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ORIGINAL ARTICLE

Addition of seaweed powder and sulphated polysaccharide on shelf_life extension of functional fish surimi restructured product

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Abstract This study aimed to investigate the performance of equal amounts of edible green seaweed, *Ulva intestinalis* powder (2.77 g kg^{-1}), and its sulphated polysaccharide ([USP], 0.5 g kg^{-1}, based on the extraction yield from *U. intestinalis* powder) on the proximate compositions, lipid oxidation, pH, colour, textural properties, cooking yield and sensory attributes of fish-surimi restructured products during storage at − 18 °C as compared with the control. Results showed incorporation of two functional components resulted in lower TBARS values compared with the control over 6 months ($P \leq 0.05$). The USP incorporated fingers showed the least moisture loss over 6 months ($P < 0.05$). Textural properties for two functional fingers remained relatively stable from month 0 to month 6, while the hardness increased significantly ($P < 0.05$) in the control fingers (67 to 80 N). Additionally, the sensory attributes of all formulated fingers were judged acceptable; however, the USP containing fingers were preferred by the sensory panelists, due to their juicy texture as a result of less cooking loss comparing with others. In conclusion, this study suggests the potential use of such natural marine ingredients to maintain the quality and to extend the shelf life of surimi-based products with beneficial health effects.

Keywords Seaweed · Dietary fiber · Functional seafood · Oxidative stability · Quality properties

Introduction

Increasing the consumers' attention to the relationship between diet and health has caused great boom in the functional foods' markets worldwide (Cofrades et al. 2017). Among the different carriers of functional ingredients, surimi, a fish myofibrillar protein concentrate and an intermediate foodstuff, has a great potential for the development of functional seafood products via restructuring technology (Debusca et al. 2013). This is, however, possible not only by offering new opportunities to develop novel reformulated products as fish finger, fish ball and fish nuggets, but also by providing a great chance for the optimal use of underutilized/low-value fish species.

Seaweeds, so called as "superfoods", contain considerable amounts of different bioactive compounds with both health promoting potential and technological advantages (Cofrades et al. 2017). Thus, their selection could be an excellent option for the purpose of designing functional foods. Among the various seaweed originated chemical compounds, sulphated polysaccharides are of particular interest in recent years, mainly due to their diverse textural features and potential biological properties including antioxidant capacities (Roohinejad et al. 2017). Previous studied have indicated that incorporation of laminarin and fucoidan (3 and 6 mg ml^{-1}, respectively), sulphated polysaccharides of brown seaweed (*Laminaria digitata*) to pork meat homogenates enhanced the system's potential in

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preventing lipid oxidation compared with the control (Moroney et al. 2015).

Nonetheless, there is no literature available to address the antioxidant effects of seaweed sulphated polysaccharides in fishery products, and most of studies on the oxidative stability of seafoods have been performed on the use of seaweed extracts, mostly polyphenols (Roohinejad et al. 2017). In this context and considering to the perishable nature of seafood products, in one hand, and the interference of synthetic antioxidant's application in functional food formulation with the concept of healthy, on the other, the use of such safe and natural origin antioxidants as sulphated polysaccharides would be invaluable. Besides, a number of researchers have suggested use of whole seaweeds in order to benefit simultaneously from all the advantageous features of them (dietary fiber, abundant minerals, vitamins, high-quality protein, unsaturated essential fatty acids, carotenoids, polyphenols, tocopherols, etc.), instead of isolated compounds inclusion. In addition, seaweed biomass itself imparts excellent antioxidant potential due to the synergic effects of diverse natural compounds (Chojnacka et al. 2012). To this end, functionality of some brown and red macroalgae was examined in the products such as patties, steaks, frankfurters and also meat emulsion systems to develop meat-based functional foods (Cofrades et al. 2008; Lopez-Lopez et al. 2009, 2010).

High nutritional quality and low calorie of fish-based products have promoted the consumers' preference to these kinds of "ready to eat" foods in contrast to red meat-based products, which are high in cholesterol, a major risk factor of cardiovascular diseases (Vicente and Torres 2007). Surimi consumption has steadily increased in both developed and developing countries (kong et al. 2016). However, in order to further complete the health characteristics of fishery products, dietary fibers (DFs) can be applied. The utilization of DFs in fishery restructured products will also address the needs of consumers to dietary fiber intakes since seafoods contain no fiber (Cofrades et al. 2008). Besides, because of the hydrocolloidal properties of DFs, they have technological implications and can be incorporated as texturing agents in seafood restructured products in order to overcome the problems with the use of low-value fish species. Nonetheless, there is no report on the inclusion of seaweeds as sources of insoluble and soluble DFs into fish restructured products, except to a study conducted by Diaz-Rubio et al. (2011) on *Fucus vesiculosus* fiber addition to fish mince.

Green seaweeds belonging to Ulvaceae, with fast proliferation and worldwide distribution, are commonly used as food and nutritional supplement in the Asian countries such as Japan and China (Silva et al. 2013). Besides, during the last years, Ulvan, a water soluble sulphated polysaccharide of green seaweeds, has shown promising biological activities such as antioxidant, anticoagulant, immunomodulating, antitumor and antihyperlipidemic, activities (Rahimi et al. 2016). Therefore, it could represent a new opportunity for food industries to utilize such valuable ingredient comprising both functional and biological characteristics in the development of functional foods. However, there has been no attempt to introduce green algae DFs and their sulphated polysaccharides to a real food system, until now.

Studies on the addition of sulphated polysaccharides to fishery products are limited. Moreover, to the best of our knowledge, there has been no information on the comparison of seaweed powder (mainly insoluble fiber) and its sulphated polysaccharides (soluble fiber) in food products in order to examine their technological and antioxidant properties, simultaneously. Hence, the present study was undertaken to analyze how storage stability of fish fingers, surimi restructured products, is affected with two functional components, *Ulva intestinalis* powder and *U. intestinalis* sulphated polysaccharide in terms of cooking loss, colour, texture, lipid oxidation and sensory properties during six months of frozen storage at − 18 °C.

Materials and methods

Preparation of *U. intestinalis* powder and sulphated polysaccharide extraction

U. intestinalis was collected from the coast of Noor (coordinates: 30°03′01″N, 52°02′58″E), Mazandaran Province, Iran in July 2015. The collected samples were washed with sea water, followed by washing with tap water to remove any epiphyte and contamination from the algae. Then they were oven-dried at 60 °C (VO200cool, Memmert, Schwabach, Germany). The dried samples were milled using a blender, sieved (< 0.4 mm) and stored in a sealed plastic bag at − 20 °C until further usage.

U. intestinalis sulphated polysaccharide (USP) was extracted in distilled water at 65 °C according to the method described by Alipour et al. (2018). The USP was, finally, dried at room temperature and kept at − 20 °C until further usage (supplementary Fig. 1).

Fish finger prototypes manufacture

Frozen and vacuum-packed silver carp surimi blocks (1 kg each) were purchased from the National Research Center of Aquatics processing (NRCAP, Anzali, Guilan Province, Iran), transported in boxes filled with ice to the laboratory of the Department of Seafood Processing, Tarbiat Modares University, and stored at − 80 °C until use. Three fish

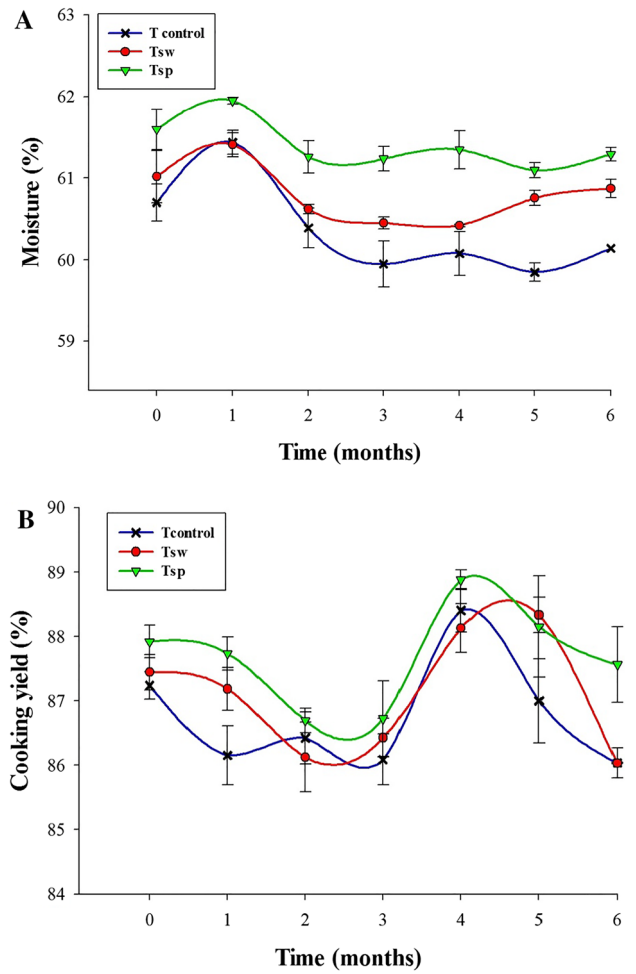

Fig. 1 Changes in (**a**) moisture content and (**b**) cooking yield values of three fish finger treatments (Control; Sw: with 27.7 g kg^{-1} *U.intestinalis* seaweed powder; Sp: with 5 g kg^{-1} *U.intestinalis* sulphated polysaccharide) during 6 months of storage at − 18 °C. Error bars indicate standard deviation (n = 3)

finger prototypes were prepared separately as follows: Frozen surimi blocks were first thawed in a refrigerator (4 °C), weighted (540 g kg^{-1} of total weight), chopped for 30 s in a food processor (FP270, Kenwood, Hong Kong, China), and then mixed with salt (20 g kg^{-1}) and other usual ingredients and seasonings based on the commercial fish finger formula (172.5 g kg^{-1} bread flour, 132.5 g kg^{-1} fresh onion, 18 g kg^{-1} lemon juice, 20 g kg^{-1} fresh parsley, 7 g kg^{-1} egg white powder, 60 g kg^{-1} soy isolate, 15 g kg^{-1} wheat starch and 15 g kg^{-1} seasonings). This original mixture was designated as the control treatment (Tc). In the treated formulations, 27.7 g kg^{-1} of the total weight of *U. intestinalis* powder (according to the optimum *U. intestinalis* powder level in terms of acceptable sensory characteristics) and 5 g kg^{-1} of the total weight of sulphated polysaccharide (according to the yield of USP extraction from 27.7 g kg^{-1} of *U. intestinalis* powder) were incorporated by replacing an equal total amount of bread flour and wheat starch in the control formulation, and were designated as Tsw and Tsp, respectively. Both *U. intestinalis* powder and USP were passed through a sieve with an aperture of 0.105 mm before incorporating into the product formula. All ingredients were thoroughly mixed to provide a uniform blend. The fish fingers formed with a rectangular former in the measure of 80 ± 1 mm, 20 ± 1 mm, and 10 ± 1 mm (supplementary Fig. 1), followed by pre-dusting, battering, breading and pre-deep frying in sunflower oil at 180 °C for 30 s (EF40, Black & Decker, China). Some of the fried fingers from each prototype were analyzed as a fresh treatment, whereas the others were wrapped in a wax paper, placed in plastic bags, and stored at − 18 °C for monthly measurements. To analyze the pre-fried samples, the frozen prototypes were taken out of the freezer randomly and thawed in a refrigerator (4 ± 1 °C). For the cooked samples' evaluation, the fish fingers were deep fried for 3 min at 180 °C in sunflower oil; after equilibrating to room temperature, they were prepared for analysis. A total of 420 fish fingers were used, 252 for the physicochemical analysis (4 fingers × 3 prototypes × 7 times) by triplicate and 168 for the sensorial analysis (4 fingers × 3 × prototypes × 7 times) by duplicated.

Physicochemical characteristics

Proximate composition

Proximate compositions (moisture, protein, lipid and ash content) of the fish fingers were determined on day 0 of storage according to the AOAC procedures (AOAC 2000). Moisture content was also measured monthly during the six months of storage. For determination of moisture content, 3 g of sample was dried at 105 °C until constant weight was obtained. Protein content was determined according to the kjeldahl method of analysis. The conversion factor used in calculating the protein content was 6.25. Fat content was determined with petroleum ether in a soxhlet apparatus and calculating the weight loss. Ash content was determined by sample ignition at 500 °C for 5 h.

Cooking yield and pH

Cooking yield was calculated by the weight differences of the thawed frozen fingers before and after deep frying in an automatic fryer, according to the following equation (Rodriguez-Carpena et al. 2012):

$$\text{Cooking yield } (\%) = (W_2 \times 100)/W_1$$

where W_2 is the weight of finger after cooking, and W_1 is the weight of finger before cooking.

The pH value of fish fingers was measured using a hand-held pH meter (Testo, 05632051, USA) equipped with a glass probe for penetration directly into the meat. The probe was calibrated before each measurement (Alipour et al. 2018).

Instrumental colour

Monthly colour measurements of the samples were recorded using a micromatch spectrophotometer (181/3, Sheen Instruments, UK) according to the method described by Selani et al. (2011). The measurement conditions were: illuminant type: D65, observer angel: 2°, aperture diameter size: 4 mm. Three measurements were taken on three randomly selected locations of each fish finger, and the results were expressed in terms of lightness (L^*), redness (a^*), and yellowness (b^*).

Textural analyses

The textural properties of fish fingers were evaluated using a texture analyzer (TexVol Instruments, Model TVT-300XP, Sweden) by the two different methods of texture profile analysis (TPA) and warner–bratzler shear force (WBS), with some modifications. The evaluations were done on cooked samples as described above and then cooled to 25 °C. TPA was performed with a 50 mm diameter cylindrical aluminum probe on the sample cuts of 2 × 2 × 1 cm of each finger (Reihani et al. 2014). Two continuous compressions were carried out to 50% of the fingers' original height at a cross speed of 60 mm/min, and the following parameters were obtained from the resulting force–time curves: hardness (N), springiness, cohesiveness, chewiness (N) and gumminess (N).

For shear force measurement, the finger samples were sheared using a Warner–Bratzler blade at a cross speed of 60 mm/min, and the maximum force required to cut the sample (shear force) was recorded (Das et al. 2008).

Lipid oxidation measurement

The peroxide value (PV, meq peroxide/1000 g lipid.) was determined in the total lipid extracts according to the method of Pearson (Egan et al. 1997). About 15 g of the sample was dissolved in 120 ml of chloroform: methanol mixture (1:1), and homogenized for 24 h at room temperature. Then, 36 ml of distilled water was added and the mixture was allowed to stand for 2 h until 3 different phases were formed. To 20 ml of the bottom phase (decanted into a 250 ml-Erlenmeyer flask through Whatman No. 4 filter paper (Whatman international, Ltd, Maidstone, England)), 25 ml of acetic acid/chloroform (3:2) and 0.5 ml of saturated potassium iodide were added, and mixed vigorously. After 1 min, 30 ml of distilled water and 1 ml of 1% starch solution were added, followed by mixing thoroughly. The liberated iodine was titrated against sodium thiosulphate solution (0.01 N $Na_2S_2O_3$), and the peroxide value was reported as the volume of 0.01 N $Na_2S_2O_3$ used in the titration.

The thiobarbituric acid value was determined calorimetrically by the method of Porkony and Dieffenbacher as described by Ojagh et al. (2010). A portion (200 mg) of sample was mixed with 1 ml of 1-butanol in a 25 ml volumetric flask. A portion (5.0 ml) of the mixture was pipetted into a dry test tube and 5 ml of TBA reagent (prepared by dissolving 200 mg of 2-TBA in 100 ml 1-butanol, filtered, stored at 4 °C for not more than 7 days) was added. The tube was stoppered, vortexed and heated in a boiling water bath (95 °C) for 120 min and cooled with running tap water. The absorbance of sample was measured at 530 nm against water blank. TBARS value was expressed as mg of malonaldehyde equivalents/kg of sample.

Sensory evaluation

Sensory attributes were evaluated according to the method of Mohamed and Mansour (2012), with slight modifications. The cooked fish fingers were assessed by eight trained panelists consisting of researchers and associate professors from the Department of Seafood Processing at TMU, Iran, according to the method of Mohamed and Mansour (2012) with slight modifications. Cooked samples from each prototype were sliced into two pieces, and coded with three-digit numbers randomly. Then they were presented to the panelists individually. Mineral water was provided for mouth rinsing between the samples. The panelists were asked to evaluate the flavor, odour, colour, juiciness, texture, and overall acceptability of the products using a hedonic scale with the following descriptive terms: flavor, odour and colour (1, extremely undesirable to 5, excellent), juiciness (1, extremely dry to 5, extremely juicy), texture (1, extremely tough to 5, extremely tender) and overall acceptability (1, dislike extremely to 9, like extremely).

Statistical analysis

One-way analysis of variance (ANOVA), Duncan' test, repeated measures and Least squares differences (LSD) were performed on the statistical package SPSS 20.0 (IBM, Armonk, New York, USA) to analyze significant differences between the variables. The sensory data were

subjected to Kruskal–Wallis test and Mann–Whitney U test. All the data were reported in the form of mean ± SD, and differences were considered significant with a probability value of < 0.05. All experiments were run in triplicate, except the pH and mechanical properties, which were run in 5 and 6 replicates, respectively.

Results and discussion

Proximate composition

Proximate composition of the three formulated fish fingers is shown in Table 1. The most ash content was recorded in Tsw followed by Tsp ($P < 0.05$). Generally, the high mineral content of seaweeds is attributed to their capacity to accumulate inorganic marine substances due to the characteristics of their cell wall sulphated polysaccharides (Bocanegra et al. 2009). Similar results were obtained by Lopez-lopez et al. (2010) in the ash content of beef patties formulated with *Undaria pinnatifida* powder addition. The addition of *U. intestinalis* powder in the fish finger formula increased the fat content of the final product ($P < 0.05$). This could be attributed to the higher fat content of seaweed powder (2.72 ± 0.28%), as compared with the replaced ingredients (López-López et al. 2010). Likewise, replacing fish finger ingredients with both *U. intestinalis* powder and USP significantly improved the protein content ($P < 0.05$). The higher protein content of Tsp compared with the control is ascribed to the close association of proteinous moieties with the cell wall polysaccharides through covalent bond, since these polymers are part of the seaweed cell wall structure (Robic et al. 2008). In the current study, there was 9% of protein recovery from the USP extraction, which was not eliminated during the alcohol precipitation.

Although both of the treated fingers contained higher moisture content compared with the control group, there was only a significant difference between the Tsp and Tc values ($P < 0.05$). Such a trend in the moisture content continued throughout the frozen storage (Fig. 1 A). No obvious significant difference was recorded within each treatment as a function of storage time. However, by the end of frozen storage (180 days), it was the control sample (Tc) that had sustained the most moisture loss (Fig. 1a). Similar results in line with this study were obtained by Kim et al. (2016) who reported the positive impact of dietary fibers on the moisture content of frozen beef patties. According to the results of these researchers, the released water from protein denaturation during frozen storage could be absorbed by dietary fibers in fiber containing treatments which lead to higher moisture content in these treatments compared with the control treatment.

Generally, physicochemical and technological properties of seaweeds are related to their main component, i.e. dietary fibers, and their effectiveness varies depending on the solubility of the fibers (Elleuch et al. 2011). Previous studies reported that polar groups of the sulphated polysaccharides including the hydroxyl, carboxyl and sulphate groups can form hydrogen bonding with water to maintain moisture, which will make them ideal to be utilized in pharmaceutical and food industries (Shao et al. 2015). Based on the achieved results, it could be said that the hydration properties of *U. intestinalis* was more relied on the USP (soluble fraction); sulphated polysaccharides exerted more affinity to water in the purified form (USP) compared to when they were in the seaweed structure (containing both soluble and insoluble fraction).

Cooking yield

Changes in cooking yield (CY) values are shown in Fig. 1b. The initial CY ranged from 88% in Tsp to 87.2% in Tc. It was 87.4% in Tsw. No significant differences was observed at the beginning of storage between treatment ($P > 0.05$).These levels are higher than the ones (83–86%) reported by Sanchez-Alonso and Borderias (2008) in minced fish with added red grape dietary fiber. It has been reported that CY in ground meat products incorporated with dietary fiber varies widely depending on the

Table 1 Proximate composition of silver carp surimi and fresh pre-fried fish finger treatments (Control; Sw: with 27.7 g kg^{-1} *U.intestinalis* seaweed powder; Sp: with 5 g kg^{-1} *U.intestinalis* sulphated polysaccharide)

Sample	Protein (g kg^{-1})	Moisture (g kg^{-1})	Fat (g kg^{-1})	Ash (g kg^{-1})
Surimi	132.5 ± 7.0	771.6 ± 1.1	25.4 ± 3.3	8.00 ± 0.50
T control	103.8 ± 0.1^{b}	607.0 ± 2.2^{b}	22.6 ± 0.3^{b}	25.5 ± 0.7^{c}
T sw	107.3 ± 1.2^{a}	610.1 ± 3.1^{ab}	25.3 ± 0.0^{a}	31.1 ± 0.0^{a}
T sp	107.4 ± 0.6^{a}	615.9 ± 2.2^{a}	23.0 ± 0.0^{b}	27.4 ± 0.0^{b}

Different letters in the same column represent significantly different means between the fish finger treatments ($P < 0.05$)

Values are mean ± standard deviation (n = 3)

physicochemical properties of additives (DFs), processing conditions, and the protein level of the product (Cofrades et al. 2008; López-López et al. 2010).

Despite the significant effect of storage period on the CY values of all treatments, no obvious trend was observed in any of the treatments. Similar results reported by Sanchez-Alonso and Borderias (2008). Changes in the CY values during frozen storage as a function of treatments, showed a higher CY values in Tsp than those of Tsw and Tc though they were not significant in all months of storage ($P > 0.05$); such significant differences was only observed in months of 1 and 6 ($P < 0.05$). There was also no significant difference between Tsw and Tsp except in the last month of storage ($P < 0.05$). Similar results were obtained on the addition of 5 g kg^{-1} *Laminaria digitata* polysaccharides to cooked minced pork patties (Moroney et al. 2013). In contrast to our results, Choi et al. (2012) found that the addition of 10–30 g kg^{-1} *Laminaria japonica* powder significantly decreased the cooking loss of pork patties, and as the levels of dietary fiber increased, the CY also increased significantly.

As reported by Ang (1993), increase in water retention during cooking as a function of dietary fiber addition results from the involvement of fibers in the hydrogen bonding with the free water released from protein as a function of thermal denaturation. Nonetheless, as described by Sanchez-Alonso and Borderias (2008); the more is the soluble ratio, the more would be the water binding capacity. Thus, the partial improvement in the cooking performance of Tsp to Tsw may lie in the differences of their dietary fiber composition. Another reason can be the effect of heating on USP gelatinization" and as a consequence its thermal stability (Alakali et al. 2010).

Colour attributes

The colour attributes results of fingers showed an obvious significant effect between treatments ($P < 0.05$) than the frozen storage period (Table 2). To be more specific, the L^* and a^* values of both Tsp and Tc were significantly higher than those of Tsw during the whole storage, whereas the b^* values of Tsw were higher than those of Tsp and Tc ($P < 0.05$). Gines et al. (2004) reported that not only muscle structure characteristics but also pigment concentrations affect the colour. Therefore, such changes in the colour attributes of Tsw can be ascribed to the seaweed pigments as chlorophylls, beta-carotene and xanthophylls, which contributed in the darkening of Tsw. seaweed pigments as chlorophylls, beta-carotene and xanthophylls are ascribed to the the darkening of Tsw. Choi et al. (2012) observed similar results in pork patties incorporated with *L. jacopina* powder.

Throughout the frozen storage, a significant effect ($P \leq 0.05$) was observed with regarding to

$L^*$and a^* values, though these trends did not follow a consistent variations. However, L^* values of Tc showed a decreasing trend from day 30 to the last months of storage ($P \leq 0.05$). The reduction in the intensity of lightness might be due to the sample's dehydration during storage. Damodaran (1997) reported that partial breakage of hydrogen bonds may occur as a consequence of ice crystal formation following re-aggregation among biopolymer chains after the removal of water from the initial network. Then such quasi-crystalline structures' formation among the protein-polysaccharide chains would reduce the light scattering ability.

With the passage of time during storage, b^* values showed no significant changes ($P > 0.05$). However, redness of the treatments showed a slightly increasing trend. Our current results are in accordance with previous findings where similar colour change in a^* was found in Grass carp surimi during cold storage, which was attributed to the light scattering changes by the substances that were formed during the denaturation of proteins and lipids (Sun et al. 2017).

pH values

Changes in the pH values of finger treatments during the storage times are presented in Table 2. The initial pH value of Tsw and Tsp was 5.70 and 5.73, respectively, which were lower than that of the control ($P > 0.05$). Such lowering effect of *U.intestinalis* powder and USP addition upon pH values continued throughout the frozen storage. This phenomenon can be ascribed to the structural features of algal hydrocolloids that contain a large amount of acidic functional groups (Wei et al. 2013). Similar results obtained by Choi et al. (2012) who reported a decrease in pH value of pork patties with *Laminaria japonica* powder addition and attributed such trend to the strong acidic components of fucoidan and alginic acid.

Regarding the effect of frozen storage, the pH of all samples increased significantly after 4 months of storage. This increase could be attributed to increase in the secondary oxidation compounds and other alkaline compounds, which increase the pH of meat (Eymard et al. 2005). Throughout the remaining storage time, the pH values showed a significant decreasing trend ($P < 0.05$). Based on the previous findings (Rodriguez- Carpena et al. 2012), a tendency towards higher acidity occurs during the frozen storage probably due to an increase in the concentration of substances in the water that remains unfrozen in frozen foods, which will then modify the acid–base equilibrium.

Table 2 Colour attributes and pH values of three fish finger treatments (Control; Sw: with 27.7 g kg^{-1} *U.intestinalis* seaweed powder; Sp: with 5 g kg^{-1} *U.intestinalis* sulphated polysaccharide) during storage time at − 18 °C

Parameters & Treatments	Months of storage						
	0	1	2	3	4	5	6
L* *(Lightness)*							
T control	53.7 ± 1.5^{Aab}	54.8 ± 1.1^{Aa}	52.8 ± 1.3^{Aab}	51.0 ± 0.9^{Bc}	50.1 ± 0.6^{Bc}	52.3 ± 1.0^{Abc}	53.0 ± 2.7^{Aabc}
T sw	43.2 ± 1.6^{Bb}	45.7 ± 1.3^{Ba}	44.2 ± 1.5^{Bab}	43.2 ± 1.6^{Cb}	45.4 ± 1.1^{Ca}	42.6 ± 0.9^{Bb}	46.0 ± 1.3^{Ba}
T sp	54.9 ± 1.0^{Aa}	54.4 ± 1.3^{Aab}	52.8 ± 0.8^{Abc}	54.2 ± 1.4^{Aab}	54.0 ± 0.9^{Aab}	51.7 ± 0.9^{Ac}	53.4 ± 1.0^{Aab}
a* *(Redness)*							
T control	-0.15 ± 0.06^{Abc}	-0.04 ± 0.01^{Abc}	0.58 ± 0.43^{Aab}	0.26 ± 0.28^{Aabc}	0.74 ± 0.82^{Aab}	-0.22 ± 0.50^{Ac}	0.24 ± 0.67^{Aabc}
T sw	-3.15 ± 0.24^{Cb}	-2.32 ± 0.45^{Bab}	-2.61 ± 0.70^{Bab}	-2.60 ± 0.82^{Bab}	-2.67 ± 0.18^{Cab}	-1.93 ± 0.68^{Ba}	-3.22 ± 0.42^{Bb}
T sp	-0.56 ± 0.21^{Bc}	-0.27 ± 0.13^{Ab}	0.20 ± 0.07^{Aa}	-0.15 ± 0.08^{Ab}	-0.47 ± 0.10^{Bc}	0.15 ± 0.09^{Aa}	-0.26 ± 0.09^{Ab}
b* *(Yellowness)*							
T control	10.4 ± 1.0^{Ba}	10.7 ± 0.4^{Ba}	11.6 ± 1.9^{Ba}	11.7 ± 0.6^{Ba}	11.7 ± 1.3^{Ba}	11.5 ± 1.6^{Ba}	10.2 ± 0.3^{Ba}
T sw	14.0 ± 0.6^{Aa}	14.8 ± 0.7^{Aa}	14.3 ± 1.1^{Aa}	14.2 ± 0.6^{Aa}	14.0 ± 0.4^{Aa}	15.0 ± 0.6^{Aa}	14.4 ± 0.5^{Aa}
T sp	11.0 ± 0.7^{Ba}	11.2 ± 1.0^{Ba}	11.4 ± 0.5^{Ba}	11.3 ± 0.5^{Ba}	10.4 ± 1.2^{Ba}	11.8 ± 0.3^{Ba}	11.2 ± 1.1^{Ba}
pH							
T control	5.74 ± 0.01^{Abc}	5.78 ± 0.02^{Aab}	5.71 ± 0.03^{Acd}	5.75 ± 0.02^{Abc}	5.80 ± 0.03^{Aa}	5.70 ± 0.01^{Ad}	5.68 ± 0.04^{Ad}
T sw	5.70 ± 0.03^{Ab}	5.72 ± 0.02^{Bb}	5.69 ± 0.01^{Ab}	5.70 ± 0.02^{Bb}	5.81 ± 0.01^{Aa}	5.59 ± 0.03^{Cc}	5.69 ± 0.03^{Ab}
T sp	5.73 ± 0.02^{Ab}	5.73 ± 0.02^{Bb}	5.71 ± 0.02^{Ab}	5.73 ± 0.01^{Bb}	5.79 ± 0.02^{Aa}	5.65 ± 0.01^{Bc}	5.67 ± 0.01^{Ac}

Values are mean ± standard deviation (n = 3 for colour and n = 5 for pH)

Different capital letters in same column for each parameter at the same months represent significantly different means ($P < 0.05$)

Different small letters in same row for each parameter with the same treatments represent significantly different means ($P < 0.05$)

Lipid oxidation

Peroxide value (PV)

Propagation of primary lipid oxidation during the frozen storage is shown in Fig. 2 A. The initial peroxide value in the control finger was 2.83 meq peroxide/kg oils. It was 3.58 and 3.27 meq peroxide/kg oils for Tsw and Tsp, respectively. With the passage of 2 months of storage, the PV of the all samples increased progressively; then a gradual decrease occurred up to the end of storage ($P < 0.05$). As peroxides are unstable compounds, their decomposition to secondary oxidation products (i.e. aldehydes) decreased the formation of PV. A slight fluctuation which was found in this period (months 3–6), could be attributed to the similar rate of decomposition and formation of hydroperoxide in the samples (Maqsood et al. 2012).

Throughout the storage period, both Tsp and Tsw showed less PV than the control ($P \leq 0.05$). At the end of storage, it was the control sample that showed more increase in PV value than two other treatments. However, the differences between the treatment groups were statistically significant only in months 4 and 5 ($P < 0.05$). No significant difference was observed between Tsw and Tsp in PV values during the whole storage time ($P > 0.05$). Lopez-Lopez et al. (2009) reported that seaweeds may be regarded as natural antioxidants for improving the stability of meat products. They observed high antioxidant activity in the meat samples containing *Himanthalia elongate*, which was attributed to their remarkably high phenolic contents such as phenolic acids, hydroxycinnamic acids and flavonoids.

Regarding the beneficial role of sulphated polysaccharides in the antioxidant effects of seaweeds, the mechanism of their antioxidant activity is still not well understood. However, Moroney et al. (2015) reported that electron transfer reaction is the probable mechanism in charged polysaccharides, like ulvan, which is due to the negative charge of the sulphate groups.

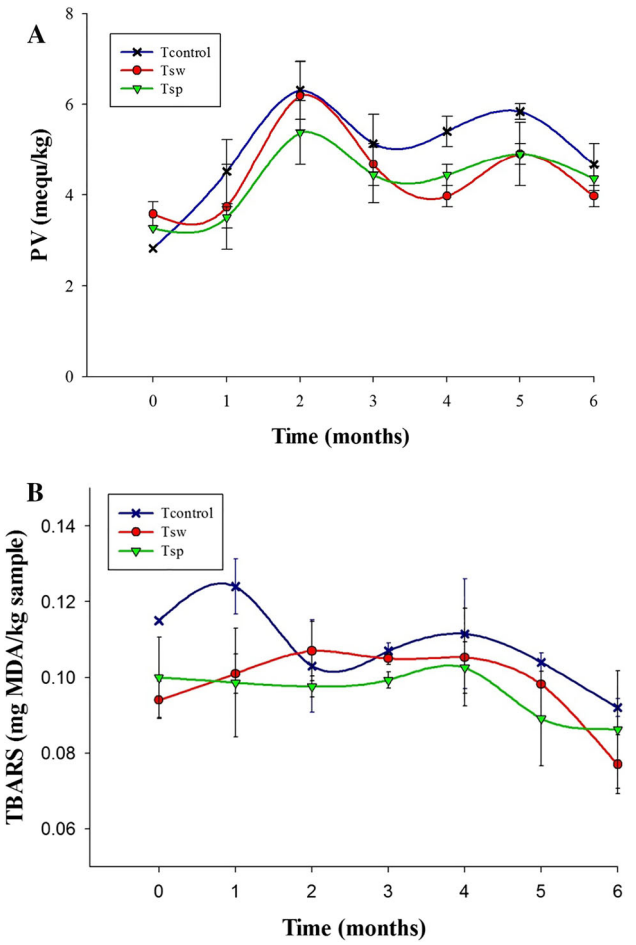

Fig. 2 Changes in (**a**) peroxide value (meq/kg oil) and (**b**) thiobarbituric acid reactive substance/TBARS (mg MDA/kg sample) value of three fish finger treatments (Control; Sw: with 27.7 g kg^{-1} *U.intestinalis* seaweed powder; Sp: with 5 g kg^{-1} *U.intestinalis* sulphated polysaccharide) during 6 months of storage at − 18 °C. Error bars indicate standard deviation (n = 3)

Thiobarbituric acid reactive substance (TBARS)

TBARS is another widely-used indicator of lipid oxidation in foodstuffs, which is based on the spectrophotometric determination of malondialdehyde (MDA). The initial value was significantly lower ($P < 0.05$) in the treated samples than in the control (Fig. 2b). Due to degradation of lipid hydroperoxides (Mi et al. 2016), a significant increase was observed in the MDA formation of the control sample during the first month of storage, while both of the treated samples decelerated such increase in the development of MDA.

TBARS value of Tsp showed no significant changes during frozen storage ($P > 0.05$), while a significant decrease was found in the values of control and Tsw in months 2, 6 and 6, respectively ($P < 0.05$). The decrease in TBARS values during storage may be attributed to the non-stable nature of MDA which is then decomposed to other organic compounds or reacts with free amino acids, proteins and peptides (Maqsood et al. 2012). Trends during storage indicated that the control treatment had higher TBARS values and also showed more fluctuation when compared with the two other treatments (except in the second month). However, the lowest TBARS value occurred in the USP containing samples with the average mean value of 0.096 MDA/kg. The TBARS value of Tsp was also significantly lower in months 2 and 3 compared with that of Tsw values ($P < 0.05$).

In accordance with the findings of current study, tea polyphenols and rosemary extract showed a reduction in the TBARS values of whole crucian carp (*Carassius auratus*) during storage (Li et al. 2012). Wang et al. (2010) studied the effect of seaweed (*Fucus vesiculosus*) extract on washed cod muscle and cod protein isolates during ice storage, and described an inhibitory effect on lipid peroxidation. These were, however, in contrast with the study of Moroney et al. (2013), who reported the pro-oxidative effects of laminarin and fucoidan in fresh minced pork patties, due to the structure of laminarin as well as high ash content of the extracts that counteracted the antioxidant activity of other constituents.

Texture

The textural attributes and shear force of the treatments are presented in Table 3. Most of the parameters were affected more by the type of formulation than by frozen storage ($P < 0.05$). The results indicated that incorporation of both *U. intestinalis* powder and particularly USP produced fingers with softer texture compared with the control ($P < 0.05$). According to Pinero et al. (2008), changes in the hardness of meat products as a function of texture-modifying ingredients' addition may be associated with the water retention properties of the ingredients. Therefore, the softer texture of Tsp compared with the two other treatments ($P < 0.05$) could be attributed to the higher moisture content of USP containing fingers (Fig. 1).

Softer texture of the treated samples compared to that of the control significantly affected the chewiness and gumminess of fish fingers (Tsw and Tsp) and reduced them ($P < 0.05$). Cohesiveness, referred to as the strength of the internal bonds, showed no significant difference between Tsw and Tsp ($P > 0.05$); however, it was decreased significantly in both treatments as compared to that of control sample ($P < 0.05$). The addition of USP and *U. intestinalis* powder to the fish fingers produced less degree of springiness as compared to Tc; such decrease was more pronounced in the USP added fingers ($P < 0.05$). The results of warner–bratzler shear force test were also in accordance with the TPA parameters. The harder was the texture, the more force was needed to shear the product. However, no significant difference was observed between Tc and Tsw in some textural characteristics within several months of storage ($P > 0.05$).

It has been reported that the mechanisms of dietary fibers in modifying food product textures depend on such factors as fiber solubility, water binding capacity, processing condition, and also the swelling properties of dietary fibers (Cofrades et al. 2008). With regard to te hydrophilic characteristics of dietary fibers, especially the soluble form, it could be speculated from the results of current study that addition of fibers resulted in competing between proteins and fibers for water molecules; this hindered the surimi protein's access to enough water in order to form a three-dimensional gel network. Therefore, the least textural values were observed in the USP containing fingers with more swelling ability and affinity to water.

The similar influence of soluble dietary fiber addition on the TPA parameters and the shear force of meat products has been reported by Selgas et al. (2005), and Pinero et al. (2008), respectively. However, the addition of powdered *Himantalia elongata*, *Porphyra umbilicalis* and *Undaria pinnatifida* (25 g kg^{-1} and 50 g kg^{-1}) increased ($P < 0.05$) the hardness and chewiness of low-salt meat emulsion (Cofrades et al. 2008).

During the frozen storage period, a gradual hardening effect was observed in the control treatment ($P < 0.05$). The effects of storage time on other textural parameters were small ($P > 0.05$). The hardening effect of frozen storage has been mainly attributed to the chemical and structural changes in myofibrillar protein during storage, which results in the toughening of fish fingers (Lopez-Lopez et al. 2010). Due to the moisture retention ability of fibers, there were no changes in the hardness of Tsw and Tsp during this period ($P > 0.05$). Moreover, Maqsood et al. (2012) pointed to the protective effect of antioxidants on the structural properties of final product through maintaining the integrity of muscle fibers and reducing the moisture loss.

Sensory evaluation

Table 4 shows the sensory analysis results of different fish finger treatments during the frozen storage. Among the different sensory parameters measured in this study, only juiciness and tenderness showed clear treatment-related changes ($P < 0.05$). It was observed that the USP containing treatments were significantly juicier than Tc and Tsw during most of the storage periods (0, 3, 4, 5 and 6 months). Similarly, the texture data indicated that incorporation of 5 g kg^{-1} soluble fiber (USP) to the finger formula resulted in a detectable tender texture compared with the two other treatments ($P < 0.05$).

Altogether, these results are similar to those reported with the texture instrumental evaluations (Table 3). In agreement, Pinero et al. (2008) reported a significant increase in juiciness score in beef patties with added oat's soluble fiber ($P < 0.05$). Conversely, Choi et al. (2012) described a decreasing trend in the tenderness and juiciness of beef patties with *Laminaria jacopina* powder concentration of higher than 30 g kg^{-1}, remarking the impact of the amount and type of dietary fibers added to different meat products.

Table 3 Instrumental texture analyses and shear force of three fish finger treatments (Control; Sw: with 27.7 g kg^{-1} *U.intestinalis* seaweed powder; Sp: with 5 g kg^{-1} *U.intestinalis* sulphated polysaccharide) during 6 months of storage at − 18 °C

Parameters	Months of storage						
	0	1	2	3	4	5	6
Hardness (N)							
T control	67.35 ± 4.71^{Ab}	79.32 ± 3.39^{Ab}	76.92 ± 3.72^{Ab}	79.59 ± 5.42^{Aa}	76.88 ± 8.61^{Aa}	79.40 ± 8.98^{Aa}	89.32 ± 10.58^{Aa}
T sw	71.58 ± 6.9^{Aa}	67.90 ± 9.72^{Ba}	69.63 ± 3.23^{Ba}	73.80 ± 5.44^{Aa}	74.82 ± 5.99^{Aa}	70.13 ± 4.35^{Ba}	68.46 ± 10.45^{Ba}
T sp	55.33 ± 5.3^{Ba}	54.54 ± 4.19^{Ca}	59.20 ± 4.57^{Ca}	57.99 ± 7.58^{Ba}	55.29 ± 5.46^{Ba}	54.52 ± 4.93^{Ca}	51.52 ± 5.35^{Ca}
Gumminess (N)							
T control	35.38 ± 3.87^{Ab}	43.06 ± 2.98^{Aa}	42.80 ± 3.59^{Aa}	43.49 ± 3.88^{Aa}	42.34 ± 5.55^{Aa}	43.30 ± 8.20^{Aa}	48.11 ± 4.91^{Aa}
T sw	33.19 ± 4.89^{Aa}	29.78 ± 5.64^{Ba}	31.28 ± 2.55^{Ba}	32.84 ± 3.24^{Ba}	32.65 ± 5.78^{Ba}	29.64 ± 3.11^{Ba}	30.95 ± 7.53^{Ba}
T sp	25.10 ± 3.30^{Ba}	23.61 ± 2.69^{Ca}	26.82 ± 3.00^{Ca}	25.99 ± 5.46^{Ca}	23.63 ± 3.82^{Ca}	22.53 ± 2.7^{Ba}	22.16 ± 3.40^{Ca}
Chewiness (N)							
T control	21.39 ± 2.99^{Aa}	28.08 ± 2.22^{Ab}	27.23 ± 2.81^{Aab}	27.91 ± 2.79^{Ab}	27.18 ± 4.21^{Ab}	28.15 ± 5.40^{Ab}	29.00 ± 2.80^{Ab}
T sw	19.15 ± 3.35^{Aa}	16.87 ± 3.64^{Ba}	17.84 ± 1.84^{Ba}	19.30 ± 2.54^{Ba}	22.89 ± 4.76^{Aa}	17.01 ± 2.24^{Ba}	17.65 ± 4.97^{Ba}
Tsp	13.64 ± 2.00^{Ba}	12.47 ± 1.74^{Ca}	14.35 ± 1.99^{Ca}	13.94 ± 3.62^{Ca}	12.67 ± 2.55^{Ba}	11.94 ± 1.71^{Ca}	11.78 ± 2.09^{Ba}
Springiness							
T control	0.60 ± 0.01^{Aa}	0.63 ± 0.01^{Aa}	0.62 ± 0.01^{Aa}	0.63 ± 0.01^{Aa}	0.63 ± 0.02^{Aa}	0.63 ± 0.02^{Aa}	0.63 ± 0.02^{Aa}
T sw	0.57 ± 0.01^{Ba}	0.56 ± 0.01^{Ba}	0.56 ± 0.01^{Ba}	0.58 ± 0.02^{Ba}	0.58 ± 0.02^{Ba}	0.57 ± 0.02^{Ba}	0.56 ± 0.02^{Ba}
T sp	0.54 ± 0.01^{Cb}	0.52 ± 0.01^{Ca}	0.53 ± 0.01^{Ca}	0.53 ± 0.02^{Ca}	0.53 ± 0.02^{Ca}	0.52 ± 0.01^{Ca}	0.53 ± 0.01^{Ca}
Cohesiveness							
T control	0.52 ± 0.03^{Aa}	0.53 ± 0.02^{Aa}	0.55 ± 0.02^{Aa}	0.54 ± 0.03^{Aa}	0.54 ± 0.02^{Aa}	0.53 ± 0.05^{Aa}	0.53 ± 0.02^{Aa}
T sw	0.46 ± 0.02^{Ba}	0.43 ± 0.02^{Ba}	0.44 ± 0.01^{Ba}	0.44 ± 0.01^{Ba}	0.47 ± 0.04^{Ba}	0.42 ± 0.02^{Ba}	0.44 ± 0.04^{Ba}
T sp	0.45 ± 0.01^{Ba}	0.43 ± 0.02^{Bab}	0.44 ± 0.01^{Ba}	0.45 ± 0.02^{Ba}	0.42 ± 0.02^{Bab}	0.41 ± 0.01^{Bb}	0.42 ± 0.02^{Bab}
Shear force (N)							
T control	13.87 ± 1.94^{Aa}	15.07 ± 1.74^{Aa}	15.54 ± 1.58^{Aa}	16.34 ± 1.57^{Aa}	15.98 ± 1.63^{Aa}	16.87 ± 1.70^{Aa}	16.82 ± 1.11^{Aa}
T sw	15.07 ± 1.44^{Aab}	12.56 ± 0.68^{Bc}	13.79 ± 1.21^{Aabc}	14.61 ± 0.91^{Aabc}	15.798 ± 2.29^{Aa}	13.23 ± 1.17^{Bbc}	12.91 ± 0.55^{Bc}
T sp	9.55 ± 0.35^{Ba}	8.79 ± 0.99^{Ca}	10.07 ± 0.96^{Ba}	9.93 ± 0.99^{Ba}	10.37 ± 0.86^{Ba}	9.84 ± 0.87^{Cab}	9.66 ± 1.11^{Ca}

Values are mean ± standard deviation (n = 6)

Different capital letters in same column for each parameter at the same months represent significantly different means ($P < 0.05$)

Different small letters in same row for each parameter with the same treatments represent significantly different means ($P < 0.05$)

Table 4 Sensory attributes of three fish finger treatments (Control; Sw: with 27.7 g kg^{-1} *U.intestinalis* seaweed powder; Sp: with 5 g kg^{-1} *U.intestinalis* sulphated polysaccharide) during 6 months of storage at − 18 °C

Parameters	Months of storage						
	0	1	2	3	4	5	6
Flavor							
T control	4.50 ± 0.53^{A}	4.62 ± 3.39^{A}	4.37 ± 0.51^{A}	4.25 ± 0.46^{A}	4.12 ± 0.35^{A}	4.12 ± 0.35^{A}	4.00 ± 0.53^{A}
T sw	4.37 ± 0.74^{A}	4.37 ± 0.51^{B}	4.12 ± 3.23^{A}	4.00 ± 0.64^{A}	4.12 ± 0.75^{A}	3.87 ± 0.64^{A}	3.87 ± 0.64^{A}
Tsp	4.62 ± 0.51^{A}	4.50 ± 0.53^{A}	4.50 ± 4.57^{A}	4.37 ± 0.51^{A}	4.25 ± 0.46^{A}	4.12 ± 0.35^{A}	4.12 ± 0.35^{A}
Odour							
T control	4.62 ± 0.51^{A}	4.62 ± 0.51^{A}	4.50 ± 0.53^{A}	4.50 ± 0.53^{A}	4.37 ± 0.51^{A}	4.25 ± 0.46^{A}	4.25 ± 0.70^{A}
T sw	4.50 ± 0.53^{A}	4.50 ± 0.51^{A}	4.12 ± 0.64^{A}	4.12 ± 0.92^{A}	4.12 ± 0.64^{A}	4.12 ± 0.35^{A}	4.00 ± 0.53^{A}
T sp	4.62 ± 0.51^{A}	4.50 ± 0.53^{A}	4.37 ± 0.51^{A}	4.50 ± 0.53^{A}	4.50 ± 0.53^{A}	4.50 ± 0.53^{A}	4.37 ± 0.51^{A}
Colour							
T control	4.37 ± 0.51^{A}	$4.2\ 5 \pm 0.46^{A}$	4.25 ± 0.46^{A}	4.12 ± 0.35^{A}	4.12 ± 0.35^{A}	4.00 ± 0.35^{A}	4.00 ± 0.53^{A}
T sw	4.25 ± 0.88^{A}	4.25 ± 0.46^{A}	4.00 ± 0.53^{A}	4.12 ± 0.60^{A}	3.87 ± 0.60^{A}	3.75 ± 0.70^{A}	3.62 ± 0.51^{A}
T sp	4.50 ± 0.53^{A}	4.37 ± 0.51^{A}	5.50 ± 0.53^{A}	4.25 ± 0.70^{A}	4.12 ± 0.35^{A}	4.25 ± 0.46^{A}	4.12 ± 0.35^{A}
Texture							
T control	4.12 ± 0.64^{A}	$4.0\ 0 \pm 0.01^{B}$	4.00 ± 0.02^{A}	3.87 ± 0.00^{A}	3.87 ± 0.02^{AB}	3.75 ± 0.02^{A}	3.62 ± 0.00^{B}
T sw	3.87 ± 0.64^{A}	4.00 ± 0.53^{B}	4.00 ± 0.53^{A}	3.87 ± 0.64^{A}	3.75 ± 0.46^{B}	3.87 ± 0.64^{A}	3.62 ± 0.51^{B}
T sp	4.50 ± 0.53^{A}	4.62 ± 0.51^{A}	4.50 ± 0.53^{A}	4.37 ± 0.51^{A}	4.50 ± 0.53^{A}	4.25 ± 0.46^{A}	4.37 ± 0.51^{A}
Juiciness							
T control	4.25 ± 0.46^{B}	4.12 ± 0.60^{A}	4.12 ± 0.83^{A}	4.00 ± 0.53^{B}	3.75 ± 0.46^{B}	3.75 ± 0.46^{B}	3.62 ± 0.51^{B}
T sw	4.25 ± 0.46^{B}	4.25 ± 0.46^{A}	4.00 ± 0.75^{A}	3.87 ± 0.64^{B}	3.75 ± 0.46^{B}	3.62 ± 0.51^{B}	3.50 ± 0.53^{B}
T sp	4.87 ± 0.35^{A}	4.62 ± 0.51^{A}	4.50 ± 0.53^{A}	4.62 ± 0.51^{A}	4.50 ± 0.53^{A}	4.50 ± 0.53^{A}	4.37 ± 0.51^{A}
Overall acceptability							
T control	7.62 ± 0.51^{A}	7.62 ± 0.91^{A}	7.35 ± 1.30^{A}	7.25 ± 0.46^{AB}	7.25 ± 0.46^{AB}	7.00 ± 0.53^{B}	6.87 ± 0.64^{B}
T sw	7.50 ± 0.75^{A}	7.12 ± 0.83^{A}	7.00 ± 0.92^{A}	7.00 ± 0.75^{B}	7.00 ± 0.75^{B}	6.75 ± 0.88^{B}	6.37 ± 0.74^{B}
T sp	8.00 ± 0.53^{A}	8.00 ± 0.75^{A}	7.75 ± 0.70^{A}	7.87 ± 0.83^{A}	7.75 ± 0.70^{A}	7.87 ± 0.64^{A}	7.50 ± 0.53^{A}

Values are mean ± standard deviation

Different capital letters in same column for each parameter at the same months represent significantly different means ($P < 0.05$)

The overall sensory acceptability of fish fingers was rated by the panelists as follows: Tsp > Tc ≥Tsw (Table 4). In general, in the current study, the average score of at least 6.3 indicated that the fish fingers formulated with *U. intestinalis* powder and especially sulphated polysaccharides were well received by the panelists during the whole six months of frozen storage, implying the possibility of their utilization not only without any adverse effect on organoleptic properties but also with retaining the product's quality.

Conclusion

The performance of seaweed powder (soluble and insoluble DFs) as compared with its sulphated polysaccharide (soluble DF) was evaluated in the present study on the quality parameters of fish fingers during frozen storage. The results revealed that incorporation of sulphated polysaccharide as an isolated component can be comparable with using whole algae in giving functional attributes (such as retarding lipid oxidation) to food products. However, thanks to its solubility, USP had a more positive impact on the product's texture preservation during storage. Overall, this work indicates the possibility of using both seaweed powder and SP utilization in the fish finger formula without any adverse effects, though dose dependency should be regarded for sensorial acceptance.

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