Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 23 October 2023
DOI 10.3389/fsufs.2023.1145946

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OPEN ACCESS

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RECEIVED 16 January 2023
ACCEPTED 11 October 2023
PUBLISHED 23 October 2023

CITATION
Maisont S, Samutsri W, Khamweera P, Phae-ngam W and Limsuwan P (2023) Value-added asparagus (*Asparagus officinalis* L.) as healthy snacks using vacuum frying.
Front. Sustain. Food Syst. 7:1145946.
doi: 10.3389/fsufs.2023.1145946

Value-added asparagus (*Asparagus officinalis* L.) as healthy snacks using vacuum frying

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This study investigated the possibility of using asparagus (*Asparagus officinalis* L.) to produce healthy snacks using vacuum frying. The tip and middle part of asparagus Grade C were soaked in 0.1% Calcium chloride solution and blanched at 95–98°C for 45 s, immediately soaked in water at 30°C for 2 min and packed in the bags to freeze at –18°C before vacuum frying. The samples were fried at 80°C and 986 mbar for 38, 40 and 42 min, and then excess oil in the sample was removed by a centrifuge before being measured properties. The effects of different frying times on the physicochemical and sensory characteristics of the vacuum-fried asparagus were analysed. A scanning electron microscope was used to study the structure of the vacuum-fried product. The result reveals that increasing frying time decreased moisture content, a_w, yield, greenness value and crispiness of vacuumed snacks but increased lightness and yellowness values. SEM showed that vacuumed snacks with increasing frying time resulted in a gradual increase in the size of pores inside the product. When the frying time increased to 42 min, collapsed pores were observed, indicating a breakdown structure. A sensory evaluation of seasonings on vacuum-fried asparagus found that fried asparagus with truffle seasoning had the highest preference levels for all sensory attributes. The truffle seasoned fried asparagus at 80°C under vacuum at a pressure of 986 mbar for 40 min contained protein and fibre content of 14.21 and 15.55%, respectively, vitamin A and beta-carotene of 2.717 μg and 16.30 μg, respectively, and calcium and iron of 182.68 mg and 2.88 mg, respectively. Microorganisms found are under the regulated amount according to the Notification of the Ministry of Public Health. This study demonstrates that asparagus Grade C can be used to produce healthy and acceptable fried snacks.

KEYWORDS

asparagus, snack, vacuum frying, SEM, crispiness, sensory quality

1. Introduction

Asparagus officinalis L. (green asparagus), a classification of the family Asparagaceae, is a cash crop currently widespread in cultivation. It can be grown in many regions worldwide, mainly in the United States and Western developed countries (Guo et al., 2020). The crop has a good taste and is a source of nutrients, vitamins, and minerals (Negi et al., 2010). The nutrient-rich source contains bioactive compounds, including bioactive oligosaccharides and polysaccharides, dietary fibre, flavonoids, steroidal, and saponins (Pegiou et al., 2019; Guo et al., 2020). Due to its composition, and functional attributes, such as antioxidant (Yu and Fan, 2021), antitumor (Sullivan et al., 2017; Xu et al., 2021), and immunomodulatory (Wang et al., 2020), asparagus is an essential healthy food source.

In Thailand, asparagus is grown mainly in the central regions such as Nakhon Pathom, Ratchaburi, Subhan Buri, Phetchaburi, and Lop Buri provinces. A recent study by the Department of Agricultural Extension, Ministry of Agriculture and Cooperative reported that the asparagus annual producing yield in Thailand during the year 2019–2021 was 9,335–19,233 metric tons. Particularly, in Lop Buri province, farmers have been supported and encouraged by the government to grow organic asparagus for both domestic consumption and exportation. According to Thai Agricultural Commodity and Food Standards (TACFS) 1500 (2004), raw asparagus is graded into Grades A, B, AB, C, and undergrade by their thickness, straightness, freshness, and tip tightness. During grade processing, the asparagus may not meet the standards for Grades A, B or AB is culled. The undergrade could have more significant defects, such as curved or misshapen spears, discolouration, or damaged tips. This grade is used for processing purposes, such as canning or freezing, rather than being sold fresh in the market. Thus, this research focuses on introducing small-size asparagus (Grade C) as raw material for food processing to be value-added asparagus as a healthy snack. Currently, these products are in high demand in the US market, worth up to 193 billion US dollars in 2021 (Grand View Research Inc., 2022). According to Euromonitor International, the snack market in Thailand was worth up to 45,338 million baht (1 US dollar ∼34 bath) from 2021 to 2022 (Food Intelligence Center, 2022). The desired snack is made from natural ingredients with less odour and is high in nutrients (Lusas and Rooney, 2001). Therefore, a snack developed from asparagus is a sensible choice.

Snacks are typically made from starch and contain sugar, fat, and flavour enhancers (Lusas and Rooney, 2001). Snacks are granularly prepared and cooked through baking, frying, or extrusion processes. The process chosen depends on the raw material and the final product required. Frying is the most common method for snack processing, resulting in characteristic colours and aromas of fried products. Furthermore, snack processed with conventional tends to have a high oil (Dong et al., 2022). Vacuum frying is a frying process that requires lower pressure, lower temperature, and less oxygen content than the conventional method. It preserves the nutrition of foods and their natural flavour and colour (Da Silva and Moreira, 2008; Dueik and Bouchon, 2011; Diamante et al., 2015). Albertos et al. (2016) reported that vacuum-fried fish patties undergo less oxidation than conventional frying. Foods products processed by vacuum frying are also shown to have a brighter colour (Yamsaengsung et al., 2017), reduced hardness and lower acrylamide content (Belkova et al., 2018), require lower frying temperatures, and be produced faster than deep-fried products (Castillo et al., 2021). In the past years, the advantages and health claims of vacuum frying for food processing have been previously investigated for many applications in agricultural products, including pumpkin chips (Piyalungka et al., 2019), banana chips (Sothornvit, 2011; Udomkun et al., 2018), gold kiwi fruit slices (Diamante et al., 2011), purple yam (Fang et al., 2011), apricot slices (Diamante et al., 2012), potato chips (Mariotti-Celis et al., 2017), mango chips (Ayustaningwarno et al., 2020a,b), and germinated soybean seeds (Lien, 2019).

The use of small-size asparagus as an alternative raw material for producing crip snacks is an attempt to convert this low-price agricultural product into value-added products. In addition, asparagus can be used as a potential ingredient instead of commercial starches to produce healthy snacks. Therefore, in this study, Grade C is introduced as raw material for vacuum frying to be value-added asparagus as a healthy snack, studying the frying process of asparagus using a vacuum fryer with recycled oil to make it more economically sustainable, developing fried asparagus with various tastes, and investigating the chemical and physical properties, microorganisms, and nutritional values of fried asparagus are shown.

2. Materials and methods

2.1. Materials

Green asparagus were obtained from the community enterprise of Sublanga asparagus farmers in Kho Rung, Chai Badan district, Lop Buri province. Rice bran oil (Jaikao Rice Bran Oil) was ordered from Siam Crystal Rice Co., Ltd. (Bangkok, Thailand). Calcium chloride was purchased from KemAus™ (New South Wales, Australia) and seasonings were acquired from Adinop Company Ltd. (Bangkok, Thailand).

2.2. Preparation of asparagus

Green, undamaged asparagus were selected. Asparagus is graded into Grades A, B, AB, C, and undergrade by their stem periphery, straightness, and tip firmness, as shown in Figures 1A–E. In this work, all asparagus used were C-grade. Green asparagus were washed, trimmed and cut into three parts 7-8 cm in length, the tips, middle part, and bottom, with circumferences of 1.58 cm, 1.88 cm, and 2.22 cm, respectively (Figure 1F). The asparagus parts used in this study, called asparagus spears, were the tips and middle segments of the asparagus stem, while the bottom parts were discarded because they were tough. The yield of fresh asparagus was measured from the difference in the average weight of asparagus before and after discarding the bottom part. The results were reported as a percentage. A colourimeter (Minolta, model CR-10, Japan) was then gauged in triplicate to determine the colour of the raw asparagus. Proximate analyses of fresh asparagus were performed before further processing. The moisture content measurements were carried out using the oven drying method according to AOAC (2000). About 3 g of the samples were taken out and dried in the oven (Hot air oven, BINDER, FD, Germany) at 105°C for 3 h, then cooled in a desiccator until a constant weight was achieved (Tanita, KD-200, Thailand). Finally, the moisture content of the products was determined and reported as a percentage. The Kjeldahl method with Nx6.25 was used to quantify crude protein. Ash content was determined in a muffle furnace at 550°C for 3 h until white or light grey ash was obtained. The Soxhlet extraction method was used for the determination of fat content. The crude fibre was analysed by the loss on ignition of the dried residue remaining after digestion of the sample and determined by weight difference. Carbohydrate content was calculated by subtracting the crude protein, fat, fibre, and ash contents from the sample difference and presented as a percentage. The samples were soaked in 0.1% calcium chloride

FIGURE 1
Photographs of five grades of asparagus depend on the size of stem and tip tightness: **(A)** extra-large stem size with tight tips; Grade A, **(B)** large stem size with tight tips; Grade B, **(C)** variations in stem size with spread tips; Grade AB, **(D)** small stem size; Grade C, **(E)** curved stem or misshapen spears, or flowering tips; undergrade, and **(F)** a cutting of asparagus for food processing.

solution and blanched in water at 95–98°C for 45 s before being immediately cooled by soaking in water at room temperature (~30°C) for 2 min. The prepared asparagus samples were packed in the bags to freeze at −18°C before vacuum frying.

2.3. Vacuum frying process

The vacuum frying equipment was fabricated and assembled by Phu Pha Farm Co., Ltd., Bangkok, Thailand (Figure 2). The machine consists of a vacuum chamber and frying basket, inverter and temperature controller, oil receiving tank with a filtering system for residue after frying, and a cooling system, vacuum pump, condenser, and cooling tower. The vacuum chamber was designed from stainless steel with a diameter of 670 mm, height of 640 mm, and wall thickness of 10 mm. The stainless steel of the frying basket had a thickness of 3 mm. The power of the rotary pump was 2.35 kW, and the electric power of the equipment was 15 kW. A study by Diamante et al. (2012) found that increasing the temperature and time during vacuum-frying of apricots at 230 mbar from 70 to 90°C and 35 to 65 min, respectively, led to a higher maximum braking force. In a similar study, Shyu and Hwang (2001) discovered that increasing the frying time of apple chips from 5 to 30 min at 80 mbar resulted in a crisper texture. However, Yamsaengsung et al. (2017) concluded that increasing the temperature from 100 to 120°C had no significant effect on the crispness of banana chips. Thus, for the quality analysis of vacuum-fried asparagus in this study, the main parameters adjusted were a temperature of 80°C and a frying time ranging from 38 to 42 min at a vacuum pressure of 986 mbar. Each bath consisted of 10 kg of the asparagus samples to 100 L of rice bran oil. The samples were fried at 80°C and 986 mbar for 38, 40, and 42 min. After the frying, the oil was recovered from the frying chamber to the reservoir oil tank while the fried product was further oil removing process. The excess frying oil on the surface of the vacuum-fried sample was removed by the centrifugal method up to 1,450 rpm for 5 min. The yield for the fried sample was calculated from the difference in the average weight of asparagus before and after vacuum frying each condition using an electronic digital balance (Tanita, KD-200, Thailand). Finally, these crisp asparagus snacks were stored in sealed plastic boxes for further study.

2.4. Characterisation of vacuum-fried asparagus

2.4.1. Moisture content

The moisture content of vacuum-fried asparagus samples was performed by the oven drying method according to AOAC (2000) in section 2.2.

2.4.2. Water activity

Measuring water activity is crucial for snack products because it directly influences the product's shelf life, safety, and quality, especially the texture, crispiness, and overall sensory attributes of snacks. Water activity (a_w) of food is a measure of the heat expressed as a ratio of the vapour pressure of the water in the sample divided by the vapour pressure of pure water at a given temperature. This study measured water activity using a water activity meter (Aqua Lab, Series 3 WA, United States). Approximately 2 g of each ground vacuum-fried asparagus sample was placed in the water activity tray, a_w was recorded and reported as a ratio without units. Three replicates of the asparagus were performed for each sample.

2.4.3. Colour

The typical 3 g of each ground vacuum-fried asparagus sample was transferred into a petri dish and measured by reading the values at the surface of the ground sample using a colourimeter (Minolta, model CR-10, Japan). Sample colour was evaluated in triplicates according to the method of Maisont et al. (2022). The colourimeter measured the colour parameters of the sample in CIE chromaticity coordinates. Regarding lightness (L*) on a scale of 0–100 (0 black and

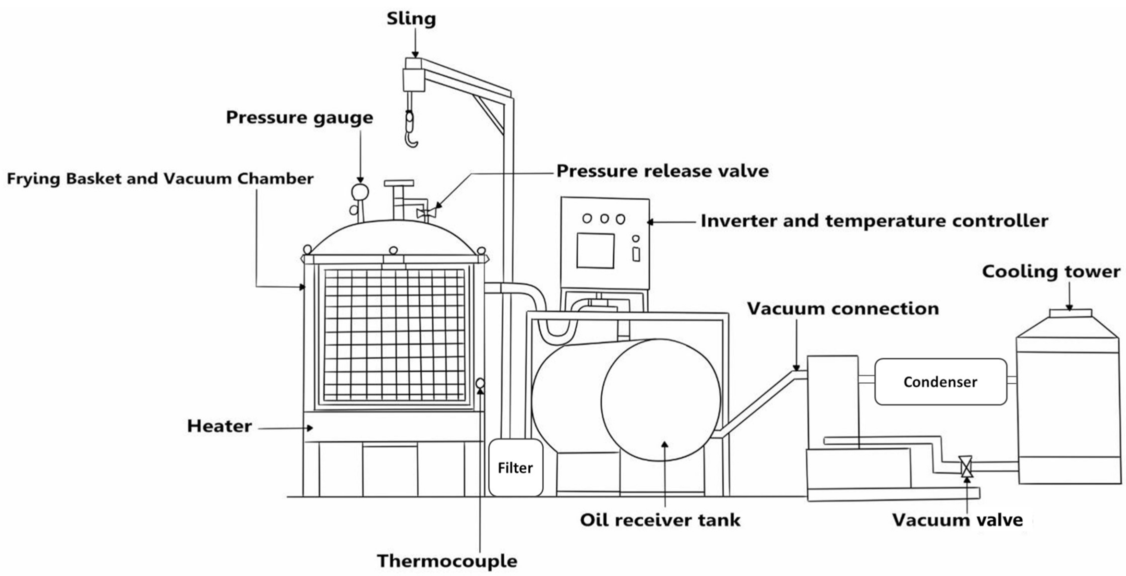

FIGURE 2
Schematic of vacuum fryer used for vacuum frying asparagus.

100 white), redness (a*) in which positive values indicate undertone red and negative values indicate undertone green, and yellowness (b*) in which positive values indicate undertone yellow and negative values indicate undertone blue. The colourimeter was calibrated using a standard white porcelain plate.

2.4.4. Crispiness

The crispiness of the vacuum-fried asparagus was examined through a three-point bending experiment with an applied force in a compression test using a TA.XT Plus Texture Analyser (CTX50K Brookfield, United States). The test was conducted using a TA-TPB three-point bend probe. The instrument includes a steel blade of 3 mm in thickness with a flat edge that fractures the samples at a constant speed rate of 10 mm/s. About twenty replications per sample treatment were used in this study. The plot's highest force (g) value was taken as the breakage resistance for each sample.

2.5. Structural morphology analysis of vacuum-fried asparagus

Scanning electron microscope (SEM: JEOL, JSM-IT300) was used to observe structural morphology within the asparagus after vacuum frying. The voltage was 10 kV, and a magnification of 30× was applied in this experiment. Vacuum-fried asparagus was prepared by defatting with petroleum ether for 12 h before monitoring via SEM to obtain clear images.

2.6. Sensory evaluation of vacuum-fried asparagus

Sensory evaluation of the vacuum-fried asparagus with various flavours was conducted. Five seasoning powders at 6% (w/w) were mixed with the fried asparagus, with the suitability of each flavour determined using a sensory assessment. A kilogram of fried asparagus was mixed with 60 g of seasoning in a 5 L plastic box per batch, shaking for 5 min until fried asparagus was coated with the powder. Samples were served to 30 untrained panelists with a separate booth design in a sensory laboratory in the Food Science and Technology programme at Phranakhon Rajabhat University. 6–8 pieces of each seasoned vacuum-fried asparagus were served in a white plastic cup for them to sample, a total of 30–40 pieces were used. The panelists were required to rate their preference for five different seasonings of vacuum-fried asparagus samples. There were then informed about scaling each attribute, including appearance, colour, taste, flavour, crispiness, and overall liking. They used a seven-point hedonic scale ranging from 1, indicating they immensely disliked it, to 7, indicating they extremely liked it.

The nutritional content and microorganisms of the chosen vacuum-fried asparagus were finally determined by Central Laboratory (Thailand) Co., Ltd.

2.7. Statistical analysis

Three replicates of the asparagus were performed for each sample. The results were expressed through calculated mean and standard deviation. Statistical analysis was performed using SPSS software (SPSS Statistics 19.0). Data were analysed by analysis of variance with a one-way ANOVA, and Duncan's test was used to determine the mean difference between treatments at the 5% significance level.

3. Results and discussion

3.1. Characteristics of fresh asparagus

The proximate analysis results of the asparagus samples indicated that the moisture, protein, fat, crude fibre, ash, and carbohydrate content were 91.98, 2.33, 1.03, 1.06, 1.00, and 2.60%, respectively. However, it is an excellent source of essential nutrients such as protein, amino acids, and dietary fibre. The edible portion of asparagus contains up to 92% moisture content, and the primary nutrients in asparagus, such as fibre and protein, are not more than 3–4%. The asparagus parts used in this study were the tips and middle segments, while the bottom parts were discarded, thus, the yield of fresh asparagus was 45–47%. The colour of fresh asparagus was dark green according to the low L* value of 40.77, while the a* and b* values were also low at −1.87 and 20.98, respectively.

3.2. Physicochemical properties of vacuum-fried asparagus

The asparagus were fried at the temperature of 80°C, vacuum pressure of 986 mbar and frying times of 38, 40, and 42 min. Each fried asparagus was passed to the centrifuge tank to remove excess oil for 5 min while the oil was economically reused in a vacuum fry process for 10–12 batches. The physicochemical properties of vacuum-fried asparagus were measured.

The moisture content, the water of activity (a_w), and the yield of the vacuum-fried asparagus are shown in Table 1. The moisture content, a_w, and yield ranged from 5.36–8.81%, 0.31–0.52, and 13.30–16.42%, respectively. It was found that the moisture content, a_w, and yield of vacuum-fried asparagus at 80°C under different frying times of 38, 40, and 42 min significantly decreased ($p \leq 0.05$) with an increasing frying time. A similar decrease in moisture content was also observed in the vacuum frying of mango chips (Ayustaningwarno et al., 2020a). According to Ayustaningwarno et al. (2020b), the change in moisture content during vacuum frying can be described by an exponential model with a low correlation coefficient for its parameters. By applying thermodynamic theories, it is possible to calculate the temperature of the products during frying based on the boiling point of the moisture present in the sample. This boiling point increases as the water content of the sample decreases.

Moreover, the moisture content, a_w, and yield of the tip segment were slightly higher than the yield of the middle segment. This phenomenon is because heat reduces the moisture content of the sample, in this study from 97% to 5.36–8.81%, and a long frying process results in the evaporation of much water, which resulted in asparagus that was lightweight and with reduced yields. Generally, the a_w value for the dried product is below 0.6, resulting in the fried product can be stored over a prolonged period. The dried products are kept long because a_w correlates with microbial growth rates and many degradative reactions, indicating product stability and microbial safety.

The colour measurement L*, a*, and b* values of vacuum-fried asparagus are shown in Table 2. The L* value of vacuum-fried asparagus at 80°C under different frying times for 38, 40, and 42 min significantly increased ($p \leq 0.05$). In contrast, the b* value decreased with increased frying times, and the negative a* values indicate a green undertone. Thus, the product colour was green-brown with brighter middle parts (Figure 3). The vacuum-treated samples became darker, less green, and more yellow compared to the fresh asparagus sample which was dark green according to the low L* value of 40.77, while the a* and b* values were also low at −1.87 and 20.98, respectively. Moreover, the brown colour of the vacuum-fried product increased with a longer vacuum frying time. A non-enzymatic browning reaction during heating could be the cause. The high temperature used in processed foods leads to non-enzymatic browning reactions, which may occur between reducing sugars and amino acids and between ascorbic acid and other oxidized ascorbic acids, which step into Millard-type browning reactions (Da Silva and Moreira, 2008; Dueik and Bouchon, 2011; Diamante et al., 2012). Diamante et al. (2011,

TABLE 1 Moisture content, water activity (a_w), and yield of vacuum-fried asparagus at 80°C.

Frying time (min)	Asparagus parts	Moisture content (%)	a_w (–)	Yield (%)
38	Tip	$8.81^a \pm 0.07$	$0.52^a \pm 0.01$	$16.42^a \pm 0.44$
	Middle part	$7.06^b \pm 0.15$	$0.40^b \pm 0.00$	$15.11^c \pm 0.51$
40	Tip	$6.72^c \pm 0.02$	$0.36^c \pm 0.00$	$15.51^b \pm 0.20$
	Middle part	$6.12^d \pm 0.02$	$0.31^e \pm 0.00$	$14.58^d \pm 0.35$
42	Tip	$5.62^e \pm 0.02$	$0.34^d \pm 0.00$	$13.60^e \pm 0.26$
	Middle part	$5.36^f \pm 0.00$	$0.32^e \pm 0.01$	$13.30^f \pm 0.39$

Mean ± standard deviation in the same column with different superscripts are significantly different ($p \leq 0.05$).

TABLE 2 Colour and crispiness of vacuum-fried asparagus vacuum fried at 80°C.

Frying time (min)	Asparagus parts	Colour			Crispiness (*N*)
		L*	a*	b*	
38	Tip	$30.04^c \pm 0.36$	$-2.46^d \pm 0.15$	$10.50^c \pm 0.33$	$2.45^b \pm 0.30$
	Middle part	$32.66^b \pm 0.13$	$-3.80^e \pm 0.12$	$13.58^a \pm 0.78$	$3.11^a \pm 0.48$
40	Tip	$29.64^{cd} \pm 0.18$	$-0.26^b \pm 0.05$	$9.16^d \pm 0.22$	$2.36^{bc} \pm 0.34$
	Middle part	$32.78^b \pm 0.20$	$-0.64^c \pm 0.09$	$13.52^a \pm 0.32$	$2.42^{bc} \pm 0.44$
42	Tip	$29.60^d \pm 0.44$	$0.10^a \pm 0.10$	$7.44^e \pm 0.57$	$2.06^c \pm 0.30$
	Middle part	$33.50^a \pm 0.39$	$-0.18^b \pm 0.16$	$11.20^b \pm 0.51$	$2.14^{bc} \pm 0.46$

Mean ± standard deviation in the same column with different superscripts are significantly different ($p \leq 0.05$).

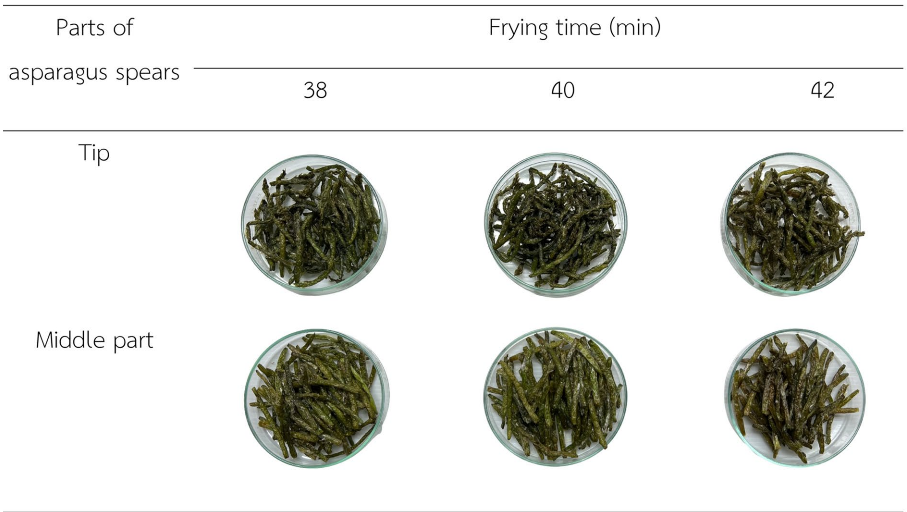

FIGURE 3
Photographs of fried asparagus at 80°C under different frying times for each part.

2012) reported that vacuum frying apricot and gold kiwi slices with different processes in terms of temperature and time resulted in products with higher browning indices. However, these reactions may be impeded under the vacuum frying process due to low temperatures and the absence of oxygen (Da Silva and Moreira, 2008; Dueik and Bouchon, 2011). In addition, the samples underwent milling and were then analyzed for colour using the Hunter Lab colourimeter. It is important to note that the colour of the milled material may differ from that of the surface due to the exposure of the inner material. Ayustaningwarno et al. (2021) reported that the homogenization process involves mixing the light and dark colour areas, as well as blending the surface material with the internal tissue and oil in vacuum-fried fruits.

The textural properties in vacuum-fried products result from chemical changes in the frying process. An indicator of crispiness was considered by the force required to break the fried asparagus. This value means that a lower breaking force indicates greater crispiness. As can be observed from Table 2, the crispiness value of vacuum-fried asparagus showed that it tended to decrease with longer frying times of 40 and 42 min for both the tip and middle part asparagus segments. This result could be due to the lower moisture content of the sample when the frying time was increased (Table 2), which consequently caused a crisper texture of the vacuum-fried asparagus. The moisture content in the product dramatically decreased, when water is removed from within the product toward the product surface, and the gas vapour expands inside the product causing a pressure build-up and the product puffing (Yamsaengsung et al., 2017), resulting in a crunchy texture. The texture of the vacuum-fried asparagus was affected by the chemical component differences among the asparagus part as well. The matrix of food refers to the chemical components of food and their molecular relationships, as well as the way these components are structurally organized, such as the role of pectin. Pectin is crucial in glueing adjacent cells, resulting in tissue rigidity and firmness (Huyskens-Keil et al., 2005). It is also essential in maintaining matrix cohesiveness during frying (Ayustaningwarno et al., 2018). In the case of asparagus, the pectin content of its shoot tissues, which are involved in growth and development, is lower compared to mature permanent tissues in the middle part of the plant (Huyskens-Keil et al., 2005). This can explain why the middle part of asparagus has a higher breaking value, as it contains more pectin, which helps form a crust. Yamsaengsung et al. (2017) found that the high starch content in vacuum-fried banana chips also helps form a crust. However, to obtain accurate information about the effects of pectin content in asparagus shoots compared to permanent tissues in the middle part of asparagus on quality attributes of fried asparagus should be investigated further.

3.3. Structural morphology of vacuum-fried asparagus

In Figure 4, SEM images capture the inner structure of the vacuum-fried asparagus at 80°C and different frying times of 38, 40, and 42 min for each spear part. It was found that when the frying time was increased to 40 min, there was a gradual increase in the size of pores within the product, while they broke when the frying time increased to 42 min. The effects of vacuum frying on the structure of the vacuum-fried product using different parts of the asparagus were observed. The results indicate slight differences in the number and size of pores with different parts. Compared to the middle part, more extensive and fewer pores were observed in the tip of vacuum-fried asparagus.

Different characteristics of plant matrix could impact the quality of vacuum-fried products as mentioned. These factors include cell size, cell wall, flesh thickness, firmness, intracellular spaces, sugar and fibre content, and fibre type. It is possible that the pectin content in the middle part of the asparagus, which consists of permanent tissues, is higher compared to the actively dividing cells found in the shoot tissues at the tip of the asparagus (Huyskens-Keil et al., 2005). The crispiness value of the middle part of the asparagus is also higher than the tip (Table 2), indicating a crispy and porous matrix.

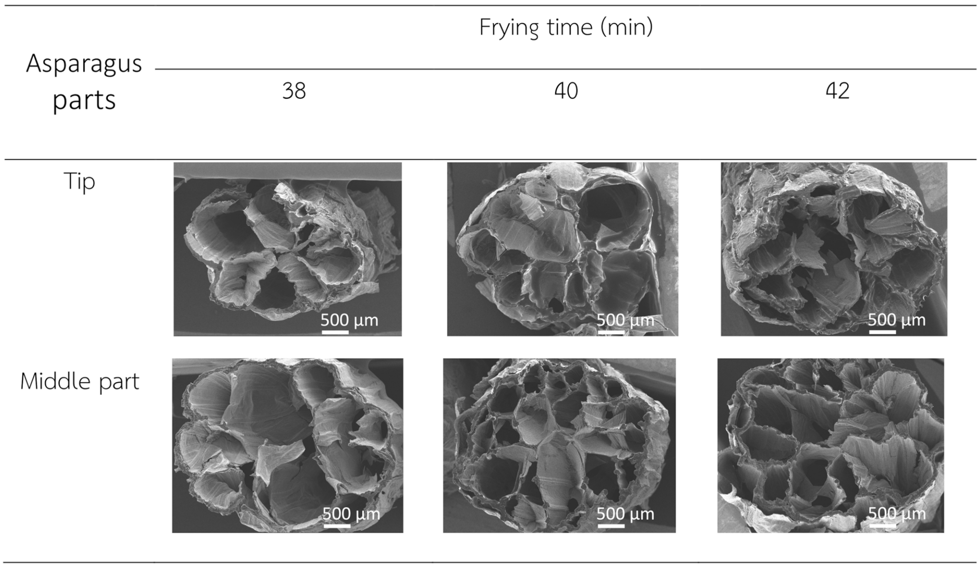

FIGURE 4
SEM images with 30× magnification of vacuum-fried asparagus at 80°C under different duration times for each part.

TABLE 3 Sensory analysis of vacuum-fried asparagus with various seasonings.

Sensory attributes	Seasonings				
	Tom-Yum	Nori Seaweed	Truffle	Salted egg	Cheese
Appearance[ns]	6.05 ± 0.94	5.60 ± 1.45	6.05 ± 0.94	5.60 ± 0.95	6.01 ± 0.82
Colour	5.85[b] ± 0.99	5.75[b] ± 0.91	5.90[a] ± 1.07	5.60[b] ± 0.90	5.60[b] ± 0.85
Flavour	5.30[b] ± 1.08	5.95[a] ± 1.00	6.00[a] ± 1.17	5.33[b] ± 0.96	5.35[b] ± 0.98
Taste	5.25[c] ± 1.02	5.95[b] ± 0.89	6.50[a] ± 0.83	5.20[c] ± 0.95	5.79[b] ± 0.89
Crispiness[ns]	6.10 ± 0.79	6.30 ± 0.98	6.45 ± 0.88	5.70 ± 0.80	5.90 ± 0.75
Overall acceptability	5.30[b] ± 0.89	6.05[a] ± 0.69	6.30[a] ± 0.80	5.45[b] ± 0.69	5.50[b] ± 0.80

Mean ± standard deviation in the same row with different superscripts is significantly different ($p \leq 0.05$). [ns]Mean ± standard deviation in the same row with different superscripts are non-significantly different ($p \leq 0.05$).

The analysis of the moisture content, a_w, yield, colour and especially textural properties also are essential characteristics. The main quality characteristic of snack products is their crispiness. The criteria for selecting fried products in this study focus on suitable product crunchy. The sample that was fried for 42 min had lower crispiness values compared to the one fried for 40 min, resulting in a crisper texture that made it more prone to collapsing. Therefore, the asparagus vacuum fried at 80°C for 40 min was chosen for further study, including the tip and middle parts. A further experiment was conducted to determine a suitable seasoning powder for the fried asparagus product, which is elaborated on in the next section.

3.4. Sensory evaluation

This section presents the results of studying various seasonings on the vacuum-fried asparagus cooked at 80°C for 40 min. The moisture content and a_w ranged from 5.63–6.06% to 0.40–0.46, respectively. The moisture content and a_w of each flavour were not statistically different ($p > 0.05$).

The sensory attributes in terms of appearance, colour, flavour, taste, crispiness, and overall acceptability for vacuum-fried asparagus cooked at 80°C with a frying time of 40 min are presented in Table 3. Crispiness is the key quality characteristic of snack products for consumer sensory to determine the acceptance. Using various seasoning powders can affect the crispiness of the product in different ways. The results showed that there were no significant differences ($p \leq 0.05$) in the appearance and crispiness of the seasoned vacuum-fried asparagus samples. In contrast, the liking scores of the sample ranged between 5.6 (like) – 6.05 (like very much) for appearance and 5.7 (like) – 6.45 (like very much) for crispiness, respectively. However, there were significant ($p \leq 0.05$) differences in colour, flavour, taste, and overall acceptability of the vacuum-fried asparagus seasoned with Tom-Yum, Nori seaweed, truffle, salted egg, and cheese flavours. Moreover, the highest colour, flavour, taste, and overall acceptability score was for vacuum-fried asparagus seasoned with truffle. Thus, the nutrition values and microorganisms of the chosen vacuum-fried asparagus were determined. The sensory attributes in terms of appearance, colour, flavour, taste, crispiness, and overall acceptability for vacuum-fried asparagus cooked at 80°C with a frying time of 40 min are presented in Table 3. There were no significant differences ($p \leq 0.05$) in the

TABLE 4 Analysis of the nutritional value of vacuum-fried asparagus seasoned with truffle*.

List of analysis	Per 100 g	Per serving size
Total energy (kcal)	587.45	70
Energy from fat (kcal)	392.13	45
Total fat (g)	43.57	5
Saturated fat (g)	10.89	1.5
Cholesterol (mg)	Not detected	0
Protein (g)	14.21	2
Carbohydrate (g)	34.62	4
Fibre (g)	15.55	2
Sugar (g)	1.15	0
Sodium (g)	349.53	40
Vitamin A (μg)	2.717	0.33
Beta-carotene (μg)	16.30	1.96
Vitamin B1 (mg)	0.041	0.00
Vitamin B2 (mg)	0.069	0.01
Calcium (mg)	182.68	21.92
Iron (mg)	2.88	0.35
ash (g)	5.04	-

*Analysed by Central Laboratory (Thailand) Co., Ltd. (2023).

appearance and crispiness of the seasoned vacuum-fried asparagus samples. In contrast, the liking scores of the sample ranged between 5.6 (like) – 6.05 (like very much) for appearance and 5.7 (like) – 6.45 (like very much) for crispiness, respectively. However, there were significant ($p \leq 0.05$) differences in colour, flavour, taste, and overall acceptability of the vacuum-fried asparagus seasoned with Tom-Yum, Nori seaweed, truffle, salted egg, and cheese flavours. Moreover, the highest colour, flavour, taste, and overall acceptability score was for vacuum-fried asparagus seasoned with truffle. Thus, the nutrition values and microorganisms of the chosen vacuum-fried asparagus were determined.

The nutritional value of the final product vacuum-fried asparagus seasoned with truffle is shown in Table 4. It was found that the truffle seasoned fried asparagus contained protein and fibre content of 14.21 and 15.55%, respectively, vitamin A and beta-carotene of 2.717 μg and 16.30 μg, respectively, and calcium and iron of 182.68 mg and 2.88 mg, respectively. The finding showed that vacuum-fried asparagus truffle flavour provides high nutrients, making them an excellent choice for consumers interested in eating healthy among plenty of crispy starchy snacks.

Crisp snacks are known for their low moisture content. However, even with low moisture, microorganisms can still affect the quality and safety of the product over time. Regulatory agencies often have specific microbiological standards and guidelines for food products, including crisp snacks. Meeting these standards is essential for complying with food safety regulations and ensuring consumer safety. Microorganisms in the vacuum-fried asparagus seasoned with truffle were analysed by Central Laboratory (Thailand) Co., Ltd., (2023). The study found that *Bacillus cereus*, *Clostridium perfringens*, Salmonella spp., and *Staphylococcus aureus* were 4.5×10 cfu/g, less than 10 cfu/g, non-detected, and less than 10 cfu/g, respectively, which is under the regulated amount according to the Notification of the Ministry of Public Health (No.416): Prescribing the quality or standard, principles, conditions, and methods of analysis for pathogenic microorganisms in foods.

4. Conclusion

This study successfully provided the potential use of undergrade asparagus in vacuum-fried crisp products and the development of healthy snacks, especially dietary fibre, rather than commercial starch-based snacks. The small-size asparagus (grade C) was fried at 80°C and 986 mbar for 38, 40, and 42 min with a ratio of asparagus to rice bran oil 10 kg to 100 L per batch. The increasing frying time significantly affected the physicochemical properties of vacuum-fried products. The moisture content, a_w, and yield of the products were significantly decreased with more prolonged frying time. The colour of vacuum-fried asparagus was green-brown. Moreover, the green-brown colour of the vacuum-fried products was increased with a more extended vacuum frying. The crispiness of vacuum-fried asparagus decreased when frying time increased. The vacuum-fried asparagus cooked at 80°C and 986 mbar for 40 min was considered acceptable regarding crispiness and colour aspects to produce a crunchy snack. Additionally, vacuum-fried asparagus seasoned with truffle flavour was sensorially acceptable from consumers among Tom-Yum, Nori seaweed, truffle, salted egg, and cheese flavours. These findings demonstrated the scope for value-added utilisation of undergrade asparagus derived from agricultural waste to produce nutritious snacks.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Funding

This work was supported by the National Science and Technology Development Agency (NSTDA) 2021.

Acknowledgments

The authors would like to thank Phu Pha Farm Co. Ltd. for providing the vacuum frying equipment and Phranakhon Rajabhat University for their support to complete this work.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Albertos, I., Martin-Diana, A. B., Jaime, I., Diez, A. M., and Rico, D. (2016). Protective role of vacuum vs. atmospheric frying on PUFA balance and lipid oxidation. *Innov. Food Sci. Emerg.* 36, 336–342. doi: 10.1016/j.ifset.2016.07.006

AOAC. (2000). *Official methods of analysis*. Association of official analytical chemists. Washington, DC.

Ayustaningwarno, F., Dekker, M., Fogliano, V., and Verkerk, R. (2018). Effect of vacuum frying on quality attributes of fruits. *Food Eng. Rev.* 10, 154–164. doi: 10.1007/s12393-018-9178-x

Ayustaningwarno, F., Fogliano, V., Verkerk, R., and Dekker, M. (2021). Surface color distribution analysis by computer vision compared to sensory testing: vacuum fried fruits as a case study. *Food Res. Int.* 143:110230. doi: 10.1016/j.foodres.2021.110230

Ayustaningwarno, F., Ginkel, E. V., Vitorino, J., Dekker, M., Fogliano, V., and Verkerk, R. (2020a). The nutritional and physicochemical quality of vacuum-fried mango chips is affected by the ripening stage, frying temperature, and time. *Front. Nutr.* 7:95. doi: 10.3389/fnut.2020.00095

Ayustaningwarno, F., Verkerk, R., Fogliano, V., and Dekker, M. (2020b). The pivotal role of moisture content in the kinetic modelling of the quality attributes of vacuum fried chips. *Innov. Food Sci. Emerg. Technol.* 59:102251. doi: 10.1016/j.ifset.2019.102251

Belkova, B., Hardecky, J., Hurkova, K., Forstova, V., Vaclavik, L., and Hajslova, J. (2018). Impact of vacuum frying on quality of potato crisps and frying oil. *Food Chem.* 241, 51–59. doi: 10.1016/j.foodchem.2017.08.062

Castillo, P. M. M., Díaz, L. T., Díaz, S. T., Correa, D. A., and Gómez, R. J. M. (2021). Mass transfer during atmospheric and vacuum frying of chorizo. *Int. J. Food Sci.* 2021, 1–9. doi: 10.1155/2021/9142412

Central Laboratory (Thailand) Co., Ltd., (2023). Analysis of the nutritional value and microorganisms of vacuum-fried asparagus seasoned with truffle. Bangkok, Thailand: Bangkok Branch, Kasetsart University.

Da Silva, P. F., and Moreira, R. G. (2008). Vacuum frying of high-quality fruit and vegetable-based snacks. *LWT-Food Sci Technol.* 41, 1758–1767. doi: 10.1016/j.lwt.2008.01.016

Diamante, L. M., Presswood, H. A., Savage, G. P., and Vanhanen, L. (2011). Vacuum fried gold kiwifruit: effect of frying process and pre-treatment on the physic-chemical and nutritional qualities. *Int. Food Res. J.* 18, 643–649.

Diamante, L. M., Savage, G. P., Vanhanen, L., and Ihns, R. (2012). Effects of maltodextrin level, frying temperature and time on the moisture, oil and beta-carotene contents of vacuum-fried apricot slices. *Int. J. Food Sci. Tech.* 47, 325–331. doi: 10.1111/j.1365-2621.2011.02842.x

Diamante, L. M., Shi, S., Hellmann, A., and Busch, J. (2015). Vacuum frying foods: products, process and optimization. *Int. Food Res. J.* 22, 15–22.

Dong, L., Qiu, C.-Y., Wang, R.-C., Zhang, Y., Wang, J., Liu, J.-M., et al. (2022). Effects of air frying on French fries: the indication role of physicochemical properties on the formation of Maillard hazards, and the changes of starch digestibility. *Front. Nutr.* 9:889901. doi: 10.3389/fnut.2022.889901

Dueik, V., and Bouchon, P. (2011). Vacuum frying is a route to produce novel snacks with desired quality attributes according to new health trends. *J. Food Sci.* 76, E188–E195. doi: 10.1111/j.1750-3841.2010.01976.x

Fang, Z., Wu, D., Yu, D., Ye, X., Liu, D., and Chen, J. (2011). Phenolic compounds in Chinese purple yam and changes during vacuum frying. *Food Chem.* 128, 943–948. doi: 10.1016/j.foodchem.2011.03.123

Food Intelligence Center. (2022). Food Market Share in Thailand. Available at: https://www.nfi.or.th/datas/files/News/Issue-July-10%20top%20trend1.pdf. (Accessed November 23, 2022).

Grand View Research Inc., (2022). Healthy Snacks Market Size, Share & Trends Analysis Report. Available at: https://www.fortunebusinessinsights.com/industry-reports/healthy-snacks-market-101454. (Accessed November 23, 2022).

Guo, Q., Wang, N., Liu, H., Li, Z., Lu, L., and Wang, C. (2020). The bioactive compounds and biological functions of *Asparagus officnalis* L. *A review. J. Func. Foods* 65:103727. doi: 10.1016/j.jff.2019.103727

Huyskens-Keil, S., Herppich, W. B., and Kadau, R. (2005). Textural properties and cell wall metabolism of white asparagus spears (*Asparagus officinalis* L.) during postharvest. *J. Hort. Sci.* 68, 431–437. doi: 10.17660/ActaHortic.2005.682.55

Lien, D. T. P. (2019). Kinetics of quality changes during vacuum frying of germinated soybean seeds. *Int. J. Multidisc. Res. Anal.* 2, 2643–9875.

Lusas, E.W, and Rooney, L.W. (2001). *Snack Foods Processing*. Technomic Publishing Company, Inc. Pennsylvania, USA.

Maisont, S., Samutsri, W., Sansomboon, A., and Limsuwan, P. (2022). Drying edible jellyfish (*Lobonema smithii*) using a parabolic greenhouse solar dryer. *Food Res.* 6, 165–173. doi: 10.26656/fr.2017.6(6).883

Mariotti-Celis, M. S., Cortes, P., Dueik, V., and Bouchon, P. (2017). Application of vacuum frying as a furan and acrylamide mitigation technology in potato chips. *Food Bioprocess Technol.* 10, 2092–2099. doi: 10.1007/s11947-017-1981-5

Negi, J. S., Singh, P., Joshi, G. P., Rawat, M. S., and Bisht, V. K. (2010). Chemical constituents of asparagus. *Pharmacogn. Rev.* 4, 215–220. doi: 10.4103/0973-7847.70921

Pegiou, E., Mumm, R., Acharya, P., de Vos, R. C. H., and Hall, R. D. (2019). Green and white asparagus (*Asparagus officinalis*): a source of developmental, chemical and urinary intrigue. *Meta* 10:17. doi: 10.3390/metabo10010017

Piyalungka, P., Sadiq, M. B., Assavarachan, R., and Nguyen, L. T. (2019). Effect of osmotic pretreatment and frying conditions on quality and storage stability of vacuum-fried pumpkin chips. *Int. J. Food Sci. Technol.* 54, 2963–2972. doi: 10.1111/ijfs.14209

Shyu, S.-L., and Hwang, L. S. (2001). Effects of processing conditions on the quality of vacuum fried apple chips. *Food Res. Int.* 34, 133–142. doi: 10.1016/S0963-9969(00)00141

Sothornvit, R. (2011). Edible coating and post-frying centrifuge step effect on the quality of vacuum-fried banana chips. *J. Food Eng.* 107, 319–325. doi: 10.1016/j.jfoodeng.2011.07.010

Sullivan, S. A., Tran, A. Q. M., Xu, G., Yin, Y., Zhou, C., and Bae-Jump, V. L. (2017). Asparagus polysaccharide inhibits cell proliferation, adhesion and invasion in endometrial cancer cells. *Abstr. Gynecol. Oncol.* 145:133. doi: 10.1016/j.ygyno.2017.03.312

Thai Agricultural Commodity and Food Standards (TACFS) 1500. (2004). *Asparagus*. National Bureau of Agricultural Commodity and Food Standards, Ministry of Agriculture and Cooperatives. Bangkok, Thailand.

Udomkun, P., Innawong, B., and Njukwe, E. (2018). Effect of vacuum frying conditions on physicochemical properties of banana chips. *Sci., Eng. Health Stud.* 12, 169–178. doi: 10.14456/sehs.2018.16

Wang, N., Zhang, X., Wang, S., Guo, Q., Li, Z., Liu, H., et al. (2020). Structural characterisation and immunomodulatory activity of polysaccharides from white asparagus skin. *Carbohydr Polym. Jan* 227:115314. doi: 10.1016/j.carbpol.2019.115314

Xu, G., Kong, W., Fang, Z., Fan, Y., Yin, Y., Sullivan, S. A., et al. (2021). *Asparagus officinalis* exhibits AntiTumorigenic and anti-metastatic effects in ovarian cancer. *Front. Oncol.* 11:688461. doi: 10.3389/fonc.2021.688461

Yamsaengsung, R., Yaeed, S., and Ophithakorn, T. (2017). Vacuum frying of fish tofu and effect on oil quality usage life. *J. Food Process Eng.* 40:e12587. doi: 10.1111/jfpe.12587

Yu, Q., and Fan, L. (2021). Improving the bioactive ingredients and functions of asparagus from efficient to emerging processing technologies: a review. *Food Chem.* 358:129903. doi: 10.1016/j.foodchem.2021.129903