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Vacuum frying below the triple point of water (VFBTPW) of frozen unmarinated beef slices

Lemuel M. Diamante[1*]

A b s t r a c t: The study was carried out: a) to conduct vacuum frying below the triple point of water (VFBTPW) of frozen unmarinated beef slices using constant amount of sample used and frying temperature with different frying times and to determine the moisture and fat contents, product yield and rehydration, colour, and texture properties of the resulting vacuum fried products; b) to compare the physicochemical properties of VFBTPW and freeze-dried products; and c) to evaluate the structure of the vacuum fried beef slices using the scanning electron microscope. Vacuum frying of frozen unmarinated beef slices at 79±1°C, the lower the frying time the higher the moisture content of the vacuum fried product. The fat contents of the products were not significantly different with each other The frying time of 5 minutes gave the highest product yield due its high moisture content. The rehydration rate and rehydration ratio of the products were not affected by frying time despite a decreasing chamber pressure with increasing frying time. The chroma value of the products were not different from each other. The integrated force of the products decreased with frying time above 7.5 minutes. The vacuum fried product had lower moisture content but had higher fat content and product yield compared with the freeze-dried product. The rehydration rate and rehydration ratio of the vacuum fried product were lower than the freeze-dried product. The beef muscle fibres of the low moisture product were looser and more porous compared with the high moisture product which were more compact. The freeze-dried product was more porous than the low moisture vacuum fried unmarinated beef based on a transversal cut, but the reverse was observed when it was based on a longitudinal cut.

Keywords: *vacuum frying, beef slices, physicochemical, rehydration properties.*

Introduction

Meat drying may be fundamentally defined as the removal of most of the water present in meat by evaporation of liquid water or sublimation of ice (*Sanchurn et al*., 2012). Drying is a complex process involving simultaneous heat and mass transfer. It results in significant changes in the chemical composition, structure, and physical properties of foods. The heating process and loss of water cause stresses in the cellular structure that lead to changes in microstructure, such as the formation of pores and shrinkage (*Laopoolkit and Suwannaporn*, 2011).

Dehydrated meat, seafoods and vegetables are usually used to enhance the product value of instant noodles. Instant noodles are one of Japan's favourite foods. The taste of instant noodles has been improving significantly in past years and some of them can easily compete the fresh noodles (*Nihei*, 2021). The addition of dried meats sachets add value to instant noodles.

When processing meat, several physicochemical changes appear when different treatments are applied. During heating, the different proteins in meat denature and these cause structural changes, such as destruction of cell membranes, shrinkage of fibres, the aggregation and gel formation of myofibrillar and sarcoplasmic proteins and solubilisation of the connective tissue (*Garcia-Segovia et al*., 2007). When frozen storage is required, as in freeze-drying, quality deterioration cannot be avoided during freezing because of the formation of ice crystals, which leads to distortion of tissue structure and mechanical damage and denaturation of protein (*Jeong et al*., 2011).

A freeze-dried process could provide a porous structure product with little shrinkage, superior taste and aroma retention, and better rehydration capability. Even though high-quality dehydrated foods could be obtained by this process, it is usually considered too expensive to be used in the instant noodle industry. The freeze-dried process is uneconomical due to the large capital outlays required, high operating cost, and relatively long drying time (*Laopoolkit and Suwannaporn*, 2011).

Several attempts have been made to reduce freeze-drying costs by using newer drying technol-

[1] *Seperex, Center for Innovation, 9054 Duendin, PO Box 56, New, Zeland.*

***Coresponding author:** Lemuel Diamante, *LMdiamante2002@yahoo.com*

ogies like vacuum frying. Vacuum frying of meat is another method of drying meat. In this process, the hot oil serves as the heating medium to drive out the water from inside the meat and evaporated accordingly but under chamber pressures below atmospheric pressure (vacuum) which speeds up the drying process. When frozen meat is used, and the chamber pressure is below the triple point of water of 0.01°C and 0.611 kPa (*Guildner et al.*, 1976) then the ice particles sublimes resulting in a porous structure and with minimal shrinkage. Hence, vacuum frying of frozen foods at very low chamber pressure can hopefully yield products with similar characteristics as freeze drying but with a shorter processing time.

However, vacuum frying is the technique of deep-fat frying foods under pressures well below atmospheric levels, preferably below 6.65 kPa, which serves to reduce oil content, discolouration and losses of vitamins and other compounds normally associated with oxidation and high temperature processing (*Garayo and Moreira*, 2002). Vacuum fried products are prepared using fresh fruits and vegetables that are peeled and cut into small pieces. The operating pressure used is usually lower than 7 kPa which produces a good reduction in the boiling point of water and allows the frying temperature to be lower than 90°C (*Dueik and Bouchon*, 2011). *Fan et al.* (2005) reported to have vacuum fried frozen carrot chips at –18°C but use a vacuum frying pressure of 5 kPa which was still above the triple point pressure of water mentioned above. *Diamante and Yamaguchi* (2021) were able to carry out vacuum frying of selected frozen shellfish products at a pressure of 0.4 kPa using a special design of a vacuum fryer where their condenser was similar to that used in freeze dryers in order to achieve chamber pressure below the triple point pressure of water. Hence, they carried out vacuum frying below the triple point of water (VFBTPW) of frozen shellfish products. Unfortunately, they did not present supporting data such as the products porosity and structure for this new technology.

The development of pores and shrinkage depended upon the variation in moisture transport mechanisms and the external pressure. The strength of the solid matrix can also be affected by ice formation, case hardening, permeability of crust, and matrix reinforcement (*Rahman*, 2003). Thus, the drying method and conditions applied has a significant effect on product characteristics such as porosity, shrinkage, and bulk density. The % rehydration of dehydrated foods depends on its water absorption capability and water holding capacity (*Lewicki*, 1998).

It is hypothesized that the VFBTPW of frozen unmarinated beef slices would give a product with closer rehydration properties with the freeze-dried product, and hopefully give a product with a porous structure nearly like a freeze-dried product.

Hence, a study was carried out: a) to conduct vacuum frying below the triple point of water (VFBTPW) of frozen unmarinated beef slices using constant amount of sample used and frying temperature with different frying times and determine the moisture and fat contents, product yield and rehydration, colour, and texture properties of the resulting vacuum fried products; b) to compare the physicochemical properties of VFBTPW and freeze-dried products; and c) to evaluate the porosity and structure of the vacuum fried and freeze-dried beef slices using the scanning electron microscope.

Materials and Methods

Materials

The topside cut meat used in this study was taken from cross breeds of Angus/Hereford beef which were raised in Geraldine, New Zealand, fed with grass and slaughtered at the age of 18 months. After 3 days of chilling by hanging carcasses, the muscle fiber rich meat was used for the experiments.

Sample preparation and storage conditions

The meat was sliced into 4 mm thickness and were hand cut into 2–3 cm slices. The beef slices were spread on aluminum trays and frozen at –35 ± 2°C at an air velocity of about 1.7 m/s in a blast freezer (Skope Refrigeration, Christchurch, New Zealand). The freezing was interrupted after 18 hours to take out the meat slices from the trays and put them into polyethylene bags each with 525 g ±15 g frozen unmarinated beef slices. The samples were stored at –25°C in a laboratory freezer until use.

Vacuum frying system

The equipment used for the experiments consisted of a sealable fryer vessel connected to a condensation unit and a vacuum pump as shown in Figure 1. The heating of the oil was done using band

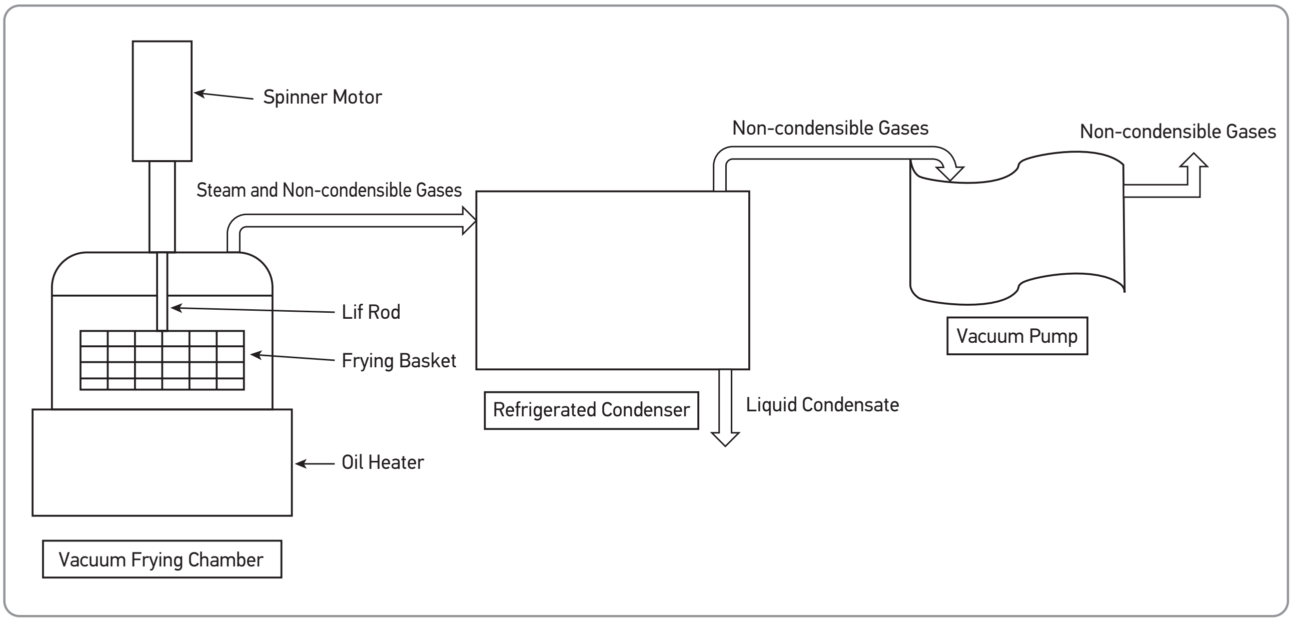

Figure 1. Schematic diagram of the vacuum frying system for the experiments (*Diamante et al.*, 2015).

heaters on the fryer walls and the condenser was cooled using a refrigeration system. Inside the vessel, a frying basket was located, which can be rotated within the chamber. For every trial, 20 litres of canola oil (Seafrost, Kuala Lumpur, Malaysia) were poured in the frying vessel and heated up to the target temperature which took approximately one hour.

The content of a bag of frozen sample was loaded into the frying basket. After closing the vessel lid, the valve to an already operating vacuum pump was opened. When a pressure of 0.4 kPa was reached, the basket with the samples was immersed into the hot oil at the target temperature. From this moment, the time was started, the temperature and chamber pressure were recorded. With the help of the vacuum pump and condensation unit, the escaping steam was taken out of the vessel. Because of the high amount of steam generated at the beginning, the pressure increased for a short period and dropped down again to about 0.4 kPa. The temperature fluctuated with decreasing amplitudes and settled down to the required temperature due to the temperature controller. When the required frying time was reached the basket was completely brought out of the oil and centrifuged using 670 rpm for 4 minutes still at the same chamber pressure to enhance the removal of residual oil from the sample surface. After this procedure, the system was pressurised back to atmospheric pressure. The product was removed out of the basket, cooled down to room temperature, placed inside aluminium laminated bags and then stored at room temperature until analyses.

Freeze-drying of frozen unmarinated beef slices

Freeze-drying of 0.5 kg and 4 mm thick frozen unmarinated beef slices was carried out in another laboratory using the following conditions: chamber temperature of 60°C and chamber pressure of 0.0.01 kPa for about 30 hours

Moisture content determination

The moisture content of the VFBTPW product from each trial run were determined using the air oven method. The products were dried at a constant temperature of 105°C in an air oven (Watson Victor Ltd, Clayson Laboratory Apparatus Ltd, NZ) for exactly 16 hours after which time a constant weight was reached (Diamante et al., 2010). The weight of samples was determined in an analytical balance with an accuracy of 0.0001g (Mettler Toledo, Greifensee, Switzerland) before and after drying in the air oven in 5 replicate measurements. The moisture content was calculated by using the equation,

$$M_{DB} = \frac{B-C}{C-A} \tag{1}$$

where:

M_{DB} = moisture content calculated on % dry basis
A = weight of container [g]
B = weight of container and product before drying [g]
C = weight of container and product after drying [g]

Product yield calculation

The product yield of the VFBTPW product was obtained from its initial and final weights. The amount of frozen sample was determined using a weighing balance with an accuracy of 0.01g (Mettler Toledo, Greifensee, Switzerland). After vacuum frying, the product was cooled down before weighing. The product yield was determined using the following equation,

$$\text{Product Yield} = \frac{\text{Weight of the final vacuum fried product}}{\text{Weight of the initial frozen sample}} \times 100 \quad (2)$$

Fat content determination

The fat content of the ground VFBTPW product was determined gravimetrically by solvent extraction using the Soxhlet technique as described in Bouchon *et al.* (2003). The fat content of the samples was calculated on a percent dry basis and the average value of the 5 replicate measurements were used.

Integrated force analysis

The texture property of the VFBTPW product was determined by measuring the integrated force of the sample using a texture analyser (Texture Analyser Model: TA-XT plus, Serial No: 10781, Stable Micro Systems, Surrey, UK) equipped with a 5 kg load cell. The integrated force measures the area of force versus time curve of the sample. When the integrated force value is low, the product easily breaks up indicating a crunchier product. A ball probe (5 mm diameter) was used to penetrate the samples at a constant speed rate of 1.0 mm/s. Measurements were done on 5 pieces of samples for all the products.

Colour properties determination

The colour properties of the VFBTPW product were determined using a Minolta Reflectance Chroma Meter CR 210 (Minolta Corp., Osaka, Japan) by measuring the L*, a* and b* colour values. The L* value range from 0 (Black) and 100 (White), the a* value from −a* (Green) and +a* (Red) while the b* value range from −b* (Blue) and +b (Yellow). The different products were ground in a multi grinder (Sunbeam Corp., Botany, NSW, Australia) and then a 10g sample was placed on a petri dish without cover. Five sets of ground samples were obtained from each trial run and the average of five readings was used. Before each measurement, the instrument was calibrated using a white ceramic tile (L = 98.06, aX= –0.23, b = 1.88). The Chroma which is the saturation and intensity of colour of the vacuum fried products were determined using the following equation,

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (3)$$

where:

a* and b* = colour values of the vacuum fried product

Rehydration properties calculations

The rehydration properties of the VFBTPW product were determined by weighing a piece of dried product in a weighing balance with 0.01g accuracy (Mettler Toledo, Greifensee, Switzerland) and then putting the piece of dried product in a heat resistant glass bowl with boiling water. A heavier glass bowl was placed on top of the dried product so that it was fully submerged in the hot water. The dried product was left to rehydrate for 3 minutes. At the end of rehydration, the product was taken out of the water and put on three sets of thick tissue paper to dry out all surface moisture. The rehydrated product was weighed in the same weighing balance. The same procedure was repeated for 5 pieces of dried products. The Percentage Gain, Rehydration Rate and Rehydration Ratio of the individual pieces were calculated as follows,

$$\text{Percentage Gain} = \frac{\text{Initial product weight} - \text{Rehydrated weight}}{\text{Initial product weight}} \times 100 \quad (4)$$

$$\text{Rehydration Rate} = \frac{\text{Percentage Gain}}{3\ \text{minutes}} \quad (5)$$

$$\text{Rehydration Ratio} = \frac{\text{Rehydrated weight}}{\text{Initial product weight}} \quad (6)$$

Statistical analyses

A two-way analysis of variance (ANOVA) using Minitab 15 (Minitab Inc., State College, Pennsylvania, USA) was carried out on the moisture content, fat content, product yield, colour values (L*, a* and b*) and chroma and integrated force to determine the significance of the results. The Tukey's test was used to locate the difference between the means (*Walpole et al*., 1998).

Results and Discussion

Preliminary experiments on vacuum frying of frozen unmarinated beef slices

The moisture, fat and product yield of VFBTPW unmarinated beef slices processed using 0.5 kg and 2.0 kg frozen sample (4 mm thick) at different frying temperature and time with chamber pressure of 0.7 ± 0.4 kPa and centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours are summarised in Table 1. The results show that the use of 0.5 kg in vacuum frying resulted to a product with low moisture content, high fat content and higher product yield even with a shorter frying time. When the amount of sample used in vacuum frying was increased to 4-times (2.0 kg) and using a frying time that was 4-times (60 minutes) the product gave a higher moisture content, lower fat content and product yield. By using a frying temperature of 73°C and frying time of 88 minutes can bring down the product moisture content to 2.0% dry basis and attain a fat content of 30.0% dry basis and product yield of 31.7%.

A VFBTPW unmarinated beef slices can be a ready-to-eat product, or it can be incorporated in instant noodles with beef flavour. Hence, the rehydration properties such as the rehydration rate and rehydration ratio are important properties for the VFBTPW products as a noodle ingredient. Table 2 shows the rehydration rate and rehydration ratio of VFBTPW unmarinated beef slices processed with different frying temperature of and time and chamber pressure of 0.7 ± 0.4 kPa with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours. The results show that the use of 0.5 kg frozen sample in vacuum frying resulted

Table 1. Moisture, fat, and product yield of vacuum fried unmarinated beef slices processed using 0.5 kg and 2.0 kg frozen sample (4 mm thick) at different frying temperature of and time and chamber pressure of 0.7 ± 0.4 kPa with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours.

Treatment	Amount (kg)	Oil Temperature (°C)	Frying Time (mins)	Moisture Content (% db)	Fat Content	Product Yield
T1	0.5 kg	79±1*	15	1.9a	37.5a	36.4a
T2	2.0 kg	79**	60	2.8b	16.9b	27.0c
T3	2.0 kg	73**	88	2.0a	30.0a	31.7b
FD	0.5 kg	NA	NA	2.4ab	19.4b	12.0d

Legend: * mean of 3 runs; ** – mean of 2 runs; mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level; NA – not applicable

Table 2. Rehydration rate and ratio of vacuum fried unmarinated beef slices processed with different frying temperature of and time with chamber pressure of 0.7 ± 0.4 kPa and centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours.

Sample	Amount (kg)	Oil Temperature (°C)	Frying Time (mins)	Rehydration rate** (% /min)	Rehydration ratio** (kg rehydrated/ kg dried product)
T1	0.5 kg	79	15	18.7b	16b
T2	2.0 kg	79	60	7.9d	1.2c
T3	2.0 kg	73	88	15.5c	1.5b
FD	0.5 kg	NA	NA	28.5a	1.9a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level; NA – not applicable to a product with high rehydration rate and rehydration ratio even with a shorter frying time. When the amount of sample used in vacuum frying was increased to 2.0 kg (4-times) and using a frying time of 60 minutes (4-times) the product gave lower rehydration rate and rehydration ratio. By using a frying temperature of 73°C and frying time of 88 minutes gave a product rehydration rate of 15.5%/min and rehydration ratio of 1.5 kg rehydrated/kg dried product. Hence, in the succeeding experiments the use of 0.5 kg with a frying temperature of 79±1°C for vacuum frying were used.

Effect of frying temperature on the different properties of vacuum fried beef slices

Vacuum frying experiments were carried out using a frying temperature of around 80°C for vacuum frying of frozen unmarinated beef slices at different frying times. The moisture, fat and product yield of VFBTPW unmarinated beef slices processed using 0.5 kg of frozen sample (4 mm thick) with a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes are summarised in Table 3. The results show that frying times of 5 to 10 minutes resulted to higher VFBTPW product moisture content especially with the shortest frying time. The fat contents of the products were not significantly different from each other at all frying times. It was observed that the fat content of the products had high variability. The frying time of 5 minutes gave the highest product yield due its high moisture content. The fat content and product yield of the vacuum fried mussel and cooked prawn products were 27 to 39% dry basis and 24 to 32%, respectively (*Diamante and Yamaguchi*, 2021) which were slightly lower than the vacuum fried unmarinated beef slices. But the moisture content of the vacuum fried mussel and cooked prawn products were 1.3 to 1.9% dry basis (*Diamante and Yamaguchi*, 2021) which compared well with the vacuum fried beef products.

Table 4 shows the rehydration rate and ratio of VFBTPW unmarinated beef slices processed using 0.5 kg of frozen sample (4 mm thick) with a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes. The results suggest that the rehydration rate and rehydration ratio of the vacuum fried products were not affected by frying time despite a decreasing chamber pressure with increasing frying time. *Diamante and Yamaguchi* (2021) reported the rehydration rate of vacuum fried mussel and cooked prawn products were 12 to 18 %/min and the rehydration ratio were 1.36 to 1.54 kg rehydrated/kg dried product which compared well with the vacuum fried unmarinated beef slices in this study.

The L*, a* and b* colour values, chroma and integrated force of VFBTPW unmarinated beef slices processed using 0.5 kg of frozen sample (4 mm thick) with a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes are shown in Table 5. The results show that the degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the vacuum fried products decreased with frying time above 7.5 minutes. In addition, the degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the products were similar for frying time of 10 to 45 minutes. However, the chroma value of the products were not significant-

Table 3. Moisture, fat, and product yield of vacuum fried unmarinated beef slices processed using 0.5 kg frozen sample (4 mm thick) at a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried samples under the corresponding chamber pressure at 670 rpm for 4 minutes.

Treatment/ (Frying Time)	Oil Temperature (°C)	Chamber Pressure (kPa)	Moisture Content** (% db)	Fat Content** (% db)	Product Yield** (%)
T1 (5 mins)	78.1a	1.44b	35.7d	31.7a	42.2b
T2 (7.5 mins)	78.0a	1.17a	11.7c	33.4a	36.6a
T3 (10 mins)	78.0a	0.97a	4.2b	33.2a	35.0a
T4 (15 mins)	79.3a	8.4a	1.9a	37.5a	36.4a
T5 (30 mins)	79.1a	0.62a	1.7a	36.4a	35.2a
T6 (45 mins)	80.0a	0.58a	1.4a	39.6a	36.1a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level

Table 4. Rehydration rate and ratio of vacuum fried unmarinated beef slices processed using 0.5 kg frozen sample (4 mm thick) at a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the corresponding chamber pressure at 670 rpm for 4 minutes.

Treatment/ (Frying Time)	Oil Temperature (°C)	Chamber Pressure (kPa)	Rehydration rate** (% /min)	Rehydration ratio** (kg rehydrated/ kg dried product)
T1 (5 mins)	78.1	1.44	12.7a	1.4a
T2 (7.5 mins)	78.0	1.17	14.2a	1.4a
T3 (10 mins)	78.0	0.97	16.5a	1.5a
T4 (15 mins)	79.3	0.84	18.7a	1.6a
T5 (30 mins)	79.1	0.62	15.9a	1.5a
T6 (45 mins)	80.0	0.58	16.4a	1.5a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level

ly different from each other. *Hellmann and Diamante* (2022) reported that the colour values of vacuum fried marinated beef slices at the frying temperatures of 65 to 95°C, frying time of 26 to 66 minutes and centrifuge rotational speed of 20 to 670 rpm) were L* = 41 to 49, a* = 9 to 12 and b* = 14 to 22. The L* and b* colour values of the vacuum fried unmarinated beef slices from this study were different probably due to no marination of the beef slices. The integrated force of the products decreased with frying time above 7.5 minutes. Furthermore, the integrated force of the products was the same for frying time of 10 to 45 minutes of 1.2 to 2.1 kg.sec which were higher than that of vacuum fried marinated beef slices at the optimized vacuum frying conditions (85°C, 52 minutes and 517 rpm) of 0.3 kg.sec (*Hellmann and Diamante*, 2021) indicating that it was crunchier than the vacuum fried unmarinated beef products.

Physicochemical properties of vacuum fried and freeze-dried beef products

Comparison of the physicochemical properties of VFBTPW and freeze-dried unmarinated beef slices using 0.5 kg from Tables 1 and 2, showed that the vacuum fried product had lower moisture content but had higher fat content and product yield compared with the freeze-dried product. The rehydration rate and rehydration ratio of the vacuum fried product were lower than the freeze-dried product.

Effect of vacuum frying on the meat structure of VFBTPW unmarinated beef slices

The scanning electron microscope (SEM) image of the low moisture vacuum fried beef cut longitudinally and transversally to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmari-

Table 5. L*, a* and b* colour values, chroma and integrated force of vacuum fried unmarinated beef slices processed using 0.5 kg frozen sample (4 mm thick) at a mean frying temperature of 79±1°C and different frying time and chamber pressures ranging from 0.58 to 1.44 kPa with centrifugation of fried products under the corresponding chamber pressure at 670 rpm for 4 minutes.

Treatment	L* value** (no units)	a* value** (no units)	b* value** (no units)	Chroma** (no units)	Integrated Force** (kg. sec)
T1 (5 mins)	46.3b	9.9a	15.9b	18.8a	4.0b
T2 (7.5 mins)	49.1b	11.0a	14.8b	18.5a	3.4b
T3 (10 mins)	40.3a	10.9a	10.8a	15.4a	1.7a
T4 (15 mins)	34.1a	10.1a	7.9a	12.9a	1.2a
T5 (30 mins)	31.4a	9.2a	6.2a	11.8a	2.1a
T6 (45 mins)	30.9a	9.1a	6.1a	11.0a	1.6a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level nated beef slices processed with an average oil temperature of 80°C (Figure 2) and the SEM image of the high moisture vacuum fried beef cut longitudinally and transversally to the beef muscle fibre using 0.5 kg and 4 mm thick frozen unmarinated beef slices processed with an average oil temperature of 78°C (Figure 3). The results show that the beef muscle fibres of the low moisture vacuum fried product were looser and more porous compared with the high moisture product which were more compact. The porous structure of the low moisture product resulted from subliming the ice of the frozen beef sample during vacuum frying. The average chamber pressure of the process was 0.58 kPa which was below the triple point of water. Because of the short frying time (5 minutes) and the average chamber pressure of 1.44 kPa which was above the triple point of water, the ice in the high moisture product were not sublimed during the vacuum frying process and so this remained in the product as liquid water thereby facilitating the fusing of the beef muscle fibres at the end of the process. On the other hand, the SEM image of the freeze-dried beef product cut longitudinally and transversally to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef slices processed with a chamber

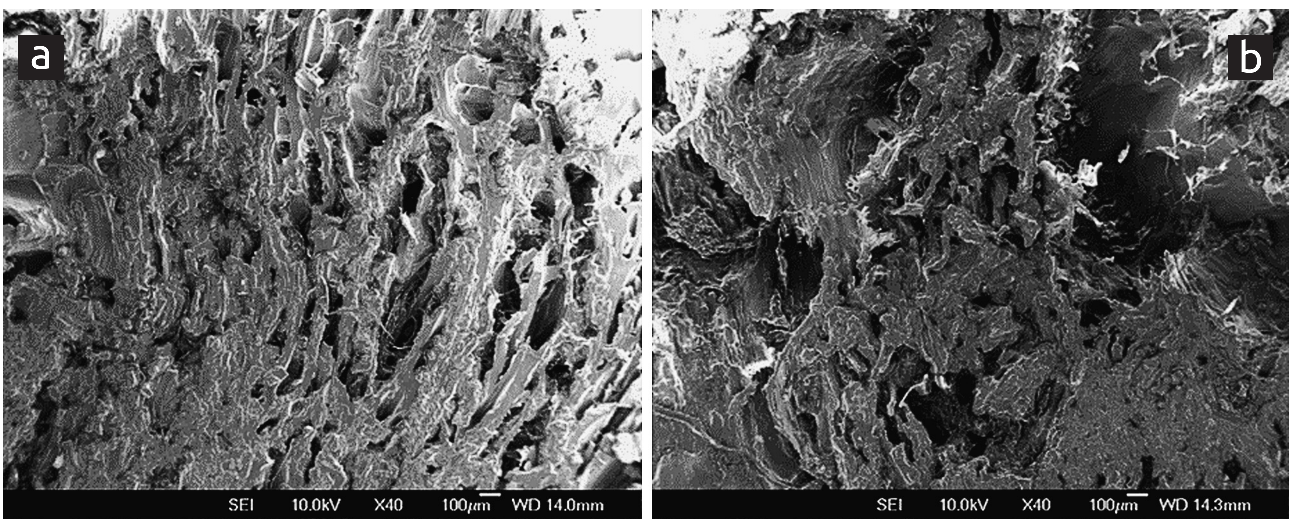

Figure 2. SEM image of low moisture vacuum fried unmarinated beef (MC=1.4% dry basis) cut longitudinally (a) and transversally (b) to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef processed with an average oil temperature of 80°C, an average pressure of 0.58 kPa and frying time of 45 minutes.

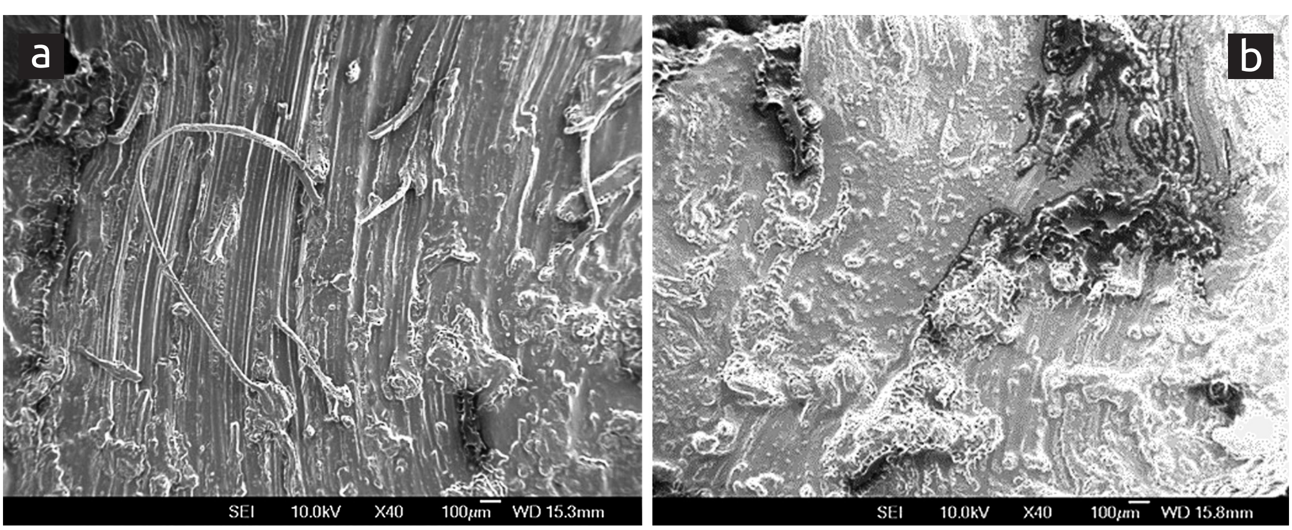

Figure 3. SEM image of high moisture vacuum fried unmarinated beef (MC=35.7% dry basis) cut longitudinally (a) and transversally (b) to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef processed with an average oil temperature of 78°C, an average pressure of 1.44 kPa and frying time of 5 minutes.

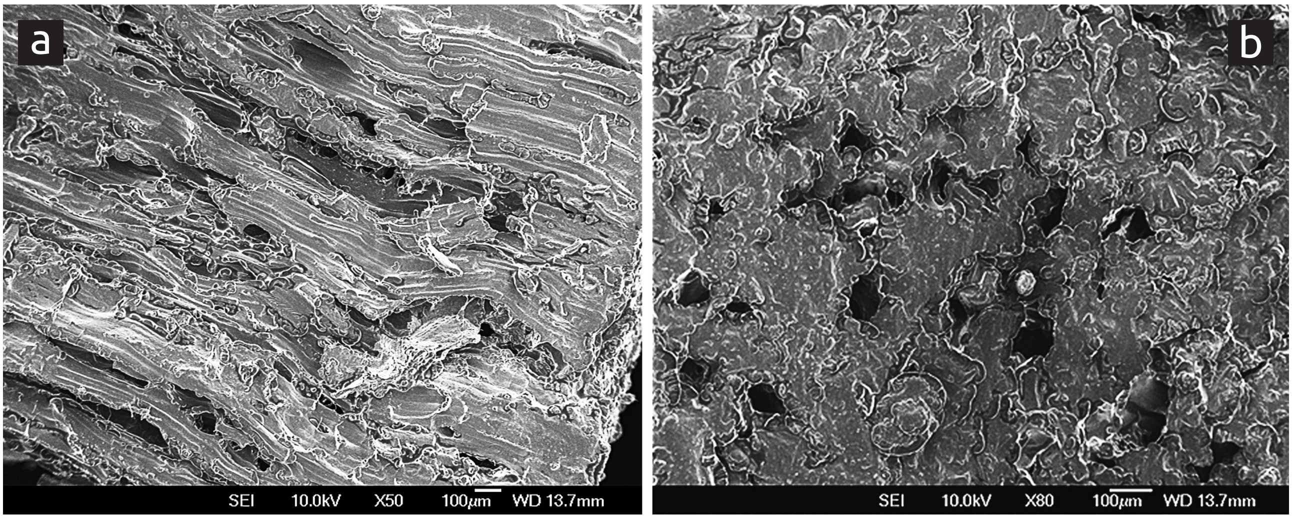

Figure 4. SEM image of freeze-dried unmarinated beef cut longitudinally (a) and transversally (b) to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef processed with a chamber temperature of 60°C and chamber pressure of 0.0.01 kPa for about 30 hours.

temperature of 60°C and chamber pressure of 0.0.01 kPa for about 30 hours (Figure 4). The freeze-dried product was more porous than the low moisture vacuum fried unmarinated beef based on a transversal cut, but the reverse was observed when it is based on a longitudinal cut. *Lapoolkit and Suwannaporn* (2011) reported the SEM image of the longitudinal and transversal structure of freeze-dried pork and *Messina et al.* (2015) of the SEM image of the transversal structure of freeze-dried beef which compared ell with the SEM image of the low moisture vacuum fried unmarinated beef. The freeze-dried pork though had slightly more pores than the vacuum fried beef.

Implications of the results

The results suggest that the vacuum frying below the triple point of water (VFBTPW) of frozen food is a new technology that can be used to produce dried meat and seafood products, especially as an ingredient for instant noodles that will have good rehydration properties closer to freeze-dried products. The VFBTPW dried product had higher fat content which resulted in higher product yield compared with freeze-dried product. High fat content dried beef product in instant noodles is acceptable because some manufacturers add an oil sachet to enhance the flavour. In addition, the dried product from VFBTPW can be produced in a much shorter time (about 15 minutes) compared to freeze-dried products (about 30 hours). Hence, the VFBTPW dried products will be much cheaper compared with the freeze dried product, especially when used in instant noodles.

Conclusion

Using 0.5 kg frozen unmarinated beef slices in vacuum frying below the triple point of water (VFBTPW) at 79°C resulted to a product with low moisture content, high fat content, higher product yield and high rehydration rate and rehydration ratio even with a shorter frying time compared to a 2.0 kg frozen sample. The frying times of 5 to 10 minutes resulted to higher VFBTPW product moisture content especially with the shortest frying time. The fat contents of the VFBTPW products were not significantly different with each other at all frying times. The frying time of 5 minutes gave the highest product yield due its high moisture content. The rehydration rate and rehydration ratio of the VFBTPW products were not affected by frying time despite a decreasing chamber pressure with increasing frying time. The degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the VFBTPW products decreased with frying time above 7.5 minutes. The degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the products were similar for frying times of 10 to 45 minutes. The chroma value of the products were not significantly different from each other.

The VFBTPW product had lower moisture content but had higher fat content and product yield compared with the freeze-dried product. The rehydration rate and rehydration ratio of the VFBTPW product were lower than the freeze-dried product.

The beef muscle fibres of the low moisture VFBTPW product were looser and more porous compared with the high moisture product which were more compact.

Prženje smrznutih nemariniranih komada govedine u vakuumu ispod trostruke tačke vode (VFBTPV)

Lemuel M. Diamante

A p s t r a k t: Istraživanje je sprovedeno: a) kako bi se smrznuti nemarinirani tanki komadi goveđeg mesa pržili u vakuumu ispod trostruke tačke vode (VFBTPV — Vacuum Frying Below the Triple Point of Water) koristeći konstantnu količinu korišćenog uzorka i temperaturu prženja sa različitim vremenima prženja, odredio sadržaj vlage i masti , kao i prinos proizvoda i rehidratacija, svojstva boje i teksture dobijenih proizvoda prženih u vakuumu; b) kako bi se uporedile fizičko-hemijske osobine VFBTPV i proizvoda osušenih zamrzavanjem; i c) kako bi se procenila struktura vakuumski prženih komada govedine pomoću skenirajućeg elektronskog mikroskopa. Prženjem u vakuumu zamrznutih nemariniranih komada goveđeg mesa na 79±1°C, zaključeno je da što je vreme prženja kraće, to je veći sadržaj vlage u vakum prženom proizvodu. Sadržaj masti u proizvodima nije se značajno međusobno razlikovao. Vreme prženja od 5 minuta dalo je najveći prinos proizvoda zbog visokog sadržaja vlage. Vreme prženja nije uticalo na stopu rehidratacije i odnos rehidratacije proizvoda, uprkos smanjenju pritiska u komori sa povećanjem vremena prženja. Vrednosti za boju proizvoda nisu se razlikovale međusobno. Integrisana sila proizvoda smanjila se sa vremenom prženja iznad 7,5 minuta. Proizvod pržen u vakuumu imao je niži sadržaj vlage, ali je imao veći sadržaj masti i prinos proizvoda u poređenju sa liofilizovanim/suvo zamrznutim proizvodom. Brzina/stopa rehidratacije i odnos rehidratacije proizvoda prženog u vakuumu bili su niži nego kod liofilizovanog/suvo zamrznutog proizvoda. Mišićna vlakna goveđeg mesa kod proizvoda sa malom vlagom bila su labavija i poroznija u poređenju sa proizvodom sa visokom vlagom koj je bio kompaktniji. Liofilizovani /suvo zamrznuti proizvod bio je porozniji od nemarinirane govedine pržene u vakuumu sa niskom vlagom na osnovu poprečnog reza, ali obrnuto je uočeno kada se radi o uzdužnom rezu.

Ključne reči: *prženje u vakuumu, komadi goveđeg mesa, fizičko-hemijska, rehidrataciona svojstva.*

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