Effects of multiple freezing (-18 ± 2 °C) and microwave thawing cycles on the quality changes of sea bass (*Dicentrarchus labrax*)

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Abstract Sensory, chemical [pH, total volatile basic nitrogen (TVB-N), trimethylamine (TMA-N), thiobarbituric acid (TBA)] and composition (crude protein and crude lipid) analyses were carried out on whole, gutted and fillets of seabass that were frozen (-18 ± 2 °C) and thawed more than once in microwave. It was detected that the sensorial acceptability values decreased certainly for all fish samples (whole, gutted and fillets of sea bass) when compared with control group. While chemical (pH, TVB-N, TMA-N, TBA) values increased, crude protein and crude lipid values decreased after the multiple freezing and thawing cycles under microwave. The obtained results offered that thawing by microwave is not appropriate sea bass because of the undesirable cooking effect of microwave to the some parts of fish such as tail, eye and fins. Also skin dryness, moisture losses in eye fluids and textural deteriorations were observed. Significant differences ($P<0.05$) were found in general acceptability values and pH, TVB-N, TBA and crude protein results among the sea bass groups thawed in microwave conditions.

Keywords Sea bass · *Dicentrarchus labrax* · Microwave · Quality changes · Frozen · Thawing

Introduction

Storage life and the quality of frozen fish depend on the handling conditions of the fish, freezing rate, packing, rate of freezing-thawing, freeze-thaw abuse, temperature of storage, temperature fluctuations and sustainability. However, especially the chemical changes that occur during storage

decrease the nutritional quality and eventually the acceptability. Quick freeze and thaw processes are widely used at home and restaurants (Olgunoglu et al. 2002; Mol et al. 2004; Tokur and Kandemir 2008; Özeren and Ersoy 2008). Applying inaccurate freezing, storage and thawing treatments to foods generally cause microbiological, chemical and physical deteriorations (Bulduk 2002). The most common thawing methods used in Turkey are refrigerator thawing, microwave thawing, water thawing and thawing at room temperature (Turan et al. 2006).

Fish and fish products undergo several chemical and physical changes during frozen storage. These changes adversely affect frozen-fish product quality and storage stability. Although commercially used frozen storage temperatures suppress bacterial growth and spoilage with chemicals such as trimethylamine, fish endogenous lipases and proteases remain active causing lipids and proteins deterioration (Al-Bulushi et al. 2011). Frozen storage is an important preservation method for sea-foods. Its effectiveness stems from internal dehydration or immobilization of water and lowering of temperature. However, meat and fish may undergo quality losses such as protein denaturation, colour deterioration, weight loss, oxidation of lipids and textural changes due to the freezing and thawing processes. The extent of quality loss depends on careful pre-freezing preparation, control of the freezing rate, storage conditions and thawing conditions. During thawing, foods can be damaged by chemical, physical and microbiological changes. The freezing and thawing processes can have a profound effect on muscle physicochemical characteristics (Foegeding et al. 1996; Ersoy et al. 2008).

There are many commercial methods for thawing fish. The satisfactory techniques for thawing large portions of animal tissue include thawing in a refrigerator and microwave (Ersoy et al. 2008; Karel and Lund 2003). Microwave thawing is a popular thawing method in recent days, especially for thawing small portions of food at homes and

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restaurants. In microwave thawing, 3,000 mhz frequency is used for heating up the product. Water is a perfect microwave absorber. As seafood contains a significant amount of water, microwave heating occurs on each side of the product quickly. Microwave thawing is 10 times faster than dielectric thawing which is not suitable for commercial use (Gokoglu 2002). Microwave thawing requires shorter thawing time and smaller space for processing and reduces drip loss, microbial problems and chemical deterioration. The thawing rates of frozen samples in microwave thawing depend on material properties and dimensions and the magnitude and frequency of the electromagnetic radiation (Li and Wen Sun 2002).

The aim of the present study was to investigate the quality of sea bass that treated with multiple freeze ($-18\pm2\text{ }^{\circ}\text{C}$) and thaw cycles in microwave. The quality assessments were done in terms of sensory, chemical (pH, Total volatile basic nitrogen, Trimethylamine, Thiobarbituric acid) and composition (crude protein and crude lipid) changes.

Material and methods

Material Aqua-cultured sea bass (*Dicentrarchus labrax* L.1758) (totally 20 kg) were purchased from Muğla (Kılıç Fisheries Co./TURKEY). The fish were divided into three groups; Group B, whole with scale ($350\pm10\text{ g}$); Group P, whole gutted, scaleless ($300\pm10\text{ g}$) and Group F, scaleless fillets ($100\pm10\text{ g}$). Gutting and descaling were carried out in the plant manually. Fish were packed in separate polystyrene boxes with flake ice and transported to the laboratory.

Freezing and thawing process The samples were frozen for 15 days and they were taken out for thawing and were put into the freezer again for 6 times for 3 months. We preferred this method because deep freezes whose temperatures varied between -18 and -24 were used in houses and restaurants. Three fish from each group; whole with scale (Group B), whole, gutted and scaleless (Group P) and scaleless fillets (Group F) were put into foam plates, sealed with plastic wrap (Özgülmak, Turkey) and stored in $-18\pm2\text{ }^{\circ}\text{C}$ freezer (Uğur, Turkey) until the thawing treatments. Thawing process in microwave was carried out by putting samples on proper glass material. During this process, foam was not used. For each analysis, all of the groups were taken from the freezer and thawed in the microwave. Samples that would not analyzed at that day were put into the freezer again although they had been thawed. These samples were kept in the freezer up to the next analysis period. Groups were put in the microwave under 135 Watt, and the duration was $45\pm2.04\text{ min}$ for Group B, $40\pm2.04\text{ m}$ for Group P and $34\pm3.76\text{ m}$ for (Group F) (Fig. 1). Each thawing process was carried out until the middle point temperature reached to $4\pm2\text{ }^{\circ}\text{C}$. The temperature change of the sea bass samples

Fig. 1 The flow diagram of thawing process under microwave. *Steps between 3 and 6 were repeated once a 15 days and there were totally 6 freezing and thawing cycles throughout the study

was measured using T-type thermocouple. The thermocouple was nestled to the upper part of the fish sample.

Preparing the samples Sensorial, pH, TVB-N, TMA-N, TBA, crude protein % and crude lipid % analysis were carried out initially and once every 15 days after storing at $-18\pm2\text{ }^{\circ}\text{C}$. For each analysis, all of the groups were taken from the freezer and thawed in the microwave. Samples that would not analyzed at that day were put into the freezer again although they had been thawed. These samples were kept in the freezer up to the next analysis period. Analyses were duplicated after 3 months.

Analyses

Sensory analysis The freshness of the fish was evaluated according to Aubourg (2001) by 6 panelists. Scale 3–4=best quality, 2–3=good quality, 1–2=moderate quality and ≤1 =not acceptable.

Proximate analysis The proximate composition of sea bass was determined as crude protein ($N\times6.25$) and crude lipid values, using the method of AOAC (1998).

Chemical analysis Inolab WTW pH meter was used for pH analysis. 10 g of fish samples were weighted, diluted 1:1 and homogenized. The prob of the pH meter was dipped into the solution and the pH values recorded according to Manthey et al. (1988). Total volatile basic nitrogen (TVB-N) values were determined according to Antonocopoulos (1973). Volatile bases were separated by steam distillation

of homogenized samples, those separated bases were collected in 0.1 N HCl and titrated back with 0.1 N NaOH. TVB-N was calculated and expressed as mg/100 g sample. Trimethylamine (TMA-N) amount of the homogenized sample was calculated and expressed as mg/100 g sample according to Schormüller (1968). Samples were extracted with trichloroacetic acid. Bases in the extract were fixed with formaldehyde and after adding picric acid, the absorbance was measured at 410 nm. Thiobarbituric acid (TBA) was calculated and expressed as mg malonaldehyde/kg fish sample according to Tarladgis et al. (1960). HCl was added to the fish samples and processed in a condenser. TBA solution prepared with 90 % glacial acetic acid was added to the distilled solution and left in a water bath. The absorbance was determined by a spectrophotometer at 538 nm.

Statistical analysis SPSS 14 for Windows was used and LSD test (comparisons of means using the least significant difference method) was carried out for comparisons of the significance levels of the groups ($P < 0.05$).

Results

Sensory attributes The results of sensory analysis are given in Table 1. Changes in the sensory quality of sea bass that were subjected to multiple freeze and thaw cycles are shown in Table 1. After the first thawing treatment in microwave, the average sensory scores of whole, gutted and fillets of sea bass samples were 3.55 ± 0.03 , 3.56 ± 0.02 and 3.57 ± 0.07 , respectively. At the end of the last thawing period (6th), the sensory scores were 0.74 ± 0.02 , 0.68 ± 0.03 and 0.74 ± 0.02 , respectively. After microwave thawing, fish samples remained below the acceptability levels. The whole and fillets of sea bass had the best quality aspects while the gutted group had the worst ($P < 0.05$).

Proximate analysis results Although protein content of sea bass was average 19.69 ± 0.27 %, after the first microwave thawing this value at whole, gutted and fillet samples were detected as 19.08 ± 0.10 , 18.93 ± 0.29 , 19.34 ± 0.21 %, respectively; after the end of 6th thawing period the values were 18.45 ± 0.25 , 18.75 ± 0.25 and 18.09 ± 0.22 % (Fig. 2).

Crude protein value of sea bass groups that thawed in microwave conditions decreased through thawing period and especially after sixth thawing the lowest protein rate was determined in filleted samples with 18.09 %, whereas the highest rate was found in gutted samples with 18.75 %. When the amount of crude protein evaluated statistically in this study, significant difference between all fish groups was detected ($P < 0.05$).

Although crude lipid content of sea bass was average 8.54 ± 0.12 %, after the first microwave thawing this value

at whole, gutted and fillet samples were detected as 9.63 ± 0.17 , 7.36 ± 0.09 , 9.08 ± 0.28 %, respectively; after the end of 6th thawing period the values were 7.20 ± 0.09 , 7.18 ± 0.24 and 7.28 ± 0.24 % (Fig. 2).

It had been seen that crude lipid value of sea bass groups thawed in microwave conditions decreased after sixth thawing period. After sixth thawing crude lipid value of all three group samples showed variation between 7.18 and 7.28 %. When lipid amount evaluated statistically, it can be seen that there was an important difference between gutted fishes and whole&fillet fishes, there was not a significant difference between whole and fillet fishes. Due to the fact that dehydration occurred in the products during storage and thawing processes, it was thought that the crude protein and lipid values were decreased.

pH analysis results Although the pH was calculated as 6.48 ± 0.00 for fresh sea bass, after the first microwave thawing period, pH values were detected as 6.46 ± 0.00 , 6.41 ± 0.00 and 6.39 ± 0.00 for whole, gutted and fillets of sea bass, respectively. At the end of the freezing-thawing cycles (6th thawing period), the pH values were found to be 6.58 ± 0.00 , 6.58 ± 0.00 and 6.58 ± 0.00 for whole, gutted and fillets of sea bass, respectively (Fig. 3).

When comparing the pH values of the fresh and frozen-thawed sea bass groups, there was a decrease after the first thawing period in microwave but at the end of the multiple freezing-thawing cycles (6th thawing period), the pH values increased. Statistically there were significant differences in pH value among the groups ($P < 0.05$).

TVB-N analysis results Although the mean TVB-N was calculated as 18.85 ± 0.10 mg/100 g for fresh sea bass, after the first microwave thawing period, TVB-N values were detected as 17.49 ± 0.10 , 18.01 ± 0.13 and 18.11 ± 0.05 mg/100 g for whole, gutted and fillets of sea bass, respectively. At the end of the freezing-thawing cycles (6th thawing period), the TVB-N values were 21.88 ± 0.17 , 23.70 ± 0.36 and 21.61 ± 0.32 mg/100 g for whole, gutted and fillets of sea bass, respectively (Fig. 3).

When comparing the results obtained after the microwave thawing cycles, it was detected that TVB-N values decreased after the first thawing treatment but they increased after the following cycles. At the end of the last thawing cycle (6th thawing period), the lowest TVB-N values were obtained for whole and fillets of sea bass and the highest TVB-N value as 23.70 mg/100 g were found in the gutted group samples. Statistically there were significant differences in TVB-N value among the groups ($P < 0.05$).

TMA-N analysis results Although the mean TMA-N was calculated as 3.16 ± 0.00 mg/100 g for fresh sea bass, after the first microwave thawing period, TMA-N values were

Table 1 Sensorial changes of sea bass groups thawed in microwave conditions

	Whole						Gutted					
	Skin	Eye	Gill	Smell	Stiffness	Tissue	General accept	Skin	Eye			
Flesh	3.88±0.02 ^{aA}	3.80±0.02 ^{aA}	3.67±0.02 ^{aA}	3.79±0.02 ^{aA}	3.91±0.01 ^{aA}	3.89±0.01 ^{aA}	3.82±0.01 ^{aA}	3.88±0.02 ^{aA}	3.80±0.02 ^{aA}			
1st thawed	3.68±0.01 ^{aA}	3.42±0.03 ^{aA}	3.45±0.04 ^{aA}	3.53±0.02 ^{aA}	3.64±0.03 ^{aA}	3.66±0.01 ^{aA}	3.55±0.06 ^{aA}	3.61±0.01 ^{aA}	3.39±0.02 ^{aA}			
2nd thawed	3.47±0.02 ^{aA}	3.11±0.02 ^{bAB}	3.03±0.02 ^{bAB}	3.14±0.02 ^{bAB}	3.34±0.02 ^{aAB}	3.34±0.01 ^{aA}	3.24±0.03 ^{aAB}	3.36±0.01 ^{aA}	3.06±0.01 ^{bB}			
3rd thawed	2.79±0.02 ^{aB}	2.48±0.02 ^{aB}	2.47±0.02 ^{aB}	2.53±0.02 ^{aB}	2.72±0.02 ^{aB}	2.63±0.01 ^{aB}	2.60±0.01 ^{aB}	2.88±0.02 ^{aB}	2.50±0.02 ^{aB}			
4th thawed	2.02±0.01 ^{aB}	1.36±0.01 ^{bC}	1.43±0.02 ^{bC}	1.65±0.01 ^{bCD}	1.81±0.03 ^{aC}	1.68±0.02 ^{bC}	1.65±0.1 ^{bC}	1.90±0.01 ^{aC}	1.40±0.01 ^{bC}			
5th thawed	1.39±0.01 ^{aBC}	1.08±0.02 ^{aBC}	0.98±0.01 ^{bCD}	1.03±0.02 ^{bD}	0.98±0.02 ^{bD}	0.98±0.01 ^{bD}	1.12±0.03 ^{aBCD}	1.33±0.01 ^{aCD}	1.19±0.01 ^{aBC}			
6th thawed	0.93±0.01 ^{aC}	0.59±0.03 ^{bD}	0.45±0.01 ^{bD}	0.65±0.02 ^{bD}	0.76±0.01 ^{bD}	0.65±0.01 ^{bD}	0.74±0.04 ^{bD}	0.93±0.01 ^{aD}	0.57±0.02 ^{bD}			

	Fillet						General accept					
	Gill	Smell	Stiffness	Tissue	General accept	Skin	Smell	Stiffness	Tissue			
Flesh	3.67±0.02 ^{aA}	3.79±0.02 ^{aA}	3.91±0.01 ^{aA}	3.89±0.01 ^{aA}	3.82±0.01 ^{aA}	3.88±0.02 ^{aA}	3.79±0.02 ^{aA}	3.91±0.01 ^{aA}	3.89±0.01 ^{aA}	3.82±0.01 ^{aA}	3.82±0.01 ^{aA}	3.82±0.01 ^{aA}
1st thawed	3.44±0.03 ^{aA}	3.54±0.02 ^{aA}	3.65±0.03 ^{aA}	3.66±0.01 ^{aA}	3.56±0.05 ^{aA}	3.46±0.02 ^{aA}	3.57±0.01 ^{aA}	3.55±0.02 ^{aA}	3.49±0.02 ^{aA}	3.57±0.06 ^{aA}	3.57±0.06 ^{aA}	3.57±0.06 ^{aA}
2nd thawed	3.11±0.02 ^{bAB}	3.25±0.02 ^{abA}	3.25±0.01 ^{abAB}	3.23±0.02 ^{abAB}	3.23±0.03 ^{abAB}	3.22±0.02 ^{abAB}	3.26±0.02 ^{abAB}	3.28±0.02 ^{abAB}	3.17±0.01 ^{bAB}	3.24±0.04 ^{abA}	3.24±0.04 ^{abA}	3.24±0.04 ^{abA}
3rd thawed	2.43±0.03 ^{aB}	2.62±0.01 ^{aB}	2.68±0.02 ^{aB}	2.63±0.01 ^{aB}	2.65±0.03 ^{aB}	2.79±0.01 ^{aB}	2.70±0.02 ^{aB}	2.73±0.01 ^{aB}	2.64±0.02 ^{aB}	2.73±0.01 ^{aB}	2.73±0.01 ^{aB}	2.73±0.01 ^{aB}
4th thawed	1.44±0.01 ^{bC}	1.66±0.01 ^{bC}	1.68±0.02 ^{bC}	1.58±0.02 ^{bC}	1.65±0.01 ^{bC}	1.87±0.01 ^{aC}	1.70±0.01 ^{bC}	1.62±0.02 ^{bC}	1.53±0.01 ^{bC}	1.68±0.01 ^{bC}	1.68±0.01 ^{bC}	1.68±0.01 ^{bC}
5th thawed	1.13±0.01 ^{aBC}	1.08±0.02 ^{abCD}	1.05±0.01 ^{abC}	0.99±0.01 ^{bD}	1.14±0.02 ^{abCD}	1.34±0.01 ^{aCD}	1.16±0.01 ^{abCD}	1.06±0.01 ^{abCD}	0.98±0.01 ^{bCD}	1.19±0.03 ^{abD}	1.19±0.03 ^{abD}	1.19±0.03 ^{abD}
6th thawed	0.42±0.01 ^{bD}	0.71±0.01 ^{bD}	0.75±0.02 ^{bD}	0.66±0.01 ^{bD}	0.68±0.02 ^{bD}	0.88±0.02 ^{aD}	0.72±0.03 ^{bD}	0.68±0.01 ^{bD}	0.63±0.01 ^{bD}	0.74±0.04 ^{bD}	0.74±0.04 ^{bD}	0.74±0.04 ^{bD}

Values with different letters in the column (a, b...) and in the row (A, B...) differ significantly ($p < 0.05$) ($n = 6$)

Fig. 2 Changes in proximate analysis results in frozen sea bass during repeated thawing under microwave conditions ($n=3$)

detected as 3.31 ± 0.01 , 3.04 ± 0.01 and 3.03 ± 0.06 mg/100 g for whole, gutted and fillets of sea bass, respectively. At the end of the freezing-thawing cycles (6th thawing period), the TMA-N values were 3.49 ± 0.06 , 3.33 ± 0.01 and 3.29 ± 0.01 mg/100 g for whole, gutted and fillets of sea bass, respectively (Fig. 3).

When comparing the results obtained after the microwave thawing cycles, it was detected that TMA-N values decreased after the second thawing treatment but there was a balanced increase after the following cycles. At the end of

the last thawing cycle (6th thawing period), the lowest TMA-N values were obtained for gutted and fillets of sea bass and the highest TMA-N value as 3.49 mg/100 g were for the whole group samples. Statistically there were significant difference in TMA-N value between the gutted group and the other groups ($P < 0.05$) and there was not a significant difference between the whole and fillets of sea bass.

TBA analysis results Although the mean TBA was calculated as 0.43 ± 0.01 mg malondialdehyde/kg for fresh sea bass, after

Fig. 3 Changes in chemical quality parameters in frozen sea bass during repeated thawing under microwave conditions ($n=3$)

the first microwave thawing period, TBA values were detected as 0.43 ± 0.01 , 0.45 ± 0.01 , 0.47 ± 0.01 mg malondialdehyde/kg for whole, gutted and fillets of sea bass, respectively. At the end of the freezing-thawing cycles (6th thawing period), the TBA values were 0.71 ± 0.04 , 0.89 ± 0.05 and 0.88 ± 0.05 mg malondialdehyde/kg for whole, gutted and fillets of sea bass, respectively (Fig. 3).

There was a regular increase in TBA values of samples thawed in microwave through the thawing cycles. At the end of the freezing-thawing cycles (6th thawing period), TBA values remained below 1 mg for all samples. The lowest TBA value was obtained as 0.71 mg malondialdehyde/kg for whole sea bass. Statistically there were significant differences in TBA value among the groups ($P < 0.05$).

Discussion

Özeren and Ersoy (2008), found that the odor of eel (*Anguilla anguilla*) which they thawed under microwave conditions were better than other thawing conditions. It is suggested that thawing under microwave conditions is the best thawing method in terms of protecting the color quality of the fish, muscle structure and taste quality. In another study about the different thawing methods of frozen mussel, Gunel (2005) found out that the thawing process did not affect the natural odor but when the colour, tissue and appearance changes are considered, the most significant difference was determined in the samples thawed at room temperature. Baygar et al. (2004) stated that anchovies and blue fish thawed under refrigerator conditions lost their sensory freshness after the third thawing cycle. Srinivasan et al. (1997) express that frozen freshwater shrimps exhibit losses in their physicochemical and tissue properties after the third thawing cycle. In a study where they thawed frozen codfish at $+4^\circ\text{C}$ in icy water, Hallier et al. (2008) stated that fillets of European catfish became lighter and yellower after a freezing-thawing cycle due to the oxidation and degradation of pigments caused by mechanical damage. They also indicated that becoming less bright after a freezing thawing cycle is owing to an alteration of the optical properties of the muscle caused by muscle protein denaturation. Sensory analysis results of our study indicated that multiple freezing and thawing cycles cause quality changes such as moisture losses in fish flesh and eye, skin dryness and color changes in gills and deformed the fish texture.

The pH value in cultivated sea bass found by Periago et al. (2005) and Orban et al. (2003) were 6.44 and 6.27, respectively. In a study about the quality differences of whole ungutted sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) while stored in ice, Cakli et al. (2007) detected important differences in pH values considering to the storage time. In a study about the quality differences of whole ungutted sea bream

(*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) while stored in ice, Cakli et al. (2007) detected important differences in pH values considering to the storage time. They also found out the initial TBA values as 0.26 and 0.36 mg malondialdehyde/kg, TVB-N values as 17.11 and 18.61 mg/100 g, TMA-N values as 0.27 and 0.44 mg/100 g. Again, Cakli et al. (2006) determined the TMA-N values as 0.87 and 1.26 mg/100 g, TVB-N values as 15 and 16.2 mg/100 g; TBA value as 1.15 and 0.63 mg malondialdehyde/kg for gutted sea bream and sea bass just at the beginning of the storing period. It is defined in another study about sea bass that TMA value of sea bass fillets stored in ice increase slower than the whole fish stored in ice. In a study about the effects of multiple freezing and microwave thawing cycles on anchovies and blue fish, Baygar et al. (2004) detected the initial sensory scores as 8.70 and 8.85, pH value as 6.21 and 6.01, TVB-N values as 21.88 and 17.70 mg/100 g, TMA-N values as 4.02 and 3.55 mg/100 g, respectively. At the end of the fourth (the last thawing period) microwave thawing cycle, pH, TVB-N, TMA-N results of anchovies and blue fish were 6.36 and 6.34; 34.89 and 27.35; 5.56 and 3.91, respectively. In another study where they exposed European eel to different thawing processes in refrigerator, water, room temperature and microwave, Ersoy et al. (2008) found the initial pH value as 6.23, TVB-N value as 12.47 mg/100 g flesh of fish, and TBA value as 1.10 mg malondialdehyde/kg flesh of fish. According to the authors, after freeze-thaw cycles, the decreasing pH value caused a significant difference statistically and the decrease of TBA amount was considered to be caused by the interactions of the lipid oxidation products.

Gunel (2005) determined the pH value of refrigerator thawed mussel as 6.66, its TVB-N as 7.09 mg/100 g, TBA as 3.05 mg malondialdehyde/kg. In another study about codfish (*Gadus morhua*) and amberfish (*Sebastes marinus*), results of TMA measurements showed slower formation of TMA on freshly frozen fillets than those frozen after a freeze-thaw cycle. The longer the fillets were kept frozen, the slower the TMA occurred in fillets. Tokur and Kandemir (2008), stated that there was an important decrease in the protein solubility of frozen trout and sardine after being thawed under microwave (180 W) and although the TVB-N values increased during the freeze-thaw processes, this was not as much as the other thawing methods. According to the results, thawing methods did not directly affect the pH of sardine and they suggested that the most appropriate thawing method is microwave thawing for sardines. Boonsumrej et al. (2006) applied three different thawing methods to the tiger shrimps frozen under air-blast freezing and frozen in cryogenic freezer. They detected that freeze-thaw cycles affect the TBA values of the shrimps and the combined effect of thawing method and freeze-thaw cycle of the shrimps frozen under both methods had the influence on thawing loss%. They concluded that the microwave thawing the samples with the higher thawing loss % than

those thawed at refrigerator temperature in every cycle and the increase in the freeze–thaw cycles the samples having the higher thawing loss %.

Srinivasan et al. (1997) were subjected frozen prawns to multiple freeze–thaw cycles and determined their quality loss. They detected important quality losses and physico-chemical changes in muscle after the third freezing–thawing cycle. They defined that the myosin denaturation of prawn's muscles decreased clearly after the freezing–thawing cycles. Tironi et al. (2007) defined that muscle cell damages which formed during the freezing and thawing cycles of wild sea bass may cause negative alterations on the colour and protein. Benjakul and Bauer (2001) stated that the freezing–thawing cycles cause instability in muscle structure and increase in lipid oxidation of catfish. The highest level of water loss was observed as the number of freezing and thawing cycles increased. It was emphasized that ice crystals which formed as a result of repeated thawing cycles damaged the cell membrane and organelles.

When interpreting the results; it was detected that, at the end of the freezing–thawing cycles (6th thawing period), all fish groups were at the same condition in terms of pH content. Fillets of sea bass had the best value for TVB-N and TMA-N contents. The lowest value for TVB-N content was seen for the gutted sea bass. The lowest value for TMA-N content was seen for the whole sea bass. The best value for TBA for whole sea bass but the lowest value for TBA was seen for the gutted sea bass.

Conclusion

Microwave thawing is thought to be more appropriate for fillets in terms of the microwave oven specifications that are used at houses, equal distribution of microwave thawing in fish flesh and short time required for microwave thawing. From analyses that were performed in this study, only sensory analyses exceed the limit values after fifth thawing. Products that are not preferred in terms of sensory do not have an importance for consumer/customer whatever other properties are. It had been seen in all thawing methods TVB-N stayed under limit values. During the thawing processes fish samples stayed at very low levels in terms of TBA. It has been established that thawing in microwave conditions is not very suitable for fishes that are big and have more meat thickness such as sea bass according to cooking process at tail, eye and fin parts. In the same way again negations were detected such as dry skin, moisture losses in eye fluid and crumbling at tissue. Although after fifth thawing, fishes started to have unacceptable sensory aspects, all frozen food should be consumed immediately after thawed only once. This situation become more important when reasons like; irregularity of frozen storage

conditions especially at home, restaurants and fish sale market places, not applying necessary hygiene measures, freshness status at the moment that fishes taken to store, the type and amount of food in freezer, electric outages, opening the freezer door continuously and long term are considered.

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