Asia-Pacific Journal of Science and Technology: Volume: 30. Issue: 01. Article ID.: APST-30-01-06. Research Article

APST

Asia-Pacific Journal of Science and Technology

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

Published by Research Department,
Khon Kaen University, Thailand

Development of crispy-sweet pickled radish products by vacuum frying and water pretreatment

Sawanya Punyanunt[1], Boontiwa Ninchan[2], Damrongchai Sithisam-ang[3], Wannarat Chalermsanyakorn[1] and Krongsakda Phakthanakanok[1,*]

[1]Department of Food Processing Technology, Faculty of Science and Technology, Muban Chombueng Rajabhat University, Ratchaburi, Thailand
[2]Sugar and Derivatives Analytical Laboratory, Department of Biotechnology, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand
[3]Research and Development Group for Bio-Industries (RDB), Thailand Institute of Scientific and Technological Research, Pathum Thani, Thailand
[*]Corresponding author: krongsakdapha@mcru.ac.th

Received 30 April 2023
Revised 13 February 2024
Accepted 25 July 2024

Abstract

Sweet pickled radish (Huah Chai Bpoh in Thai), which is a famous fermented food in Thailand, is made from white radish (*Raphanus sativus* L.). To add to its value, sweet pickled radish is processed by vacuum frying to produce a ready-to-eat snack. Water pretreatment was introduced to improve the quality of the sweet pickled radish product. The mass ratios for the pretreatment of sweet pickled radish to tap water were 1:3, 1:6, and 1:9. Then, it was fried at temperatures of 85, 90, and 95°C for 60, 90, and 100 min under vacuum conditions. The product quality parameters such as average diameter, visual appearance, color, and textural characteristics were examined. The results found that water pretreatment also decreased the total soluble solid content (TSS, °Brix) in the pickled radish sample, and the lowest TSS was observed at a ratio of 1:9. Such a pretreatment ratio induced the highest average diameter of fried product because the losing cellular structure strength after pretreatment promoted larger volume expansion during vacuum frying. Vacuum frying conditions comprising a temperature of 85°C for 100 min exhibited less browning and produced the highest hard texture. Moreover, Scanning electron microscopy (SEM) images of the fried product were different from fresh sweet pickled radish, as observed by larger pore sizes contained inside the fried product structures.

Keywords: Crispy vegetable, Pickled radish, Preserved radish, Vacuum frying, Water pretreatment

1. Introduction

Sweet pickled radish (Huah chai bpoh in Thai) is a well-known traditional preserved radish in Thailand that is made by fermenting fresh white radish (*Raphanus sativus* L.). The production of sweet pickled radish involves a solid-state fermentation process with osmotic pressure using salt and sugar. The first step is a dry-salting process, in which fresh white radish is fermented with dry salt (about 30% w/w) for 45 days to reduce water activity. After the pickling process, it is sliced into thicknesses of 2±1 mm. The last step is immersion, which is employed to achieve about 25-50% (w/w) of sugar for 7 days to complete the process. Sweet pickled radish is fermented similar to the production of sweet pickled mango, also known as Ma-muang Chae-Im in Thailand [1]. Sweet pickled radish has a unique flavor. It has a sweet and salty taste, which is prominent in Thai dishes such as Pad Thai. Ratchaburi Province is an important source of sweet pickled radish production in Thailand. The sweet pickled radish market is quite large, accounting for at least 300-400 million baht per year in Chet Samian sub-district, Photharam district, Ratchaburi Province. Nowadays, fermented radish root is produced with distinguishing characteristics in various countries. It is called paocai, takuan-zuke, and kimchi in China, Japan, and Korea, respectively, and is included in common vegetable dishes throughout Eastern Asia [2]. However, there are many processes for radish products in Asia, such as radish roots in pickles, dried radish, or canned pickles, that are very common [3]. Interestingly, sweet pickled radish is a fermented vegetable that keeps its salty, sweet, and natural flavors from fermentation, as mentioned previously. The growing demand for high-quality, healthy snacks has led the food industry to develop new products based on novel pseudo-cereals, vegetables, and legumes.

Vacuum-frying technology is one attractive technique for processing various fruits and vegetables such as potatoes [4, 5], bananas [6], jackfruit, carrots, and pineapple [7], as well as other vegetables [8]. Vacuum frying is performed under depressed atmospheric pressures, preferably at 50 Torr (6.65 kPa). The advantages of this technique include (1) less oil content inside fried food structures, (2) preservation of the natural color and flavor of products due to the low processing temperature and fewer oxygen molecules, (3) fewer adverse effects on oil quality, (4) decreased acrylamide content, and (5) preservation of nutritional compound contents [9].

The high sugar content of fresh sweet pickled radish, however, causes more non-enzymatic browning reaction during vacuum frying. Therefore, pretreatment is usually used to improve the color quality of crispy products. Tabtiang et al. [10] reported that osmotic pretreatment by sucrose solution potentially improved the color quality of crispy banana snacks compared to non-osmotically treated crisps. This could be because monosaccharides, glucose, and fructose, are leached from foods during osmotic pretreatment. Hence, the lowering of monosaccharides causes less brown color of crisps that are processed by thermal processing, i.e., drying and frying. Furthermore, frying temperature and frying time have a significant effect on color and textural characteristics [6, 7]. Yamsaengsung et al. [6] reported that a longer frying time significantly decreased the degree of volume shrinkage and increased the expansion ratio of fried bananas. Further, a higher frying temperature caused lower hardness or breaking force in fried apple chips [11].

Based on the aforementioned, the objective of this study was to investigate the effects of water pretreatment, frying temperature, and frying time on the qualities of crispy pickled radish products in terms of diameter, color, hardness, morphology, and nutritional value.

2. Materials and methods

2.1 Raw materials

The sweet pickled radish (huah chai bpoh in Thai) was prepared with slice thicknesses of approximately 2±1 mm using a cutting and slicing machine provided by the Maeboonsong Partnership in Ratchaburi Province, Thailand. Palm oil was purchased from a local market in Thailand.

2.2 Chemical composition analysis

The proximate composition of fresh sweet pickled radish was measured following the method set forth by the Association of Official Analytical Chemists (AOAC) [12, 13]. Moisture content was performed gravimetrically by a hot-air oven (Memmert, UM500, Germany). A fresh sweet pickled radish sample (5 g) was dried until reaching a constant weight and calculated on a dry weight basis (%) by AOAC (2016) of 925.45. Protein content was determined in the form of total nitrogen multiplied by 6.25 (conversion factor) using the Kjeldahl method by AOAC (2016) of 991.20. Ash content was determined by heating the sample in a furnace at 550°C until light gray or attaining a constant weight by AOAC (2019) of 923.03. Lipid in a fresh sample was extracted using petroleum ether as an extractor in an extracting unit (FOSS, Soxtec system 2055 Tecator, Hillerød, Denmark) that was gravimetrically determined by AOAC (2019) of 2003.05. Total dietary fiber content was examined using the enzyme-gravimetric method by AOAC (2019) of 985.29 to focus on food containing fiber components. Sampling was carried out in triplicate. Total carbohydrate content was calculated using equation (1) below.

$$\text{Total carbohydrates} = 100 - (\%\text{moisture} + \%\text{ash} + \%\text{lipid} + \%\text{protein} + \%\text{fiber}) \quad (1)$$

2.3 Water pretreatment process

The fresh sweet pickled radish was cut into thin slices by the Maeboonsong Partnership. Water pretreatment was applied to the samples. Soaking experiments were studied to reduce the total soluble solid content (TSS, °Brix). All experiments were done by soaking in tap water (ratio of sweet pickled radish to tap water (w/w); 1:3, 1:6, 1:9, and no soaking) at room temperature (25°C) for 1 h. After soaking, samples were drained thoroughly for comparison with the control sample that did not undergo soaking pretreatment. The squeezed juice of samples was measured immediately by the TSS content using a portable refractometer (Atago, MASTER-53alpha, Tokyo, Japan). Subsequently, all experiments (4 samples) were frozen at -40°C overnight before frying. The vacuum fryer used for experiments (Toptech Company, Thailand) was assembled and located at the authors' laboratory. Each batch was made up of 3 kg of samples in 20 liters of palm oil. The frying conditions were set to a target frying temperature of 85°C for 60 min in vacuum pressure (9 kPa), and then centrifuged for 10 min in the automatic machine system. The vacuum-fried samples were measured for the diameter of about 50 pieces by Vernier calipers

(Mitutoyo, Standard model 0-150 mm, Japan) to compare the appearance of fresh sweet pickled radish. The moisture content of fresh and vacuum-fried samples was determined using AOAC (2016) of 925.45.

2.4 Vacuum frying process

The appropriate soaking conditions were used in the pretreatment of vacuum-fried sweet pickled radish. In this part, frying temperature and frying time were investigated as color parameters of vacuum-fried products. Vacuum frying temperature experiments were conducted at 85, 90, and 95°C for 90 min. The obtained optimal frying temperature can be developed for textural characteristics. Thus, frying time experiments were determined for 60, 90, and 100 min. The measurement of textural properties was carried out in this experiment. The optimum vacuum-fried samples were stored in sealed aluminum foil bags with a nitrogen atmosphere to analyze their preliminary quality parameters.

2.4.1 Color measurement

The color of the crispy-sweet pickled radish samples was measured for L*, a*, and b* values with a colorimeter (Hunter Lab, ColorQuest XE, Virginia, U.S.A.) in the reflectance mode. Each sample was chopped in a blender, after which it was sealed in a plastic bag until analyzed. The average color value was reported at 5 different positions. The L* value is a measurement of lightness (ranging from 0 as black to 100 as white), a* indicates redness (+ is red, while – is green), and b* indicates yellowness (+ is yellow, while - is blue). All data were represented as the mean of three replicates.

2.4.2 Texture measurement

The hardness of the crispy-sweet pickled radish samples was analyzed with a texture analyzer (Ametek Brookfield, CT3 Texture analyzer, U.S.A.) equipped with a puncture probe (TA 44 cylindrical flat-probe; 4 mm diameter). Each sample was set as follows at a constant speed of 0.5 mm/s.; the probe punctured through a sample distance of 2 mm or until the sample cracked. Each experimental condition was measured in five samples. Texture properties were derived from the force (N)- distance (mm) curves. The hardness of samples was defined as the amount of maximum force. The number of peaks in the force-deformation curve was indicated as crispness [14]. All the crispy-sweet pickled radish samples were taken and stored in separate foil bags to protect them from the humidity in the environment [14].

2.4.3 Structure analysis

For comparison of the microstructures, an optimized vacuum-fried sample was compared with fresh sweet pickled radish. The samples were defatted by immersion in petroleum ether for 2 h after frying [15]. Thereafter, samples were dehydrated with a critical-point drying technique to ensure maximum structural preservation and to provide valuable data. Scanning electron microscopy (SEM) sample preparation methods were employed to minimize the structural changes associated with drying [16]. The microstructure was examined using a Scanning Electron Microscope (JEOL, JSM-IT300, Tokyo, Japan). The voltage was set between 10 and 20 kV based on the topography of the sample, while the magnification was set to 150x.

2.4.4 Nutrition analysis

Properly vacuum-fried samples were analyzed for their nutrition information using the AOAC method [13, 17] from the Institute of Food Research and Product Development (IFRPD), Kasetsart University, Thailand.

2.5 Statistical analysis

All experiments were designed to be completely random. Each experiment was conducted in triplicate, and the mean values with standard deviations were reported. The data were analyzed using one-way analysis of variance (ANOVA). SPSS 16.0 software (IBM SPSS software for Windows, SPSS Inc., USA) was used for statistical analysis and Duncan's multiple range tests. Significance was established at a 95% confidence level ($p<0.05$).

3. Results and discussion

3.1 Chemical composition of sweet pickled radish

Table 1 presents the chemical composition of sweet pickled radish (huah chai bpoh). The primary constituents of this radish were high moisture content, followed by carbohydrates, ash, and total dietary fiber. Carbohydrate content, representing the starch and sugar in the pickling process, accounted for 34.35% of the chemical composition. The results indicate that it is rich in carbohydrates and fiber. Total dietary fiber content mainly consists of the structural components of the cell wall of the radish, which are polysaccharides in vegetables including cellulose, hemicellulose, and pectin [18]. According to Table 1, carbohydrate content such as sucrose, starch, and pectin strongly affect the quality of fried products. However, radish is classified as a starch-free material [18]. Typically, radish has a low-calorie value and is rich in dietary fiber, vitamins, flavonoids, phenolics, and glucosinolates (GLs), making it valuable as a functional food [3]. Conversely, the pectin content of sweet pickled radish decreased because the methyl group on galacturonic acid was hydrolyzed into water-soluble pectin. This may be one reason for the loss of pectin during the pickling process. In addition, fruits and vegetables contain mono-/disaccharides. It is the main component in carbohydrate molecules such as fructose, sucrose, and glucose [19].

Table 1 Chemical composition of sweet pickled radish.

Composition	Amount (%, dry weight)
Moisture	53.25 ± 0.65
Carbohydrate	34.35 ± 0.64
Ash	5.98 ± 0.11
Total dietary fiber	5.08 ± 0.46
Protein	1.08 ± 0.04
Lipid	0.26 ± 0.05

3.2 Optimum water pretreatment

The development of vacuum-fried sweet pickled radish as a ready-to-eat snack can create a new product with value-added for sweet pickled radish. Before vacuum frying, the fresh sweet pickled radish was water pretreated by soaking in tap water or not soaking (fresh sweet pickled radish). Fresh sweet pickled radish showed the highest TSS content of about 47.33°Brix. The results indicated that TSS content was caused by high sugar concentration during the immersion step with about 25-50% (w/w) sugar. Table 2 presents the experimental samples with sweet pickled radish to tap water ratios of 1:3, 1:6, and 1:9 (w/w) after water pretreatment exhibited the reduction of TSS content, respectively.

Table 2 Water pretreatment, diameter, and moisture content of vacuum-fried sweet pickled radish at 85°C for 60 min.

Water pretreatment (Ratio of sweet pickled radish to tap water, w/w)	TSS content (°Brix)	Average diameter (mm)		Moisture content (% dry weight)	
		Before Vacuum fried	After Vacuum fried	Before Vacuum fried	After Vacuum fried
Fresh sweet pickled radish (No soaking, control)	47.33±5.03^{a}	21.00±7.01^{c}	12.22±2.09^{d}	53.25±0.65^{c}	23.44±1.90^{a}
1:3	18.00±1.00^{b}	26.38±5.98^{b}	16.50±3.79^{c}	75.03±1.37^{b}	6.02±0.15^{b}
1:6	12.33±1.53^{c}	29.42±6.66^{a}	18.54±3.04^{b}	75.42±1.95^{b}	5.96±0.11^{b}
1:9	6.00±1.00^{d}	29.23±5.80^{a}	20.54±3.05^{a}	78.52±1.57^{a}	5.01±0.40^{b}

$^{a–d}$: Means ± SD (standard deviation) within a column with different letters were significantly different ($p<0.05$).

Average diameter differences of the samples before (Figure 1A-1D) and after vacuum frying (at 85°C for 60 min) (Figure 1E-1H) were compared between pretreated samples. The results showed that the vacuum-fried products from the soaked sample at 1:9 (Figure 1H) were significantly different in terms of the highest average diameter (20.54 mm) among them ($p<0.05$). This is likely because the increased swelling of the cell wall structure from water absorption also causes a loss of cellular strength [20]. Hence, the larger puffed volume of samples is generated during the frying process.

Not soaking the sample (Figure 1E) resulted in the lowest average diameter ($p<0.05$). This is due to the strongest cellular structure of the non-soaked sample retarding cellular expansion during frying. This result agrees with [21], who also reported that the stronger cellular structure of the Namwa banana caused lower puffed volume during high temperatures and short-time puffing. Therefore, the lowest puffed volume and strong cellular structure retards moisture movement from food during thermal processing. In addition, Thongcharoenpipat and Yamsaengsung [22] also reported that the higher sugar content inside food increased the boiling point of water during the frying process. Hence, the non-soaked fried radish sample contained the highest moisture content, which then resulted in a non-crispy texture.

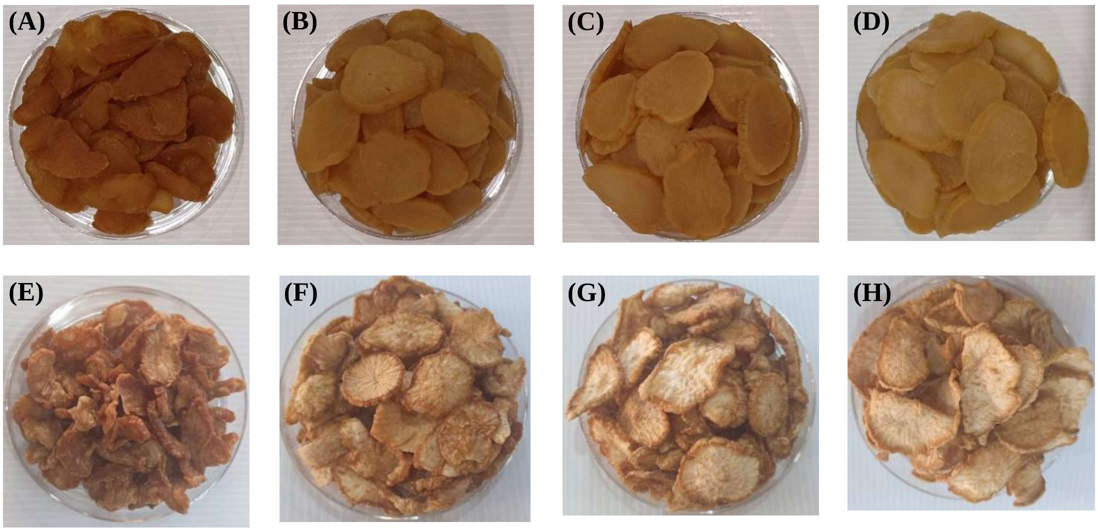

Figure 1 Soaking pretreatment of fresh sweet pickled radish with no soaking (A), soaking ratio of sweet pickled radish to tap water (w/w) at 1:3 (B), 1:6 (C), and 1:9 (D) to compare with vacuum-fried sweet pickled radish at 85°C for 60 min, and after vacuum-fried (E), (F), (G), and (H), respectively.

3.3 Optimum vacuum frying process on the quality of crispy-sweet pickled radish

The frying temperature of crispy-sweet pickled radish was investigated using vacuum pressure at three different temperatures of 85, 90, and 95°C for a duration of 90 min. The mean color values (L*, a*, and b*) of the sweet pickled fried radish were recorded and analyzed, as shown in Table 3.

Table 3 Color values for crispy-sweet pickled radish using the vacuum-frying process.

Vacuum frying process		Color values			Moisture content (% dry weight)
		L*	a*	b*	
Fresh sweet pickled radish (control, no frying)		38.62±1.51^{d}	7.16±0.15^{c}	28.01±1.24^{a}	53.25±0.65^{a}
85ºC	90 Min	50.53±0.58^{a}	6.58±0.25^{a}	13.89±0.41^{c}	4.78±0.19^{c}
90ºC	90 Min	45.17±0.93^{b}	5.62±0.14^{b}	11.41±0.40^{c}	4.14±0.27^{c}
95ºC	90 Min	49.69±0.56^{a}	6.08±0.69^{ab}	12.82±0.99^{c}	4.04±0.75^{c}
85°C	60 Min	44.45±0.48^{c}	6.54±0.19^{a}	12.76±0.55^{c}	5.89±0.49^{b}
85°C	100 Min	64.43±0.97^{a}	6.82±0.11^{a}	18.97±0.76^{b}	4.25±0.54^{c}

$^{a–d}$: Mean ± SD (standard deviation) values within a column with different letters were significantly different (*p*<0.05).

The L* values of the vacuum-fried samples indicated a decrease in lightness with increasing frying temperature. However, the redness (a*) and yellowness (b*) values remained similar across all experimental temperatures. The crispy-sweet pickled radish samples had higher L* values but lower a* and b* values, indicating less browning reaction at 85°C for 90 min under vacuum pressure. According to previous research by Diamante et al. [23], these findings suggest that lower frying temperatures could reduce both the energy costs and nutritional losses associated with higher temperature treatments.

The results of the impact of different frying times (60, 90, and 100 min) at 85°C under vacuum pressure on the color values (L*, a*, and b*) of crispy-sweet pickled radish are presented in Table 3. The results indicated that there were significant differences (*p*<0.05) in the values of L* and b* as the frying time increased, with L* being a critical parameter in the frying industry and an important quality control factor [24]. The L* value of crispy-sweet pickled radish demonstrated the highest lightness under appropriate conditions for vacuum frying (at 85°C for 100 min under vacuum pressure). Additionally, the study explored the textural characteristics of the crispy-sweet pickled radish as a function of frying time, as shown in Figure 2. The investigation of the texture profile curves of crispy-sweet pickled radish, measured in terms of hardness, is presented in Figure 2. Hardness is defined as the maximum force at rapture. Crispness is indicated by the number of peaks in the force-deformation curve [14]. The figure shows the impact of frying time (60, 90, and 100 min) at 85°C on the hardness of vacuum-fried samples. The results indicated that the hardness increased significantly with frying time, with the highest value (9.72 N) observed at 100 min of frying time. Nonetheless, frying time had no significant effect on the crispness of fried radish samples.

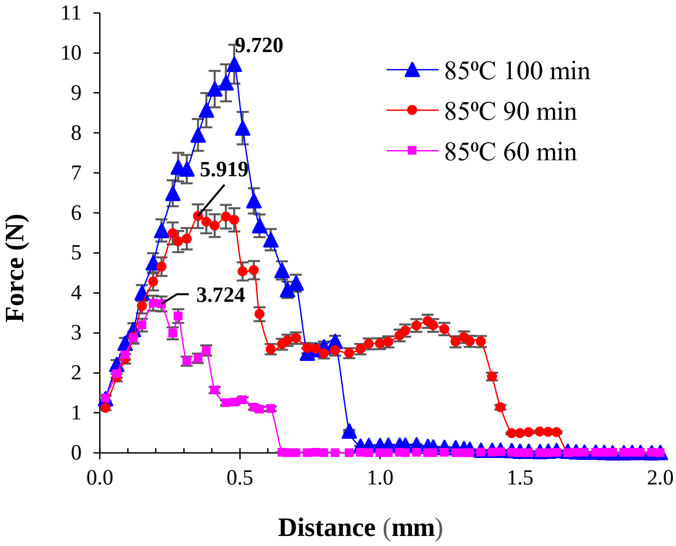

Figure 2 Texture profile curve of crispy-sweet pickled radish under different frying times (60, 90, and 100 min) at 85°C under vacuum conditions.

As shown in Figure 3A and 3B, a comparison of the microstructures in the optimized vacuum-fried sample (vacuum frying process at 85°C for 100 min) was carried out with fresh sweet pickled radish using scanning electron microscopy (SEM).

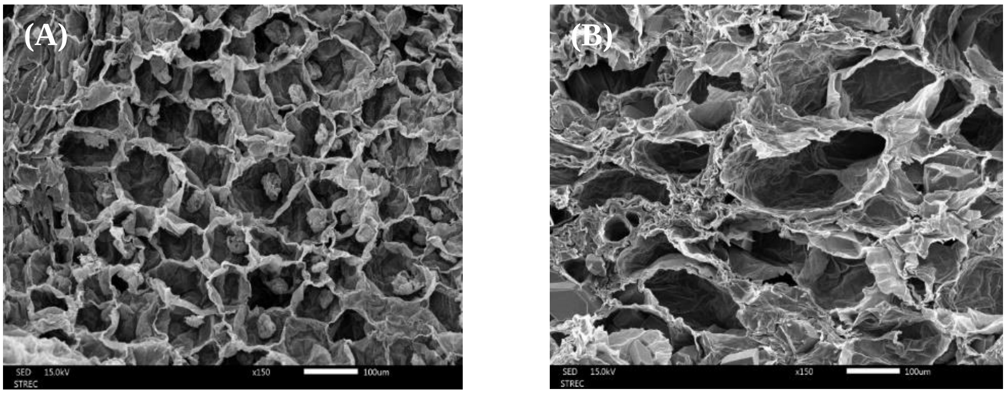

Figure 3 SEM (150x) of sweet pickle radish (A) and optimized crispy-sweet pickled radish (B) by vacuum frying at 85°C for 100 min under vacuum conditions.

The optimized crispy-sweet pickled radish exhibited larger pore sizes, whereas the fresh sweet pickled radish had smaller pore sizes and starch granules (with a diameter > 20 µm) embedded in intracellular spaces. These observations can be attributed to the high carbohydrate and moisture content of sweet pickled radish, as shown in Table 1. The gas expansion of water vapor within sweet pickled radish due to its high moisture content has been reported in previous studies. However, starch content is usually indicated for volume expansion during frying [15, 22]. These results support the notion that the vacuum frying technique can enhance the thickness expansion, puffing, and texture quality of crispy-sweet pickled radish products.

Table 4 displays the nutrition information for crispy-sweet pickled radishes with a serving size of 15 g per package. The aggregate energy value of the product was determined to be 60 kcal, with 10 kcal of this total being derived from fat. Analysis revealed that the high carbohydrate content was predominantly composed of dietary fiber and sugar. The primary emphasis of the crispy-sweet pickled radish was the intrinsic sodium content present within the raw materials.

Notably, the crispy radish contained sodium content of approximately 290 mg per 15 g of serving unit or 1.93% of sodium per serving unit. The sodium content of crispy pickled radish products was lower when compared to commercial products, which contained 2.3-2.75% sodium per serving unit. This is due to the water pretreatment before vacuum frying causing reduced salt content in the pickling process.

Table 4 Nutrition information for crispy-sweet pickled radish.

Nutrition Information			
Serving size: 1 bag (15 g)			
Servings per package: 1			
Amount per serving			
Total energy: 60 kcal (10 kcal from fat)			
			Percent of Thai Recommended Daily Intakes
Total Fat	1	g	2%
Saturated fat	0	g	
Cholesterol	0	mg	
Protein	0	g	
Total Carbohydrates	13	g	4%
Dietary Fiber	3	g	12%
Sugar	7	g	
Sodium	290	mg	15%

The development of the crispy-sweet pickled radish was motivated by the desire to tap into the growing trend of fried vegetable snacks enhanced with Thai seasoning. Such snacks typically incorporate ingredients such as chili and ginger to improve the flavor profile. Opportunities exist to market the product to the segment of consumers seeking convenience and novelty in their consumption habits, particularly those following vegetarian or health-oriented diets that prioritize reduced sodium intake [17].

4. Conclusion

This study investigated the effect of water pretreatments to reduce TSS content, frying temperature, and frying time, on the quality of crispy-sweet radish. Higher carbohydrate content may be caused by higher sugar content inside food material. Therefore, water pretreatment was used to reduce the sugar content and improve the quality of fried sweet pickled radish products. The water pretreatment increased the diameter of crispy products significantly compared to non-soaked products. A picked radish-to-water mass ratio of 1:9 provided the largest diameter of the fried product. Frying at a temperature of 85°C resulted in a lower browning reaction. Furthermore, the textural characteristic of hardness under vacuum conditions was found to be the highest at 85°C for 100 min. SEM images confirmed an increase in the pore size of the optimized crispy-sweet pickled radish compared to raw material. The nutrition data indicated that the water pretreatment potentially reduced salt content inside fried radish products when compared with the commercial product. In future work, energy consumption and production capacity should be analyzed and could include sensory evaluation of the product and product development with appropriate flavor or herbal Thai seasoning.

5. Acknowledgements

The authors are highly grateful to STI coupon for OTOP upgrade project by Office of the Ministry of Higher Education, Science, Research, and Innovation. Raw material was supported by the Maeboonsong partnership in Ratchaburi Province, Thailand.

6. References

[1] Indrati N, Phonsatta N, Poungsombat P, Khoomrung S, Sumpavapol P, Punya A. Metabolic profiles alteration of Southern Thailand traditional sweet pickled mango during the production process. Front Nutr. 2022;9:934842.

[2] Li X, Liu D. Effects of wheat bran co-fermentation on the quality and bacterial community succession during radish fermentation. Food Res Int. 2022;157:111229.

[3] Wu S-M, Wu C-P, Lin Y-H, Wu Y-H, Huang B-C, Wang C-Y. Effect of high pressure pretreatment on myrosinase-glucosinolate system, physicochemical and bacterial properties during fermentation of brine-pickled radishes. Food Res Int. 2022;162(Pt A):112018.

[4] Manzoor S, Masoodi FA, Rashid R, Ganaie TA. Quality changes of edible oils during vacuum and atmospheric frying of potato chips. Innov Food Sci Emerg Technol. 2022;82:103185.

[5] Belkova B, Hradecky J, Hurkova K, Forstova V, Vaclavik L, Hajslova J. Impact of vacuum frying on quality of potato crisps and frying oil. Food Chem. 2018;241:51-59.

[6] Yamsaengsung R, Ariyapuchai T, Prasertsit K. Effects of vacuum frying on structural changes of bananas. J Food Eng. 2011;106(4):298-305.

[7] Patra A, Prasath VA, Sutar PP, Pandian NKS, Pandiselvam R. Evaluation of effect of vacuum frying on textural properties of food products. Food Res Int. 2022;162(Pt B):112074.

[8] Ledbetter M, Blidi S, Ackon S, Bruno F, Sturrock K, Pellegrini N, et al. Effect of novel sequential soaking treatments on Maillard reaction products in potato and alternative vegetable crisps. Heliyon. 2021;7(7):e07441.

[9] Andrés-Bello A, García-Segovia P, Martínez-Monzó J. Vacuum Frying: An alternative to obtain high-quality dried products. Food Eng Rev. 2011;3(2):63-78.

[10] Tabtiang S, Prachayawarakorn S, Soponronnarit S. Optimum condition of producing crisp osmotic banana using superheated steam puffing. J Sci Food Agric. 2017;97(4):1244–1251.

[11] Shyu S-L, Hwang LS. Effects of processing conditions on the quality of vacuum fried apple chips. Food Res Int. 2001;34(2–3):133-142.

[12] AOAC International. Official methods of analysis of AOAC international. 20th ed. Maryland: Asssociation of Official Analytical Chemists; 2016.

[13] AOAC International. Official methods of analysis of AOAC international. 21st ed. Washington: Asssociation of Official Analytical Chemists; 2019.

[14] Saencom S, Chiewchan N, Devahastin S. Production of dried ivy gourd sheet as a health snack. Food Bioprod Process. 2011;89(4):414-421.

[15] Akinpelu OR, Idowu MA, Sobukola OP, Henshaw FO, Sanni SA, Bodunde G, et al. Optimization of processing conditions for vacuum frying of high quality fried plantain chips using response surface methodology (RSM). Food Sci Biotechnol. 2014;23(4):1121-1128.

[16] Murtey MD, Ramasamy P. Life science sample preparations for scanning electron microscopy. Acta Microsc. 2021;30(2):80-91.

[17] Thuy NM, My LTD, Ben TC, Tai NV. Development and quality evaluation of healthy soup for children making from banana and other vegetables. Asia Pac J Sci Technol. 2023;28(01):APST-28-01-9.

[18] Feng S, Bi J, Yi J, Li X, Li J, Ma Y. Cell wall polysaccharides and mono-/disaccharides as chemical determinants for the texture and hygroscopicity of freeze-dried fruit and vegetable cubes. Food Chem. 2022;395:133574.

[19] Hu Y, Liu X, Wu X, Zhang Z, Wu D, Chen C, et al. Several natural phytochemicals from Chinese traditional fermented food-pickled *Raphanus sativus* L.: Purification and characterization. Food Chem X. 2022;15:100390.

[20] Tabtiang S, Yodrux A, Nimmol C, Prachayawarakorn S, Soponronnarit S. Effects of thermal pretreatment and puffing medium variously modify the microstructure and quality of crisps obtained from two banana varieties. J Stored Prod Res. 2023;104:102199.

[21] Tabtiang S, Yodrux A, Nimmol C, Prachayawarakorn S, Soponronnarit S. Effects of variety and ripening level on chemical composition, microstructure change, and qualities of crisp bananas. J Food Process Preserv. 2022;46(3):1-15.

[22] Thongcharoenpipat C, Yamsaengsung R. Microwave-assisted vacuum frying of durian chips: Impact of ripening level on the drying rate, physio-chemical characteristics, and acceptability. Food Bioprod Process. 2023;138:40-52.

[23] Diamante L, Presswood HA, Savage G, Vanhanen L. Vacuum fried gold kiwifruit: Effects of frying process and pre-treatment on the physico-chemical and nutritional qualities. Int Food Res J. 2011;638:632-638.

[24] Mesias M, Delgado-Andrade C, Morales FJ. Risk/benefit evaluation of traditional and novel formulations for snacking: Acrylamide and furfurals as process contaminants. J Food Compost Anal. 2019;79:114-121.