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Wheat fiber as a functional ingredient in restructured fish products

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Abstract

The technological effect of wheat fiber as an ingredient in minced fish was tested. Thus 3% and 6% of wheat fiber with different size particles were added to minced hake (*Merluccius merluccius*) and horse mackerel (*Trachurus trachurus*) muscle and water was also added to maintain the original moisture of the sample. The addition of fiber increased the water holding capacity (WHC). The water binding capacity (WBC) also increased, but only when water was not added to maintain the moisture constant. The cooking drip was lower when 3% or 6% of fiber was added. In general, when the drip was released by gravity, the 250 μm particle fiber bound more water than the 80 μm particle fiber, but when the water was extracted by a centrifugal force the opposite was observed. Restructured products with fiber were whiter and their rigidity and cohesiveness were lower. Products with 3% of fiber were well rated by the sensory panel, unlike the products with 6% of fiber. No unusual flavors were apparent when the wheat fiber was added. The effect of fiber as a stabilizing agent on protein and lipid was not apparent, either.

Keywords: Dietary fiber; Wheat fiber; Fish; Functional properties; Physical properties

1. Introduction

Despite widespread use in dairy, meat, bakery and other products, there are scarcely any references to fishery products with added highly insoluble dietary fiber. Cereal fibers, which have a great proportion of insoluble fiber, have physiological advantages such as the chewing mechanism, stimulation of intestine function and influence on intestine transit period (Bollinger, 2000). In addition to these physiological properties, cereal fibers consisting mainly of cellulose have advantageous technological properties such as a high water and fat binding capacity and they are optimal ingredients for achieving high yields and reduced cost. One to three percent fiber in certain foods can also reduce lipid retention when these foods are fried (Ang, 1993; Thebaudin, Lefebre, Harrington, & Burgeois, 1997). Moreover, cryoprotectant properties are described for cellulose in the freeze-thaw stability of surimi-based shellfish analogue products (Yoon & Lee, 1990).

Fish is a good example of a "nutraceutical" food because it is an important source of nutraceutical products such as fish oil. It also contains a readily-digested protein and hence is ideal for people with delicate stomachs. Nevertheless, such a good food would be more complete if its fiber content was increased. Many children and adolescents in western Europe consume products containing essentially proteins or fats but consume hardly any foods providing the necessary intake of fiber.

Many of the fibers currently used for technological purposes in fishery products are very soluble and come from algae such as carrageenans (Borderías, Montero, & Marti de Castro, 1996; DaPonte, Herfst, Roozen, & Pilnik, 1985; Gómez-Guillén, Solas, Borderías, & Montero, 1996), or seeds such as garrofin, guar, xanthan and others (Montero, Hurtado, & Pérez-Mateos, 2000; Pérez-Mateos, Hurtado, Montero, & Fernández-Martín, 2001). There is very limited experience on using insoluble fibers, such as cellulose in fishery products (Ang & Miller, 1991; Yoon & Lee, 1990).

There are two ways of introducing these fibers into fishery products. One is by injecting dispersions of fiber into

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fillets and another more effective way is by introducing fiber into restructured products. Restructured fishery products are products made from minced and/or chopped muscle and which, with or without other ingredients, are used to make other products with a new appearance and texture. For a long time now there have been products in the form of fingers or other shapes intended basically for children's foods, which are covered in breadcrumbs or batter, prefried and then frozen for use as fried products. Furthermore, the last 25 years have witnessed a new generation of fishery products based on gelation (in cold or thermic conditions) of their muscular proteins, called analogues, most of which mimic seafood or other high-value products.

The present study aims to test the technological effect of a very purified insoluble wheat fiber (Vitacel®) consisting mainly of cellulose and hemicellulose as a functional ingredient on two types of frozen-stored minced fish muscle. It has the advantage of being white, odorless and tasteless, so it seems ideal for use in white fish-based products. Another advantage of this kind of fiber is that it is inert towards other ingredients and practically calorie free (Ang, 1993; Ang & Crosby, 2005). Its high water binding capacity is also described (Ang, 1991; Ang, 1993; Ang & Miller, 1991).

2. Materials and methods

2.1. Raw material and additives

Two fish species were used in the experiments: frozen on board hake (*Merluccius capensis*) fillets caught 45 days before use and stored at −25 °C and ice-stored horse mackerel (*Trachurus trachurus*) caught in the northwest of Spain two days before use.

The fiber used was wheat fiber Vitacel® (Campi y Jové, S.L., Barcelona, Spain). This fiber consists of 74% cellulose, 26% hemicellulose and <0.5 of lignin; two types of fiber were studied: WF200 with 250 μm long and 25 μm wide particles and WF600 with 80 μm long and 20 μm wide particles.

2.2. Reagents

All of the chemicals used were of analytical grade and were obtained from Panreac Química S.A. (Barcelona. Spain). Sigma–Aldrich Co. or Merck (Darmstadt, Germany).

2.3. Preparation of fish and samples

For the preparation of the restructured minced hake muscle, the fillets were thawed (approx 16 h at 4 ± 2 °C) and passed once through a meat mincer model FTS111 (Mainca, Granollers, Spain) fitted with a plate with 0.42 cm-diameter holes. Five different samples were formulated. The procedure was as follows: the fish was mixed in a mixer-machine model RM-20 (Mainca, Granollers, Spain). The wheat fiber was dispersed in cold water (according to the formulation) and added to the minced fish muscle. The mixing time was standardized to 6 min (the final temperature was below 6 °C in all cases). Lots were formulated as follows: control without fiber (HO); 3% long particle fiber added with water to adjust the moisture (HL3); 6% long particle fiber added with water to adjust the moisture (HL6); 3% long particle fiber added (HL3*); 3% short particle fiber (HS3) added with water to adjust the moisture. In all the lots except HL3* the moisture was adjusted at 81.5%.

Horse mackerel were filleted without removing the skin at the local seafood company and transported to the pilot plant. The muscle was extracted using a Baader model 694 deboner machine (Lübeck, Germany) equipped with a drum with 3 mm holes. Three different samples were formulated: control without added fiber (MO); 3% long particle fiber added with water to adjust the moisture (ML3); 6% particle fiber added with water to adjust the moisture (ML6). The final moisture in the different samples was 77.5% like in the original muscle. The procedure was the same as for hake.

The samples were placed on 21.5 × 15 × 3.5 cm aluminum trays and were then frozen in a Saubre "Benjamin" model horizontal plate freezer (Hanst-Moller, Germany) that cooled the thermic core to −20 °C. The samples were then vacuum packed in bags (Wipak7gryspeert, PAE 110KFP) using a Multivac machine packer (Germany). Afterwards they were stored at −20 °C. The samples were analyzed at the beginning of the experiment and then every month for 6 months.

2.4. Proximate analyses

Moisture, fat and ash content of the raw samples was determined (AOAC, 1995) in quadruplicate. The crude protein content was measured in quadruplicate using a Nitrogen determinator LECO FP-2000 (Leco Corporation, St Joseph, MI).

2.5. Mechanical properties

The instrumental texture analysis was conduced using a TA-TX2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). Measurement of the cooked samples was carried out at room temperature. Texture profile analysis (TPA) was performed as described by Bourne (1978). Three probes (Ø = 2 cm, height = 1.5 cm) of cooked samples were axially compressed to 40% of their original height to avoid fracturability. Force-time deformation curves were derived with a 50 N load cell applied at a crosshead speed of 0.8 mm/s. Attributes were calculated as follows: hardness: peak force (*N*) required for first compression; cohesiveness: ratio of active work done under the second compression curve to that done under the first compression curve (dimensionless) and springiness: distance (mm) the sample recovers after the first compression. Chewiness

($N \times$ mm) is the product of the attributes mentioned and from the sensory point of view corresponds to the energy required to chew a solid food product (Bourne, 2002).

The shear strength was measured with a Kramer shear cell attachment (model HDP/KS5). For this purpose, three sample portions ($5.5 \times 1.5 \times 2.5$ cm) per formulation were cooked. A load cell of 50 N was used and the crosshead speed was 2.0 mm/s. Data were expressed as a maximum load per gram of sample (N/g).

2.6. Water binding capacity (WBC)

A frozen sample (2 g) cut into small pieces was placed in a centrifuge tube (Ø = 10 mm) along with enough filter paper (3 filter Whatman no. 1 Ø = 110 mm). Centrifugation took place after thawing the muscle in the tube. A Jouan MR1812 centrifuge (Saint Nazaire, France) was used: 5000 rpm (3000*g*) for 10 min at room temperature. WBC was expressed as percent water retained per 100 g water present in the muscle prior to centrifuging.

2.7. Water holding capacity (WHC) and cooking yield

Paralepipedic $7 \times 3 \times 1.5$ cm frozen pieces of the sample were cut from the mince blocks and placed in a plastic bag where small holes had been made to drain the drip. This bag with the sample inside was put inside another bag and hung with the holes at the bottom at a constant temperature of 2–4 °C. The samples were in this condition overnight and the drip was measured. Then the samples were cooked in the same way in an oven (Rational Combi-Master CM6) at 100 °C for 15 min. After the oven was set at room temperature and the drip collected was measured.

2.8. Protein solubility

This was determined in triplicate essentially according to the Ironside and Love procedure (1958) by analyzing the amount of soluble protein in a chilled aqueous solution of 5% NaCl. The protein was analyzed in a LECO FP2000 analyzer, and the results were expressed as a percentage of soluble protein over total protein.

2.9. Measurement of color

Color measurements consisted of determining L^*, a^* and b^* using a CIELab scale (Park, 1995; Young & Whittle, 1985) where L^* is the parameter that measures lightness, $+b^*$ the tendency towards yellow and $+a^*$ the tendency towards red. Measurements were done in a HunterLab model D25-9 colorimeter (D45/2°) (Hunter Associates Laboratory Inc. Reston, VA, USA), with measurements standardized with respect to the white calibration plate. Whiteness was determined using the following formula: $100 - [(100 - L^*)^2 + a^{*2}b^{*2}]^{1/2}$ (Park, 1995).

2.10. The thiobarbituric acid index (TBA-i)

It was determined according to Vynke (1970) on a 5% trichloracetic acid extract of the restructured fish muscle. The results were expressed as mg malondialdehyde per kilogram of sample. The spectrophotometer used was a Perkin–Elmer Lambda 15, UV/VIS Spectrophotometer.

2.11. Sensory analyses

The triangular test (UNE 88 006 92) and hedonic analyses (UNE 87 020 93) were performed in every lot. Thus 0.7 cm thick slices were cut from semi-frozen blocks and battered with a special mix and fried in sunflower oil at 180 °C for 3 min. Seven semi-trained panelists tasted the samples in a standard sensory panel room following the norms mentioned above. For the hedonic analyses, a 10 cm non-structured scale with verbal anchors at the ends and in the center (like very much, neither like nor dislike, dislike very much) was used for three properties: flavor, texture and overall rating acceptance. The panelists had to mark a vertical line on the scale; afterwards these marks were measured with a ruler.

2.12. Statistical analysis

One and two-way ANOVA was analyzed using Statgraphics 2.1 (STSC Inc. Rockville, MD). The difference in means was analyzed using a Tukey HSD test ($p < 0.05$).

3. Results and discussion

3.1. Protein solubility

Differences among protein solubility mean values for the two kinds of muscle samples with and without fiber were not significantly different throughout frozen storage. However, Yoon and Lee (1990) conferred cryoprotectant properties on cellulose when it partially substituted sucrose in formulas using sorbitol and sodium tripolyphosphate. DaPonte et al. (1985) reported stabilization of frozen fish muscle when some fibers, other than cellulose were added.

3.2. Water binding capacity

If the sample of hake muscle without fiber (HO) is compared with the sample with 3% of fiber where the moisture was not kept constant (HL3*), it is observed (Table 1) that this fiber helps retain water ($p < 0.05$) when pressure is exerted, especially from day 60 of frozen storage. These data can be compared bearing in mind that the value of the retained water is a ratio with the total water in the sample, so the difference in moisture is corrected. If when the fiber is added, water is also added to maintain the moisture (HL3, HL6), it is observed that the added fiber (3% and 6%) cannot efficiently bind the extra quantity of water, so there are significant differences with the control sample

Table 1
Water binding capacity (%)[a]

Days	H0	HL3	HL6	HL3*	HS3	M0	ML3	ML6
0	58,20 a/1	54,84 a/123	52,26 a/3	57,39 a/12	53,13 ab/23	45,09 ab/1	29,72 a/2	27,60 a/2
30	53,02 bc/1	41,97 cd/3	37,51 c/4	53,44 ab/1	47,82 bc/2	46,54 ab/1	32,60 a/2	29,57 a/2
60	49,58 cd/1	41,55 cd/2	40,85 c/2	53,10 ab/1	41,75 d/2	42,99 a/1	31,24 a/2	29,29 a/2
90	48,22 de/12	47,32 bc/12	44,67 abc/12	50,80 b/2	44,43 cd/1	49,35 b/1	31,97 a/2	27,44 a/3
120	49,47 d/1	40,81 d/2	45,13 abc/12	54,89 ab/3	49,58 bc/1	45,86 ab/1	32,92 a/2	27,02 a/3
150	45,92 e/1	40,01 d/2	43,94 abc/12	56,66 a/3	55,48 a/3	46,22 ab/1	34,52 a/2	25,57 a/3
180	47,91 de/1	44,19 bcd/1	43,00 bc/1	63,58 c/2	57,57 a/3	43,93 a/1	30,38 a/2	25,82 a/2

Different letters in the same column indicate significant time differences ($p < 0.05$). Different numbers in the same row for each type of fish indicate significant differences ($p < 0.05$) among the samples.

[a] H0: Control without fiber; HL3: 3% long particle fiber added (moisture adjusted to 8.15%); HL6: 6% long particle fiber added (moisture adjusted to 81.5%); HL3*: 3% long particle fiber added; HS3: 3% short particle fiber (moisture adjusted to 81.5%).

(H0), although there are hardly any differences between the samples with 3% (HL3) and 6% (HL6) of fiber. The same occurs with the horse mackerel samples (Table 1), but the difference between the control (M0) and the samples with added fiber (ML3, ML6) is still greater than in the hake muscle. There are also hardly any differences between the horse mackerel samples with 3% (ML3) and 6% (ML6) of fiber, whereas these differences are always significant and more than 10% with the control sample. Yoon and Lee (1990) recommended adding a maximum of 2% of cellulose to surimi, since, with a greater proportion of cellulose, gels, with more expressible moisture and firmness were obtained.

If the samples of minced hake with 3% different grain length fiber are compared, it is observed that the water is more firmly bound in most of the controls when the grain is shorter (80 μm) (HS3). This is in accordance with the work done by Yoon and Lee (1990) where it was observed that in cellulose particles longer than 20 μm the expressible moisture (by compression) was higher, although the size range used in the present work was different (80 and 250 μm). On the other hand, Ang and Miller (1991) reported that the water retention of cellulose increases as the fiber length increases, but they also reported that water retention with fiber lengths greater than 110 μm did not vary as much as for fiber lengths between 35 and 100 μm.

3.3. Water holding capacity

In minced hake muscle, only the long grain fiber (HL3, HL6) absorbed the thaw drip effectively ($p < 0.05$) (Table 2). Ang and Crosby (2005) report that the larger the particle size (or fiber length), the more water can be retained as a result of the greater internal pore volume. There were very few significant differences when 3% (HL3) or 6% (HL6) fiber was used. The same results were obtained when the fiber was added to minced horse mackerel (ML3, ML6).

If 3% fiber was added to minced hake muscle without adjusting the final moisture (HL3*), the water was absorbed significantly more than when water was added (HL3). In applications using minced beef, insoluble fibers from cereals help reduce the amount of free water that can occur during pre-frying which is very important to improve the yield of the final cooked product and prevent the breadcrumb coating from breaking during frying because of the excessive drip release (Anonymous, 1999).

3.4. Cooking yield

Data are shown in Table 3. Addition of 3% fiber (long or short grain) to hake (HL3, HS3) and minced horse mackerel muscle (ML3) did not lend to binding of significantly more water than the respective control (H0, M0) when the moisture in both samples was adjusted to the original muscle moisture. The addition of 3% of fiber without adjusting the water (HL3*) was effective to bind the cooking drip; this is an important point to take into account in order to avoid dripping during broiling or frying. Adding 6% of fiber (HL6, ML6) helped bind the water and the data were significantly different from the respective control (H0, M0) and the samples with 3% (HL3, ML3) of fiber in both muscles.

When water was lost, the muscle fibers shrank upon heating, but when high-fiber ingredients were added, the structural integrity was maintained (Nelson, 2001). Troutt

Table 2
Water holding capacity (%)[a]

Days	H0	HL3	HL6	HL3*	HS3	M0	ML3	ML6
0	89,64 a/1	97,94 ab/2	99,38 a/2	100 a/2	89,67 a/1	92,15 a/1	96,64 a/2	100 ab/3
30	95,12 b/1	97,76 ab/12	99,85 a/2	100 a/2	91,63 ab/3	92,31 a/1	99,40 bc/2	99,98 abc/2
60	91,85 ab/1	97,62 ab/2	99,53 a/2	100 a/2	93,08 ab/1	95,52 ab/1	99,95 c/2	99,94 c/2
90	90,18 ab/1	94,87 b/2	97,90 b/23	100 a/3	89,95 a/1	93,31 a/1	98,44 b/2	99,95 bc/2
120	94,65 ab/12	96,57 ab/2	99,77 a/3	100 a/3	93,80 ab/1	99,71 c/1	99,97 c/1	99,98 abc/1
150	94,09 ab/1	97,93 ab/2	99,38 a/3	100 a/3	96,36 b/4	99,77 c/1	99,98 c/2	99,99 abc/2
180	93,27 ab/1	96,08 ab/12	99,53 a/2	99,98 a/2	96,13 b/12	98,21 bc/1	100 c/2	100 a/2

[a] See note to Table 1.

Table 3
Cooking yield (%)[a]

Days	H0	HL3	HL6	HL3*	HS3	M0	ML3	ML6
0	86,41 a/1	87,07 a/12	90,30 ab/2	88,04 a/12	85,31 a/1	74,48 a/1	76,19 a/1	77,11 a/1
30	85,57 ab/1	86,33 a/12	88,01 abc/2	87,92 a/2	83,49 a/3	73,82 a/1	74,87 a/1	81,28 b/2
60	84,64 ab/12	85,94 a/123	86,73 ac/23	87,53 a/3	83,72 a/1	75,39 a/1	76,10 a/1	85,35 d/2
90	82,68 b/1	84,15 a/1	87,44 ac/2	90,45 a/3	84,29 a/1	75,57 a/1	75,14 a/1	81,59 bc/2
120	86,51 a/1	85,94 a/1	91,76 b/1	89,55 a/1	84,91 a/1	74,83 a/1	75,47 a/1	83,46 bcd/2
150	82,22 b/1	83,95 a/1	86,01 c/2	88,22 a/3	82,30 a/1	72,40 a/1	76,80 a/2	84,18 d/3
180	84,55 ab/1	83,17 a/1	88,25 abc/2	89,00 a/2	83,37 a/1	72,29 a/1	77,32 a/2	84,02 cd/3

[a] See note to Table 1.

et al. (1992) reported that 2% of oat fiber, which is a cereal fiber, incorporated into meat hamburger (with no water added) reduced cooking losses by 20–40%. This reduction is about 2–4 times more than in the present experiment in fish. Moreover, Pszczola (1991) reported that the addition of oat brand to ground beef resulted in increased cooking yield. Katsanidis, Meyer, Epley, and Ruan (2001) reported the important role of introducing cellulose into comminuted beef because it reduced the cooking drip; this water is not retained at all if an external force (it can be shrinkage during cooking) is applied because it takes out the water that is physically and not chemically entrapped. On the other hand, Ang (1993) reported that the increase in water retention during cooking could be due to the hydrogen bonds forming between the water molecules and cellulose fibers. Thus the hydrogen bonds weaken with the cooking temperatures and water cannot be bound so easily. Consequently, a larger amount of fiber is necessary.

3.5. Whiteness index

The addition of an increasing proportion of wheat fiber whitened the minced raw hake (HL3, HL6) and horse mackerel (ML3, ML6) samples significantly. The horse mackerel cooked samples were much whiter than the raw ones and the amount of fiber added also enhanced the color. Non-enzymic browning that develops in frying when cellulose is used (Ang, 1993) was not observed in minced muscle probably because the coating protects the muscle from the very high temperatures responsible for enzymic browning. This is an important fact because European consumers consider whiteness as a quality factor for hake and other fish products (Ang, 1993).

3.6. Mechanical properties

Shear strength: There were no significant differences in the hake and horse mackerel control samples (H0, M0) and the samples with 3% fiber, irrespective of the size of the fiber when water was added to maintain the initial moisture of the muscle (HL3, HS3, ML3) (Table 4). If water was not added to keep the moisture in the sample constant (HL3*), hardness increased, probably because the fiber absorbed part of the water and this hardened the muscle particles. It is important to highlight that this test analyzes shear strength with a method using complex combinations of compression, extrusion, shear, friction and other effects (Bourne, 2002) between small particles of food and the Kramer cell. Thus the measurement of shear strength is on these particles and the procedure is similar to the one we use when we chew. Hardness did not increase either in any sample during frozen storage.

Chewiness: At 0 days of frozen storage, when fiber was added (HL3, HL6, ML3, ML6), chewiness was lower than in the control samples (H0, M0) in both the minced hake and horse mackerel muscles although there were no significant differences in many instances among the samples containing fiber (Table 5). These results are in agreement with the results for fish surimi gel samples with cellulose added from wood or cotton, where hardness and cohesiveness were reduced by adding 2% cellulose (Anonymous, 1981). Aleson-Carbonell, Fernández-López, Pérez-Álvarez, and Kuri (2005) report that the addition of fibers and other ingredients to meat products produces less rigid structures. Troutt et al. (1992) also reported that firmness and cohesiveness were reduced when oat fiber was added to ground beef with low fat content.

Table 4
Shear strength (N/g)[a]

Days	H0	HL3	HL6	HL3*	HS3	M0	ML3	ML6
0	5,85 a/1	4,55 a/1	5,10 a/1	7,26 ab/1	6,14 a/1	7,70 ab/1	6,84 a/2	7,35 a/12
30	5,75 a/1	5,45 a/1	6,35 ab/1	8,71 bcd/2	5,75 a/1	7,42 ab/1	6,93 c/1	7,58 a/1
60	6,30 a/123	5,95 a/12	7,92 b/3	7,52 abc/23	4,72 a/1	6,73 a/1	8,54 cd/2	7,48 a/1
90	5,39 a/1	5,89 a/12	7,52 ab/2	5,24 a/1	6,35 a/12	8,41 bc/1	7,83 bc/1	8,36 ab/1
120	6,02 a/1	5,99 a/12	7,09 ab/1	11,43 d/2	6,84 a/1	9,18 c/1	7,64 ab/2	9,70 c/1
150	5,84 a/1	6,53 a/1	5,98 ab/1	9,56 bcd/2	5,90 a/1	8,42 bc/1	8,76 d/1	7,71 a/1
180	5,87 a/1	5,72 a/1	7,17 ab/1	10,36 cd/2	6,74 a/1	8,60 bc/1	8,58 cd/1	9,30 bc/1

[a] See note to Table 1.

Table 5
Chewiness ($N \times$ mm)[a]

Days	H0	HL3	HL6	HL3*	HS3	M0	ML3	ML6
0	35,00 ab/1	18,75 ab/23	13,50 a/3	24,58 abcd/2	21,59 ab/2	61,34 a/1	44,36 a/2	37,79 abc/3
30	34,98 ab/1	12,54 a/3	13,11 a/3	27,71 bcde/2	23,05 abc/2	79,66 d/1	65,58 b/2	43,84 c/3
60	37,52 b/1	18,17 a/3	22,68 b/23	28,09 cde/2	22,26 abc/3	43,93 c/1	44,64 a/1	35,09 ab/1
90	31,69 a/1	17,93 a/23	15,26 a/3	18,17 ab/23	22,44 abc/2	55,14 ab/1	43,28 a/2	36,44 abc/3
120	33,65 ab/1	18,63 ab/2	16,16 a/2	15,81 a/2	30,11 c/1	57,41 ab/1	49,23 a/12	40,56 bc/2
150	42,77 c/1	26,27 bc/3	25,38 b/3	32,77 de/2	29,45 bc/23	47,71 bc/1	48,39 a/1	30,84 a/2
180	33,57 ab/2	28,38 c/123	21,45 b/3	35,89 e/1	23,20 abc/23	47,79 bc/1	40,02 a/12	31,10 a/2

[a] See note to Table 1.

Throughout frozen storage the hake muscle sample with 3% fiber (HL3) was not significantly different from the one with 6% (HL6), but both were different from the samples without fiber (H0). In the case of horse mackerel, the sample with 3% fiber (ML3) was significantly different from the sample without fiber (ML0) only at the beginning of frozen storage, but both were different from the samples with 6% of fiber (ML6). These data depend more on hardness and cohesiveness than on springiness. The values of the different analyses were similar for the samples with 3% of long and short particle fiber (HL3, HS3) throughout frozen storage. Yoon and Lee (1990) reported that the addition of 0–2% of cellulose in frozen surimi products decreased firmness and cohesiveness and increased cellulose concentration, although more than 2% of cellulose increased firmness. The effect on the texture parameters is different depending on the amount and type of insoluble fiber that is added to meat products (Cofrades, Guerra, Carballo, Fernández-Martín, & Jiménez-Colmenero, 2000) and also on the water binding capacity and swelling properties of the fiber (Thebaudin et al., 1997).

3.7. Lipid oxidation

There is no significant variation in the evolution of the TBA-index throughout frozen storage in the different lots for both types of muscles with and without fiber. Aleson-Carbonell et al. (2005) report that some cereal fibers have antioxidant properties, but they use fibers that are not very purified containing phenolic compounds. This is not the case for the fiber used in this study.

3.8. Sensory analysis

The triangular analysis detected significant differences in all the samples and the two muscles studied. According to the panelists, the difference in the hake samples was more in the texture than in the flavor. In the case of the horse mackerel samples, as well as the differences in texture, the fiber reduced the strong taste of the muscle.

According to the hedonic analysis done with non-structured scales, the flavor of the hake samples without fiber (H0) was slightly better (6.0–7.0) than the lots with 3% (HL3, HS3, HL3*) although the score for these lots was always around the middle point (4.9–5.5, neither like or dislike). The lot with 6% of fiber (HL6) had the lowest score (4.0–4.6). In the case of horse mackerel, the samples with fiber (ML3, ML6) exhibited slightly higher values (6.5–7.0) than the lot M0 without fiber (5.0–6.0), since the fiber reduced the strong flavor of the muscle. The panelists did not detect any unusual flavors throughout frozen storage in either of the two muscles studied.

The texture analysis of the hake samples also exhibited slightly higher values (5.0–6.3) in the control lot (H0), especially during the first 30 days of storage. The rest of the lots exhibited values slightly lower than the middle point of the scale (3.0–5.1) and the lowest values were in the lot HL6 with 6% of fiber (2.8–4.4). According to the panelists, this lot was too dry. It is strange that the lot with 6% of added fiber had a lower cooking loss and yet the panel of tasters mentioned that it was drier. Although there were fluctuations in the data throughout frozen storage, there was no deterioration in the texture during frozen storage. In the case of horse mackerel, the sample with 3% of fiber (ML3) was well accepted by the panel of tasters (values 6.0–7.0) compared with values 6.5–6.6 in the sample without fiber (M0). However, the horse mackerel sample with 6% of fiber (ML6) exhibited lower values (2.5–4.0) due to the "sandy" texture and low cohesiveness.

Regarding the overall rating of the hake samples, higher values (5.0–7.3) in the lot H0 without fiber and values near the middle point of the scale (3.9–6.2) in the lots with 3% of fiber (HL3) were observed, except for the lot where water was not added to keep the moisture constant (HL3*) which was drier (3.6–5.8). The lot with 6% of fiber (HL6) had lower acceptance (2.9–4.2). As for the overall rating of the horse mackerel samples, the samples with 3% of fiber (ML3) exhibited values of 6.0–7.0 compared to 6.5–6.6 in the sample without fiber (MO) throughout frozen storage. The sample with 6% of fiber (ML6) exhibited a lower rating of 3.0–4.0.

4. Conclusions

No cryoprotectant effect of the wheat fiber was observed on the protein in the two muscles studied.

The introduction of 3% of wheat fiber improved the water binding capacity when a force was used to extract it. However, if, together with the 3% or 6% of fiber, water was added to keep the moisture constant, this fiber could not bind more water than the control sample. The loss in thaw drip without applying any external force was significantly less when 250 μm grain cellulose was introduced, and no change was observed with the 80 μm particle.

The loss from the cooking drip was very similar throughout frozen storage when 3% of fiber and water was added to keep the moisture constant in the sample. However, it was less if 6% of fiber or 3% of fiber without water was added. The 80 μm particle fiber bound less cooking drip than the 250 μm particle fiber.

In all the cases studied, the addition of wheat fiber whitened the samples, especially those with a darker muscle as is the case of horse mackerel. This is considered to be a commercial advantage.

The restructured product with added fiber was less rigid and cohesive. However, the shear strength of the product particles was similar in the lots with and without fiber when water was added to maintain the same moisture as in the original muscle.

In the sensory analysis there were differences in the lots with and without fiber. The lots with 3% of fiber were all accepted, while the lots with 6% fiber were rated worse. This negative rating was primarily due to the sensation of dryness.

In the present work wheat fiber was not found to have an antioxidant capacity.

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