Fishery Technology 59 (2022) : 187 - 196

Effect of Frozen Storage on Physical and Chemical Quality Changes in White Leg *Litopenaeus vannamei*, Beheaded at Various Stages of Rigor

Tariq Hussain Bhat[1]*, Mithilesh Kumar Chouksey[2], Amjad Khansaheb Balange[2] and Binaya Bhusan Nayak[2]

[1] *Division of Post-Harvest Technology, Faulty of Fisheries Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K)*

[2] *Central Institute of Fisheries Education (CIFE) Seven Bungalows, Versova, Andheri (W), Mumbai, India - 400 061*

Abstract

In this study effect of severing skeletal muscle by beheading at different stages of rigor on the quality of pacific white shrimp *Litopenaeus vannamei* during frozen storage for a period of six months was investigated by physical, chemical and sensory evaluation. Moisture content, NPN and Sarcoplasmic proteinshowed a decreasing trend, whereas total protein content increased in all the treatments during frozen storage. pH value showed anincreasing trend during the storage study in all the treatments. TMA-N, TVB-N, Peroxide value and Thiobarbituric acid value also increased in all the treatments during the storage study, however all the values were well within the acceptable limit. There was a significant decrease in the hardness, cohesiveness, springiness and chewiness in all the treatments during the storage. The final lower value of hardness was recorded in T3 indicating that severing of skeletal muscle in pre-rigor stage resulted in the better textural properties. The initial highest L* value was found in T2 followed by T1 and T3. Values of a* and b* showed a decreasing trends during the storage study indicating greener and blue colouration. Colour parameters showed significant differences ($p<0.05$) as storage progressed. Sensory score showed a decreasing trend with the storage reaching to the final value of as low as 6.38. However the shrimp were still acceptableafter six months of frozen storage. There was not a significant difference among different treatments indicating that severing of skeletal muscle in different stages of rigor does not affect the quality of the shrimp.

Keywords: shrimp; rigor stages; processing; frozen storage

Introduction

India's export of fish and fishery products during the financial year 2019-20 stood at 12.89 lakh tons and fetched an amount to the tune of 46662.85 crores (MPEDA, 2020). The major contributor to the export is frozen shrimp which has been possible only due to the introduction of pacific white shrimp *Litopenaeus vannamei* for cultivation purpose. Shrimp is the most preferred seafood item for human consumption because it is an excellent source of protein (Yanar & Celik, 2006) and unsaturated fatty acids like eicosapentaenoic (20:5n3, EPA) and docosahexaenoic (22:6n3, DHA) (González-Félix et al., 2002). Quality of the shrimp may be attributed to many factors such as such as methods of harvesting, handling, transportation, storage besides freezing rate (Sikorski et al., 2020), temperature (Love, 1962), time of frozen storage (Love & Olley, 1965), and the rate and method of thawing (Love and Haq, 1970). Important quality changes during frozen storage of shrimp are discoloration (Chandrasekaran, 1994), oxidation of lipid (Riaz & Qadri, 1990). sublimation and recrystallization of ice (Londahl, 1997), increase in volatile basic nitrogen (Yamagata & Low, 1995). Method of handling such as catching, killing, transportation and storage affected the quality of the shrimp (Bhat et al., 2018a). Shrimp frozen immediately after harvest can yield highest quality meat (Fennema, 1990), Most of the shrimp cultivated in India is

Received 21December 2021; Revised 7 July 2022; Accepted 16 July 2022

Email: tariqbhatt@gmail.com

oriented for export purpose and is frozen before export. Therefore present study is of the great importance looking into the effect of severing skeletal muscle at different stage of rigor on the quality of shrimp after freezing and storage under frozen condition.

Material and Methods

Shrimp with a head count of 35-40 per kg were harvested from a private fish farm located at Dhanu Alibagh Maharashtra and transported to the lab in live condition in a plastic tank filled with pond water supplied with air using an aerator. Upon reaching the laboratory shrimps were killed by immersing under frozen conditionswater slurry and beheading at 0, 5 and 35 h post mortem corresponding *to pre-rigor* (T1), *in-rigor* (T2) and *post-rigor* (T3) stages respectively. After beheading, shrimps were individually quick frozen, packed in polythene bags and stored at -20±2°C. Sampling was done on monthly basis.

The moisture, crude protein, NPN and peroxide value of shrimp beheaded at different stages of rigor and stored under frozen conditions were analysed according to the methods of (Official Methods of Analysis of AOAC International - 18th Edition, Revision 3, n.d.).

Sarcoplasmic protein of shrimps beheaded at different stages of rigor and stored under frozen conditions was extracted according to the method of Benjakul et al. (2004a & 2004b).

Total volatile basic nitrogen (TVB-N) and Trimethylamine nitrogen (TMA-N) was measured using Conway's micro-diffusion method (Conway, 1947).

Water holding capacity of the shrimp samples beheaded at different stages of rigor and stored under frozen conditions was determined by centrifugation based on the method described by Eide et al. (1982) with slight modification. 3g shrimp muscle was taken and immediately centrifuged at 1460g for 5 min, at 10°C (Eltek MP 400R). The weight loss due to centrifugation was divided by the water content of the shrimp before centrifugation and expressed as % WHC.

Thiobarbituric acid reactive substances (TBARS) content was determined according to the method of (Tarladgis et al., 1960).

Texture profile analysis of shrimps beheaded at different stages of rigor and stored under frozen conditions was carried out using TA.XT2i Texture analyser (Stable Microsystems, UK). Sample was compressed twice using the 36 mm probe. Test conditions used were as, pre-test speed 2.0 mm/s, test speed 1.0 mm/s, post-test speed 10.0 mm/s, Distance 6.0 mm, Time 5s, Load cell 50 kg and Force 10 g.

The color of shrimp beheaded at different stages of rigor and stored on ice was determined using Lab Scan XE Instrument (Hunter Lab Scan XE, USA) which gives acceptance level based on L* a* and b* respectively. Whole shrimp was placed on the port for color analysis.

The sensory evaluation of the shrimp beheaded at different stages of rigor and stored under frozen conditions was performed by 10 trained panellists. Samples were evaluated for texture, color, appearance, odor and overall acceptability on 10-point scale (IS: 6273 [II], 1971).

Statistical package for Social Science software version 16.0 (SPSS Inc., Chicago, IL) was used for analyzing the data obtained for various parameters. Data analysis was done by using one-way analysis of variance (ANOVA). Significance of differences was established at $P<0.05$ using Duncan's test.

Results and Discussion

Data pertaining to moisture, crude protein and non-protein nitrogen (NPN) content and sarcoplasmic protein of shrimp beheaded in different stages of rigor and stored under frozen conditions is summarised in Table 1. Moisture content initially was 78.82%, 78.34% and 78.69% respectively in shrimp beheaded in pre-rigor, in-rigor and post-rigor stages of rigor. It showed a decreasing trend in all the treatments during the frozen storage. Final moisture content recorded in pre-rigor, in-rigor and post-rigor stages was found as 75.44, 74.86 and 74.56 percent respectively. Protein content showed an increasing trend during the frozen storage. The protein content at the beginning of the study was recorded as 16.87, 17.64 and 16.61 in the shrimp beheaded in in pre-rigor, in-rigor and post- rigor stages of rigor respectively. Final value recorded at the end of the study for protein in different treatments was 18.54, 18.38 and 17.85 respectively for shrimp beheaded in in pre-rigor, in-rigor and post-rigor stages of rigor. The initial values of NPN

Table 1. Changes in moisture, protein, NPN and sarcoplasmic protein of Pacific white shrimp beheaded at different stages of rigor during frozen storage

Month	Treatment	Moisture (%)	Protein (%)	NPN (%)	Sarcoplasmic protein (%)
	T1	78.82±0.66^{a}	16.87±0.16^{b}	0.756±0.014^{a}	4.53±0.08^{a}
0	T2	78.34±0.74^{a}	17.64±0.28^{a}	0.748±0.015^{ab}	4.30±0.04^{c}
	T3	78.69±0.40^{a}	16.61±0.31^{b}	0.743±0.014^{b}	4.39±0.04^{b}
	T1	77.24±0.45^{a}	17.59±0.09^{b}	0.713±0.017^{a}	4.00±0.03^{a}
1	T2	76.82±0.11^{a}	17.97±0.30^{a}	0.691±0.019^{b}	3.93±0.03^{a}
	T3	77.19±0.89^{a}	17.21±0.17^{c}	0.687±0.14^{b}	3.97±0.05^{a}
	T1	77.27±0.80^{a}	17.85±0.30^{ab}	0.668±0.016^{a}	3.87±0.04^{a}
2	T2	76.48±0.21^{a}	18.03±0.24^{a}	0.656±0.020^{b}	3.85±0.04^{ab}
	T3	76.57±0.30^{a}	17.56±0.18^{b}	0.661±0.015^{ab}	3.79±0.01^{b}
	T1	76.50±0.42^{a}	17.94±0.19^{b}	0.599±0.015^{a}	3.82±0.01^{a}
3	T2	75.66±0.20^{b}	18.17±0.15^{a}	0.586±0.009^{a}	3.56±0.38^{a}
	T3	76.25±0.32^{a}	17.43±0.25^{c}	0.591±0.023^{a}	3.70±0.06^{a}
	T1	75.77±0.18^{a}	18.24±0.21^{a}	0.569±0.019^{a}	3.65±0.02^{a}
4	T2	75.07±0.21^{a}	18.20±0.20^{b}	0.578±0.022^{a}	3.44±0.07^{b}
	T3	74.67±0.43^{b}	17.59±0.19^{b}	0.564±0.015^{a}	3.57±0.03^{b}
	T1	75.31±0.29^{a}	18.63±0.15^{a}	0.538±0.015^{a}	3.46±0.09^{a}
5	T2	74.93±0.27^{b}	18.29±0.29^{b}	0.534±0.018^{a}	3.43±0.04^{b}
	T3	74.93±0.65^{b}	17.76±0.22^{c}	0.529±0.015^{a}	3.22±0.03^{c}
	T1	75.44±0.28^{a}	18.54±0.14^{a}	0.468±0.015^{b}	3.40±0.03^{a}
6	T2	74.86±0.65^{b}	18.38±0.31^{a}	0.486±0.015^{a}	3.36±0.06^{b}
	T3	74.56±0.56^{b}	17.85±0.17^{c}	0.459±0021^{b}	3.15±0.04^{b}

Data (n=3) are presented as means ± SD,
Mean values in the same column bearing different letters differ significantly ($p<0.5$)

of the shrimps beheaded in pre-rigor, inrigor and post rigor stages were found as 0.756, 0.748 and 0.743 percent respectively. Final NPN content recorded in the shrimps beheaded in in pre-rigor, in-rigor and post-rigor stages were recorded as 0.468, 0.486 and 0.459 percent respectively indicating a decrease during the frozen storage in the all the treatments. Sarcoplasmic protein content recorded in shrimp beheaded in pre-rigor, in-rigor and post-rigorstage was found as 4.53, 4.30 and 4.39 percent respectively. A decreasing trend was also observed in sarcoplasmic protein content in all the treatments during the study with final values at the end of the storage study as 3.40, 3.36 and 3.15 percent respectively in shrimp beheaded in pre-rigor, in-rigor and post-rigor stage. Shrimp and other shellfish products undergo quality changes due to oxidation, denaturation of proteins, sublimation and recrystallization of ice crystals (Londahl, 1997) thus resulting in off-flavors, rancidity, dehydration, weight loss, loss of juiciness, drip loss and toughening (Bhobe & Pai, 1986; Londahl, 1997), 1986, as well as microbial spoilage and autolysis (Bhobe & Pai, 1986). Consumer acceptability of the product is affected by the pattern of industrial transformations, besides organoleptic features and nutritional quality of the shrimp. (Bhat et al., 2018b) Dehydration drip loss, protein denaturation and discoloration are the major causes of the quality loss during frozen storage and thawing (Garthwaite, 1997). Processing shrimp at different stages of rigor affects the physical properties, such as moisture and weight loss, of the product. Peeling and beheading in the post-rigor stage can save approximately 7% weight loss compared to pre-rigor (Bhat et al., 2017).

TVB-N and TMA-N content increased in all the treatment during the frozen storage (Fig.1). The initial lowest (2.32 mg %) TVB-N value was observed in shrimp beheaded in pre-rigor stage. The TVBN values in all the treatments gradually increased but remained comparatively lowerin shrimp beheaded in pre-rigorin every monthly sampling. However, there was no significant ($p<0.05$) difference among the treatments. The initial highest TMA-N value was recorded in shrimp beheaded in In-rigor stage followed by shrimp beheaded in post-rigor stage and pre-rigor stage. The final lowest value of TMA-N was recorded in shrimp beheaded in pre-rigor stage followed by shrimp beheaded in in-rigor stageandpost-rigor stage. However, values of TVB-N and TMA-N did not cross the acceptable limit during the storage study in any of the treatments. According to (Tarladgis et al., 1960), the offensive fishy odour occurs when the TMA concentration of fish exceeds 10 mg/100 g.

The pH and water holding capacity of shrimps beheaded at different stages of rigor and stored in frozen condition are presented in Table 2. pH value showed an increasing trend during the storage study in all the treatments. Initially lowest value (6.9±0.1) of pH was found in T1. Water holding capacity decreased in all the treatments during the storage study indicating that protein denaturation occurred during the storage. Initially water holding

Table 2. Changes in pH and water holding capacity of Pacific white shrimp beheaded at different stages of rigor during frozen storage

Month	Treatment	pH	WHC (%)
0	T1	6.9 ± 0.1^{a}	96.15 ± 0.70^{a}
	T2	7.0 ± 0.1^{a}	95.70 ± 0.52^{a}
	T3	7.0 ± 0.0^{a}	96.07 ± 0.40^{a}
1	T1	7.1 ± 0.1^{a}	95.64 ± 0.41^{a}
	T2	7.1 ± 0.0^{a}	95.09 ± 0.61^{c}
	T3	7.2 ± 0.1^{a}	95.41 ± 0.62^{b}
2	T1	7.1 ± 0.1^{a}	95.19 ± 0.45^{a}
	T2	7.2 ± 0.1^{a}	94.94 ± 0.43^{a}
	T3	7.2 ± 0.0^{a}	94.98 ± 0.48^{a}
3	T1	7.2 ± 0.0^{a}	93.70 ± 0.37^{a}
	T2	7.3 ± 0.1^{a}	93.11 ± 0.49^{a}
	T3	7.4 ± 0.0^{a}	92.70 ± 0.53^{b}
4	T1	7.5 ± 0.0^{a}	92.61 ± 0.20^{a}
	T2	7.6 ± 0.0^{a}	92.08 ± 0.51^{b}
	T3	7.5 ± 0.1^{a}	92.43 ± 0.30^{ab}
5	T1	7.6 ± 0.0^{b}	92.14 ± 0.55^{a}
	T2	7.6 ± 0.0^{b}	92.03 ± 0.40^{a}
	T3	7.7 ± 0.0^{a}	91.80 ± 0.31^{b}
6	T1	7.6 ± 0.0^{c}	91.82 ± 0.46^{a}
	T2	7.7 ± 0.0^{b}	91.06 ± 0.22^{ab}
	T3	7.8 ± 0.0^{a}	90.89 ± 0.30^{c}

Data (n=3) are presented as means ± SD,
Mean values in the same column bearing different letters differ significantly ($p<0.5$)

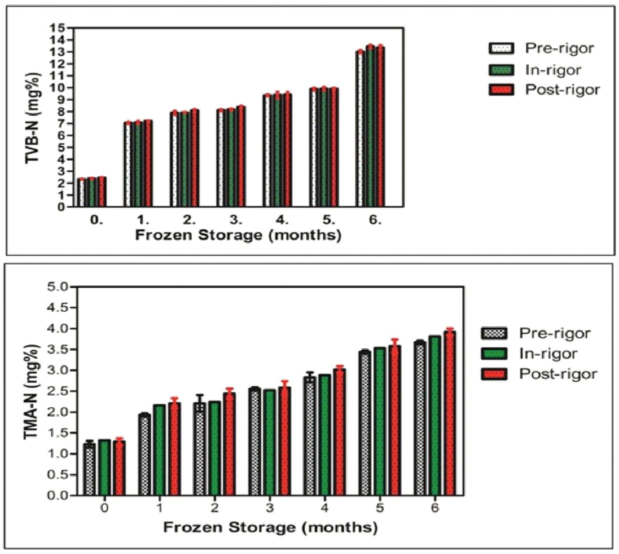

Fig. 1. Changes in TMA-N and TVB-N of Pacific white shrimp beheaded at different stages of rigor during frozen storage

capacity was found to be similar in all the treatments. However, at the end of study water holding capacity showed a significant difference ($p<0.05$) among the treatments with lowest value recorded in T3. The water holding capacity of gilthead sea bream frozen fillets decreased with storage time and was associated with the damage in muscle structures (protein content in centrifugal tissue fluids) and denaturation of myofibrillar proteins as reported by Makri (2009).

The peroxide and TBARS values of shrimps beheaded at different stages of rigor and stored under frozen conditions are given in Table 3. Peroxide value showed an increasing trend in all the treatments during the storage study. The initial peroxide value in T1, T2 and T3 were observed as 1.77, 2.07 and 2.07 respectively. The final values at the end of the experiment were found to be 8.33, 9.16 and 9.35 in T1, T2 and T3 respectively. There

Table 3. Changes in Peroxide value and TBARS value of Pacific white shrimp beheaded at different stages of rigor during frozen storage

Month	Treatment	PV (meq/kg)	TBARs (mgMDA/Kg)
	T1	$1.77{\pm}0.15^{b}$	$0.057{\pm}0.004^{a}$
0	T2	$2.07{\pm}0.19^{a}$	$0.059{\pm}0.005^{a}$
	T3	$2.07{\pm}0.09^{a}$	$0.060{\pm}0.027^{a}$
	T1	$3.04{\pm}0.33^{a}$	$0.84{\pm}0.020^{a}$
1	T2	$3.23{\pm}0.42^{a}$	$0.88{\pm}0.024^{a}$
	T3	$3.47{\pm}0.26^{a}$	$0.88{\pm}0.024^{a}$
	T1	$4.64{\pm}0.27^{a}$	$0.98{\pm}0.015^{a}$
2	T2	$4.27{\pm}0.41^{b}$	$0.96{\pm}0.027^{a}$
	T3	$3.87{\pm}0.46^{c}$	$0.94{\pm}0.016^{a}$
	T1	$6.00{\pm}0.47^{a}$	$1.05{\pm}0.025^{a}$
3	T2	$5.67{\pm}0.94^{b}$	$1.01{\pm}0.036^{a}$
	T3	$5.67{\pm}0.28^{b}$	$1.03{\pm}0.027^{a}$
	T1	$7.34{\pm}0.47^{a}$	$1.21{\pm}0.015^{a}$
4	T2	$6.67{\pm}0.47^{b}$	$1.23{\pm}0.031^{a}$
	T3	$6.67{\pm}0.47^{b}$	$1.40{\pm}0.036^{a}$
	T1	$8.00{\pm}0.47^{a}$	$1.31{\pm}0.024^{a}$
5	T2	$8.34{\pm}0.94^{a}$	$1.33{\pm}0.066^{a}$
	T3	$8.33{\pm}0.21^{a}$	$1.37{\pm}0.018^{a}$
	T1	$8.33{\pm}0.28^{b}$	$1.58{\pm}0.027^{a}$
6	T2	$9.16{\pm}0.47^{a}$	$1.54{\pm}0.027^{a}$
	T3	$9.35{\pm}0.47^{a}$	$1.56{\pm}0.019^{a}$

Data (n=3) are presented as means ± SD,
Mean values in the same column bearing different letters differ significantly ($p<0.5$)

Table 4. Changes in TPA values of Pacific white shrimp beheaded at different stages of rigor during frozen storage

Month	Treatment	Hardness (Kg)	Cohesiveness	Springiness	Chewiness (Kg)
	T1	7.93±0.58^{a}	0.43±0.05 ^{a}	0.53±0.02^{a}	1.13±0.14^{b}
0	T2	8.00±0.75^{a}	0.42±0.02 ^{a}	0.61±0.03^{a}	1.57±0.15^{a}
	T3	7.49±0.61^{a}	0.46±0.02 ^{a}	0.64±0.12^{a}	1.56±0.17^{a}
	T1	7.31±0.90^{a}	0.42±0.04^{a}	0.52±0.04^{a}	1.12±0.13^{a}
1	T2	6.93±0.31^{a}	0.42±0.10^{a}	0.51±0.04^{a}	1.45±0.16^{a}
	T3	6.99±0.85^{a}	0.43±0.11^{a}	0.61±0.03^{a}	1.18±0.21^{a}
	T1	5.71±0.46^{b}	0.39±0.08^{a}	0.48±0.06^{a}	1.12±0.14^{a}
2	T2	6.92±0.74^{a}	0.37±0.07^{a}	0.51±0.06^{a}	1.03±0.13^{a}
	T3	6.86±0.62 ^{a}	0.35±0.11^{a}	0.53±0.03^{a}	1.16±0.12^{a}
	T1	5.23±0.33^{b}	0.37±0.05^{a}	0.46±0.04^{a}	1.05±0.13^{a}
3	T2	6.49±0.74^{a}	0.36±0.04^{a}	0.47±0.05^{a}	0.97±0.15^{a}
	T3	5.58±0.58^{b}	0.34±0.05^{a}	0.47±0.07^{a}	0.78±0.16^{b}
	T1	5.16±0.31^{a}	0.31±0.06 ^{a}	0.36±0.09^{a}	0.77±0.13^{a}
4	T2	5.22±0.72^{a}	0.35±0.02 ^{a}	0.39±0.06^{a}	0.94±0.15^{a}
	T3	5.55±0.74^{a}	0.34±0.03^{a}	0.34±0.06^{a}	0.76±0.14^{a}
	T1	4.87±0.23^{a}	0.30±0.04^{b}	0.34±0.06^{a}	0.39±0.13^{a}
5	T2	4.15±0.77^{b}	0.40±0.05^{a}	0.33±0.09^{a}	0.33±0.35^{a}
	T3	4.53±0.58^{ab}	0.31±0.06^{b}	0.32±0.07^{a}	0.37±0.14^{a}
	T1	3.25±0.88^{a}	0.23±0.05^{a}	0.32±0.07^{a}	0.35±0.10^{a}
6	T2	3.11±0.47^{a}	0.24±0.04^{a}	0.31±0.09^{a}	0.33±0.15^{a}
	T3	3.36±0.43^{a}	0.16±0.07^{b}	0.29±0.04^{a}	0.23±0.12^{a}

Data (n=3) are presented as means ± SD,
Mean values in the same column bearing different letters differ significantly ($p<0.5$)

was no significant difference ($p>0.05$) in the peroxide value among the different treatments. Thiobarbituric acid value also showed an increasing trend during the study. The initial values of TBARS were 0.057, 0.059 and 0.060 in T1, T2 and T3 respectively and increased to final values to 1.58, 1.54 and 1.56 in T1, T2 and T3 respectively. TBARS value in different treatments did not vary significantly on any of the sampling months till the end of the storage. The results corroborate the findings of Natseba et al., (2005) who also reported increase in TBARs value of frozen Nile perch.

Changes in the texture (hardness, cohesiveness, springiness and chewiness) of shrimps beheaded at different stages of rigor and stored under frozen conditions are presented in Table 4. There was a significant decrease in the hardness, cohesiveness springiness and chewiness in all the treatments during the storage. Initially hardness was found higher in T2 and T3 remained highest among three treatments till the end of the storage with slightest aberration on the 2nd, 3rd and 5th months. The final lower value of hardness was recorded in T3 indicating that serving of skeletal muscle in pre-rigor stage results in the better textural properties. Similarly cohesiveness, springiness and chewiness also showed a decreasing trend during the storage period indicating that the texture is affected by the frozen storage and it may be attributed to protein denaturation and sublimation and recrystallization of ice crystals (Londahl, 1997). During frozen

Table 5. Changes in colour parameters of Pacific white shrimp beheaded at different stages of rigor during frozen storage

Month	Treatment	L*	a*	b*
0	T1	43.8±1.3[a]	-0.3±0.10[b]	-2.0±0.12[a]
	T2	41.9±1.7[a]	-0.1±0.08[a]	-3.6±0.25[b]
	T3	44.6±1.8[a]	-0.2±0.03[a]	-2.8±0.14[ab]
1	T1	41.1±1.2[a]	-0.1±0.08[a]	-2.2±0.18[a]
	T2	38.9±1.3[b]	-0.3±0.08[a]	-2.5±1.2[ab]
	T3	39.9±1.3[a]	-0.2±0.09[a]	-3.4±0.09[b]
2	T1	39.8±1.4[a]	-0.2±0.07[a]	-2.8±0.17[a]
	T2	38.3±1.7[a]	-0.4±0.06[b]	-2.8±0.13[b]
	T3	38.6±1.7[a]	-0.4±0.09[b]	-2.7±0.15[b]
3	T1	38.1±1.2[a]	-0.3±0.04[a]	-3.5±0.25[a]
	T2	39.4±1.1[a]	-0.4±0.05[b]	-3.1±0.14[a]
	T3	38.9±1.9[a]	-0.5±0.09[c]	-4.2±0.14[b]
4	T1	38.5±1.2[a]	-0.6±0.03[a]	-3.8±0.15[c]
	T2	36.1±1.6[b]	-0.8±0.07[b]	-2.4±0.13[a]
	T3	37.7±1.6[a]	-1.0±0.08[c]	-2.7±0.12[b]
5	T1	36.2±1.6[a]	-0.7±0.10[a]	-2.2±0.18[a]
	T2	38.4±1.0[a]	-0.8±0.04[b]	-4.2±0.17[b]
	T3	36.1±1.5[a]	-0.8±0.06[b]	-2.4±0.12[a]
6	T1	35.5±1.7[a]	-1.2±0.12[ab]	-2.2±0.15[a]
	T2	34.2±1.2[a]	-1.1±0.06[a]	-4.1±0.11[c]
	T3	35.3±1.8[a]	-1.3±0.07[b]	-3.6±0.18[b]

Data (n=3) are presented as means ± SD,
Mean values in the same column bearing different letters differ significantly ($p<0.5$)

storage there is an alteration in functional properties of muscle proteins like juiciness, texture and loss of water holding capacity (Hui, 2006).

Changes in colour of shrimps beheaded at different stages of rigor and stored under frozen conditions in form of data are shown in Table 5. There was a decrease in the L* value in all the treatments during the storage study. The initial highest L* value was found in shrimps beheaded and frozen in T3 stage followed by T2 and T1. Values of a* and b* showed a decreasing trends during the storage study indicating greener and blue colouration. Compared to other parameters, colour parameters showed significant differences ($p<0.05$) as storage progressed. Colour change in fish muscle occurs due to the reaction of myoglobin with the other muscle components especially myofibrillar protein (Hanan & Shaklai, 1995). The significant decrease in L* values during the frozen storage might be ascribed to changes in light absorption and light scattering caused by the freeze-denaturation of shrimp proteins (Lopkulkiaert et al., 2009). The decrease in a* values could be mainly attributed to the degradation of astaxanthin and lipid oxidation (Sundararajan et al., 2011). Also, it had been reported in many studies that lipid oxidation caused colour degradation during storage (Cadun et al., 2008).

The result of sensory evaluation of shrimp beheaded in different stages of rigor and stored under frozen conditions is given in Table 6. Initially, all the treatments had a very good sensory overall acceptability score (8.08 to 8.71). Sensory score showed a decreasing trend with the storage reaching to the final value of as low as 6.38. The T1 had higher

Table 6. Changes in sensory data of Pacific white shrimp beheaded at different stages of rigor during frozen storage

Month	Treatment	Colour	Appearance	Hardness	Overall acceptability
	T1	8.50±0.96^{a}	8.67±0.82^{a}	8.14±1.29^{a}	8.71±0.96^{a}
0	T2	8.33±1.29^{a}	8.33±0.96^{a}	8.08±1.00^{a}	8.14±1.26^{a}
	T3	8.21±1.29^{a}	8.25±1.15^{a}	8.07±2.45^{a}	8.08±2.45^{a}
	T1	7.83±0.39^{a}	8.11±0.61^{a}	8.00±1.02^{a}	8.08±0.63^{a}
1	T2	7.81±0.57^{a}	8.00±0.29^{a}	7.80±0.85^{a}	7.90±0.57^{a}
	T3	7.80±0.65^{a}	8.00±0.61^{a}	7.80±1.04^{a}	7.79±0.61^{a}
	T1	7.80±1.10^{a}	7.94±0.45^{a}	7.80±0.45^{a}	7.75±1.14^{a}
2	T2	7.79±0.84^{a}	7.88±0.84^{a}	7.79±0.84^{a}	7.75±0.89^{a}
	T3	7.78±0.97^{a}	7.83±1.00^{a}	7.78±0.84^{a}	7.75±0.97^{a}
	T1	7.70±0.83^{a}	7.80±0.79^{a}	7.75±0.88^{a}	7.70±0.50^{a}
3	T2	7.67±0.50^{a}	7.80±0.33^{a}	7.75±0.44^{a}	7.60±0.54^{a}
	T3	7.63±0.53^{a}	7.75±0.85^{a}	7.72±0.44^{a}	7.60±0.53^{a}
	T1	7.50±0.74^{a}	7.63±0.83^{a}	7.67±0.53^{a}	7.57±0.46^{a}
4	T2	7.50±0.93^{a}	7.57±0.74^{a}	7.50±0.46^{a}	7.51±0.89^{a}
	T3	7.50±1.67^{a}	7.56±1.25^{a}	7.50±1.04	7.44±1.19^{a}
	T1	7.50±0.64^{a}	7.50±0.71^{a}	7.44±1.18^{a}	7.29±0.59^{a}
5	T2	7.44±0.92^{a}	7.25±1.07^{a}	7.06±1.21^{a}	7.25±1.02^{a}
	T3	7.44±0.98^{a}	7.00±1.13^{a}	7.00±0.85^{a}	7.16±1.03^{a}
	T1	7.25±0.52^{a}	7.00±0.82^{a}	6.75±0.82	7.00±0.66^{a}
6	T2	7.13±0.75^{a}	6.75±0.76^{b}	6.44±0.61^{a}	6.91±0.66^{b}
	T3	6.25±0.45^{b}	6.13±0.52^{b}	6.25±0.92^{a}	6.38±0.46^{a}

Data (n=3) are presented as means ± SD,
Mean values in the same column bearing different letters differ significantly ($p<0.5$)

sensory scores compared to other two treatments. There were no significant difference ($p > 0.05$) among the treatments and on sixth month of sampling some differences could be observed. Deteriorative changes are the result of several post-mortem biochemical alterations and may be perceived by changes in sensorial scores (Mendes et al., 2005; Mendes, 2006). Shrimps were well within the acceptable limit during the study and were not rejected by the sensory panel indicating that the shrimp beheaded before freezing have a storage life of more than 6 months.

The head portion of the shrimp is inedible, removing it before the frozen storage can result in a good product. However, there is no difference in the quality of the shrimp beheaded in different stages of the rigor. Beheading the head immediately after the death can reduce the transportation and storage charges by occupying less space.

Acknowledgment

Authors are grateful to director/vice chancellor ICAR-Central Institute of Fisheries Education for providing necessary facilities for carrying out this research.

References

Benjakul, S., Visessanguan, W. and Chantarasuwan, C. (2004b) Effect of high temperature setting on gelling characteristic of surimi from some tropical fish. Int. J. Food. Sci. Technol. 39: 671-680

Benjakul, S., Visessanguan, W. and Chantarasuwan, C. (2004a) Cross-linking activity of sarcoplasmic fraction from bigeye snapper (Priacanthustayenus) muscle. LWT- Food. Sci. Technol. 37(1): 79-85

Bhat, T. H., Chouksey, M. K., Balange, A. K. and Nayak, B. B. (2017) Effect of heat treatment at different stages of rigor on the quality of pacific white shrimp *(Litopenaeus vannamei).* J. Aquat. Food Prod. Tech. 26(7): 770-780

Bhat, T. H., Chouksey, M. K., Balange, A. K. and Nayak, B. B. (2018b) Effect of severing skeletal muscle at different stage of rigor on the quality of pacific white shrimp (*Litopenaeus vannamei*) J. Food Proc. and Pres. 42(1): e13363

Bhat, T. H., Hassan, M. A., Chouksey, M. K., Balange, A. K., & Nayak, B. B. (2018a) Yield and Quality of Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) in response to different Killing Methods. Fish. Technol. 55(3): 183-187

Bhobe, A. M. and Pai, J. S. (1986) Study of the properties of frozen shrimps. J. Food Sci. Technol. (Mysore). 23(3): 143-147

Cadun, A., Kýþla, D. and Çaklý, Þ. (2008) Marination of deep-water pink shrimp with rosemary extract and the determination of its shelf-life. Food Chem. 109(1): 81-87

Chandrasekaran, M. (1994) Methods for preprocessing and freezing of shrimps: a critical evaluation. J. Food Sci. Technol. 31: 441-452

Conway, E. J. (1947) Microdiffusion analysis and volumetric error. Microdiffusion Analysis and Volumetric Error

Eide, O. L. A., Børresen, T. O. R. G. E. R. and Strøm, T. E. R. J. E. (1982) Minced fish production from capelin (*Mallotus villosus*). A new method for gutting, skinning and removal of fat from small fatty fish species. J. Food. Sci. 47(2): 347-349

Fennema, O. R. (1990) Comparative water holding properties of various muscle foods: A critical review relating to definitions, methods of measurement, governing factors, comparative data and mechanistic matters. J. Muscle Foods. 1(4): 363-381

Garthwaite, G. A. (1997) Chilling and freezing of fish. Fish process. Technol. 93-118

González-Félix, M. L., Gatlin III, D. M., Lawrence, A. L. and Perez-Velazquez, M. (2002) Effect of dietary phospholipid on essential fatty acid requirements and tissue lipid composition of Litopenaeus vannamei juveniles. Aquac. 207(1-2): 151-167

Hanan, T. and Shaklai, N. (1995) Peroxidative interaction of myoglobin and myosin. Eur. J. Biochem. 233(3): 930-936

Hui, Y. H. (Ed.). (2006) Handbook Food. Sci. Technol. Engrg. (Vol. 149). CRC press

IS:6273[II]. (1971) Indian Standard, Guide for sensory evaluation of foods (Part-II, Methods and evaluation cards). New Delhi, India: Indian Standards Institution Londahl, G. (1997) Technological aspects of freezing and glazing shrimp. Infofish Int. 49-56

Lopkulkiaert, W., Prapatsornwattana, K. and Rungsardthong, V. (2009) Effects of sodium bicarbonate containing traces of citric acid in combination with sodium chloride on yield and some properties of white shrimp (*Penaeus vannamei*) frozen by shelf freezing, air-blast and cryogenic freezing. LWT-Food Sci. Technol. 42(3): 768-776

Love, R. M. (1962) Protein denaturation in frozen fish. VI.- Cold storage studies on cod using the cell fragility method. J. Sci. Food Agric. 13(5): 269-278

Love, R. M. and Haq, M. A. (1970) The connective tissues of fish. IV. Gaping of cod muscle under various conditions of freezing, cold storage and thawing. Int. J. Food. Sci. Technol. 5(3): 249-260

Love, R. M. and Olley, J. (1965) Cold-storage deterioration in several species of fish, as measured by two methods. The Technol. Fish Utilization. 116

Makri, M. (2009) Full Length Research Paper Biochemical and textural properties of frozen stored (-22 C) gilthead seabream (*Sparus aurata*) fillets. Afr. J. Biotechnol. 8(7)

Mendes, R. (2006) Guidebook on melanosis inhibitors and processing technology of crustaceans. INIAP/IPIMAR: Project QLK1-CT-2002-71517 (CRUSTAMEL New Approaches to the Crustaceans Prevention of Melanosis and Quality Indices). 41

Mendes, R., Gonçalves, A., Pestana, J. and Pestana, C. (2005) Indole production and deepwater pink shrimp (*Parapenaeus longirostris*) decomposition. Eur. Food Res. Technol. 221(3): 320-328

Natseba, A., Lwalinda, I., Kakura, E., Muyanja, C. K. and Muyonga, J. H. (2005) Effect of pre-freezing icing duration on quality changes in frozen Nile perch (*Lates niloticus*). Food Res. Int. 38(4): 469-474

Official Methods of Analysis of AOAC International—18th Edition, Revision 3. (n.d.). https://www.techstreet.com/standards/official-methods-of-analysis-of-aoac-international-18th-edition-revision-3?product_id=1678986

Riaz, M. A. S. A. R. R. A. T. and Qadri, R. B. (1990) Time-temperature tolerance of frozen shrimp. 2. Biochemical and microbiological changes during storage of frozen glazed shrimps. Trop. Sci. 30(4): 343-356

Sikorski, Z. E., Kolakowska, A. and Pan, B. S. (2020) The nutritive composition of the major groups of marine food organisms. In: Seafood Resources, nutritional composition, and preservation. CRC Press. 29-54

Sundararajan, S., Prudente, A., Bankston, J. D., King, J. M., Wilson, P. and Sathivel, S. (2011) Evaluation of green tea extract as a glazing material for shrimp frozen by cryogenic freezing. J. Food. Sci. 76(7): E511-E518

Tarladgis, B. G., Watts, B. M., Younathan, M. T. and Dugan Jr, L. (1960) A distillation method for the quantitative determination of malonaldehyde in rancid foods. J. Am. Oil Chem.' Soc. 37(1): 44-48

The Marine Products Exports Development Authority (MPEDA) (n.d.). https://mpeda.gov.in/MPEDA/#

Yamagata, M. and Low, L. K. (1995) Banana shrimp, *Penaeus merguiensis*, quality changes during iced and frozen storage. J. Food. Sci. 60(4): 721-726

Yanar, Y. and Celik, M. (2006) Seasonal amino acid profiles and mineral contents of green tiger shrimp (*Penaeus semisulcatus* De Haan, 1844) and speckled shrimp (*Metapenaeus monoceros Fabricus*, 1789) from the Eastern Mediterranean. Food Chem. 94(1): 33-36