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Research Article

Effects of glazing and coriander (*Coriandrum sativum*) leave extract on chemical spoilage indices in narrow-barred Spanish mackerel (*Scomberomorus commerson*) fillets during frozen storage

Hosseini S.F.[1]; Motalebi A.A.[1*]; Rokni N.[2]; Sharif Rohani M.[2]

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Abstract

In this study, the combined effect of glazing and coriander (*Coriandrum sativum*) leave extract were evaluated on the chemical spoilage indices of narrow-barred Spanish mackerel (*Scomberomorus commerson*) at frozen temperature. Antioxidant activity (DPPH, ABTS and FRAP) of coriander leaf hydroalcoholic extract was examined, however, 5 treatments including: Unglazed (UG) without immersion in water and coriander extract; Water glazed (WG); 0.5% of coriander extract-glazed (CG 0.5%); 1% of coriander extract-glazed (CG 1%); and 1.5% of coriander extract-glazed (CG 1.5%) were prepared for mackerel fillets storage. They were then stored at -18°C. The examined parameters in frozen samples were water holding capacity (WHC), drip loss, cooking loss, total volatile basic nitrogen (TVB-N), peroxide value (PV) and thiobarbituric acid (TBA) after 1, 2, 3, 4, 5 and 6 months at -18°C. The results showed that DPPH, ABTS and FRAP and the percent of inhibition significantly increased as the concentration of the extract increased reaching 68.58%, 9.25 mM trolox/kg dw and 13.46 mM trolox/kg dw at concentration of 700 mg/l, respectively. Variation range of PV, TVN and TBA after 180 days increased to 10.221-14.450 meq O2/kg lipid, 0.460-0.635 mg MDA/kg and 28.76-37.31 mg/100g, respectively. After six months WHC and drip loss of UG, and CG 1.5% treatments reached 49.23%, and 63.36% and to 15.23% and 10.55%, respectively. The CG 0.5%, CG 1%, and CG 1.5% treatments had a low average cooking loss among all the groups. According to the results of the performed parameters (TVB-N and TBA), the shelf life of fish fillets kept at -18 ºC was up to 180 in the acceptable range, but in terms of PV, it was outside the standard range, while in the control treatment, the parameters examined on day 150 were outside the standard range.

Keywords: Coriander leaves extract, Glazing, Frozen storage, Chemical changes, *Scomberomorus commerson*

1- Department of Hygiene, Science and Research Branch, Islamic Azad University, Tehran, Iran
2- Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension (AREEO), Tehran, Iran
*Corresponding author's Email: abbasalimotallebi@gmail.com

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Introduction

Fish due to its high nutritional value, play an important role in the diet of people. It is a good source of polyunsaturated fatty acids (PUFA's), protein, minerals and vitamins (Tacon and Metian, 2013). Although the nutritional value of fish is high, but due to its rapid spoilage, it has a low shelf life. The extension of shelf life can be performed by freezing, chilling, salting, smoking, glazing, etc. Fish trade, and its import and export in world markets, accounts for a high volume of turnover in most countries. Storage at low temperatures, especially refrigeration and freezing temperatures are the most important methods of food preservation (Campañone *et al.*, 2006). Freezing temperatures are used for long-term storage of food that does not require the use of chemical agents or preservatives (Pavlov, 2007). However, during the frozen storage, fish muscle can undergo a number of changes, such as denaturation and aggregation of the myofibrillar proteins. This results in alteration of the functional properties of muscle proteins directly resulting in economic losses (Lina *et al.*, 2013; Barroso da Silva *et al.*, 2020). Storage time and temperature are the index parameters in evaluating the quality and shelf life of fish because they affect their chemical, microbial and sensory factors (Arannilewa *et al.*, 2006).

Some methods using nano-compounds (Ghorabi and Khodanazary, 2020; Khanipour *et al*., 2020; Kargar *et al.*, 2021) and herbal extracts (Mardoukhi *et al*., 2021; Seifzadeh and Rabani Khorasgani, 2020; Ganjian *et al*., 2020; Khadem *et al*., 2020) were applied to increase the shelf life of fillet during the cold or freezing storage. Sensory and nutritional properties of fish are preserved when stored in freezing temperature. If fish are kept in inappropriate conditions, they would be exposed to oxidative spoilage for a long time and lipids would be converted to secondary metabolites such as free fatty acids and thiobarbituric acid (Fernandes, 2009). The glazing process is used to prevent lipid oxidation process during freezing. The ice layer from glazing, controls moisture and also prevents penetration of oxygen. In order to improve the effects of ice coating, various materials are used in combination with glazing such as hydrolyzed proteins, polysaccharides and other natural compounds (Wang *et al.*, 2020). Natural compounds, due to their antioxidant properties, improve the quality of fishery products in freezing conditions.

When the glazing coating is thin (<6%) there is a possibility of its fragility and as a result it would not have a positive effect on the quality of the fish. It will also be harmful to the consumer when the coating thickness is more than the standard level (>15%). The standard thickness for the glazing process is around 12% (Popelka *et al.*, 2012).

Narrow-barred Spanish mackerel (*Scomberomorus commerson*) is a member of the tuna family and belongs to the group of fatty fish, and therefore, it undergoes oxidative spoilage in

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freezing conditions faster than other fish species and its functional and nutritional properties are affected (Sahari *et al.*, 2009). In fatty fish, such as herring, anchovies, mackerel, and salmon, oxidation is the main cause of spoilage. Fish lipids contain high amounts of polyunsaturated fatty acids that are sensitive to oxidation process, in which the lipids are converted to compounds such as aldehyde, alkyl radicals and semialdehydes (Chen *et al.*, 2008).

Coriander is a plant that in its various parts (roots, seeds and leaves) has nutritional value and is rich in polyphenols, linoleic acid and trace elements. This plant has antioxidant, anti-diabetic, anti-cancer and antimicrobial properties and has an inhibitory effect on a variety of gram-positive, gram-negative bacteria and some fungi (Bhat *et al.*, 2014).

In a study by Sancho *et al.* (2011), the effect of coriander leaves as a natural antioxidant in white hake meatballs during freezing was investigated. The results showed that 0.5% of coriander leaf powder controlled the lipid oxidation process at -18°C and thus retained essential fatty acids during 120 days of storage.

In a study by Wangensteen *et al.* (2004), the antioxidant effects of coriander seeds and leaves were investigated. The results showed that antioxidant effects of leaves were more than seeds and extraction using ethyl acetate showed the highest antioxidant properties. In another study, the antioxidant effects of coriander were also confirmed (Mirzaei *et al.*, 2011). In the study of Hussein *et al.* (2016), the effect of coriander extract on *Lucioperca* fillets was evaluated and microbial and chemical spoilage indices were examined. The results showed that the treatments containing coriander had better condition compared to the control treatment.

The aim of this study was to investigate the combined effect of glazing and coriander extract on the chemical spoilage indices of narrow-barred Spanish mackerel at freezing temperature.

Material and methods

Materials

Coriander (*Coriandrum sativum*) leaves were collected from Sari (north of Iran) and dried at 25-30°C for 4 days. Dried leaves were separated from branches, then blended in a blender and kept in refrigerator at 4°C until use. Fish samples narrow-barred Spanish mackerel (*Scomberomorus commerson*) were obtained from Bandar Abbas (South of Iran). All chemicals used were manufactured by Merck (Germany) and were of analytical grade.

Preparation of coriander extract

Dried blended coriander leaves were subjected to Soxhlet extraction using hydroalcoholic solution as solvent. 10 g of the plant material and 100 ml of ethanol (90%) were mixed in water (50:50%). The extract was then filtered through Whatman filter No. 1 and the solvent was vacuum-distilled at 40°C in a rotary evaporator. The remaining

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extract was finally dried in oven at 30°C for 18 hours. The final extract was kept in a dark bottle in refrigerator at 4°C until use (Guerro *et al.*, 2005; Deepa and Anuradha, 2011; Nimish *et al.*, 2011).

Determination of antioxidant activity by DPPH assay

DPPH radical scavenging assay was performed according to the method described by Maleki *et al.* (2016) with slight modification. 1.5 mL of DPPH solution was added to different concentrations of the coriander extract. The solution was mixed, covered with parafilm and protected from light for 30 min in dark. UV/Vis Spectrophotometer (Shimadzu UV-1800, Kyoto, Japan) was applied and the absorbance was detected at 517 nm using ethanol as blank. The assay was carried out in triplicate and the radical scavenging percentage of each sample was measured using equation (1):

$$\text{Inhibition (\%)} = \left(\frac{\text{Abs}_{\text{control}}\text{-Abs}_{\text{sample}}}{\text{Abs}_{\text{control}}}\right) \times 100 \quad (1)$$

Determination of antioxidant activity by ABTS Assay

2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) was determined after the reaction, between 7 mM ABTS solution and 2.45 mM potassium persulfate (K2S2O8) solution at ambient temperature in the dark condition. After 16h incubation, ABTS radical solution was diluted with methanol to get an absorbance reading of 0.675 ± 0.025 at 734 nm. ABTS solution was prepared for each absorbance. 2.9 mL of the ABTS solution was mixed with 0.1 mL leaf extract, left to the incubation at ambient conditions for 30 min, in the dark condition, then the absorbance was read at 734 nm. Results were calculated as mM trolox equivalents per kg dry weight of plant material (Rajurkar and Hande, 2011).

Determination of antioxidant activity by FRAP Assay

The extracts were analyzed according to the method described in Jiménez *et al.* (2015). In reaction, the (2,4,6-Tris(2-pyridyl)-s-triazine 2) TPTZ–Fe (III) was reduced. The FRAP solution was prepared in water at a ratio of 10:1:1 with 300 mM (pH 3.6) acetate buffer, 40 mM TPTZ and 20 mM FeCl3•6H2O, respectively. FRAP solution and herbal extracts were mixed at 1:20 ratio and allowed reaction at 37ºC in dark for 15 min. The absorbance was measured at 593 nm. The results are expressed in mM trolox/kg dry weight of plant material (Jiménez *et al.*, 2015).

Preparation of samples and glazing solution

Narrow-barred Spanish mackerel (*Scomberomorus commerson*) samples were obtained from Bandar Abbas City (Hormozgan Province, Iran) in January 2020. The samples were transported well-iced in six hours by airline to laboratory (Sari Iran) and then were washed, headed, gutted and filleted by hand and treated in five different forms. In total, 150 fillets (300 g) were prepared. For the glazing process, the samples were first immersed in water (1-2°C) for 30 seconds and then placed at -

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30°C for 3 hours. After the completion of glaze treatment, the samples were stored at -18°C (Olgunoglu, 2010).

Treatments include the following:

1. Unglazed (UG) without immersion in water and coriander extract;
2. Water glazed (WG);
3. 0.5% of Coriander extract-glazed (CG 0.5%);
4. 1% of Coriander extract-glazed (CG 1%);
5. 1.5% of Coriander extract-glazed (CG 1.5%).

Samples were packaged in polyethylene bags and stored at -18°C. The examined parameters in frozen samples, after 1, 2, 3, 4, 5, and 6 months at -18°C, included (WHC), drip loss, cooking loss ,TVN, PV and TBA. Triplicate samples, from each treatment, were examined each month. The samples were thawed in a refrigerator (4±1°C) overnight, and analytical samples were drawn from different parts of the thawed fillets.

Water-holding capacity (WHC)

WHC was determined according to Mousakhani-Ganjeh *et al.* (2015). The frozen tuna was thawed in air at ambient temperature, and central temperature changes were measured. The endpoint of thawing was the rise of central temperature to 5°C. The surface water of the sample was dried with filter paper. The sample was cut into blocks (about 2g), and the blocks were weighed as M1. Then the sample blocks were wrapped in filter paper and centrifuged for 10 min (5000 r/min, 4°C). After centrifuging, the sample blocks were weighed again (M2). The water-holding capacity (WHC) was calculated using Equation (2):

$$WHC\ (\%)=M2/\ M1\times100\% \quad (2)$$

Drip loss and cooking loss were determined according to Mousakhani-Ganjeh *et al.* (2015) with some modifications. Before storage, tuna without glazing was weighed and recorded as M3. After storage, tuna was thawed and dried of surface water. The weight of tuna was recorded as M4. The drip loss was calculated using Equation (3):

$$Drip\ loss(\%)=\ M3-M4/\ M3\times100\% \quad (3)$$

The thawed tuna was cut into sample cubes (1 cm ×1 cm ×1 cm) and weighed as M5. Then, tuna cubes were placed in plastic bags and cooked in a water bath at 85°C for 10 min. After cooling, tuna sample cubes were taken out of the bag and reweighed as M6. The cooking loss was calculated using Equation (4):

$$Cooking\ loss\ (\%)=M5-M6/M5\times100\% \quad (4)$$

Determination of peroxide value (PV)

Peroxide value of the coriander extract was estimated as described by AOCS official method (Brühl, 1996). A volume of 25 mL of acetic acid: chloroform solution (3:2 v/v) was added into 5g of minced fish meats and mixed in saturated potassium, iodide starch solution and distilled water was added in volumes of 0.5, 0.5 and 30 mL, respectively. Titration of released iodine with 0.01 N sodium thiosulphate was held until intense blue color disappeared. PV was then reported by means of the (meq) peroxide/kg of fish oil, using

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equation (5). Were W is the weight (g) of fish sample, V is the volume (mL) of sodium thiosulphate and N is the normality of the solution:

$$PV = \frac{V \times N \times 1000}{W} \qquad (5)$$

Determination of thiobarbituric acid (TBA)

Colorimetric method was applied to evaluate TBA values (Kirk *et al.*, 1991). 1-butanol was added into 200 mg of minced fish meat 25 mL in volumetric flask and later was made to volume vortexed. After filtration, 5 mL of this mixture was placed into a test tube, in which it was mixed with 5 mL of TBA reagent, then it was capped and kept in a water bath at 95ºC for 2h. After the time elapsed, it was cooled to room temperature and the absorbance of samples at 530 nm was detected using a UV/Vis spectrophotometer. In this measurement distilled water was used as a blank sample. TBA value was then expressed as mg of malondialdehyde (MDA)/kg of fish meat and calculated according to the equation (6):

$$TBA = \frac{(Abs_{sample} - Abs_{control}) \times 50}{200} \qquad (6)$$

Determination of total volatile base nitrogen (TVB-N)

TVB-N was determined according to Kirk *et al.* (1991) followed by distillation after addition of magnesium oxide to the homogenized fish sample. Steam distillation was performed by a Kejeldahl Apparatus. The distillate was then collected in a flask containing 10 mL of 2% boric acid and mixed indicator solution of bromocresol green/methyl red (1:1 v/v) in ethanol. The volatile base components were absorbed by aqueous acid solution and color turned to green. The boric acid solution was then titrated with 0.1 mol/L hydrochloric acid solution. When complete neutralization was achieved the color turned pink with only one drop of hydrochloric acid. TVB-N value was then expressed as mg nitrogen/100 g of fish sample.

Sensory analysis

Ten experienced panelists were chosen to evaluate the quality of fillets. Samples were steam cooked for 20 minutes and served warm to the panelists. Sensory parameters included taste, aroma, texture, and appearance and scored on a 5-point hedonic scale (5: very good, 1: very bad) (Simeonidou *et al.*, 1997).

Statistical analysis

Results were presented as mean±standard division (SD) and the statistical test was done using SPSS 26.0. One-way analysis of variance (ANOVA) was used to detect significant differences between treatments in periods of frozen storage.

Results

Antioxidant activity

Antioxidant activity and the percentage of inhibition significantly increased as the concentration of the extract increased reaching 68.58% , 9.25 mM trolox/kg dw and 13.46 mM trolox/kg dw at concentration of 700 mg/L, respectively (p<0.05) (Table1). Results indicated that there was a linear relation

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between the amount of coriander extract and its antioxidant activity.

Table 1: DPPH, ABTS and FRAP assay of coriander (*Coriandrum sativum*) leaves extract.

Antioxidant activity indexes Concentration	DPPH (%)	ABTS (mM trolox/kg dw)	FRAP (mM trolox/kg dw)
300	25.56±1.25c	4.36±0.12c	9.17±0.61b
500	42.68±1.48b	7.17±0.54b	10.28±1.06b
700	68.58±2.35a	9.25±0.28a	13.46±1.25a

Small letters in each column represent significant differences (p<0.05).

Changes in the WHC, drip loss, and cooking loss

WHC of all groups is shown in Table 2. The water-holding capacity of all samples exhibited decreasing trends during storage. After six months, the water-holding capacity of UG, WG, CG 0.5%, CG 1%, and CG 1.5% treatments decreased to 49.23%, 57.10%, 62.43%, 62.22% and 63.36%, respectively.

Table 2: Changes in WHC (%) of unglazed, water-glazed, and coriander-glazed *Scomberomorus commerson* during frozen storage at -18°C.

Time (day) Treatment	30	60	90	120	150	180
UG	79.36±4.25aB	74.68±4.45bC	68.36±4.25cC	61.45±4.87dC	56.22±3.25eC	49.23±3.36fC
WG	81.45±5.12aB	77.22±5.11bB	71.41±5.17cB	66.32±5.45dB	60.35±6.28eB	57.10±4.55fB
CG 0.5%	82.30±4.45aA	80.21±5.30bA	73.60±5.21cA	69.41±3.22dA	66.17±4.45eA	62.43±5.42fA
CG 1%	82.26±6.25aA	80.16±3.41bA	73.77±3.27cA	69.25±6.36dA	66.32±5.31eA	62.22±3.16fA
CG 1.5%	82.80±4.19aA	80.63±6.18bA	74.11±4.29cA	70.19±5.41dA	67.28±4.48eA	63.36±4.46fA

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each row and column represent significant differences (p<0.05).

Table 3 shows changes in drip loss of samples with different glazing materials during frozen storage. It can be seen that drip loss of unglazed samples increased the fastest and drip loss of WG was also increased during the storage time. Drip loss of CG 0.5%, CG 1%, and CG 1.5% growth tended to continuously increase with storage, and the CG 1.5% treatment had the lowest drip loss after 180 days of storage. At the beginning of the 30 days, there was no significant difference among drip loss of groups. After 90 days of storage, drip loss of UG was significantly higher than that of other groups. It was noted that drip loss of CG 0.5%, CG 1%, and CG 1.5% treatments was significantly lower than that of UG treatment. After six months, drip loss of UG, WG, CG 0.5%, CG 1%, and CG 1.5% treatments were 15.23%, 11.36%, 11.25%, 11.17% and 10.55%, respectively.

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The cooking loss of all groups is shown in Table 4. In the process of storage, with extension of the storage time, the overall cooking loss did not change significantly, and CG 0.5%, CG 1%, and CG 1.5% treatments had a low average cooking loss among all the groups.

Table 3: Changes in drip loss (%) of unglazed, water-glazed, and coriander-glazed *Scomberomorus commerson* during frozen storage at -18°C.

Time (day) / Treatment	30	60	90	120	150	180
UG	7.86±1.11eA	10.50±2.32dA	12.55±2.27bcA	13.11±2.30abA	14.16±2.36aA	15.23±2.24aA
WG	7..36±1.17cdA	7.86±1.43cdB	8.96±2.25bcB	9.89±2.21abB	10.56±2.20aB	11.36±2.50aB
CG 0.5%	7.25±1.21cdA	7.77±1.36cdB	8.65±2.35bcB	9.68±2.26abB	10.44±2.4aB	11.25±2.27aB
CG 1%	7.24±1.30cdA	7.56±2.17cdB	8.60±2.08bcB	9.52±2.33abB	10.35±2.34aB	11.17±2.19aB
CG 1.5%	7.20±1.17cdA	7.34±1.42cdB	8.46±2.30bcB	9.37±2.39abB	10.17±2.40aB	10.55±1.44aB

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each row and column represent significant differences (p<0.05).

Table 4: Changes in cooking loss (%) of unglazed, water-glazed, and coriander-glazed Scomberomorus commerson during frozen storage at -18°C.

Time (day) / Treatment	30	60	90	120	150	180
UG	30.41±3.45cdA	25.25±4.56fA	27.24±3.31eA	31.56±3.35cA	33.33±4.32bA	35.28±4.23aA
WG	27..32±3.25abB	21.36±5.30dB	26.42±4.55bcA	28.36±4.24aB	27.25±4.26abB	29.30±3.55aB
CG 0.5%	24.27±4.37bC	24.45±4.25bA	23.36±4.23bcB	22.77±3.22cC	24.46±5.14bC	26.22±4.25aC
CG 1%	23.33±3.25abC	22.36±5.18bcB	23.55±3.61abB	21.56±3.35cdC	22.30±4.33bcD	24.27±4.15aD
CG 1.5%	23.14±3.10abC	24.41±5.30aA	22.37±4.28bcB	21.41±3.33cdC	22.27±4.45bcD	24.51±3.43aD

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each row and column represent significant differences (p<0.05).

PV changes

The results of PV in mackerel fillets treated with glazing system and coriander extract are shown in Table 5. The results confirm that PV changes during 30 days in different treatments were between 1.917 - 2.750 meq O2/ kg lipid which after 180 days increased to 10.221 - 14.450. The most ascending changes and the least changes were related to the control treatment (without glazing) and the combined treatment (glazed fillet with 1.5% coriander extract).

Table 5: Changes in PV (meq O2/kg lipid) of unglazed, water-glazed, and coriander-glazed *Scomberomorus commerson* during frozen storage at -18°C.

Time (day) / Treatment	30	60	90	120	150	180
UG	2.750±0.014fA	4.640±0.023deA	7.285±0.049cdA	9.500±0.042cA	12.310±0.056bA	14.450±0.043aA
WG	1.956±0.024dB	2.665±0.021cdB	4.531±0.027bcB	6.364±0.035abB	8.652±0.07aB	10.620±0.051aB
CG 0.5%	1.940±0.007dB	2.536±0.033cdB	4.483±0.014bcB	6.250±0.031abB	8.570±0.021aB	10.580±0.013aB
CG 1%	1.935±0.016dB	2.450±0.042cdB	4.372±0.028bcB	6.180±0.049abB	8.360±0.023aB	10.335±0.011aB
CG 1.5%	1.917±0.014dB	2.318±0.035cdB	4.215±0.021bcB	6.115±0.021abB	8.247±0.042aB	10.221±0.017aB

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each row and column represent significant differences (p<0.05).

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TBA changes

The changes of TBA in different treatments of mackerel fillet kept at -18°C are shown in the Table 6. According to the results, the range of TBA changes in 30 days was between 0.217- 0.256 that reached to 0.460 - 0.635 mg of malonaldehyde / kg of fish flesh in 180 days. The highest changes were in the control sample and the least changes were in the combined sample (glazing and 1.5% coriander extract). The changes of TBA in the treatment containing 0.5% of coriander extract and glazing treatment were not significant (p>0.05). With increasing concentration of the extract to 1.0 and 1.5%, significant difference was observed between the extract and individual glazing (p<0.05).

Table 6: Changes in TBA (mg MDA/kg) of unglazed, water-glazed, and coriander-glazed *Scomberomorus commerson* during frozen storage at -18°C.

Time (day) Treatment	30	60	90	120	150	180
UG	0.256±0.004bcA	0.294±0.003bA	0.380±0.002bA	0.511±0.007aA	0.635±0.003aA	0.635±0.003aA
WG	0.238±0.003cdA	0.276±0.005cA	0.323±0.003bcA	0.463±0.003abA	0.522±0.001aA	0.522±0.001aA
CG 0.5%	0.231±0.002cA	0.260±0.002bcA	0.320±0.002bA	0.455±0.002aA	0.510±0.002aAB	0.510±0.002aAB
CG 1%	0.225±0.002cA	0.251±0.007cA	0.314±0.002bA	0.440±0.004aA	0.488±0.002aC	0.488±0.002aC
CG 1.5%	0.217±0.003bA	0.242±0.002bA	0.293±0.003bA	0.430±0.009aAB	0.460±0.002aC	0.460±0.002aC

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each row and column represent significant differences (p<0.05).

TVB-N changes

The changes of TVB-N in mackerel fillet under different treatments of glazing and coriander extract are shown in Table 7. The results showed that the amount of TVN in 30 days in different treatments was between 17.73 - 20.96 mg / 100g and increased to 28.76- 37.31 on day 180 and the most and the least changes were in the control treatment and the combined treatment of glazing and extract (1.5% of coriander), respectively (p<0.05). Changes in TVB-N were not significant between individual glazing treatments and concentrations of 0.5 and 1% coriander extract.

Table 7: Changes in TVB-N (mg/100g) of unglazed, water-glazed, and coriander-glazed *Scomberomorus commerson* during frozen storage at -18°C.

Time (day) Treatment	30	60	90	120	150	180
UG	20.960±0.565fA	25.210±0.215eA	27.320±0.320dA	29.410±0.226cA	32.290±0.113bA	37.317±0.210aA
WG	19.025±0.063fA	22.515±0.063eB	24.710±0.042dB	26.320±0.042cB	28.575±0.049bB	30.563±0.049aB
CG 0.5%	18.495±0.084fA	22.185±0.010eB	24.310±0.084dB	26.210±0.014cB	28.300±0.056bB	30.321±0.056aB
CG 1%	18.180±0.098fA	22.120±0.063eB	24.240±0.056dB	26.195±0.021cB	28.225±0.077bB	29.653±0.077aB
CG 1.5%	17.735±0.050eAB	21.310±0.042dB	23.840±0.038cBC	25.171±0.070abB	27.350±0.012aB	28.763±0.053aB

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each row and column represent significant differences (p<0.05).

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Sensory evaluation

The results of sensory analysis in mackerel fillet under different treatments of glazing and coriander extract are shown in Table 8. There was no significant difference between control treatment and water glazed treatment. However, changes between control treatment and the combined treatment of glazing and 0.5%, 1% and 1.5% of coriander extracts were significant (p<0.05).

Table 8: Sensory analysis scores of the unglazed, water-glazed, and coriander-glazed *Scomberomorus commerson* during frozen storage at -18°C.

Time (day) / Sensory analysis / Treatment		30	60	90	120	150	180
Taste	UG	4.5±0.12aA	4.1±0.1aA	3.2±0.2bB	2.5±0.2bcC	2.3±0.2bCD	1.8±0.1bD
	WG	4.7±0.23aA	4.4±0.11aA	3.2±0.14bB	2.8±0.13bcC	2.6±0.16abC	2.2±0.3abD
	CG 0.5%	4.5±0.2aA	4.3±0.17aA	4.1±0.3aA	3.2±0.21abB	2.8±0.1abC	2.5±0.12abC
	CG 1%	4.6±0.1aA	4.3±0.1aA	4.1±0.24aAB	3.3±0.32abC	2.8±0.17abD	2.5±0.16abD
	CG 1.5%	4.7±0.28aA	4.3±0.21aA	4.1±0.1aAB	3.6±0.2aC	3.2±0.2aC	3.0±0.22aD
Aroma	UG	4.4±0.1aA	4.0±0.2aA	3.0±0.1bB	2.2±0.2bcC	2.0±0.1bC	1.5±0.1bcD
	WG	4.5±0.3aA	4.2±0.4aA	3.0±0.3bB	2.7±0.2bcBC	2.3±0.1bCD	2.1±0.4bD
	CG 0.5%	4.5±0.3aA	4.2±0.2aA	4.0±0.3aAB	3.0±0.3abC	2.5±0.2bCD	2.2±0.3abD
	CG 1%	4.5±0.2aA	4.3±0.1aA	4.0±0.2aAB	3.1±0.2abC	2.5±0.2bCD	2.2±0.1abD
	CG 1.5%	4.5±0.2aA	4.3±0.1aA	4.0±0.1aAB	3.4±0.2aC	3.0±0.1aCD	2.7±0.3aD
Texture	UG	4.4±0.2aA	4.2±0.1aA	3.7±0.3abB	3.2±0.1abBC	2.8±0.1abD	2.2±0.2abE
	WG	4.4±0.4aA	4.2±0.2aA	3.7±0.2abB	3.3±0.2abBC	2.8±0.2abD	2.5±0.2abD
	CG 0.5%	4.5±0.2aA	4.3±0.1aA	4.1±0.5aA	3.5±0.2aB	3.0±0.1aBC	2.7±0.4aC
	CG 1%	4.5±0.4aA	4.3±0.4aA	4.1±0.1aA	3.5±0.1aB	3.1±0.1aB	2.7±0.1aC
	CG 1.5%	4.5±0.1aA	4.3±0.3aA	4.1±0.1aA	3.6±0.1aB	3.2±0.1aB	2.8±0.2aC
Appearance	UG	4.6±0.3aA	4.3±0.2aA	4.0±0.2aAB	3.6±0.5aBC	3.2±0.2aC	2.7±0.1aD
	WG	4.6±0.2aA	4.4±0.4aA	4.2±0.1aAB	3.7±0.2aC	3.2±0.1aC	2.5±0.4aD
	CG 0.5%	4.6±0.4aA	4.4±0.2aA	4.2±0.4aAB	3.7±0.1aC	3.3±0.2aC	2.9±0.3aD
	CG 1%	4.6±0.2aA	4.4±0.3aA	4.2±0.2aAB	3.7±0.5aC	3.3±0.1aC	2.9±0.1aD
	CG 1.5%	4.6±0.2aA	4.4±0.4aA	4.2±0.1aA	3.8±0.2AB	3.3±0.3BC	3.0±0.1C

UG: Unglazed, WG: Water glazed, CG 0.5%: 0.5% of coriander extract-glazed, CG 1%: 1% of coriander extract-glazed, CG 1.5%: 1.5% of coriander extract-glazed. Small and capital letters in each column and row represent significant differences (p<0.05).

Discussion

Antioxidant activity

DPPH, ABTS and FRAP were used to evaluate antioxidant activity of the coriander extract. The high antioxidant properties of coriander is due to the presence of phenolic and carotenoid compounds which could be used as radical scavengers to inhibit the lipid oxidation of fish in frozen storage. Dua *et al.* (2014) reported that the most important polyphenols in coriander seeds extract include gallic acid (173.656 µg), caffeic acid (80.185 µg), ellagic acid (162.861 µg), quercetin (608.903 µg) and kaempferol (233.70 µg)/g dry seeds. In the study conducted by Sultana *et al.* (2010), the antioxidant percentage of coriander was reported to be 58.36%, which is consistent with the present study. Wong and Kitts (2006) have reported free radical scavenging and antibacterial activity in the extracts of coriander leaves and stem. Free radical scavenging and lipid peroxidation inhibition activity in the

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dichloromethane and aqueous extracts of coriander leaves and seeds have also been reported by Wangensteen *et al.* (2004).

Changes in the WHC, drip loss, and cooking loss

WHC, drip loss, and cooking loss as primary determinants of sensory appeal and important indicators were used to measure tuna freshness, which is related to tuna muscle protein and its organizational structure (Hughes *et al.*, 2014). The water-holding capacity (WHC) of CG 0.5%, CG 1%, and CG 1.5% treatments was significantly higher. This may be due to the glazing treatment, especially CG, which can prevent destruction of hydrophobic and hydrophilic bonds around proteins during freezing storage (Benjakul *et al.*, 2003).

Cooking loss of UG was significantly higher than that of other groups. This may be due to the denaturation of tuna myofibrillar protein during the frozen storage, which leads to increased loss of nutrients and water in cooking (Hughes *et al.*, 2014). The cooking loss was less affected by the storage time and more affected by the glazing materials. Using coriander extract as the glazing material could keep the myofibrillar protein stable, maintain the muscle structure, and reduce the cooking loss.

PV changes

Lipid breakdown is one of the main causes of reduced shelf life of fatty fish that is due to progressive oxidation and enzymatic hydrolysis of unsaturated fatty acids (Sarma *et al.*, 2000). In the study of Xuan *et al.* (2017), it was found that the main cause of primary lipid spoilage is accumulation of compounds produced by oxidation of unsaturated fatty acids. In general, the factors associated with lipid spoilage are higher in fatty fish than in non-fatty fish (Sarma *et al.*, 2000). Peroxide value is one of the main factors in lipid oxidation and indicates the initial spoilage of fish in the preservation process. The primary products produced at this stage are mainly hydroperoxides that are gradually decomposed into compounds such as carbonyl, hydrocarbons and furans, which causes unpleasant taste in the product (Heydari *et al.*, 2015). The first indication of the lipid oxidation is appearance of unfavorable taste, which in turn affects the quality and color of the product (Suvanich *et al.*, 2000; Fernandes, 2009). The results of the present study showed positive effect of glazing and coriander extract on PV changes in comparison with the control treatment so that the ascending trend of PV was slower at -18°C. In the glazing process, due to formation of a thin layer of ice on the fish, oxygen exchanges are reduced and as a result, lipid oxidation is delayed (Soares *et al.*, 2015; 2017). Studies have shown that glazing alone is not able to reduce the oxidation process and control moisture in long-time storage of fish. This process depends on fish species, water temperature and coating temperature. In order to increase the effectiveness of glazing, other compounds with antioxidant and coating properties are also used which can be

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plant extracts, essential oils and various coatings (with the aim of increasing the strength, consistency and viscosity of the coating) (Sathivel *et al.*, 2007; Soares *et al*., 2015; 2017; He *et al*., 2019; Shi *et al.*, 2019). In coriander extract-glazed experimental results lipid oxidation is expected to be slower in terms of antioxidant effects of the extract, which in the treatment containing a concentration of 1.5% coriander this effect was evident. In a study conducted by Trigo *et al.* (2018) on the effect of glazing system and quinoa plant extract (with concentration of 1.36 g/L) on Atlantic mackerel kept in freezing conditions, it was found that the combination of glazing and higher concentrations of the quinoa reduced PV (as a parameter of fat oxidation index) and FFA (as an index of fat hydrolysis). The results of Trigo *et al.* (2018) study confirm the results of the present study. In the studies of Özyurt *et al.* (2011) and Sarabi *et al.* (2017) it was found that rosemary extract in fried sea bream (*Sparus aurata*) and escolar fish reduced the PV ascending trend, which is consistent with the results of the present study. The results of the study of He *et al.* (2019) regarding the novel superchilling storage-ice glazing (SS-IG) approach and the use of antioxidant and antimicrobial properties of cloves to maintain the freshness of fish showed that the combination of glazing system and essential oil slowed down the increasing trend of PV in sea bass (*Dicentrarchus labrax*) at -1°C for 25 days.

TBA changes

Thiobarbituric acid indicates secondary lipid oxidation and confirms the production of malondialdehyde. In general, TBA changes in fatty fish are faster than that in non-fatty fish. TBA not only represents the actual percentage of lipid oxidation, but also the malondialdehyde produced is able to react with other compounds, such as amines, nucleotides, proteins and phospholipids in fish that vary from species to species (Simeonidou *et al.*, 1997; Sarma *et al.*, 2000). In general, the results of TBA in this study indicated that it was low compared to other studies (Trigo *et al.*, 2018; Wang *et al.*, 2020) but this cannot confirm the control of lipid oxidation because low TBA levels may be due to use of malondialdehyde in other reaction. The study of Seydim *et al.* (2006) showed that during the glazing process, due to reduction of oxygen exchanges, ascending trend of malondialdehyde slowed down. The study of Wang *et al.* (2020) showed that the process of lipid oxidation is significantly slowed down when other substances such as rosemary and sodium lactate are added to glazing treatment. These studies were consistent with the present study findings, while this research results showed better effects of glazing and coriander extract compared to other treatments. The results of the study of Trigo *et al.* (2018) in frozen Atlantic mackerel treated with glazing system and quinoa plant extract also confirm the present study. The results of the study by He *et al.* (2018) showed a

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decrease in the ascending trend of TBA in sea bass (*Dicentrarchus labrax*) at -1°C after 25 days.

TVB-N changes

Total volatile nitrogen, or TVB-N, actually indicates the breakdown of fish proteins and is a relatively weak indicator of fish freshness. However, this factor is commonly used to assess fish spoilage (Mazorra-Manzano *et al.*, 2000). An increase in the TVB-N value is directly related to spoilage due to the activity of microbial and intracellular enzymes (Yuan *et al.*, 2016). Trimethylamine N-oxide (TMAO) is a natural compound of muscle and visceral tissue in fish and invertebrates (Castro *et al.*, 2006). This substance increases the osmotic concentration and consequently reduces the freezing point of body fluids. Freezing is not able to inhibit TMAO demethylase activity (Sikorski and Kostuch, 1982). The ratio of TMAO enzymatic degradation depends on formaldehyde and dimethylamine. In fish that do not have TMAO but still have an increase in TVB-N, this may be due to amino acid deamination. In freezing conditions, bacterial activity is reduced and tissue enzymes are responsible for producing TVB-N that is performed by a variety of mechanisms, including the breakdown of TMAO or the production of ammonia and other volatile amines. In study of Wang *et al.* (2020), the combined use of glazing, rosemary, and sodium lactate slowed down the trend of TVB-N changes, the results of which were consistent with the results of this study and showed a decrease in the trend of TVB-N changes in the combined treatments compared to the control treatment. The study of Shi *et al.* (2019) showed that shrimp treated with glazing system and rosemary extract reduced the ascending trend of TVN compared to the control treatment, which is consistent with the results of this study. He and Xiao (2016) study on tangerine peel essential oil as a glaze coating, reduced the increasing trend of TVN, which is consistent with the present study. Plant extracts prevent the breakdown of macromolecular compounds containing nitrogen.

Sensory evaluation

The fillets treated with coriander extract were the most preferred samples in terms of sensory characteristics, whereas control samples had low sensory scores. These findings were supported by instrumental analysis. Refsgaard *et al.* (1998) reported similar results for salmon. Frozen storage prevents food from undesired sensory and chemical aspects caused by microorganisms and spoilage reaction, however this cannot be totally hindered. Reactions especially occur in proteins and lipids affect sensory properties and cause unpleasant odour, taste and texture changes.

Physical and chemical changes in proteins of fish during frozen storage cause texture deterioration. This problem also affects sensory aspects. Formaldehyde formation makes cross-links with protein, lessen protein solubility and decrease water holding

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capacity (Steen and Lambelet, 1997). These alterations also cause taste losses, odour changes. Turan and Erkoyuncu (2004) reported that the control group had less preference compared with bonito applied plant extracts.

According to the results of measured parameters (TVB-N and TBA), the shelf life of fish fillets kept at -18ºC was up to 180 in the acceptable range, but in terms of PV it was outside the standard range, while in the control treatment the parameters examined on day 150 were outside the standard range. The general conclusion is that when using a combination of glazing process and natural materials such as plant extracts (coriander leave extract), the shelf life of fish in frozen storage increases and delayed the ascending process of spoilage chemical parameters.

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