, Oil Absorption, and Texture Properties of Snack

The frying temperature and duration had a significant impact the snack's properties as shown in Table 1.

3.2.1. Moiture content

Moisture content is a crucial property, given its profound influence on the unique crisp texture characteristic of snacks. The moisture content of the wheat-snacks varied within a certain range from the highest of 3.46% fried at 130 °C/7.0 minutes to the least of 1.25% fried at 140 °C/ 8.0 minutes (Table 2). The frying temperature and frying time significantly affected the moisture content of wheat-taro snack. The differences in the moisture content of the snack could be attributed to a weak negative correlation ($p < 0.05$, $r = -0.37$) and a strongly negative correlation ($p < 0.001$, $r = -0.96$) with frying time (Table 3). It was observed an inverse relationship, wherein the moisture content of the snack exhibited a notable reduction with the concurrent increase in frying temperature from 130 °C to 140 °C and frying time from 7.0 to 8.0 minutes. As the frying time and temperature were elevated, there was a noticeable reduction in the snack's moisture content. The obtained results agreed with those of Abdalrahman *et al.,* (2021) [13] reported that chips' moisture contents were lower when they were fried at higher temperatures and longer time.

Maintaining a consistent frying temperature, and elongating the frying duration led to a progressive decrease in moisture content, primarily attributed to the process of water evaporation [14]. Furthermore, in cases where the frying time was held constant, an increase in frying temperature yields a proportional decrease in moisture content [15].

These findings align with those reported by Cruz *et al.,* (2018) [16], where they noted that achieving a final moisture content of less than 2.0% contributes to the development of a crisp texture. Moisture content plays a vital role in shaping the texture of ready-to-eat snacks, as it has a direct impact on their crispness, which is a key determinant of their overall acceptability [17].

3.2.2. Expansion ratio

The expansion ratio of the snack slightly increased from 55.42% to 56.90% when frying temperature from 130 ºC to 140 ºC, and increased from 55.68% to 56.10% when frying time from 7.0 to 8.0 minutes (Table 2). The expansion ratio strongly correlated ($p < 0.001$, $r = 0.70$) with the frying temperature (Table 3). Since rapid water evaporation was responsible for the expansion of the volume, the volume expansion ratio should be accumulated during elevated frying temperature.

When wet gluten snacks were fried at higher temperatures, the rate of evaporation increased accordingly, meanwhile, the volume of water vapor was also higher. However, when the rate of evaporation was increased beyond a certain critical point, the amount of water vapor that escaped through the pores formed on the skin of the gluten, as a result of increasing the expansion ratio. This is a possible explanation of the slightly curved relationship between volume expansion and expansion ratio of gluten balls and the deep -frying temperature [18].

Table 3. Correlations between frying conditions with colour, texture, and physicochemical properties of wheat-taro snack

	Temp	Time	MC	ER	WL	OA	HD	Fr	L^*	a^*
MC	-0.37^*	-0.96^{***}								
ER	0.70^{***}	0.24	-0.40^*							
WL	0.68^{***}	0.58^{**}	-0.73^{***}	0.46^{**}						
OA	-0.48^*	0.68^{***}	-0.56^{**}	-0.12	-0.03					
HD	0.58^{**}	0.56^{**}	-0.68^{***}	0.65^{***}	0.74^{***}	0.02				
Fr	0.47^{**}	0.74^{***}	-0.83^{***}	0.50^{**}	0.73^{***}	0.05	0.76^{***}			
L^*	0.51^{**}	0.79^{***}	-0.88^{***}	0.50^{**}	0.86^{***}	0.76^{***}	0.76^{***}	0.73^{***}		
a^*	0.38^*	0.83^{***}	-0.88^{***}	0.45^{**}	0.81^{***}	0.70^{***}	0.73^{***}	0.80^{***}	0.91^{***}	
b^*	0.58^{**}	0.62^{***}	-0.75^{***}	0.49^{**}	0.83^{***}	0.71^{***}	0.71^{***}	0.75^{***}	0.84^{***}	0.74^{***}

Note: Pearson correlation coefficients indicate significance at level alpha less than 0.05. The values designated with *, **, and *** indicate significant correlations at p less than 0.05, 0.01, and 0.001, respectively. Abbreviations: Temp, temperature, MC, moisture content; ER, expansion ratio; WL, weight loss; OB, oil absorption; HD, hardness; Fr, fracturability.

3.2.3. Weight loss

The weight loss of the snack steadily increased 8.30% to 9.48% by frying temperature from 130 ºC to 140 ºC, and from 8.48% to 9.46% by frying time from 7 to 8 minutes (Table 2). The weight loss had a strong and positive correlation ($p < 0.001$, $r = 0.68$) with frying temperature and a moderate and positive relation with frying time ($p < 0.01$, $r = 0.58$) (Table 3).

Deep frying snacks caused water evaporation and weight loss. Frying temperature increases the mass transfer (water evaporation) resulting reduction of weight loss [19].

3.2.4. Oil absorption

The oil absorption showed an elevated pattern from 25.46% to 27.01% along with increased frying time from 7.0 to 8.0 minutes (Table 2). In contrast, prolonging in frying time from 7.0 to 8.0 minutes for frying temperatures 130, 135, and 140 ºC of wheat-taro snacks showed a slight decrease in oil absorption from 26.61, 26.3, and 25.72%, respectively. The oil absorption values of wheat-taro could be ascribed to a strong positive correlation ($p < 0.001$, $r = 0.68$) with the frying time but a weak negative relation ($p < 0.05$, $r = -0.48$) with the frying temperature (Table 3).

The capacity of wheat flour to absorb oil could be attributed to its relatively high protein content, which may have contributed to the absorption of excess frying oil [13].

The entry of oil into chips occurs through the water replacement mechanism, which entails alterations in cellular structures and the formation of pores during frying. These changes help fill some of the spaces created by induced dehydration [19]. The deep-frying process has the potential to disrupt the crystalline structure of starch and promote the formation of starch-lipid complexes, consequently leading to a relatively higher oil content in the food [8]. However, when frying at a very low oil temperature, such as 120 °C, the crusts display reduced firmness, allowing for easier oil penetration into the product [20]. Also, elevated frying temperatures initiated the dehydration process, and the rapid crust formation served as a barrier to prevent excessive oil absorption [13].

3.2.5. Texture properties (hardness and fracturability)

- Hardness

Hardness is typically defined as the force required to attain a specific degree of deformation. Consequently, it serves as a crucial indicator of both the degree of frying and the overall acceptability of food products [6]. Observations from Table 3 reveal a moderate positive correlation between the hardness of the deep-fried wheat-taro snack with both frying temperature ($p < 0.01$, $r = 0.58$) and duration ($p < 0.01$, $r = 0.56$). Across various frying temperatures and times, the snack exhibited a hardness range of 10.05 N to 13.04 N. Notably, the lowest hardness value (10.05 N) was recorded at 130 °C for 7 minutes, while the highest value (13.04 N) was attained at 140 °C for 8 minutes. This pattern highlighted a pronounced positive correlation between hardness and frying conditions. A similar trend has been observed in fried potato products [16]. The texture of fried products could be characterized by the development of a surface crust, which is highly appealing to consumers. Changes in the cellular structure at the product's outer layers contributed to this crispy texture [16].

- Fracturability

The greater the linear distance value, the easier the sample is fractured. Once the sample ruptured at a certain distance, the force went on decreasing [11]. The data presented in Table 3 demonstrate a moderate and strong positive correlation between the fracturability of the snack and the properties of frying temperature and duration, as indicated by correlation coefficients of ($p < 0.01$, $r = 0.47$) and ($p < 0.001$, $r = 0.74$), respectively (Table 3). The snack exhibited a fracturability range of 0.72 mm to 1.17 mm across various frying temperatures and durations. Importantly, the lowest hardness value (0.72 mm) was recorded when fried at 130 °C for 7.0 minutes, while the highest value (1.17 mm) was achieved at 140 °C for 8.0 minutes. This pattern highlighted a clear and noteworthy positive correlation between the snack's fracturability and the specific frying conditions of temperature and duration.

3.2.6. Colour values

- Lightness

The lightness value (L) of the deep-fried wheat-taro snack displayed an ascending trend, reaching 55.93, 57.70, and 59.04 as the frying temperature increased to 130 °C, 135 °C, and 140 °C, respectively (Table 2). Similarly, with longer frying times of 7.0 minutes, 7.5 minutes, and 8.0 minutes, the lightness (L) exhibited substantial elevation from 55.41, 57.02, to 60.25, correspondingly. The lightness values of this wheat-taro snack demonstrated a moderate positive correlation ($p < 0.01$, $r = 0.51$) with frying temperature and a strong correlation ($p < 0.001$, $r = 0.79$) with frying time (Table 3).

These findings are consistent with the relationship between lightness and frying time, but they diverge from the findings regarding the association between lightness and frying temperature of potato chips [6]. Their study indicated a positive correlation between lightness and frying time, but a negative correlation with frying temperature. In the current study, the deep-fried wheat-taro snacks turned out lighter when fried at higher temperatures and for longer durations. This outcome might be attributed to the degradation of certain heme pigments (anthocyanins) in taro during the frying process, resulting in increased lightness.

The colour characteristics of fried products were shaped by a complex interplay of reactions and compounds absorbed by the frying oil. Temperature and frying duration were pivotal factors influencing changes in colour and flavour during frying. The surface colour of food could arise from processes such as caramelization and the Maillard reaction (both contributing to the development of golden to brown tones), as well as the properties of heme pigments [6].

- Colour "a^*"

Similar to the impact on the lightness value, the a^* value also reacted to changes in process variables. The a^* value represents redness if the value is positive. In general, an increase in the a^* value indicated a shift towards a more red product, which was generally not desirable for fried wheat-taro snacks. As outlined in Table 2, the a^* value significantly increased during the frying process. Notably, the a^* value of the wheat-taro snack exhibited a weak positive correlation ($p < 0.05$, $r = 0.38$) with frying temperature and a strong correlation ($p < 0.001$. $r = 0.83$) with frying time, as detailed in Table 3. With higher frying temperatures, the a^* value increased, holding the frying time constant. These a^* values tended to rise with escalating temperatures.

- Value "b^*"

The b^* represents yellowness if the value is positive. The data in Table 2 indicate a noteworthy increase in the b^* value during frying. The b^* value of the wheat-taro snack manifested a moderate and positive correlation ($p < 0.01$, $r = 0.58$) with frying temperature and a strong correlation (r = 0.62) with frying time, as presented in Table 3. As the frying temperature elevated, the b^* value also increased while keeping the frying time constant. Higher b^* values generally corresponded to a more yellow colour, which were often desirable for fried products. Notably, the trends influencing the b^* values were consistent with the report by Cruz *et al*. (2018) [16] regarding the a^* values of potato chips, which increased with both frying temperature and time in fried potato chips.

In summary, the trends discussed point to the conclusion that lower oil temperatures, up to 140 °C, result in lighter and more yellow colour values, which were typically associated with more acceptable products in terms of colour. The golden colour is produced from the browning (Maillard and caramelization) reaction during frying [6].

3.3. Evaluation of the Relationship between the Snack Properties and the Frying Process

Pearson correlation coefficients to test for relationships between the deep-fried wheat-taro snack properties are shown in Table 3.

Several of the significant correlations observed between snack properties within the complete dataset were as anticipated, as they pertained to properties that were evidently interconnected (Table 3). For instance, the significant inversed relationships between moisture content and expansion ratio ($p < 0.05$, $r = -0.40$), weight loss ($p < 0.001$, $r = -0.73$), and oil absorption (p < 0.01, r = -0.56). While frying, the moisture within the snacks evaporates, and they absorbed more oil. This process led to snacks with reduced moisture content and increased oil absorption. Additionally, the vaporization contributed to the expansion of the snack's volume, resulting in a product characterized by both lower moisture content and a higher expansion ratio. While frying, snacks retained more water, resulting in less weight loss.

In addition, the negative and strong correlation between moisture content and texture properties including hardness ($p < 0.001$, $r = -0.68$), fracturability ($p < 0.001$, $r = -0.83$). Cruz *et al.* (2018) [16] noted that achieving a final moisture content of less than 2.0% is conducive to achieving a crisp texture.

However, some significantly positive correlations were noted, including moderate relationships between expansion ratio with weight loss ($p < 0.01$, $r = 0.46$), hardness (p < 0.001, r = 0.65), and fracturability ($p < 0.01$, $r = 0.50$). Actually, the snack that was fried at a high temperature and for an extended duration experienced substantial weight loss and a significant expansion ratio. Consequently, subjecting the snack to prolonged high-temperature frying led to a higher content of gelatinized starch. This, in turn, resulted in a smoother surface for the snack and the entrapment of numerous air bubbles. The cumulative effect of these factors led to a substantial expansion in the snack volume.

4. Conclusion

All the properties like moisture, weight loss, expansion ratio, oil absorption, hardness, and fracturability were found to be greatly affected by frying conditions. Frying temperature was strongly and positively correlated with the expansion ratio, weight loss, and hardness of the deep-fried wheat - taro snacks, although contributions to variability from the frying time were significant. Frying time had mainly and negative effects on variance for moisture but positive relationships with oil absorption, fracturability, and the colour values (*L*, a^*, and b^*). There were strong and negative correlations between moisture content and weight loss, texture of the snack. The positive relationships between expansion ratio and texture were found. The findings suggested that a frying temperature of 135 °C for a duration of 8.0 minutes was proper for producing the wheat-taro snack with the desirable colour and texture. The results could be applied to snack processing as in the industry.

References

[1] M. M. Tosif, A. Najda, J. Klepacka, A. Bains, P. Chawla, A. Kumar and R. Kaushik, A concise review on taro mucilage: Extraction techniques, chemical composition, characterization, applications, and health attributes, Polymers, vol. 14. no. 6, pp. 1163, Mar. 2022. https://doi.org/10.3390/polym14061163

[2] A. A. Anton, and F. B. Luciano, Instrumental texture evaluation of extruded snack foods: A review. Ciencia y Tecnologia Alimentaria., vol. 5, iss. 4, pp. 245-251, Oct. 2009. https://doi.org/10.1080/11358120709487697

[3] P. Zang, Y. Gao, P. C. Chen, and G. Zhao, Recent advances in the study of wheat protein and other food components affecting the gluten network and the properties of noodles, Foods, vol. 11, Nov. 2022. https://doi.org/10.3390/foods11233824

[4] A. Yıldız, T. K. Palazoğlu and F. Erdoğdu. Determination of heat and mass transfer parameters during frying of potato slices, Journal of Food Engineering, vol. 79, pp. 11-17, Mar. 2007. htttp://doi.org/10.1016/j.jfoodeng.2006.01.021

[5] R. Jowitt, The terminology of food texture, Journal of Texture Studies, vol. 5, iss.3, pp. 351-358, Oct. 1974. https://doi.org/10.1111/j.1745-4603.1974.tb01441.x

[6] F. Mendoza, P. Dejmek and J. M. Aguilera. Colour and image texture analysis in classification of commercial potato chips, Food Research International, vol. 40, pp. 1146-1154, Nov. 2007. htttp://doi.org/10.1016/j.foodres.2007.06.014

[7] O. Luigi. AOAC: Official methods of Analysis, AOAC 967.21 IFU Method No 17, Arlington, USA, 2004, The Association of Official Chemists.

[8] L. M. Smith, A. J. Clifford, R. K. Creveling, and C. L. Hamblin, Lipid content and fatty acid profiles of various deep-fat fried foods, J. Am Oil Chem Socciety, vol. 62, pp. 996-999, Jun. 1985. https://doi.org/10.1007/BF02935700

[9] R. H. Lane, H. Nguyen, S. W. Jone and V. C. Midkiff, The effect of fryer temperature and raw weight on yield and composition of deep-fat fried chicken thighs, Poultry Science, vol. 61. iss. 2, pp. 294-299, Feb. 1982. https://doi.org/10.3382/ps.0610294

[10] S. Y. Yu. Acceptability of fish crackers (keropok) made from different types of flour, ASEAN Food Journal, vol. 6. no. 3, pp. 114-116, 1991.

[11] M. C. Bourne, J. F. Kenny and J. Barnard, Computer-assisted readout of data from texture profiles analysis curves 1, Journal of Texture Studies, vol. 9, iss. 4, pp. 481-494, Dec. 1978. https://doi.org/10.1111/j.1745-4603.1978.tb01219.x

[12] E. V. Hecke, K. Allaf and J. M. Bouvier, Texture and structure of crispy puffed food products, PartII: Mechanical properties in puncture, Journal of Texture Studies, vol. 29, iss. 6, pp. 617-632, Dec. 1998. https://doi.org/10.1111/j.1745-4603.1998.tb00189.x

[13] H. Abdalrahman, A. L. Jumayi and A. M. Darwish, Frying time and temperature conditions' influences on physicochemical, Texture, and Sensorial Quality Parameters of Barley-Soybean Chips, Journal of Food Quality, vol. 2021, Oct. 2021. https://doi.org/10.1155/2021/5748495

[14] O. P. Sobukola and P. Bouchon, Mass transfer kinetics during deep fat frying of wheat starch and gluten based snacks, Heat Mass Transfer, vol. 50, pp. 795-80, Jan. 2014. https://doi.org/10.1007/s00231-014-1288-2

[15] A. Ziaiifar, N. Achir, F. Courtois, I. Trezzani and G.Trystram, Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process, International Journal of Food Science & Technology, vol. 43, pp. 1410-1423, Jul. 2008. https://doi.org/10.1111/j.1365-2621.2007.01664.x

[16] G. Cruz, J. P. Cruz-Tirado, K. Delgado, Y. Guzman, F. Castro, M. L. Rojas and G. Linares, Impact of pre-drying and frying time on physical, properties and sensorial acceptability of fried potato chips, Food Sciencde Technology, vol. 55, pp. 138-144, Dec. 2017. https://doi.org/10.1007/s13197-017-2866-3

[17] P. Mazumder, B. S. Roopa and S. Bhattacharya, Textural attributes of a model snack food at different moisture contents, Journal of Food Engineering, vol. 79. iss. 2, pp. 511-516, Mar. 2007. https://doi.org/10.1016/j.jfoodeng.2006.02.011

[18] C. S. Chen, J. J. Chen, T. P. Wu and C. Y. Chang, Optimising the frying temperature of gluten balls using response surface methodology, Science of Food and Agriculture, vol. 77, iss.1, pp. 64-70, May. 1998.

[19] M. T. Mosavian and V. M. Karizaki, Determination of mass transfer parameters during deep fat frying of rice crackers, Rice Science, vol. 19. iss. 1, pp. 64-69, 2012. https://doi.org/10.1016/S1672-6308(12)60022-5

[20] M. M. Blumenthal and R. F. Stier, Optimization of deep-fat frying operations, Trends in Food Science & Technology, vol. 2, pp. 144-148, 1991. https://doi.org/10.1016/0924-2244(91)90659-7