

## Effects of different freezing and thawing methods on the quality of giant red shrimp (*Aristaeomorpha foliacea*)

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### Abstract

The aim of this study was to investigate the effects of different freezing and thawing methods on physical, chemical, and sensory characteristics of red shrimp (*Aristaeomorpha foliacea*). Shell-on and shell-off shrimps were subjected to three different freezing (blast freezing, still freezing and cryogenic freezing) and thawing (on air, in refrigerator and in microwave oven) methods and stored for 30 days at -18°C. Quality control analyses were carried out in samples after thawing. The lowest total volatile nitrogen and trimethylamine contents, pH values and cooking losses were found in cryogenically frozen shrimp, compared with other freezing methods. However, cryogenic freezing caused colour fading and softening in texture. It was determined that microwave thawing conditions used in this study are not suitable for thawing of frozen shrimp as it negatively affects texture and colour and increases cooking loss. It was found that blast freezing, and thawing methods preserved the physical, chemical and sensory properties of shrimp better than other methods.

**Keywords:** *Aristaeomorpha foliacea*; Freezing; Red shrimp; Shrimp quality.

### 1. Introduction

Shrimps are one of the most valuable commercial crustaceans in the world. They are produced both by catching and farming. Total production was reported as 8.7 million tons in 2016 which corresponds to approximately 5-6 per cent of the world's total production at sea (FAO, 2018). Shrimps can be easily spoiled after harvest because they are very sensitive. Degradation occurs by the combined action of microbial chemical and enzymatic activities. Therefore, they are marketed chilled, or frozen.

Freezing technology is a preservation method for seafood. Long-term preservation of perishable foods such as seafood is only possible with freezing technology. Foods can be stored at -1 to + 4°C using cooling methods, but their shelf life is limited due to the slowing of microbial and biochemical events in the cold storage. However, the growth of microorganisms can be

prevented by freezing, while biochemical events and enzyme activity continue to slow down. (Gokoglu, 2002). The rate and temperature of freezing, duration of frozen storage, and thawing rate and method are all factors known to affect quality. The main causes of quality loss during frozen storage and thawing are dehydration, drip loss, protein denaturation, and discoloration (Einen et al., 2002).

Giant red shrimp has high economic importance and is a species abundantly caught by deep water bottom otter trawling in the Mediterranean. In this study, shell-on and shell-off red shrimps (*Aristaeomorpha foliacea*) were exposed to three different freezing and three different thawing methods and the effects of freezing and thawing methods on the quality of shrimp were investigated.

### 2. Materials and Methods

#### 2.1. Materials

Giant red shrimp (*Aristaeomorpha foliacea*) was purchased from fishermen. Shrimps were selected from those that were not treated with anti-browning agents on the fishing boat. They were transferred to the laboratory in a cold carrying

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bag with ice shortly after purchase. Total 10 kg shrimp were used for this study.

## 2.2. Freezing and thawing treatments

Upon arrival at the laboratory, shrimps were divided into two groups (450 shrimp per group). In one group, shells were removed, while the other group of shrimps remained with shell. After the pre-cooling process in the refrigerator with ice until the core temperature of 4°C, both groups were frozen using three different freezing methods as follows.

- 1) Air blast freezing: shrimps were placed on trays and then frozen in an air blast freezer (-40°C temperature, 4 m / s air speed).
- 2) Still freezing: shrimps were frozen in a domestic freezer at -18°C
- 3) Cryogenic freezing: shrimps were immersed in liquid nitrogen in 1 L tank for 1 minute.

The internal temperatures of the samples during freezing were measured using thermocouple. Immediately after the freezing process is completed, the frozen shrimps are packed in locked polyethylene bags (10 shrimps per bag). The packed shrimps were stored at -18°C for 30 days. At the end of the storage period, the samples were thawed using 3 different thawing methods as follows.

- 1) Refrigerator thawing: frozen shrimps were placed in a refrigerator at 4°C and held until the internal temperature reached 0°C. Thawing was completed within 15 hours.
- 2) Microwave thawing: frozen shrimps were thawed in a microwave oven at the defrost setting (at 2450 MHz). Thawing was completed in 3 minutes.
- 3) Air thawing: frozen shrimps were kept in a medium of 18-20°C. Thawing was completed in 3 hours.

The quality control analyses of thawed shrimps were performed.

## 2.3. Analysis

### 2.3.1. Total volatile basic nitrogen (TVB-N) analysis

Homogenized shrimp sample (10 g) was distilled and collected in a flask containing HCl and tashiro indicator. After distillation, the content was titrated with 0.1 N NaOH (Schormüller, 1968). Trimethylamine nitrogen (TMA-N) analysis, the shrimp sample was homogenized in 5% trichloroacetic acid (TCA) and then filtered. The filtrate (4 ml) was transferred to a test tube and 20% formaldehyde, anhydrous toluene, and 50% potassium hydroxide (KOH) were added. After the tubes were shaken well, the toluene phase was taken with the help of a pipette and 0.2% of picric acid was added. Absorbance values at 410 nm wavelength were measured in the spectrophotometer (Schormüller, 1968).

### 2.3.2. pH measurement

The measurement of pH was carried out by dipping the pH meter probe into shrimp meat homogenised with a blender and diluted with distilled water (Manthey et al., 1988).

### 2.3.3. Determination of cooking loss

For analysis of the cooking loss, the samples weighed into the glass jars (10 shrimps per jar) were heat at 90°C for 30 minutes. After heating, the samples were weighed and the cooking losses were calculated with the following formula (Hughes et al., 1997).

$$\text{Cooking loss (\%)} = (A - B) / A * 100$$

A= Uncooked sample weight    B= Cooked sample weight

### 2.3.4. Colour measurement

The colour of shrimps was measured in three separate sections on the surface of shrimp meat using a colour measurement instrument (CR-400 Minolta chromameter). The instrument was calibrated to 100 L \* with a white standard magnesium oxide plate before use. L\*, a\*, b\* values were determined which refers to brightness, redness, and yellowness under daylight.

### 2.3.5. Sensory analysis

For sensory analysis, a panel of 10 panellists was performed. Panellists (five women and five men aged between 25 and 50) who have experience in evaluating of seafood and accustomed to consuming shrimp conducted the panel. Hedonic scale between 1 and 9 was used. On this scale, 7-9 as "very good", 6.9-4 as "good", and as 3.9-1.0 "bad" were evaluated. The samples were coded using letters and randomly presented to the panellists. All assessments took place in a day light condition.

### 2.3.6. Texture analysis

Texture measurement was performed using TA.XT2 texture analyser. For texture profile analysis a TAST2 device having a 5kg load cell and a 35 mm diameter cylindrical probe was used. Two sequenced compression processes were applied by immersing the probe at a speed of 5 mm / sec from the moment it touches the product. Hardness, springiness, cohesiveness, gumminess, and chewiness were measured. Texture measurements of all samples were performed with 7 replications.

### 2.3.7. Statistical analysis

Means and standard deviations were calculated. Data were analyzed by a three factors factorial arrangement in a completely randomized design. The three factors were the three freezing treatments (blast freezing, still freezing and cryogenic freezing), the three thawing treatments (air thawing, refrigerator thawing and microwave thawing) and two shrimp groups (shell-on and shell-off). The variance analysis was applied to the data obtained in the study using SAS software (Statistical Analysis System, Cary, NC, USA). The differences of important variance sources were evaluated statistically with Duncan Multiple Comparison Test. Two replications of the experiment were conducted at separate times.

## 3. Result and Discussion

### 3.1. Effects of freezing and thawing methods on TVB-N values

The initial TVB-N value of the shrimp before freezing was found as  $13.26 \pm 5.92$  mg/100g. TVB-N value increased after freezing and storage. There were no differences between the freezing methods for TVB-N values (Table 1). When compared the thawing methods each other, it was observed that the highest ( $P < 0.01$ ) TVB-N values are in both with and without shell samples thawed at ambient temperature. No significant difference ( $P > 0.01$ ) was observed between TVB-N values of the samples thawed in the refrigerator and microwave oven. Freezing of shrimps with or without shell affected the TVB-N values. Higher ( $P < 0.01$ ) TVB-N values were determined in shell-on shrimps. It is reported that the shell removal process reduces the microbial load by 99% (Aldagal & Bazaraa, 1999).

TVB-N has a wide use as an important parameter in evaluating the quality of seafood. It is reported to be a good indicator in determining the advanced levels of degradation in fresh and frozen seafood (Ludorf & Meyer, 1973). The highest acceptable limit value for shrimps is reported as 30 mg / 100g (Shamshad, et al.; Mendes et al., 2005). In a study, TVB-N values

were determined between 10.2 and 14.16 mg / 100g in shrimps (*Penaeus monodon*) frozen by blast freezing and cryogenic freezing (Boonsumrej et al., 2007). Yu et al. (2018) reported that the highest TVB-N values are determined in the shrimps (*Macrobrachium rosenbergii*) frozen by the still freezing (-18°C), followed by the blast freezing and cryogenic freezing. At the end of storage, while the limit values were exceeded in shrimps frozen by the blast freezing and still freezing, the values were below the acceptable limit in samples frozen by cryogenic freezing. The results of that study are similar to our study results. In another study, deep-water pink shrimp (*Parapenaeus longirostris*) and Narwal shrimp (*Parapandalus narval*) were frozen at -40°C and stored at -18°C for 6 months and examined quality changes during storage. It was found that TVB-N values increased during the storage and reached 35 mg / 100g of TVB-N values of both shrimp species at the end of storage (Condurso et al., 2016).

### 3.2. Effects of freezing and thawing methods on TMA-N values

When evaluated the freezing methods, the highest ( $P < 0.01$ ) TMAN value was determined in the samples frozen by still freezing, while followed by cryogenic freezing and blast freezing (Table 1). When we compare the thawing methods, the highest ( $P < 0.01$ ) TMA-N values are seen in the samples thawed in the refrigerator. No significant difference ( $P > 0.01$ ) was found in TMA-N values between thawing at ambient temperature and thawing in microwave oven. It is thought that long-term slow thawing in the refrigerator caused this result. Higher ( $P < 0.01$ ) TMA-N values were determined in shell-on shrimps.

Determination of TMA-N amount is important to indicate the level of microbial spoilage in seafood sold as fresh. The acceptable limit value of TMA-N for shrimp was reported as 5 mg/100g (Cobb et al., 1973; Shamsad et al., 1990; Zeng et al., 2005). Although TMA-N values were significantly higher ( $P < 0.01$ ) than the fresh samples after 30 days storage, it was observed that the acceptable limit TMA-N values were not exceeded in any of our samples. The highest level of 2.87 mg / 100g TMA-N among all samples was observed.

### 3.3. Effects of freezing and thawing methods on pH values

When analysed the freezing methods, the lowest pH values were determined with cryogenic freezing, followed by blast freezing and still freezing (Table 1). In a study in which the effects of three different freezing methods on the quality of freshwater shrimp (*Macrobrachium rosenbergii*) were examined, a decrease in the pH value in the beginning weeks of storage and then increases were observed. The authors attributed this initial decrease to lactic acid formation due to anaerobic glycolysis. The subsequent increase was attributed to basic compounds formed because of bacterial and enzymatic activities. In that reported study, the lowest pH value was determined with cryogenic freezing while higher pH values were found with blast freezing (-35°C) and still freezing (-18°C). These results interpreted as preventing microbial and enzymatic activity since rapid freezing with liquid nitrogen occurred (Yu et al., 2018). In another study where two different shrimp species (*Parapenaeus longirostris* and *Parapandalus narval*) were frozen at -40°C, it was reported that the pH values of both shrimp species varied between 7.3 and 7.8 during the storage (Condurso et al., 2016).

One of the most common physical methods used in the quality control of seafood is pH measurement. Microbial and enzymatic activities change oxidation reduction balance and change the concentration of free hydrogen and hydroxyl ions which affect pH values (Condurso et al., 2016). A pH value of 7.7 or less has been reported to indicate that the shrimp is "first

grade", between 7.70 and 7.95 it shows "not good but acceptable" quality, and 7.95 is "unacceptable" (Marshall & Wiese-Lehigh, 1997). In our study, limit values were not exceeded. It is reported that the pH values are higher than that of fish and mammals, since the shellfish products generally contain a higher proportion of non-protein nitrogenous compounds (Shahidi, 1994).

When compared the thawing methods, the highest pH values were determined by air thawing, while the lowest ( $P < 0.01$ ) pH values were determined by thawing in the refrigerator. These results suggest that bacterial activity may have occurred due to high temperature during thawing at ambient temperature and this may have caused an increase in pH value. On the other hand, in the current study, a significant effect of being with or without shells for shrimps on pH values was not observed.

**Table 1**

Comparison (Duncan's test) of freezing methods, thawing methods, storage time and shrimp group factors according to TVB-N, TMA-N, pH, cooking loss parameters of shrimp (*A. foliaceae*)<sup>1,2</sup>

Factors	Parameters			
	TVB-N (mg/100g)	TMA-N (mg/100g)	pH	Cooking loss (%)
Freezing methods <sup>1</sup>				
Still Freezing	19.90 ± 1.35ba	1.30 ± 0.58a	7.95 ± 0.13b	38.81 ± 2.09 a
Blast Freezing	20.93 ± 2.52a	0.97 ± 0.28 c	7.85 ± 0.17a	38.03 ± 6.43a
Cryogenic Freezing	19.12 ± 1.35a	1.15 ± 0.32b	7.66 ± 0.18c	37.09 ± 3.57a
Thawing methods <sup>4</sup>				
Air Thawing	38.94 ± 6.348a	1.36 ± 0.35b	7.91 ± 0.16b	36.88 ± 3.38b
Refrigerator Thawing	21.68 ± 19.67b	1.89 ± 0.57a	7.71 ± 0.22a	36.86 ± 4.31b
Microwave Thawing	19.55 ± 13.54b	1.63 ± 0.42b	7.86 ± 0.19b	40.19 ± 5.14a
Shrimp group <sup>5</sup>				
Shell-on	30.54 ± 17.58a	1.74 ± 0.40a	7.83 ± 0.25a	36.70 ± 3.17a
Shell-off	22.88 ± 14.28b	1.54 ± 0.56b	7.79 ± 0.13a	39.26 ± 5.30a

- Means within the same factor and the same column with different letters (a, b, c, d) are different according to Duncan's test ( $P < 0.01$ )
- Each number represents the average value of each parameter for all samples of the same treatment
- Each number represents the average value of each parameter for all samples with the same freezing method
- Each number represents the average value of each parameter for all samples with the same thawing method
- Each number represents the average value of each parameter for all samples with the same shrimp group

### 3.4. Effects of freezing and thawing methods on cooking loss

During the freezing process, the cell membranes are damaged, accordingly, the water holding capacity decreases and the loss of cooking increases (Wheeler et al., 1990). Water holding capacity is an important feature of meats. During the freezing process, ice crystals are formed among the filaments in the muscle fibres depending on the freezing rate. While small ice crystals are formed in fast freezing, larger ice crystals are formed in slow freezing. These crystals increase the water coming out of the fibres. This reduces water retention capacity and increases cooking loss. Srinivasan et al. (1997) reported that cooking loss in shrimp (*M. rosenbergii*) exposed to multiple freezing cycles increased with increase freezing cycle. While it was determined as 11.7% in fresh shrimp, it was determined that it ranged between 17.8-15.2% in freeze-thaw cycles.

Although there is no statistical difference between freezing methods in the current study, the cooking losses of the samples frozen with liquid nitrogen were relatively found to be slightly lower (Table 1). Since rapid freezing and formation of small ice crystals cause less damage to cells also reduce cooking losses. Compared to thawing methods, higher cooking losses were found with microwave thawing. There is no significant difference between air thawing and refrigerator thawing methods. It is reported that thawing in the microwave oven may cause denaturation and destabilization of the proteins although it provides rapid thawing (Srinivasan et al., 1997; Boonsumrej et

al., 2007). Possibly, the shrimp we thawed in the microwave oven had higher cooking losses due to greater protein denaturation.

**Table 2**  
Comparison (Duncan's test) of freezing methods, thawing methods, storage time and shrimp group according to colour parameters of shrimp (*A. foliaceae*)<sup>1,2</sup>

	Colour		
	L*	a*	b*
Freezing methods <sup>3</sup>			
Still Freezing	37.13 ± 2.77c	13.38 ± 2.79a	9.75 ± 1.35a
Blast Freezing	38.85 ± 3.83b	13.85 ± 2.09b	9.83 ± 1.83a
Cryogenic Freezing	40.86 ± 1.13a	13.18 ± 1.53b	9.93 ± 1.64a
Thawing methods <sup>4</sup>			
Air thawing	37.72 ± 2.09c	14.33 ± 1.77a	9.87 ± 1.90a
Refrigerator Thawing	40.12 ± 1.92a	13.36 ± 1.49b	10.05 ± 0.99a
Microwave Thawing	38.99 ± 1.53b	13.22 ± 1.76c	9.57 ± 1.73a
Shrimp group <sup>5</sup>			
Shell-on	39.22 ± 1.17a	13.41 ± 2.86a	9.72 ± 1.16a
Shell-off	38.67 ± 1.25b	13.53 ± 2.71a	9.95 ± 1.30a

<sup>1</sup> Means within the same factor and the same column with different letters (a, b, c, d) are different ( $P < 0.01$ ).

<sup>2</sup> Each number represents the average value of each parameter for all samples of the same treatment

<sup>3</sup> Each number represents the average value of each parameter for all samples with the same freezing method

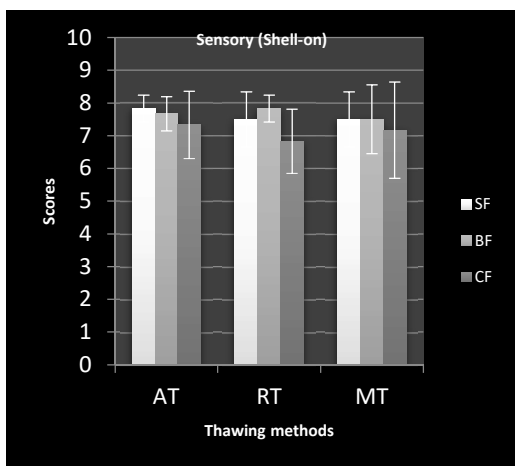
<sup>4</sup> Each number represents the average value of each parameter for all samples with the same thawing method

<sup>5,6</sup> Each number represents the average value of each parameter for all samples with the same shrimp group

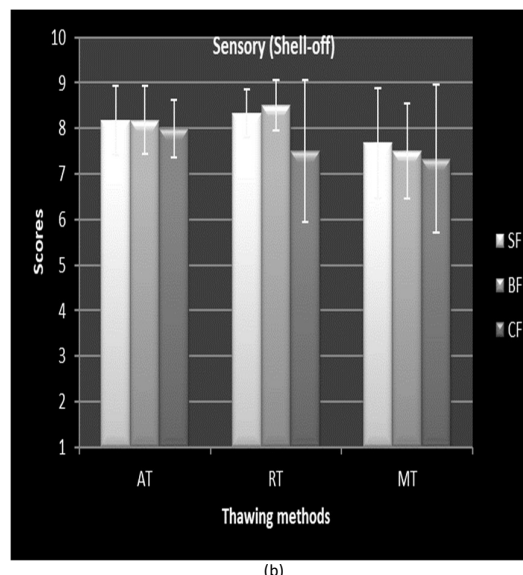
Srinivasan *et al.* (1998) reported that they observed a significant change in cooking loss in shrimp frozen with shells and subjected to various thawing processes. They also reported that the cooking loss in shell-on shrimps was independent of the thawing methods and storage time, but that in frozen shrimps without shells, more cooking loss was observed when thawed in water than in the microwave. In general, shrimp frozen with shells have been found to have lower cooking losses compared to those without shells and possibly due to the protective effect of the shell. So, they stated that they achieved such a result.

### 3.5. Effects of freezing and thawing methods on colour values

It is reported that colour is an important feature for shrimps and its acceptability depends on the colour (Niamnuy *et al.*, 2008). Colour has a significant effect on the market value of shrimp (Tume *et al.*, 2009). Red/ orange shrimp colour is associated with product quality and freshness (Latscha, 1989). The formation of this colour is due to the presence of the colour pigment astaxanthin, a carotenoid (Boonyaratpalin *et al.*, 2001). In colour measurement, L\* value refers "brightness", a\* value "redness", and b\* value "yellowness".



(a)



(b)

**Figure 1.** Sensory scores of shell-on (a) and shell-off (b) shrimps thawed after 30 days frozen storage.

SF= Still Freezing, BF= Blast Freezing, CF= Cryogenic Freezing, AT= Air Thawing, RT= Refrigerator Thawing, MT= Microwave Thawing

In the current study, the initial L\* value of shrimp before freezing was  $38.09 \pm 0.29$ . After freezing and storage, L\* values in shrimps increased. The increase in L\* value shows the increase in paleness, along with the increase in brightness. It is reported that there is some fading in the colour of shrimps during frozen storage (Chandrasekaran, 1994; Okpala & Bono, 2016). The shrimp colour is linked to its main pigment, astaxanthin and its esters. Storage conditions affect shrimp colour due to astaxanthin oxidation and isomerization reactions. Because these reactions cause the formation of colourless compounds, they affect the colour by leading to the decrease of typical redness and yellowness (Chen *et al.*, 1995; Niamnuy *et al.*, 2008).

When compared the freezing methods, it is seen that the highest L\* value is determined in the samples frozen with liquid nitrogen (Table 2). Samples frozen with liquid nitrogen it means that the brightness is higher. High freezing rates create small and great numbers of ice crystals in the product, which reflects light more intensely. Whereas lower freezing rates create larger and fewer ice crystals, this leads to refraction of light and flesh surface causes blackening. Higher L\* values may have been obtained since a rapid freezing with liquid nitrogen took place. When compared the thawing methods, it is seen that the highest L\* value is determined in the samples thawed in the refrigerator and the lowest L\* value is determined in the samples thawed at ambient temperature. This situation indicates that the thawing temperature and speed significantly affect the L\* value. It suggests that it may have lost its brightness due to the rapid loss of water from the shrimp surface during thawing at high temperatures. Freezing of shrimps with or without shell also affected L\* values significantly, and higher L\* values were obtained in shrimps with shell. It can be said that the shell has a protective effect.

The initial a\* value of shrimp before freezing was found to be  $12.89 \pm 0.28$ . After freezing and storage, a\* values of shrimps increased significantly. In a study, an increase in a\* value was reported during the frozen storage of freshwater shrimp (*M. rosenbergii*) (Yu *et al.*, 2018). It has been interpreted that this increase may be due to the reaction of phenoloxidase present in shrimp with dioxyphenylalanine to produce melanin even during

frozen storage. Similarly, Sun *et al.* (2016) reported that an increase in  $a^*$  values of Chinese shrimp (*Fenneropenaeus chinensis*) was observed during frozen storage, and this increase may have occurred due to the freezing process decomposing protein-bound carotenoids. These results show similarity to our results. In contrast, other researchers have reported that  $a^*$  values decrease in deep water pink shrimp and narwal shrimp during frozen storage (Condurso *et al.*, 2016).

When we evaluate our results according to the freezing methods, it is seen that the highest  $a^*$  values are determined with air blast freezing and the lowest values are determined with cryogenic freezing. In a study, it was reported that freezing methods did not have a significant effect on  $a^*$  value of freshwater shrimp (*M. rosenbergii*) frozen by three different methods (Yu *et al.*, 2018).

Thawing methods also influenced  $a^*$  values. Accordingly, the lowest  $a^*$  values were obtained with microwave thawing (Table 2). It is reported that oxidation may activate in microwave thawing (Boonsumrej *et al.*, 2007). Reduction of  $a^*$  value may decrease because of oxidation. On the other hand, it is reported that there may be protein denaturation during microwave thawing (Boonsumrej *et al.*, 2007), which causes the colour to appear opaquer (Einen *et al.*, 2002). Freezing of shrimps with or without shells did not affect  $a^*$  value.

Freezing methods, thawing methods, and freezing with or without shell did not affect  $b^*$  values (Table 2). While it has been reported that freezing methods (Yu *et al.*, 2018) and frozen storage (Sun *et al.*, 2016) are not effective on  $b^*$  values by some researchers, by the others, decreases have been reported during frozen storage (Condurso *et al.*, 2016).

### 3.6. Effects of freezing and thawing methods on sensory scores

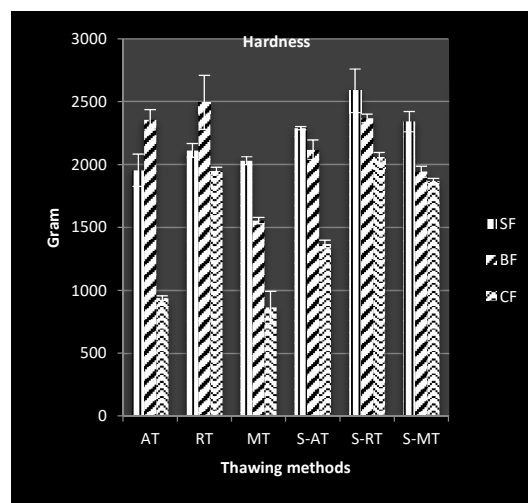
After freezing and storage, all sensory scores of shrimps decreased significantly ( $P < 0.01$ ). For this reason, it would be appropriate not to keep the frozen storage time of shrimps too long. Although the freezing process caused a decrease in sensory scores, the freezing method and thawing method did not affect the sensory scores (Fig. 1). While panellists can distinguish between the frozen and non-frozen product, it is normal that they cannot distinguish different freezing and thawing methods. The fact that the panellists are untrained is one reason why they cannot distinguish this difference. Higher sensory scores were obtained for shell-on shrimps compared to shell-off frozen shrimp (Fig. 1).

### 3.7. Effects of freezing and thawing methods on texture values

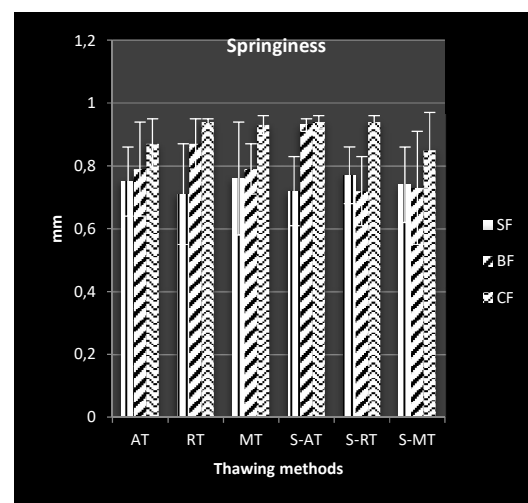
One of the biochemical changes that affect the texture is protein denaturation. Increases in tissue hardness during frozen storage of shrimps and other seafood have been reported to result from myosin denaturation as well as crosslinking and aggregation of myofibrillar proteins (Connell, 1964; Sikorski *et al.*, 1976). Muscles of seafood are more sensitive to freezing denaturation than mammalian muscles. Freezing increases the aggregation of proteins and water loss during thawing, causing the product to harden (Sikorski & Kolakowska, 1990). Lower freezing rate and higher thawing temperature is reported to cause more protein denaturation (Shenouda, 1980). The increase in drip loss with slow freezing causes the muscle to harden.

Nip & Moy (1981) reported that short-term frozen storage did not significantly affect shrimp texture. The toughness of the shrimp tissue showed no change in the initial stages of frozen storage (up to 1 month) compared to fresh unfrozen shrimps (Srinivasan *et al.*, 1997), whereas a decrease in cutting force was detected after storage of 3 and 6 months. On the other

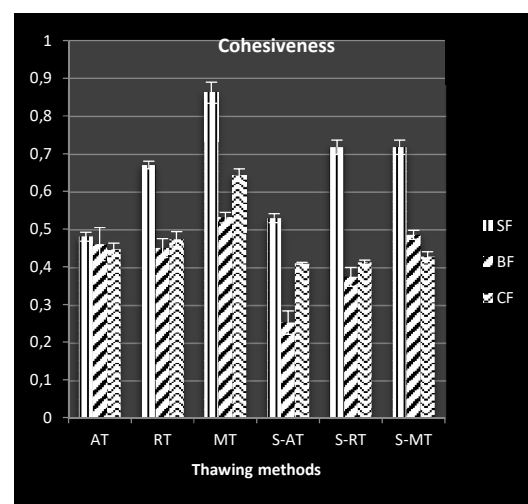
hand, it has been reported that the shrimp muscle hardens in storage of 1 and 3 months (Hale & Waters, 1981). The same researchers reported that the freezing process cause stiffness in the shrimp muscle, which is due to the shrinkage of muscle fibres and increased drip loss. Sun *et al.* (2016) determined increase in the hardness values of Chinese shrimp (*Fenneropenaeus chinensis*) during frozen storage.



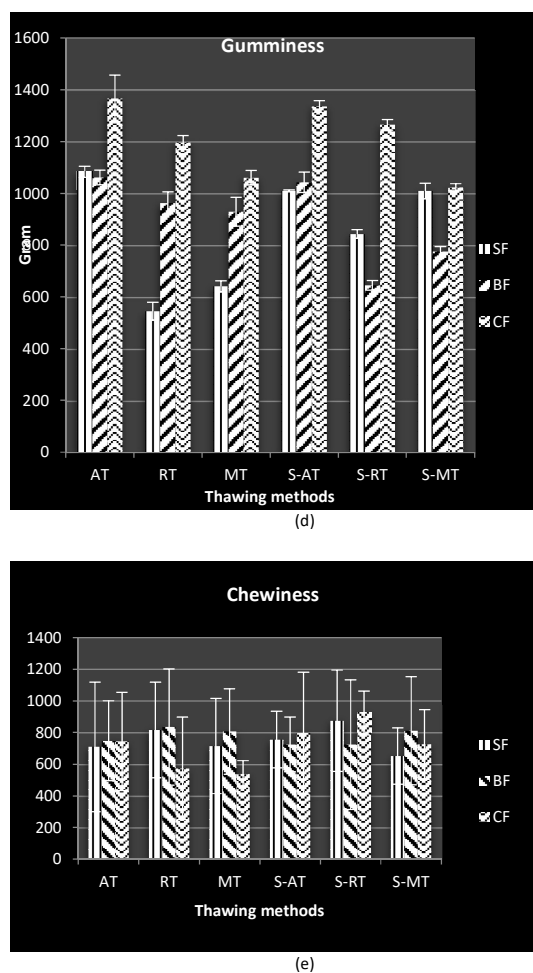
(a)



(b)



(c)



**Figure 2.** Texture analysis results of shrimps frozen and thawed by different methods (a) hardness values (b) Springiness values (c) Cohesiveness values (d) Gumminess values (d) Chewiness values.

SF= Still Freezing, BF= Blast Freezing, CF= Cryogenic Freezing, AT= Air Thawing, RT= Refrigerator Thawing, MT= Microwave Thawing,

\* The letters S in the X axis refer for frozen and thawed shelled shrimp, those without the letter S refer to shrimp frozen and thawed without shells

Hardness is defined as maximum force required to compress the sample. In the current study, the lowest hardness values were determined with liquid nitrogen (Fig. 2). No significant difference statistically ( $P > 0.01$ ) was determined between the hardness values of blast freezing and still freezing. Pan and Yeh (1993) reported that the integrity of the shrimp (*Penaeus monodon*) muscle frozen with liquid nitrogen is better preserved than shrimp frozen in blast freezer. Diaz Tenorio *et al.* (2007) determined that freezing and thawing methods influenced the texture of shrimp (*Litopenaeus vannamei*). They reported that cryogenic freezing was the least damaging method for textural characteristics. Because proteins cluster less with fast freezing and cells suffer less damage. It has been reported that liquid nitrogen is the best method in the studies of other researchers (Pan & Yeh, 1993; Chen & Pan, 1997).

In the current study, the highest hardness values were determined in the samples thawed in the refrigerator (Fig 2a). Srinivasan *et al.* (1998) reported that the toughness of shrimp (*Machrobrachium rosenbergii*) stored frozen for 1 and 6 months and then thawed in a refrigerator, were found to be higher compared to thawed in water or in a microwave oven. In the present study, the shrimp frozen with shell showed higher hardness values when compared with those without shell. Srinivasan *et al.* (1998) reported that the freezing of freshwater

shrimp (*M. rosenbergii*) with or without shell affects the texture. The toughness of frozen raw shell-on shrimp muscle showed a consistent change with the thawing method during the 6-month storage period. The toughness of the shrimp thawed in the refrigerator was found to be greater than those thawed in water or a microwave oven. In frozen shell-on shrimp, there was no consistent change in the shear strength of muscle tissue during storage. These researchers interpreted that the presence of shells delayed textural degradation during frozen storage and subsequent thawing.

Springiness is an active deformation length as mm divided into the sample height during the second compression. If springiness is high, it requires more chewing energy in the mouth. The highest springiness values were found in samples frozen by cryogenic method (Fig 2b). It has been determined that thawing methods and freezing with or without shell do not significantly affect springiness values. Decreases in springiness values in frozen storage have been reported for different shrimp species (Ma *et al.*, 2007; Yu *et al.*, 2018). Cohesiveness is defined as the measure of a material physically deformability and sensorially compression between teeth before breaking. The highest cohesiveness values were determined in still frozen, and microwave thawed samples (Fig 2c). The cohesiveness values of shell-off shrimps were higher than that of shell-on shrimps.

Gumminess is defined as the energy required breaking down a semi-solid food until it is ready to swallow. The highest gumminess values were determined with cryogenic freezing and air thawing (Fig 2d). Freezing of shrimps with or without shell did not affect gumminess. Chewiness reflects the difficulty of chewing food in the human mouth. The greater the chewing value, the more troublesome to eat. There was no observed significant effect of freezing and thawing methods and freezing with or without shell on chewiness values (Fig 2e).

#### 4. Conclusion

The quality losses that may occur in shrimps having considerably high commercial value not only cause a significant economic loss but also cause human health problems. Since the errors in freezing and thawing of a product will cause irreversible losses, to maintain quality in frozen shrimps has of great importance. In this study, it was determined that freezing and thawing methods affected the quality of giant red shrimp. Blast freezing and refrigerator thawing were found as suitable methods for preserving shrimp quality. Since there are a limited number of scientific studies on the effect of freezing and thawing on the quality of shrimps and no studies on giant red shrimp (*A. foliaceae*) in particular, this study will contribute to the elimination of the deficiency in this field and obtaining new data. We believe that the results of such a study will guide both shrimp producers and processors.

#### References

- Al-Dagal, M.M., and Bazaraa, W.A. 1999. Extension of shelf life of whole and peeled shrimp with organic acid salts and bifidobacteria. *Journal of Food Protection*, 62(1), 51-56. <https://doi.org/10.4315/0362-028x-62.1.51>.
- Boonsumrej, S., Chaiwanichsiri, S., Tantratian, S., Suzuki, T., and Takai, R. 2007. Effect of freezing and thawing on the quality changes of tiger shrimp (*Penaeus monodon*) frozen by air-blast and cryogenic freezing. *Journal of Food Engineering*, 80(1), 292-299. <https://doi.org/10.1016/j.jfoodeng.2006.04.059>.

- Boonyaratpalin, M., Thongrod, S., Supamattaya, K., Britton, G., and Schlipalius, L.E. 2001. Effects of  $\beta$ -carotenesource, Dunaliellasalina, and astaxanthin on pigmentation, growth, survival and health of *Penaeus monodon*. *Aquaculture Research*, 32 (1), 182-190. <https://doi.org/10.1046/j.1355-557x.2001.00039.x>.
- Chandrasekaran, M. 1994. Methods for preprocessing and freezing of shrimps. A critical evaluation. *Journal of Food Science and Technology*, 31, 441.
- Chen, H.E., Peng, H.Y., and Chen, B.H. 1995. Changes of carotenoids, colour and vitamin A contents during processing of carrot juice. *Journal of Agriculture and Food Chemistry*, 43 (7), 1912-1918. <https://doi.org/10.1021/jf00055a029>.
- Chen, Y.C., and Pan, B.S. 1997. Morphological changes in tilapia muscle following freezing by air blast and liquid nitrogen methods. *International Journal Food Science and Technology*, 32, 159-168. <https://doi.org/10.1046/j.1365-2621.1997.00392.x>.
- Cobb, B.F., Vanderzant, C., Thompson, C.A., and Custer, C.S. 1973. Chemical characteristics, bacterial counts and potential shelf-life of shrimp from various locations on the north western Gulf of Mexico. *Journal of Milk and Food Technology*, 36, 463-468. <https://doi.org/10.4315/0022-2747-36.9.463>.
- Conduro, C., Tripodi, G., Cincotta, F., Lanza, C.M., Mazzaglia, A., and Verzera, A. 2016. Quality assessment of Mediterranean shrimps during frozen storage. *Italian Journal of Food Science*, 28(3), 497-509. <https://doi.org/10.14674/1120-1770/ijfs.v324>
- Connell, J.J. 1964. Fish muscle proteins and some effects on them of processing. In: Shultz HW and Anglemeier AF (Eds) *Symposium on foods: proteins and their reaction*. AVI Publishing Co, Westport, Connecticut, 255 p.
- Diaz-Tenorio, L., Garcia-Carreno, F., and Pacheco-Aguliar, R. 2007. Comparison of freezing and thawing treatments on muscle properties of whiteleg shrimp (*Litopenaeus vannamei*). *Journal of Food Biochemistry*, 31(5),563-576. <https://doi.org/10.1111/j.1745-4514.2007.00130.x>.
- Einen, O., Guerin, T., Fjæra, S.O., and Skjervold, P.O. 2002. Freezing of pre-rigor fillets of Atlantic salmon. *Aquaculture*, 212, 129-140. [https://doi.org/10.1016/S0044-8486\(01\)00874-2](https://doi.org/10.1016/S0044-8486(01)00874-2).
- FAO. 2018. The State of World Fisheries and Aquaculture 2018-Meeting the sustainable development goals. Rome. Available from <http://www.fao.org/documents/card/fr/c/19540EN/>.
- Gokoglu, N. 2002. *Seafood Processing Technology*. Su Vakfi Publications, Book, 157 p. (In Turkish).
- Hale, M.B., and Waters, M.E. 1981. Frozen storage stability of whole and headless freshwater prawns *Macrobrachium rosenbergii*. *Marine Fisheries Review*, 43 (12), 18-21.
- Hughes, E., Conrades, S., and Troy, D.J. 1997. Effects of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12 and 30% fat. *Meat Science* 45, 273-281. [https://doi.org/10.1016/s0309-1740\(96\)00109-x](https://doi.org/10.1016/s0309-1740(96)00109-x).
- Latscha, T. 1989. The role of astaxanthin in shrimp pigmentation. *Advances in Tropical Aquaculture Tahiti*, 9: 319-325.
- Ludorf, W., and Meyer, V. 1973. *Fische und Fischer zeugnisse*. Paul PareyVerlag, Berlin, Hamburg. 309 p.
- Ma, L., Zhang, B., Deng, S., and Xie, C. 2015. Comparison of the cryoprotective effects of trehalose, alginate and its oligosaccharides on peeled shrimp (*Litopenaeus cannamei*) during frozen storage. *Journal of Food Science*, 80(3), C540-C546. <https://doi.org/10.1111/1750-3841.12793>.
- Manthey, M., Karnop, G., and Rehbein, H. 1988. Quality changes of European catfish (*Silurus glanis*) from warm water aquaculture during storage in ice. *International Journal of Food Science and Technology*, 23, 1-9. <https://doi.org/10.1111/j.1365-2621.1988.tb00543.x>.
- Marshall, D.L., and Wiese-Lehigh, P.L. 1997. Comparison of impedance, microbial, sensory and pH methods to determine shrimp quality. *Journal of Aquatic Food Product Technology*, 6(2),17-31. [https://doi.org/10.1300/J030v06n02\\_03](https://doi.org/10.1300/J030v06n02_03).
- Mendes, R., Gonçalves, A., Pestana, J., and Pestana, C. 2005. Indole production and deep water pink shrimp (*Parapenaeus longirostris*) decomposition. *European Food Research and Technology*, 221, 320-328. <https://doi.org/10.1007/s00217-005-1171-y>.
- Niamnuy, C., Devahastin, S., Soponronnarit, S., and Vijaya Raghavan, G.S. 2008. Kinetics of astaxanthin degradation and color changes of dried shrimp during storage. *Journal of Food Engineering*, 87(4), 591-600. <https://doi.org/10.1016/j.jfoodeng.2008.01.013>.
- Nip, W.K., and Moy, J.H. 1981. Effect of thawing and subsequent chilling on the quality of prawn, *Macrobrachium rosenbergii*. *Journal of Food Processing and Preservation*, 5(4), 207-213. <https://doi.org/10.1111/j.1745-4549.1981.tb00635.x>.
- Okpala, C.O.R., and Bono, G. 2016. Investigating the biometric and physicochemical characteristics of freshly harvested Pacific white shrimp (*Litopenaeus vannamei*): a comparative approach. *Journal of the Science Food and Agriculture*, 96, 1231. <https://doi.org/10.1002/jsfa.7211>.
- Pan, B.S., and Yeh, W.T. 1993. Biochemical and morphological changes in grass shrimp (*Penaeus monodon*) muscle following freezing by air blast and liquid nitrogen methods. *Journal of Food Biochemistry*, 17, 147-160. <https://doi.org/10.1111/j.1745-4514.1993.tb00464.x>.
- Schormüller, J. 1968. *Handbuch der lebensmittelchemie*. Springer-Verlag.
- Shahidi, F. 1994. Seafood proteins and preparation of protein concentrates. In: Shahidi F and Botta JR (Eds). *Seafoods: Chemistry, Processing Technology and Quality*. Springer, Boston, pp. 3-9.
- Shamshad, S.I., Nisa, K.U., Riaz, M., Zuberi, R., and Quarri, R.B. 1990. Shelf life of shrimp (*Penaeus merguensis*) stored at different temperatures. *Journal of Food Science*, 55, 1201-1205. <https://doi.org/10.1111/j.1365-2621.1990.tb03898.x>.
- Shamshad, S.I., Zuberi, R., and Qadri, R.B. 1992. Bacteriological status of seafood marketed in Karachi Pakistan. In: Huss, HH, Jakobsen M, Liston J (Eds). *Quality assurance in fish industry*. Elsevier Science Publishers, Amsterdam, pp.315-319.
- Shenouda, S.Y.K. 1980. Theories of protein denaturation during frozen storage of fish flesh. *Advances in Food Research*, 26, 275-311. [https://doi.org/10.1016/S0065-2628\(08\)60320-1](https://doi.org/10.1016/S0065-2628(08)60320-1).

- Sikorski, Z., Olley, J., and Kostuch, S. 1976. Protein changes in frozen fish. *CRC. Critical Reviews in Food Science and Nutrition*, 8, 97-129. <https://doi.org/10.1080/10408397609527218>.
- Sikorski, Z.E., Kolakowska, A., and Burt, J.R. 1990. Postharvest biochemical and microbial changes. In: Sikorski, ZE (Ed). *Seafood: resources, nutritional composition, and preservation*, Fl, CRC Press. Inc., Boca Raton, pp. 55-75.
- Srinivasan, S., Xiong, Y.L., Blanchard, S.P., and Tidwell, J.H. 1997. Physicochemical changes in prawns (*Macrobrachium rosenbergii*) subjected to multiple freeze-thaw cycles. *Journal of Food Science*, 62 (1), 123-127. <https://doi.org/10.1111/j.1365-2621.1997.tb04381.x>.
- Srinivasan, S., Xiong, Y.L., Blanchard, S.P., and Tidwell, J.H. 1998. Effects of freezing and thawing methods and storage time on physicochemical properties of freshwater prawns (*Macrobrachium rosenbergii*). *Journal of Aquatic Food Product Technology*, 7(2), 47-68. [https://doi.org/10.1002/\(SICI\)1097-0010\(199709\)75:1<37::AID-JSFA838>3.0.CO;2-L](https://doi.org/10.1002/(SICI)1097-0010(199709)75:1<37::AID-JSFA838>3.0.CO;2-L).
- Sun, X., Jin, Q., and Li, X. 2016. Physical quality changes of pre-cooked shrimps during frozen storage. *Advances in Engineering Research*, 63,76-81. <https://doi.org/10.1111/jfpp.13220>.
- Tume, R.K., Sikes, A.L., Tabrett, S., and Smith, D.M. 2009. Effect of background color on the distribution of astaxanthin in black tigerprawn (*Penaeus monodon*): Effective method for improvement of cooked color. *Aquaculture*, 296, 129–135. <https://doi.org/10.1016/j.aquaculture.2009.08.006>.
- Wheeler, T.L., Miller, R.K., Savell, J.W., and Cross, H.R. 1990. Palatability of chilled and frozen beef steaks. *Journal of Food Science*, 55(2), 301-304. <https://doi.org/10.1111/j.1365-2621.1990.tb06748.x>.
- Yu, L., Jiang, Q., Yu, D., Xu, Y., Gao, P., and Xia, W. 2018. Quality of giant freshwater prawn (*Macrobrachium rosenbergii*) during the storage at -18°C as affected by different methods of freezing. *International Journal of Food Properties*, 21(1), 100-2109. <https://doi.org/10.1080/10942912.2018.1484760>.
- Zeng, Q.Z., Thorarinsdotti, K.A., and Olafsdottir, G. 2005. Quality changes of shrimp (*Pandalus borealis*) stored under different cooling conditions. *Journal of Food Science*, 70 (7), 459–446. <https://doi.org/10.1111/j.1365-2621.2005.tb11493.x>.