Vacuum Frying of Selected Shellfish Products

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Abstract

Vacuum frying of frozen prawn, shrimp and mussel was carried out at 80°C frying temperature, 0.4 kPa chamber pressure and 50 minutes frying time. The vacuum fried (VF) cooked prawn and shrimp had the lowest final moisture content while the VF raw prawn had the highest. The VF cooked (VFC) whole and half mussels had the highest product yields and the VFC shrimp had the lowest. The fat contents of the VF shellfish products were very close to each other. The VFC half mussel had the lowest fracturability while the VF raw prawn had the highest. The VF raw prawn had the highest chroma value while the VFC whole mussel had the lowest. The VFC whole mussel had the highest hue angle value but the VFC shrimp had the lowest. The VFC shrimp had the highest rehydration rate and ratio while the VFC prawn had the lowest values.

Keywords: Vacuum frying, prawn, shrimp, mussel, physicochemical properties, texture, colour

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INTRODUCTION

Seafoods include fish, whether from freshwater, estuarine or marine habitats, and also shellfish which include crustaceans and mollusks. The crustacean comprises of crayfish, crab, shrimp/prawn and lobster, while mollusks could be bivalves such as mussel, oyster and scallop, univalve creatures such as abalone, snail and conch, and cephalopods which include squid, cuttlefish and octopus (Venugopal, 2005). The world's annual catch of fish and shellfish is approximately 100 million metric tons, from which only 20% is processed for food (Shahidi, 2012). Fish and shellfish are important sources of protein for some people in some areas of the world.

Shellfish such as shrimp, prawn and mussel are popular because of their unique taste, absence of fishy smell and high calcium content. Steamed green lipped mussel has a protein content of 18.8g/100g sample and calcium content of 173mg/100g sample (Lesperance, 2018). The raw and cooked shrimps have protein contents of 20.10 and 22.78g/100g sample, respectively. On the other hand, the raw and cooked shrimps have calcium contents of 64 and 91mg/100g sample, respectively (USDA-ARS National Agricultural Library, 2020). The calcium contents of these cooked shellfish products are much higher than popular cooked table fish like flounder, salmon, snapper and tuna (Lesperance, 2018).

There are different ways to process shellfish into stable products including freezing, salting, smoking, fermenting, canning and drying. Ready-to-eat shellfish products such as chilled cooked shrimp, prawn and mussel are very popular however these products need refrigerated storage. At the present, there are no available ready-to-eat shellfish products that can be stored at ambient conditions. There is therefore a need to explore other methods of producing ambient shelf stable shellfish products and one possible way is to use the vacuum frying process. In addition, the vacuum fried shellfish products can be used as ingredients for instant noodles with shellfish flavor.

Vacuum frying is an efficient method to reduce the oil content in fried foods, maintain product nutritional quality and reduce oil deterioration. It is a technology generally that can be used to obtain products from fruits and vegetables (Da Silva & Moreira, 2008) and seafoods (Andres-Bello, Garcia-Segovia & Martinez-Monzo, 2010; Pan, Ji, Liu & He, 2015) with the necessary degree of dehydration without excessive darkening or scorching of the products.

The vacuum frying process required the heating of oil to the required temperature. Then the sample to be processed was placed in the basket inside the frying chamber but suspended above the hot oil. The pressure inside the vacuum frying chamber was reduced to the required pressure. The sample was then lowered into the hot oil for the required duration and then the basket was raised above the oil and then centrifuged within the chamber for the required speed and time. The fried product can also be taken out of the chamber and centrifuged using a separate machine or stood in the frying chamber to drain the surface oil (Diamante, Shi, Hellmann & Busch, 2015). In comparison to atmospheric deep-fat frying, this technique works under pressures well below atmospheric levels, preferably below 6.65 kPa thereby decreasing the boiling point of water considerably below 100°C (Garayo & Moreira, 2002). Hence, moisture evaporation of food during frying can happen far below the 160°C temperature that is commonly used for atmospheric frying.

At the present, vacuum frying has been used mostly in different plant origin foods, including apples, apricot, beans, carrots, blue potato, jackfruit, gold kiwifruit, mangoes, potato, pineapple and sweet potato (Diamante, Savage & Vanhanen, 2013; Diamante, Savage, Vanhanen and Ihns, 2012; Yang, Park, Kim, Choi, Kim, & Choi, 2012; Yagua & Moreira, 2011; Dueik, & Bouchon, 2011; Diamante, 2009; Da Silva & Moreira, 2008; Perez-Tinoco, Perez, Salgado-Cervantes, Reynes, & Vaillant, 2008; Fan, Zhang & Mujumdar, 2005) and lately on animal origin foods such as breaded shrimp, gilthead sea bream fillets, chicken nugget (Pan et al., 2015; Teruel, Chen, Zhang & Fang, 2014; Garcia-Segovia, Martinez-Monzo, Linares & Garrido, 2014; Andres-Bello et al., 2010). Presently there are no literatures on vacuum frying of shellfish such as shrimp, prawn and mussel, hence this study.

The objectives of the study were: a) to carry out preliminary experiments on vacuum frying of a representative frozen cooked shellfish sample; b) to determine the effect of frying time on the final moisture content of vacuum fried raw and cooked prawn, shrimp and mussel; c) to conduct vacuum frying at constant conditions on selected frozen raw and cooked shellfish samples; d) to analyze and compare the physicochemical properties of the resulting vacuum fried raw and cooked shellfish products; and e) to come up with recommendations on the vacuum frying conditions for processing of selected frozen raw and cooked shellfish samples.

MATERIALS and METHODS

Materials

Survey of the local supermarkets in Christchurch, New Zealand revealed the availability of the following frozen samples including raw peeled prawn, cooked peeled prawn, cooked peeled shrimp and deshelled green-lipped mussel. Five kilograms each of frozen samples of raw peeled prawn, cooked peeled prawn and cooked peeled shrimp while 10 kilograms of deshelled green mussel were purchased from the supermarkets. Both the frozen raw peeled and cooked peeled prawn had an average length of 4.5 cm and a thickness of 1.5 cm. The frozen cooked peeled shrimp had an average length of 2.0 cm and a thickness of 0.75 cm while the deshelled whole mussel had an average length of 3.5 cm and a thickness of 1.00 cm. The samples were stored in a chest freezer at -20°C for about one month until all the experiments were done. The sample for the cooked half mussel was obtained by cutting the cooked mussel crosswise. Three hundred liters of canola oil were obtained from an ingredients company in Christchurch, New Zealand and stored at room temperature (15 to 20°C) for about one month until all were used up.

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 Fig. 1. The heating of the oil was done using band 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 liters of canola oil (Seafrost, Kuala Lumpur, Malaysia) were poured in the frying vessel and heated up to the target temperature. This took approximately one hour.

The content of a bag of frozen sample (500±10 g) was loaded into the frying basket. After closing the vessel lid, the valve to the vacuum pump was opened. When a pressure of 0.4 kPa was reached, the basket with the samples was immersed into the hot oil. From this moment, the time was started, the temperature as well as pressure was recorded. With the help of the vacuum pump and condensation unit, the escaping steam was taken out of the vessel. Because of high 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.

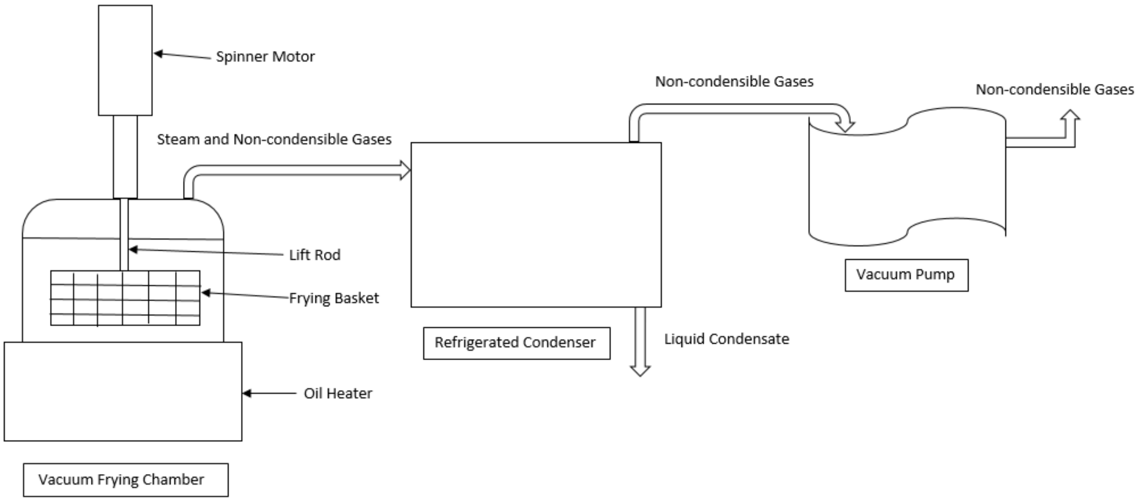

Figure 1. Schematic diagram of the vacuum frying system for the experiments (Diamante et al., 2015).

Moisture Content Determination

The moisture contents of the initial and final samples from each trial run were determined using the air oven method. The samples were dried at a constant temperature of 105°C for exactly 16 hours after that time a constant weight was reached (Diamante, Durand, Savage, & Vanhanen, 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 (Watson Victor Ltd, Clayson Laboratory Apparatus Ltd, NZ) using triplicate measurements. The moisture content was calculated by using the equation,

$$M_{WB} = \frac{B-C}{B-A} * 100 \quad (1)$$

where: M_{WB} = moisture content calculated on % wet basis

A = weight of container [g]

B = weight of container and sample before drying [g]

C = weight of container and sample after drying [g]

Product Yield Calculation

The product yield of the vacuum fried samples wa 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,

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

Fat Content Determination

The fat content of the ground vacuum fried samples 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 triplicate measurements were used.

Fracturability Analysis

Texture properties of the vacuum fried products were determined by measuring the fracturability of the sample using a texture analyzer (Texture Analyser Model: TA-XT plus, Serial No: 10781, Stable Micro Systems, Surrey, UK) equipped with a 5 kg load cell. Fracturability measures the highest peak on the force versus time curve. When the fracturability 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 vacuum fried products 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, a = -0.23, b = 1.88). Chroma and hue angle of vacuum fried samples were determined using the following equations,

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

$$\text{Hue Angle} = [\tan^{-1}(|b^*/a^*|)][180/\Pi] \qquad (4)$$

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

Π = pi constant (3.14159)

Rehydration Properties Calculations

The rehydration properties of the vacuum fried products 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 thick glass bowl with boiling water. Place a similar glass bowl on top of the dried product so that it will be 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 were 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,

$$\text{Percentage Gain} = \frac{\text{Initial product weight} - \text{Rehydrated weight}}{\text{Initial product weight}} \times 100 \qquad (5)$$

$$\text{Rehydration Rate} = \frac{\text{Percentage Gain}}{\text{3 minutes}} \qquad (6)$$

$$\text{Rehydration Ratio} = \frac{\text{Rehydrated weight}}{\text{Initial product weight}} \qquad (7)$$

Statistical Analyses

A two-way analysis of variance (ANOVA) using Minitab 15 (Minitab Inc., State College, Pennsylvania, USA) was carried out on the initial and final moisture contents, product yield, fat content, fracturability, colour values (L*, a* and b*) and colour properties (chroma and hue angle) in order 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 Cooked Shrimp

Pan et al. (2015) reported the vacuum frying of breaded shrimp at 80 to 120°C and 12 kPa using frying times of to 10 minutes. Examination of their results showed that the final moisture content of the vacuum fried breaded shrimp were still very high at 80 to 95% dry basis (44.4 to 48.7% wet basis). Longer frying times were used in the study to obtain very dry products that will have good texture qualities and shelf stable. Preliminary studies were carried on frozen cooked shrimp at a temperature of 80°C at a chamber pressure of 0.4 kPa using frying times of 15, 30 and 45 minutes; at a temperature of 90°C at a chamber pressure of 0.4 kPa using frying times of 10, 20 and 30 minutes; and at a temperature of 100°C at a chamber pressure of 0.4 kPa using frying times of 5, 10 and 15 minutes, respectively. It must be noted that the vacuum fryer chamber pressure is very much lower than in the Pan et al. (2015) study. Very low chamber pressures will result in low boiling point of water and therefore speed up the drying of frozen seafood samples to very low moisture levels. Frozen samples were also used in the study in order to enhance the physicochemical properties of the vacuum fried products (Shyu & Hwang, 2011).

Table 1 shows the results of the experiments. The results showed that the vacuum fried cooked shrimp at 80°C and 45 minutes gave a product that was reddish in colour, crunchy texture and very dry with a moisture content of 1.87% wet basis. On the other hand, the vacuum fried cooked shrimp at 90°C and 30 minutes gave a product that was reddish light brown in colour, crunchy texture and very dry with a moisture content of 2.10% wet basis. Lastly, the vacuum fried cooked shrimp at 100°C and 15 minutes gave a product that was reddish light brown in colour, crunchy texture and very dry with a moisture content of 1.76% wet basis.

The vacuum fried cooked shrimp at 80°C gave the most acceptable colour closer to the original sample. The vacuum fried cooked shrimp processed at 90 and 100°C resulted in unacceptable colour of reddish light brown which looked slightly burnt probably due to the high temperatures used. The results suggest that the vacuum frying of frozen cooked shrimp should be limited to a temperature of 80°C at a chamber pressure of 0.4 kPa and frying of about 45 minutes to give a final moisture content of around 2% wet basis and to have acceptable colour and texture properties.

Moisture Contents of Vacuum Fried Cooked Shellfish Products

The initial and final moisture contents of vacuum fried raw and cooked prawns, cooked shrimp, cooked whole and half mussels processed at a frying temperature of 80±1°C, chamber pressure of 0.4±0.1 kPa and different frying times are shown in Table 2. The results show that the cooked shrimp sample had the highest initial moisture content of 89.21% wet basis while the cooked half mussel sample had the lowest of 72.24% wet basis. After processing, the highest final moisture content was obtained for the vacuum fried raw prawn of 2.72% wet basis while the cooked shrimp had the lowest of 1.31% wet basis. The vacuum fried cooked shrimp had the lowest final moisture content in spite that it had the highest initial moisture content due its smaller size which speed up the drying process. In addition, the final moisture content of the different products decreased with increasing frying time. Pan et al. (2015) also reported that vacuum frying of breaded shrimp at 80°C and 12 kPa pressure gave a decreasing moisture content at increasing frying time from 1 to 10 minutes while Andres-Bello et al. (2010) presented a similar trend for vacuum frying sea bream fillets at 90°C and 15 kPa pressure using different frying times from 1 to 10 minutes. Preliminary studies on the vacuum frying of frozen cooked shrimp indicated a final moisture content of around 2% wet basis to give an acceptable product crunchiness. Hence, the target final moisture content of around 2% wet basis for all samples was attained at 50 to 60 minutes of frying time. As a result, the different vacuum fried products processed at 50 minutes were further analyzed for selected properties. It must be noted that when a raw prawn is cooked (steamed), it evaporated some of the moisture resulting in the initial moisture content decrease and when vacuum fried resulted in a lower final moisture content. In addition, when the whole mussel was cut in half, its surface area increased and when subjected to cooking (steaming), there was some moisture evaporation thereby lowering its initial moisture content and when vacuum fried resulted also in a lower final moisture content.

Table 1. Results on the preliminary experiments for vacuum frying of peeled cooked shrimp (Initial MC = 89.21% wet basis) processed using 500g frozen sample for each run at different frying temperatures and times, chamber pressure of 0.4 ± 0.1 kPa with centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes.

Frying temperature/	Informal observation of the product		Moisture content (MC) of the product	
Frying time	Colour description	Texture description	Description Value	(% wet basis)
80ºC/ 15 minutes	light reddish (similar to original sample)	soft (similar to original sample	slightly wet	not determined
80ºC/ 30 minutes	moderately reddish	rubbery	moderately dry	not determined
80ºC/ 45 minutes	reddish	crunchy (easily broken when pressed)	very dry	1.87
90ºC/ 10 minutes	light reddish (similar to original sample)	soft (similar to original sample	moderately wet	not determined

90°C/ 20 minutes	moderately reddish	rubbery	slightly dry	not determined
90°C/ 30 minutes	reddish light brown	crunchy (easily broken when pressed)	very dry	2.10
100°C/ 5 minutes	light reddish (similar to original sample)	soft (similar to original sample	slightly wet	not determined
100°C/ 10 minutes	moderately reddish	rubbery	moderately dry	not determined
100°C/ 15 minutes	reddish light brown	crunchy (easily broken when pressed)	very dry	1.76

Table 2. Initial and final moisture contents (MC) of vacuum fried peeled raw and cooked prawns, peeled cooked shrimp, shelled cooked whole and half mussels processed using 500g frozen sample for each run at a frying temperature of 80 ± 1°C, chamber pressure of 0.4 ± 0.1 kPa and different frying time with centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes.

Sample	Replication	Initial MC* (% wet basis)	Frying time/ Final MC* (% wet basis) 40 minutes	50 minutes	60 minutes
Raw prawn	R1	86.88^{c}	5.74^{d}	2.83^{c}	1.43^{d}
	R2		5.01^{d}	2.60^{b}	1.50^{d}
Cooked prawn	R1	83.80^{b}	3.13^{b}	1.53^{a}	1.10^{b}
	R2		3.02^{b}	1.41^{a}	1.05^{b}
Cooked shrimp	R1	89.21^{d}	2.61^{a}	1.37^{a}	0.90^{a}
	R2		2.51^{a}	1.24^{a}	0.81^{a}
Whole mussel	R1	74.00^{a}	3.94^{c}	1.87^{b}	1.34^{c}
	R2		4.06^{c}	1.88^{b}	1.20^{c}
Half mussel	R1	72.24^{a}	3.04^{b}	1.57^{a}	1.13^{b}
	R2		3.00^{b}	1.31^{a}	1.02^{b}

* Mean of 3 measurements; means with the same letter are not significantly different from each other at 95% confidence level

Product Yield, Fat Content and Fracturability of Vacuum Fried Shellfish Products

Table 3 presents the product yield, fat content and fracturability of vacuum fried raw and cooked prawns, cooked shrimp, cooked whole and half mussels processed at a frying temperature of 80±1°C, chamber pressure of 0.4±0.1 kPa and 50 minutes frying time. The vacuum fried cooked prawn (25.45%) and cooked whole mussel (27.85%) gave the highest product yields while the cooked shrimp (14.08%) yielded the lowest. When the raw prawn is cooked (steamed) before vacuum frying, it decreased its initial moisture content thereby increasing its solids content resulting in higher product yield. Furthermore, when the whole mussel was cut in half, its surface area increased resulting in some moisture evaporation and therefore increased its solids content and its product yield.

Table 3. Product yield, fat content and fracturability of vacuum fried peeled raw and cooked prawns, peeled cooked shrimp, shelled cooked whole and half mussels processed using 500g frozen sample for each run at a frying temperature of 80 ± 1ºC, chamber pressure of 0.4 ± 0.1 kPa and frying time of 50 minutes with centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes.

Sample	Replication	Product yield (%)	Fat content* (% wet basis)	Fracturability**
Raw prawn	R1	18.33	25.41^{b}	1.77^{c}
	R2	18.59	24.86^{b}	1.77^{c}
Cooked prawn	R1	27.06	28.03^{c}	0.95^{b}
	R2	23.83	25.99^{bc}	0.92^{b}
Cooked shrimp	R1	13.26	25.83^{bc}	0.87^{ab}
	R2	14.90	26.48^{c}	0.65^{a}
Whole mussel	R1	27.97	25.42^{b}	0.96^{b}
	R2	27.73	24.76^{b}	0.93^{b}
Half mussel	R1	30.90	21.10^{a}	0.66^{a}
	R2	31.54	22.70^{a}	0.69^{a}

*Mean of 3 measurements; ** mean of 5 measurements; means with the same letter are not significantly different from each other at 95% confidence level

The vacuum fried cooked half mussel (21.90 wet basis) yielded the lowest fat content while both the cooked prawn (27.02% wet basis) and shrimp (26.16% wet basis) gave the highest. Generally, the fat contents of all the vacuum fried products were relatively similar except for the cooked half mussel. Pan et al. (2015) reported that vacuum fried breaded shrimp processed at 80°C and 12 kPa pressure had a fat content of 7.5% wet basis at a moisture content of 9.1% wet basis. The lower fat content observed was due to the breading of the shrimp which restricted fat absorption during frying. When the raw prawn is cooked (steamed) and vacuum fried, its final moisture content decreased resulting in higher fat content. Vacuum fried products with higher moisture content usually will have lower fat content (Diamante, Savage & Vanhanen, 2013; Diamante, Savage, Vanhanen & Ihns, 2012; Tan & Mittal, 2006; Song, Zhang & Mujumdar, 2007; Shyu & Hwang, 2001). As pointed out earlier, when the whole mussel was cut in half, its surface area increased which resulted in the efficient centrifugation of oil resulting in lower fat content of the product.

The vacuum fried cooked half mussel (0.68 kg force) gave the lowest fracturability indicating a crunchier product while the cooked raw prawn (1.77 kg force) yielded the highest value which would be less crunchy. Pan et al. (2015) reported that the hardness of the vacuum fried breaded shrimp at 80°C and 12 kPa pressure was about 0.47 kg force (4.6 N) which was lower than that obtained from this study for the vacuum fried cooked shrimp of 0.76 kg force. The difference observed was due to the removal of the crust from breaded shrimp before texture measurement thereby exposing a high moisture and softer flesh resulting in a lower hardness value. When the raw prawn was cooked and then vacuum fried, it resulted to a product with lower fracturability due to its lower final moisture content. As shown in the previous section, the vacuum fried raw prawn had an average final moisture content of 2.72% wet basis while the cooked prawn had only 1.47% wet basis. Generally, the lower the moisture content of the vacuum fried products the crunchier their texture (Song et al., 2007; Shyu & Hwang, 2001). Furthermore, when the whole mussel was cut in half, its surface area increased resulting in lower final moisture and hence crunchier product.

Colour Properties of Vacuum Fried Shellfish Products

Table 4 shows the L*, a* and b* colour values, chroma and hue angle of vacuum fried raw and cooked prawns, cooked shrimp, cooked whole and half mussels processed at a frying temperature of 80±1°C, chamber pressure of 0.4±0.1 kPa and 50 minutes frying time. The vacuum fried raw prawn had the highest L* (74.72) value indicating a lighter colour while the cooked whole mussel had the lowest L* (35.91) value suggesting a darker colour. While the highest a* value was obtained by the vacuum fried cooked shrimp (20.89) and the lowest a* value was that of the cooked whole mussel (2.21). Lastly, the vacuum fried cooked prawn had the highest b* value (34.55) while the cooked whole mussel had the lowest b* value (13.51). When the raw prawn is cooked (steamed) and vacuum fried, its L* value decreased but its a* and b* values increased due to the effect of heating resulting in the colour change of the flesh. In addition, when the whole mussel was cut in half, it resulted to the increase in the L*, a* and b* values due to the increase in its surface area giving a significant color change of the flesh.

The highest chroma were obtained by the vacuum fried cooked prawn (38.01) and cooked shrimp (35.08) while the lowest chroma was attained by the cooked whole mussel (13.69). The high chroma values was brought about by the higher a* and b* color values as shown in both the cooked prawn and shrimp samples which were more reddish and yellowish in colour. When the raw prawn is cooked (steamed) before vacuum frying, its flesh turned reddish in colour and then when it was vacuum fried it further increased its redness and therefore its chroma. In addition, when the whole mussel was cut in half, its surface area increased thereby increasing to more reddish and yellowish changes and hence its chroma.

The vacuum fried whole mussel (80.73°) and half mussel (77.51°) had the highest hue angle and the cooked shrimp (54.44°) had the lowest value. The high hue angle values were brought about by the higher b* value against the a* value as shown in both the cooked whole and half mussels which were more yellowish in color. When the raw prawn is cooked (steamed) and vacuum fried, their a* and b* colour values increased resulting in the hue angle decrease. Furthermore, when the whole mussel was cut in half, its surface area increased thereby increasing the a* and b* colour values which also decreased the hue angle.

Table 4. L*, a* and b* colour values, chroma and hue angle of vacuum fried peeled raw and cooked prawns, peeled cooked shrimp, shelled cooked whole and half mussels processed using 500g frozen sample for each run at a frying temperature of 80 ± 1°C, chamber pressure of 0.4 ± 0.1 kPa and frying time of 50 minutes with centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes.

Sample	Replication	L* value** (no units)	a* value** (no units)	b* value** (no units)	Chroma** (no units)	Hue angle** (degree)
Raw prawn	R1	74.69[a]	7.14[c]	28.15[b]	29.04[b]	75.78[b]
	R2	74.75[a]	7.79[c]	26.61[b]	27.73[b]	73.69[b]
Cooked prawn	R1	66.53[a]	15.91[a]	34.94[a]	38.39[a]	65.52[c]
	R2	68.93[a]	15.76[a]	34.16[a]	37.62[a]	65.24[c]
Cooked shrimp	R1	72.83[a]	17.98[a]	28.31[b]	33.54[a]	57.58[d]
	R2	66.47[a]	23.80[a]	29.70[b]	38.06[a]	51.30[d]
Whole mussel	R1	35.83[c]	2.23[d]	13.29[d]	13.48[d]	80.49[a]
	R2	35.99[c]	2.18[d]	13.72[d]	13.89[d]	80.97[a]
Half mussel	R1	40.81[b]	6.23[c]	25.53[c]	26.27[c]	76.29[b]
	R2	39.49[b]	4.78[c]	24.00[c]	24.47[c]	78.73[b]

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

Rehydration Properties of Vacuum Fried Shellfish Products

A vacuum fried shellfish product can be a ready-to-eat product or it can be incorporated in instant noodles with shellfish flavor. Hence, the rehydration properties such as the rehydration rate and ratio are important properties for the vacuum fried products as a noodle ingredient. The rehydration rate and ratio of vacuum fried raw and cooked prawns, cooked shrimp, cooked whole and half mussels processed at a frying temperature of 80±1°C, chamber pressure of 0.4±0.1 kPa and 50 minutes frying time is shown in Table 5. The vacuum fried cooked shrimp had the highest rehydration rate (32.84%) while the vacuum fried cooked prawn had the lowest value (13.66%). When the raw prawn is cooked (steamed) before vacuum frying, the prawn tissue had already shrunk due to the heating process and then it further shrunk due to the additional heating during the vacuum frying resulting in lower rehydration rate. On the other hand, cutting the whole mussel in half did not affect the rehydration rate.

The highest rehydration ratio was obtained for the vacuum fried cooked shrimp (1.99 kg rehydrated product/kg dried product) while the lowest value was that of vacuum fried cooked prawn (1.41 kg rehydrated product/kg dried product). Again, when the raw prawn is cooked (steamed) before vacuum frying, the prawn tissue had already shrunk due to the heating process and then it further shrunk due to the additional heating during the vacuum frying resulting in lower rehydration ratio. While the cutting of the whole mussel in half did not also affect the rehydration ratio.

Table 5. Rehydration rate and ratio of vacuum fried peeled raw and cooked prawns, peeled cooked shrimp, shelled cooked whole and half mussels processed using 500g frozen sample for each run at a frying temperature of 80 ± 1°C, chamber pressure of 0.4 ± 0.1 kPa and frying time of 50 minutes with centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes.

Sample	Replication	Rehydration rate** (% /min)	Rehydration ratio** (kg rehydrated/kg dried product)
Raw prawn	R1	22.02^{b}	1.66^{b}
	R2	22.50^{b}	1.68^{b}
Cooked prawn	R1	12.05^{e}	1.36^{d}
	R2	15.27^{d}	1.46^{cd}
Cooked shrimp	R1	32.48^{a}	1.97^{a}
	R2	33.20^{a}	2.00^{a}
Whole mussel	R1	16.58^{cd}	1.50^{c}
	R2	16.92^{cd}	1.51^{c}
Half mussel	R1	17.96^{c}	1.54^{c}
	R2	18.09^{c}	1.54^{c}

** Mean of 5 measurements; means with the same letter are not significantly different from each other at 95% confidence level

Implications of the Results

When vacuum frying shellfish samples (prawn, shrimp and mussel), frying temperatures should be limited to 80°C when processing at longer frying times in order to achieve low final moisture for the products and obtain an acceptable crunchiness. The suggested temperature was to avoid the undesirable colour changes on the vacuum fried shellfish products.

Cooking (steaming) the raw prawn before freezing and then vacuum frying obtained a product with low final moisture content, higher product yield and low fracturability value and hence a crunchier product. The average fat content of both vacuum fried products was very close to each other.

However, the rehydration rate and ratio of this vacuum fried product both decreased which means that it is not good a noodle ingredient. The vacuum fried cooked prawn was darker, more reddish but less yellowish in colour.

Cutting in half the frozen cooked whole mussel before vacuum frying also gave a product with low final moisture content, higher product yield and low fracturability value and hence a crunchier product. The average fat content of the vacuum fried cooked half mussel was lower than that for the whole mussel product. But the rehydration rate and ratio of both vacuum fried products were similar and therefore both are not good noodle ingredients. The vacuum fried cooked half mussel was lighter, more reddish but less yellowish in colour.

Vacuum frying of frozen cooked shrimp provided a product with low final moisture content and low fracturability value and hence a crunchier product but a low product yield because of the high initial moisture content of the sample. The average fat content of the vacuum fried product was similar to that of vacuum fried cooked prawn. In addition, the vacuum fried product had high rehydration rate and ratio indicating that it is good a noodle ingredient. The vacuum fried cooked shrimp was similar to cooked prawn in terms of lightness and redness but less yellowish in colour.

CONCLUSION

The vacuum frying of frozen cooked shellfish samples (prawn, shrimp and mussel) can be carried out at 80°C frying temperature, 0.4 kPa of chamber pressure and 50 minutes frying time.

The vacuum fried cooked prawn, shrimp and half mussel had the lowest final moisture contents while the vacuum fried raw prawn had the highest.

The vacuum fried cooked half mussel had the highest product yield while the vacuum fried cooked shrimp had the lowest. The average fat content of the vacuum fried raw and cooked prawns, cooked shrimp, as well as cooked whole mussel were very close to each other but the vacuum fried cooked half mussel had the lowest. The vacuum fried cooked shrimp and half mussel had the lowest fracturability and therefore the crunchiest while the vacuum fried cooked raw prawn had the highest and would be less crunchy.

The vacuum fried cooked whole mussel had lighter colour but the vacuum fried raw prawn had darker colour. The vacuum fried raw prawn had the highest chroma value and hence the most reddish colour while the vacuum fried cooked whole mussel had the lowest. The vacuum fried cooked whole mussel had the highest hue angle value thus the most yellowish colour but the vacuum fried cooked shrimp had the lowest.

The vacuum fried cooked shrimp had the highest rehydration rate and ratio and therefore had the best rehydration abilities while the vacuum fried cooked prawn had the lowest values.

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