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The characteristics of vacuum fried pineapple cores (*Ananas comosus*) as affected by processing conditions: effect of time and temperature conditions

Onanong Naivikul [1], Usa Panritdam[2] and Aumaporn Arlai [2,*]

[1]Associate Fellows, Academic of Science, Office of The Royal Society, Bangkok 10300, Thailand

[2] Department of Food Science and Technology, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom 73000, Thailand

Abstract

The effect of frying temperature and time on the characteristics of vacuum fried pineapple cores was studied. The finding demonstrated that the severe frying conditions had a significant ($p \leq 0.05$) impact on moisture content, oil uptake, color, texture, expansion, microstructure and sensorial evaluation. A rise in frying temperature and time was inversely linked with the moisture content (10.76 to 3.17%) and hardness value (341.28 to 72. 09 g). Whereas, it positively affected on a significant increase in oil absorption (15.00 to 19.97%), expansion (20.23 to 50%), color, pore structure and overall acceptability. The optimal conditions for vacuum frying pineapple cores to obtain the greatest texture and golden yellow color, and achieve the best score (5.13 to 6.20 out of 7) in all sensory aspects, was 80°C frying for 90 minutes. It could be a potentially alternative to create snacks not only helps reduce food waste but also contributes to sustainable efforts, aligning well with the Sustainable Development Goals (SDGs).

Keywords: vacuum frying, pineapple, pineapple core, microstructure, dietary fiber

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The pineapple (*Ananus comosus*), one of the world's most important agricultural fruits, is produced in more than 10 million metric tons globally [1]. It is a rich source of phenolic bioactive compounds, dietary fiber and essential minerals like manganese and copper. The presence of phenolics in pineapple contributes to its potent antioxidant activity, which is vital for combating oxidative stress and reducing the risk of chronic diseases. Additionally, the high fiber content and bromelain in pineapple promote digestive health by supporting regularity and aiding in nutrient absorption. Therefore, the consumption of pineapple has health benefits, namely on the digestive system and helps to maintain a balanced diet [2-3]. Generally, during the pineapple processing, approximately 50% (w/w) of the total pineapple weight was co-products (29–40% shell, 9–10% core, 2–6% stem, and 2–4% crown) [4-5]. As the matter of facts, there are a variety of nutritional values, including dietary fiber, vitamins, minerals, phenolic compounds and other bioactive compounds are presented in the co-products [2]. It, therefore, has the potential to be transformed into value-added products. Utilizing agro-industrial co-products from pineapple processing not only helps to diminishing waste but also creates opportunities for producing value-added products.

Drying and dehydration are well-known techniques for removing moisture and enhancing the shelf life of the agricultural product, particularly perishable fruit and vegetables [6]. Among them, the frying process is a potential alternative strategy to decrease water and extend shelf life of the final products. In particular, deep fat frying is a common method that not only preserves but also adds value to fruits and vegetables. Even though a

*Corresponding author; e-mail: aumaporn@webmail.npru.ac.th

deep fat frying is very popular method but it is applied to a small number of materials such as potato and banana. This might be due to its high temperatures can degrade nutrients and lead to excessive oil absorption [7]. One of the newest possible ways to process fruit and vegetables with less oil consumption while maintaining desired texture and flavor characteristics is vacuum frying.

Vacuum frying occurs under low pressure, while deep- or shallow-frying is done under the atmosphere pressure. So, it is processed at a lower temperature than deep- or shallow-frying. Water then is removed at a lower boiling degree, and product quality is superior in terms of oil content, texture and nutrient retention [8]. Vacuum frying presents promising benefits, such as producing healthier fried foods with lower oil content and better retention of nutrients and flavors compared to conventional frying methods. It's worth nothing that the technique may require specialized equipment and careful process control to achieve optimal results [9]. However, as consumer demand for healthier food options, vacuum frying holds significant potential for the food industry as a method to produce nutritious and flavorful fried products. Numerous studies have examined the impact of vacuum frying on a variety of foods, including shitake mushrooms, papaya, bananas, sweet potatoes, cassava and pineapple chips [6, 10–15]. Additionally, they determined the structure of final products on the outside and inside, texture, water and oil content by varying vacuum frying condition. However, none has investigated how vacuum frying impacts the quality of high fiber fruit and co-product from the industrial segment such as the core of pineapple. Therefore, the purpose of this study was to investigate the effects of frying conditions, particularly temperature and time, on the quality of pineapple cores. Pineapple cores are often discarded as waste in food processing, so finding ways to utilize them effectively well with the principles of the bio-circular-green (BCG) economy model. This approach emphasizes sustainability by integrating scientific innovation and technology to create value from biological resources, strengthening Thai BCG industries while minimizing environmental impact [16].

2. Materials and methods

2.1. Material

The pineapple (*Ananas comosus*) was cultivated and obtained from The Farm Marketing state-owned enterprise (Ratchaburi, Thailand). It was selected at the ripening stage of 20-30% with a soluble solids concentration of 13-14 ºBrix. The pineapple cores, a leftover or co-product from pineapple juice processing, were sliced in the longitudinal direction at 1×5×0.1 cm and kept in the refrigerator at 4ºC until further processing.

Frozen pineapple juices were obtained from The Farm Marketing state-owned enterprise (Ratchaburi, Thailand). The total soluble solid of frozen pineapple juice was controlled at 30±2 °Brix.

2.2. Pineapple core preparation

Pineapple cores were immersed at a ratio of 1:1 in 30 ºBrix pineapple juices at the temperature 20±3ºC until the soluble solid in the sample reached 20±1°Brix. Then the pretreated pineapple cores were drained and frozen at -25 ºC for three hours (March cool, 2009 model, Thailand). After being frozen, from the preliminary studied, the pineapple cored were vacuum fried at the selected temperatures of 70,75 and 80ºC (700 mmHg) for the selected time of 50, 60, 70, 80 and 90 min. Extreme conditions of temperature and time gave a rejection from the sensory aspects (data not shown). Each batch of frozen pineapple cores, 700-800g of samples, was afterward fried in 20 liters of palm oil. After frying, the products were centrifuged for 20 min at 900 rpm to get rid of surplus oil and lower the oil content. The moisture and oil content were measured at each temperature for each time in triplicate according to AOAC [17].

2.3 Texture analysis

The texture of vacuum fried pineapple cores was analyzed using a Texture analyzer (TA. XT plus, UK). The sample was placed on a hollow planar base. A spherical probe of P0.5 was set to a test speed of 10 mm/s at a distance of 5mm or until the sample cracked. The maximum force from the force deformation curve of each sample was considered as hardness (g) [12].

2.4 Expansion measurement

The fresh and vacuum samples were measured the thickness by the Vernier caliper (0.05 mm precision). The percentage of expansion was described by Yamsaengsung et al [10] as follows

$$\%\,expansion = 100 \times \frac{D-D0}{D0}$$

Do is the original thickness of fresh samples

D is the end of each thickness of the vacuum fried sample

2.5 Color measurement

The color analysis was carried out with a colorimeter chroma meter (Minolta CR310, Japan) using the CIE standard (L*, a*, b*). The CIE values of L* represent the range of dark to light color, a* represent the range of green to red color, and b* represent the range of blue to yellow color [18].

2.6 Microstructure

The oil content in products prepared in section 2.2 was eliminated by the Soxhlet extraction method [15]. The deoil dried samples were cut and mounted on an aluminum stub, and then coated with gold. The microstructure of the samples was examined using a scanning electron microscope (SEM) (Tescan Mira3, Czech Republic) at a 100x magnification and 15kV accelerated voltage [19].

2.7 Sensorial evaluation

The sensory evaluation for consumer acceptance testing was performed by 30 untrained panelists, aged between 20-45 year old. All panelists were familiar with this kind of pineapple without allergies. The 7-point hedonic scale questionnaire (1 = dislike extremely, 7 = like extremely) was used to evaluate the test of the vacuum fried samples. Test attributes were appearance, color, crispiness, flavor and overall acceptance of the product. The appearance of the final products is shown in Figure 1.

2.8 Dietary fiber, total starch and resistant starch measurement

Dietary fiber was analyzed by the in-house method TE-CH-076 based on AOAC [17]. Total starch and resistant starch of the samples were measured by glucoamylase methods [20] and determined using Megazyme kits (Megazyme International Ireland, Ireland). Fresh and vacuum fried samples were conducted.

2.9 Statistical analysis

A factorial in complete randomized design 3x5 was applied to experiments related to the physical properties. A randomized complete block design was used for the sensory test. The data analysis of variance was performed and the difference among means was conducted by Duncan’s new multiple ranges test at the 95% significant confidence interval. SPSS software version 23 was carried out all statistical analysis (IBM, USA).

3. Result and discussion

3.1 Moisture and oil content

The data presented in Figure 2 clearly shows the impact of varying frying temperatures and times on the oil and moisture content of pineapple cores. It was obvious that the temperature increases from 70 to 80°C and the frying time extends from 50 to 90 minutes, there's a noticeable decrease in moisture content. Simultaneously, there was a significant rise in the oil uptake by the pineapple cores ($p \leq 0.05$). The moisture content of pineapple cores was varied between 3.17 to 10.76%. During vacuum frying, moisture migrates more quickly from interior to the food surface. At the initiate state, lower frying temperatures (70ºC) resulted in less water loss from the sample than that of high temperatures (80ºC). The results demonstrated that higher temperatures and longer frying durations lead to more efficient dehydration or more water was evaporated from the samples. The findings of this study indicated a tendency toward rising oil uptake, with values between 15.00 and 19.97%. The high amounts of oil uptake may be the result of moving into the product pore spaces through capillary channels formed due to moisture evaporation, both on the surface and inside, which led to increased oil penetration from the driving force [21-22]. The coefficient correlation (R^2) of oil absorption and water evaporation during vacuum frying was 0.73 at 70ºC, 0.82 at 75 ºC and 0.93 at 80ºC. The results related to study of Su et al (2016) [13] who reported that under intense frying at high temperatures (100, 110, and 120 ºC) and for long periods of time (0 to 10 min), that the oil content of potato chips increased while the moisture content decreased.

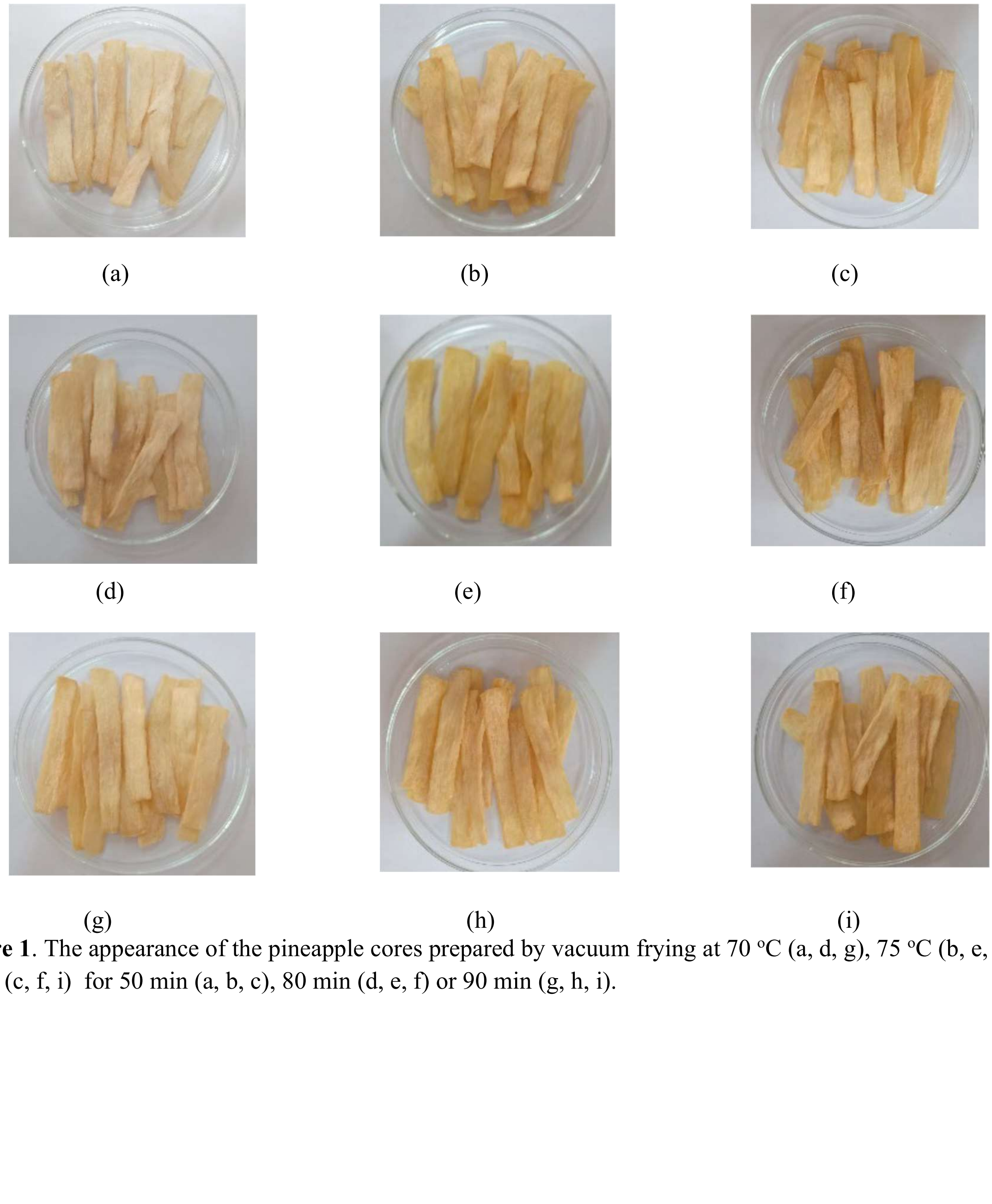
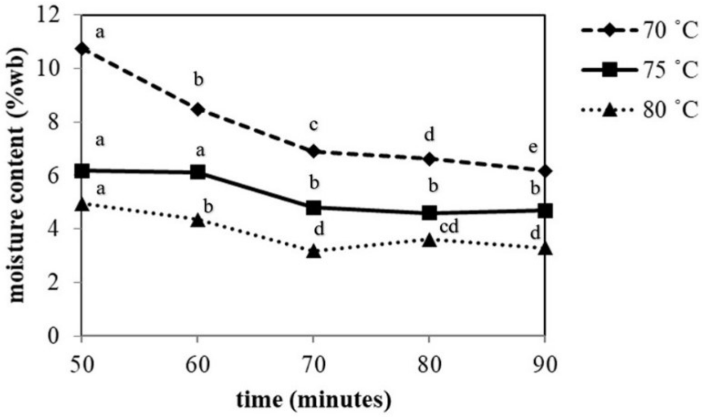
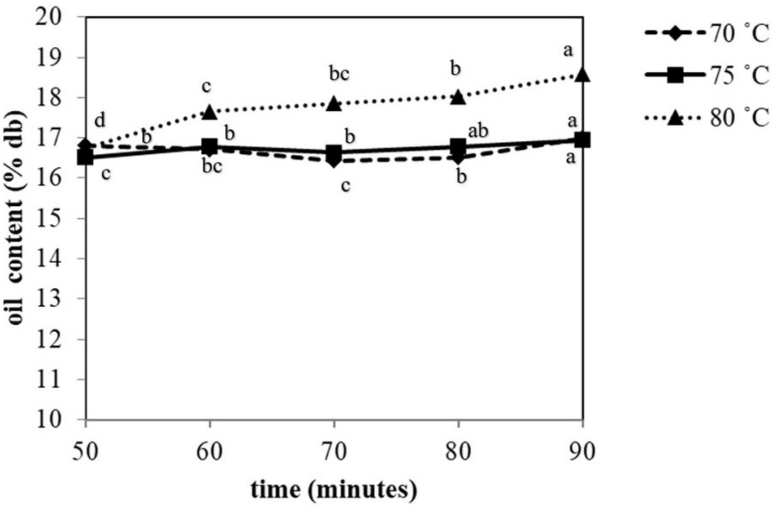


Figure 1. The appearance of the pineapple cores prepared by vacuum frying at 70 ºC (a, d, g), 75 ºC (b, e, h) or 80 ºC (c, f, i) for 50 min (a, b, c), 80 min (d, e, f) or 90 min (g, h, i).



(a)



(b)

Figure 2. Moisture (a) and oil content (b) of the vacuum fried pineapple cores at various temperatures and time conditions.

3.2 Hardness and expansion

The quality of fried products is generally affected by the frying conditions, the thickness of the products, the properties of food stuff and the desired final products especially the textural of the product [10, 21]. The breaking force can be used as an indicator of the crispiness of products. In the early stage of frying, the moisture in samples is high and the texture is then tough, with lower breaking force or hardness value indicating higher crispiness [12]. From Table 1, the hardness value tended to decrease as the frying temperature and time increased ($p\leq 0.05$). Consequently, the hardness value decreased from 341.28 g at 70°C frying for 50 minutes to 72.09g at 80°C frying for 90 minutes. Additionally, the expansion values increased under more severe frying conditions, reaching a maximum of 50% at 80°C frying for 90 minutes. According to Esan et al [11] who found that increasing oil temperature and frying time affected the texture of yellow-fleshed sweet potatoes, leading to rapid hardness changes, accelerated crust formation, and ultimately decreased hardness values. This phenomenon can be attributed to the evaporation of gases from the products during frying, which creates a porous structure and results in increased product expansion, as depicted in Figure 4. Similarly, Yamsaengsung et al [10] observed a similar effect in banana chips subjected to vacuum frying at 110°C for 20 minutes at 8 kPa. The chips exhibited a significant increase in pore size, leading to the highest volume expansion of over 20%

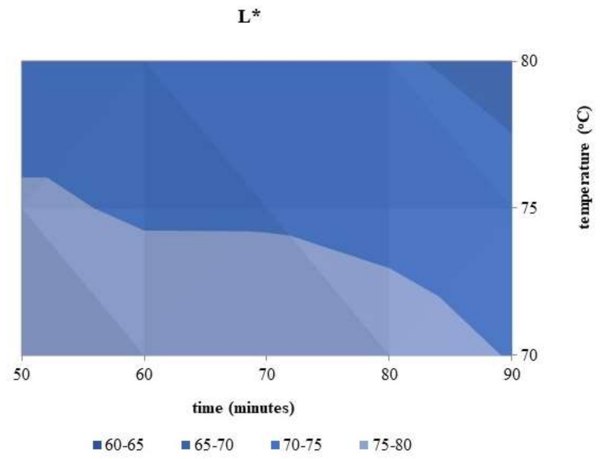
Table 1. Hardness and percentage of expansion of vacuum fried pineapple cores at various temperatures and time conditions.

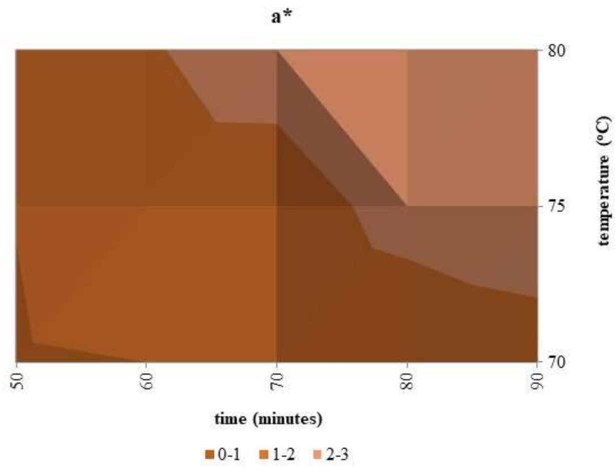
Sample no.	Temperature (°C)	Time (min)	Hardness (g)	Expansion (%)
1	70	50	341.28ᵃ±12.66	20.23ᵉ±2.83
2		60	318.07ᵃ±19.92	22.00ᵉ±1.18
3		70	320.07ᵃ±15.56	24.92ᵈᵉ±3.14
4		80	254.50ᵇᶜ±27.17	30.98ᵈ±5.66
5		90	158.17ᵈᵉ±17.36	40.32ᵇ±1.07
6	75	50	273.20ᵇ±16.22	30.17ᵈ±8.01
7		60	226.61ᶜ±32.83	35.00ᶜ±2.07
8		70	167.87ᵈ±16.74	35.17ᶜ±3.17
9		80	150.07ᵈᵉ±20.80	45.07ᵃᵇ±6.10
10		90	136.60ᵉ±12.15	45.00ᵃᵇ±6.12
11	80	50	190.51ᶜᵈ±17.62	35.00ᶜ±2.14
12		60	144.44ᵉ±14.84	45.07ᵃᵇ±6.11
13		70	128.42ᶠ±37.38	50.00ᵃ±9.22
14		80	112.49ᶠ±16.51	50.00ᵃ±6.93
15		90	72.09ᵍ±4.93	50.00ᵃ±7.07

[a,b,…] Mean values with different letters in the same column were significantly different ($p \leq 0.05$).

3.3. Color

The changes in color of vacuum fried samples were observed L* (lightness), a* (green-red chromaticity) and b* (blue-yellow chromaticity). Figure 3 shows the effects of frying time and temperature on the color of pineapple cores. The color values of the pineapple cores in the current study for all conditions ranged from 68.46 to 79.93 (L*), 0.93 to 2.84 (a*) and 20.63 to 24.57 (b*). The statistical analysis demonstrated that raising the frying temperature and time had a significant ($p \leq 0.05$) impact on the color values of samples. Higher conditions could reduce the L* value while accelerating the a* and b* value, resulting in the better desirable golden color of pineapple cores development (Figure 1). The color change that occurred during severe frying conditions could be attributed to the chemical oxidation and carbohydrate degradation [23]. The reactions that contribute to the browning of fried foods are partly due to the Maillard reaction, a complex series of reactions between amino acids and reducing sugars [13, 21]. Pineapple cores, containing 0.1% proteins and 4.3% carbohydrates [24], provide the potential material for Maillard reactions to occur during frying [22]. These reactions not only alter the color of the food but also play a significant role in developing its flavor and aroma, enhancing the overall sensory experience of the fried products [23]. Similarly, the studied of Wanakamol & Poonlarp [15] reported that the pineapple chips were fried at 90-95 ºC for 50-60 min under depressurized to 60 mmHg showed a significant impact on the lightness (from 64.21 to 55.92) and hue value (from 81.36 to 77.16) as darker color can be seen in more intense process.





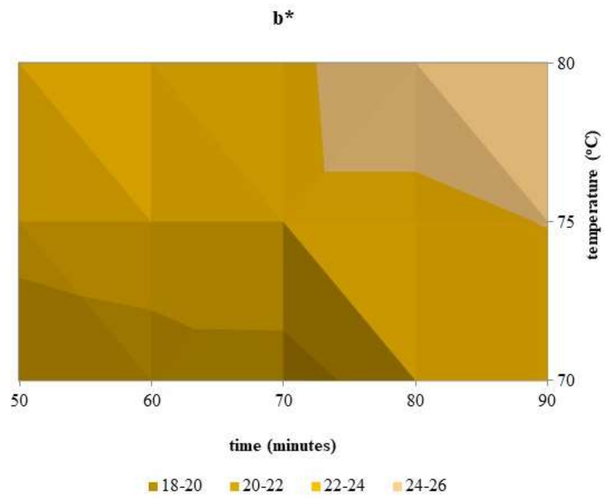


Figure 3. CIE (L*, a*, b*) color of pineapple cores were prepared by vacuum frying at 70, 75 and 80 ºC for 50, 60, 70, 80 and 90 min.

3.4. Microstructure

The study investigated the structural changes in vacuum-fried pineapple cores, particularly focusing on the microstructure alterations concerning frying temperature and time as shown in Figure 4. It was observed that both the number and size of pores within the samples increased progressively with higher frying temperatures and longer frying times. This phenomenon was attributed to the removal of free water from the cellular structure during the frying process. Before frying, the pineapple cores underwent pretreatment by being frozen at -25°C. The formation of ice crystals during freezing initially damaged the plant tissue. Subsequently, upon heating, these ice crystals within the frozen cells sublimated under vacuum conditions, leaving behind pores in the food matrix. As a result, a porous sponge-like structure was formed [25]. The findings of this study was consistent with previous researches on the microstructure of vacuum-fried potato and sweet potato [11-12]. These two studies reported that vacuum frying at

90°C induced the formation of a sponge-like pore effect in the fried samples. Similar to the findings with pineapple cores, both the number and size of pores within the product increased with higher frying temperatures and longer frying times. These results strongly support the hypothesis that internal water vapor expansion within the product leads to thickness expansion, as outlined in Table 1. Consequently, the samples exhibited the lowest hardness values, indicating greater crispiness, after exposure to high temperatures and longer frying times.

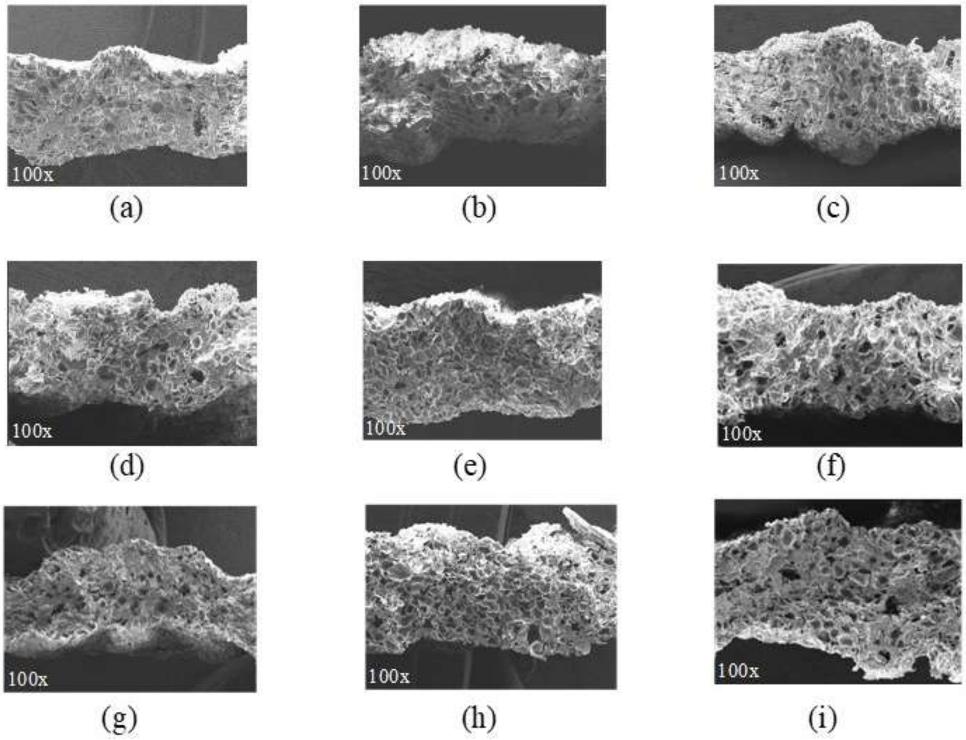


Figure 4. SEM images of the pineapple cores prepared by vacuum frying at 70 ºC (a, d, g), 75 ºC (b, e, h) or 80 ºC (c, f, i) for 50 min (a, b, c), 80 min (d, e, f) and 90 min (g, h, i) at a 100x magnification.

3.5. Sensorial evaluation

The results from the sensorial acceptance test of vacuum fried pineapple cores indicate a significant ($p \leq 0.05$) improvement in various sensorial attributes with different frying temperatures and times. At 70°C, variations in frying time between 50 to 90 minutes resulted in similar scores for appearance, color and flavor, ranging from 2.6 to 4.6. However, at 80°C for 90 minutes, attributes such as flavor, crispiness, and overall acceptability received the highest scores, exceeding 6 out of 7, with coefficients of 0.76, 0.93, and 0.79, respectively. This suggests that higher frying temperatures and longer frying times may be necessary to enhance consumer acceptability of vacuum fried pineapple cores. The vacuum fried pineapple cores produced at 80°C for 90 minutes exhibited a golden-yellow color, preferable flavor, and crispiness, as shown in Figure 1. The quality of the best recipe to produce vacuum fried pineapple cores is shown in Table 3.

Table 2. Hedonic scores of vacuum fried pineapple cores at various temperatures and time conditions.

Sample no.	Temperature (°C)	Time (min)	Appearance	Color	Crispiness	Flavor	Overall Acceptance
1	70	50	4.60^{b}±0.83	4.07^{c} ±0.30	2.60^{d} ±0.55	3.60^{c} ±0.34	3.33^{d}±0.38
2		60	4.53^{b}±0.92	4.53^{b} ±0.42	2.67^{d} ±0.23	3.67^{c} ±0.35	3.60^{c} ±0.39
3		70	4.53^{b}±1.13	4.60^{b} ±0.63	2.67^{d} ±0.18	3.60^{c} ±0.49	3.60^{c} ±0.29
4		80	4.53^{b}±0.92	4.53^{b} ±0.74	2.80^{cd} ±0.22	4.20^{bc} ±0.56	3.87^{c}±0.35
5		90	4.47^{b}±1.06	4.60^{b} ±0.83	3.07^{cd} ±0.56	4.40^{bc} ±0.39	3.80^{c} ±0.48
6	75	50	4.80^{ab}±1.08	4.20^{b} ±0.41	3.27^{c} ±0.33	4.53^{b} ±0.44	3.93^{c} ±0.36
7		60	4.67^{b}±1.18	4.40^{b} ±0.74	3.40^{c}±0.40	4.47^{bc} ±0.83	4.27^{cd} ±0.59
8		70	4.87^{ab}±0.83	4.53^{b} ±0.64	3.47^{c} ±0.26	4.73^{b} ±0.56	4.13^{cb} ±0.44
9		80	4.87^{ab}±0.52	4.67^{b} ±0.52	4.20^{b} ±0.58	4.70^{b} ±0.28	4.07^{c} ±0.20
10		90	4.53^{b}±0.92	4.73^{b} ±0.46	4.20^{b} ±0.86	4.80^{b} ±0.42	4.20^{cb} ±0.48
11	80	50	4.87^{ab}±0.24	4.87^{b} ±0.35	4.00^{b} ±0.65	4.67^{b} ±1.29	4.20^{b} ±0.56
12		60	4.40^{b}±0.44	4.33^{ab} ±0.28	4.33^{b}±0.72	4.73^{b} ±0.70	4.40^{b} ±0.51
13		70	4.87^{ab}±0.34	4.80^{b}±0.41	5.20^{ab} ±0.77	4.80^{b} ±0.48	4.60^{b} ±0.44
14		80	5.07^{a}±0.36	4.87^{b} ±0.24	5.13^{ab} ±0.44	5.13^{ab} ±0.34	4.80^{b} ±0.41
15		90	5.13^{a}±0.22	5.67^{a}±0.49	6.07^{a} ±0.70	6.07^{a} ±0.53	6.20^{a} ±0.36

[a,b,c,d] Mean values with different letters in the same column were significantly different ($p \leq 0.05$). Hedonic scores were reported in the 7-point scale; 1 = dislike extremely, 7 = like extremely.

In the vacuum fried pineapple core, neither the resistant starch nor the overall starch content could not be found. However, the pineapple exhibited a higher dietary fiber content compared to fresh pineapple. The best recipe sample (sample no.15) had a dietary fiber content of 21.31% (dry basis), higher than the 17.09% found in fresh pineapple. Dietary fiber is a plant polysaccharide that cannot be hydrolyzed and absorbed by human digestive enzymes. It has been reported that fiber intake can reduce the risk of cardiovascular disease, diabetes mellitus and cancer [26]. Additionally, when comparing the oil content of the best recipe sample to conventional French fries, it was found that the vacuum-fried pineapple core (sample no.15) contained 18% oil (Figure 2), while conventional French fries, the most popular fried food in the USA and many other countries, has a higher oil content of 43% [27]. This suggests that vacuum-fried pineapple cores offer a healthier alternative to traditional fried foods like French fries, with lower oil content and higher dietary fiber.

Table 3. Dietary fiber, total starch and resistant starch of fresh and the best recipe vacuum fried pineapple cores (sample no. 15).

Samples	Dietary Fiber (% db)	Total Starch (% db)	Resistant Starch (% db)
Fresh	$17.09^{b} \pm 1.08$	0	0
Vacuum fried (no. 15)	$21.31^{a} \pm 1.34$	0	0

^{a,b} Mean values with different letters in the same column were significantly different ($p \leq 0.05$).

4. Conclusion

The effect of vacuum conditions on the characteristics of pineapple cores were observed in this study. The variations in frying temperature and time influenced the moisture and oil contents of the pineapple cores. Additionally, the study found correlations between pore size, color, texture, SEM structures, expansion and crispiness. Products fried under pressure at 80°C for 90 minutes received the highest acceptance scores (over 6 out of 7) across all attributes, particularly overall acceptability. Noticeably, the vacuum-fried pineapple cores could serve as a potential product derived from industrial co-products. Furthermore, the study implies that these vacuum-fried cores could be positioned as a healthier alternative snack compared to traditional fried products like French fries, potentially appealing to health-conscious consumers.

Declaration of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this report.

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