International Journal of Gastronomy and Food Science 22 (2020) 100277

Contents lists available at ScienceDirect

International Journal of Gastronomy and Food Science

journal homepage: www.elsevier.com/locate/ijgfs

Nutritional, physical, microbiological, and sensory properties of marinated Irish sprat

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ARTICLE INFO

Keywords:
Sprat
Pelagic fish
Marination
Utilisation
Sensory

ABSTRACT

Atlantic Sprat (*Sprattus sprattus*) is a highly nutritious pelagic fish of great commercial value in Eastern Europe and Scandinavia which in Ireland is largely under-utilised for human consumption.

The aims of this study were to develop a marinated product from Irish sprat, to evaluate its physico-chemical characteristics; and to compare sensory qualities of the Irish sprat product (ISP) with established European analogues.

Physico-chemical analysis of the marinated product included proximate analysis, pH, sodium chloride, colour, and texture, while microbiological tests were conducted for total viable bacterial count (TVBC), total psychrophilic aerobic bacteria (TPBC), total yeast and mould, and total coliform counts (TCC). Sensory attributes of the Irish sprat product were assessed by panel tasting using hedonic and just-about-right (JAR) scales and compared to Nordic (NSP) and Mediterranean marinated (MAN) products.

This study demonstrates that the curing methods used significantly increased ash content and reduced water content of fresh sprat ($P < 0.05$) thus contributing to product preservation. Specifically, preservation was achieved by reducing the marinated product's pH value and water activity and increasing the salt content thereby inhibiting all microbial growth across all curing stages.

Hedonic and JAR data showed positive acceptance from consumers for most ISP sensory characteristics. However, JAR scores were lowered by panellist's perception of excessive acidity and fishiness indicating that broad consumer acceptance of an ISP product will depend on the freshness of the raw material available to processors.

Introduction

Sprat (*Sprattus sprattus* L.) is a small oily fish species. It is a rich source of protein, vitamins, and minerals, and it is low in saturated fat.

Currently sprat is a largely under-utilised species for human consumption in Ireland, while this species is widely exploited for human food production in Eastern European and Scandinavian countries (Rustad, 2018; Gamma-a, 2020). Sprat landings in Ireland are currently less than 3000 t/a (Marine Institute, 2017) with recent commercial values of around 150–200 €/t (SFPA, 2016). This suggests there is scope to add value to this resource by developing high-quality products for direct human consumption for the Irish market, rather than by trading it as a commodity for fishmeal and fish oil production.

One of the traditional ways to add value and preserve fish and seafood is through cold marination. Cold marinated fish are semi-preserved products made without heat treatment, where solutes, such as acid, salt, sugar, etc. play the major role for controlling microorganism activity and contribute to the organoleptic characteristics of the final product (Boziaris et al., 2013). The antimicrobial effect of organic acids depends on the nature of the acid, i.e. a degree of dissociation, nature of food and microorganisms (Ray and Bhunia, 2013).

Acetic acid is the most commonly used base for fish marination, however other organic acids either alone or combined with acetic acid are also used to good effect for both taste and preservation. These include citric acid (Šimat et al., 2019), gluconic acid (Poligne and Collignan, 2000), lactic acid (Ndaw et al., 2008), tartaric and malic acids (Šimat et al., 2011).

In this study a combination of white vinegar and cider vinegar was used to combine the preservative properties of acetic acid with pleasant organoleptic characteristics. Moreover, Beheshti et al. (2012); Iman

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https://doi.org/10.1016/j.ijgfs.2020.100277
Received 24 August 2020; Received in revised form 25 October 2020; Accepted 26 October 2020
Available online 30 October 2020

et al. (2014); Yagnik et al. (2018) all suggest that consumption of cider vinegar can reduce cholesterol levels, help to regulate blood sugar and assist with weight management.

Brining before marination is described as an essential preparatory step which significantly improves the physical quality of the product (Šimat et al., 2011; Yeannes and Casales, 2008; Kilinc and Cakli, 2004). Brining preserves fish by replacing water with salt which acts to inhibit bacterial activity and development. It is well documented that this can be achieved by immersing sprat (and sprat sized fish) in a bath of 10% of NaCl (w/v) for 1 h at room temperature, with a fish: solution ratio 1:1 (Capaccioni et al., 2011; Yeannes and Casales, 2008; Cabrer et al., 2002).

In Eastern Europe spice brine cures are a traditional and enduring method for sprat preservation and flavour enhancement (Timberg et al., 2014a, 2014b). Other methods are also described including canning of smoked sprat in brine, oil, or tomato sauce (Usydus et al., 2008; Gladyshev et al., 2009) as well as the production of pastes (Silovs and Dmitrijeva, 2018). Compared to other small pelagic species such as herring, sardine and anchovy there is a limited amount of published information on the marination of sprat. However available studies on small pelagic species stress that marinade formulation, fish species, ratios of fish to brining solution, temperature and duration are all critical factors for obtaining safe products with favourable sensory properties. Thus, Kilinc and Cakli (2004), found that to achieve complete marination of sardines (*Sardina pilchardus*) 22 days at 4 °C were required (7% acetic acid (v/v), 14% NaCl (w/v) and fish: solution ratio 1.5:1). Under these conditions inhibition of microorganism growth was also achieved. According to Yeannes and Casales (1995, cited in Capaccioni et al., 2011) anchovy (*Engraulis anchoita*) marinated for 7–9 days of marination in 3% acetic acid (v/v), 10% NaCl (w/v), (fish: solution ratio 1.3:1) at 20 °C showed a pleasant taste and pickled odour, and a firm and consistent texture. Based on Šimat et al. (2011) anchovy (*Engraulis encrasicolus,L.*) fillets marinated in 25% alcoholic vinegar (v/v), 30% wine vinegar (v/v) and 7% of NaCl (w/v), (fish: solution 1:1.5) at 4 °C for 25 days obtained the best sensory scores at the all stages of marination.

Several tools are available to measure consumer perception of new marinated fish products. Of these, hedonic testing is a widely used tool for capturing consumer sensory response, understanding drivers of liking, and identifying product strengths and weaknesses (Alexi et al., 2018). Another method, the just-about-right (JAR) scale is used to evaluate the deviation of a product's sensory attributes from "just-about-right" midpoint values, and from this identify directions for improvement (Moskowitz, 2001).

The aim of this study was to investigate the potential for development and production of an innovative value-added marinated product from Irish sprat, describe the processes, evaluate physico-chemical and sensory characteristics; and suggest ways forward.

Materials and methods

Raw materials

Irish sprat (*Sprattus sprattus*) caught in Bantry Bay (Co. Cork, Ireland) in September 2019 and landed in Castletownbere were used. The fresh sprat was purchased from Mary's Fish Company (Galway, Ireland) and blast frozen at −35 °C for 12 h and stored at −20 °C prior to use.

The frozen fish was thawed at 4 °C for 24 h (THAWED), cleaned from heads and guts, filleted, washed, drained, and brined in a 10% NaCl solution (w/v) for 1 h at 20 ± 2 °C (BRINED). The dry brined fish was marinated in a solution containing 10% NaCl (w/v), 15% sugar (w/v), 25% white vinegar (v/v) (5% acetic acid) and 35% cider vinegar (v/v) (5% acetic acid) for up to 168 h in glass container at 20 ± 2 °C with a fish: brine ratio of 1:1.3 (w/w) and agitation, and finally, storing in glass container with organic rapeseed oil (Tesco, UK) at 4 °C (Fig. 1 and Fig. 2). Marinated samples were analysed at different intervals to make up the other treatments (M12, M24 and M168, after 12, 24 and 168 h of marination, respectively).

Proximate analyses

For proximate and chemical analyses, two fillets were randomly taken from each batch, homogenized for two 5s bursts at 22.000 rpm using a food processor (SilverCrest Nutrition Mixer Pro, 900 W, Germany) at room temperature.

The water content was measured using the oven-drying procedure described in the 950.46, AOAC 2006. Ash content was determined by ignition of the dry sample in a muffle furnace at 500 ± 10 °C for 5 h as described in the AOAC method 920.153 (1995). Fat content was

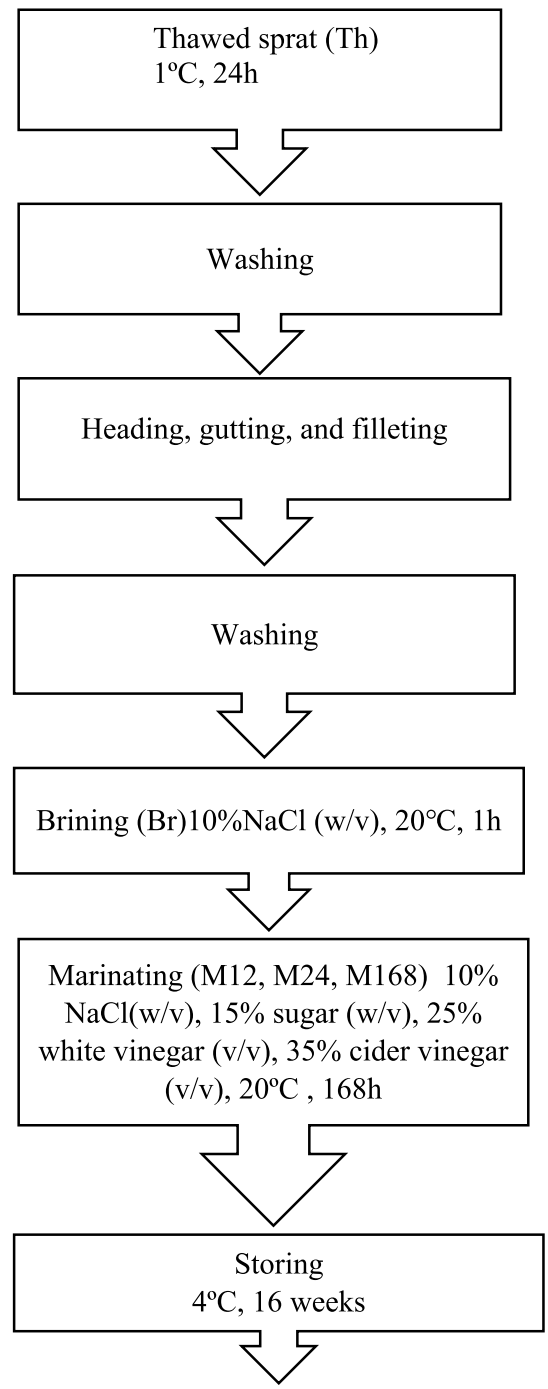

Fig. 1. Flow diagram of the marinating process of *Sprattus sprattus*

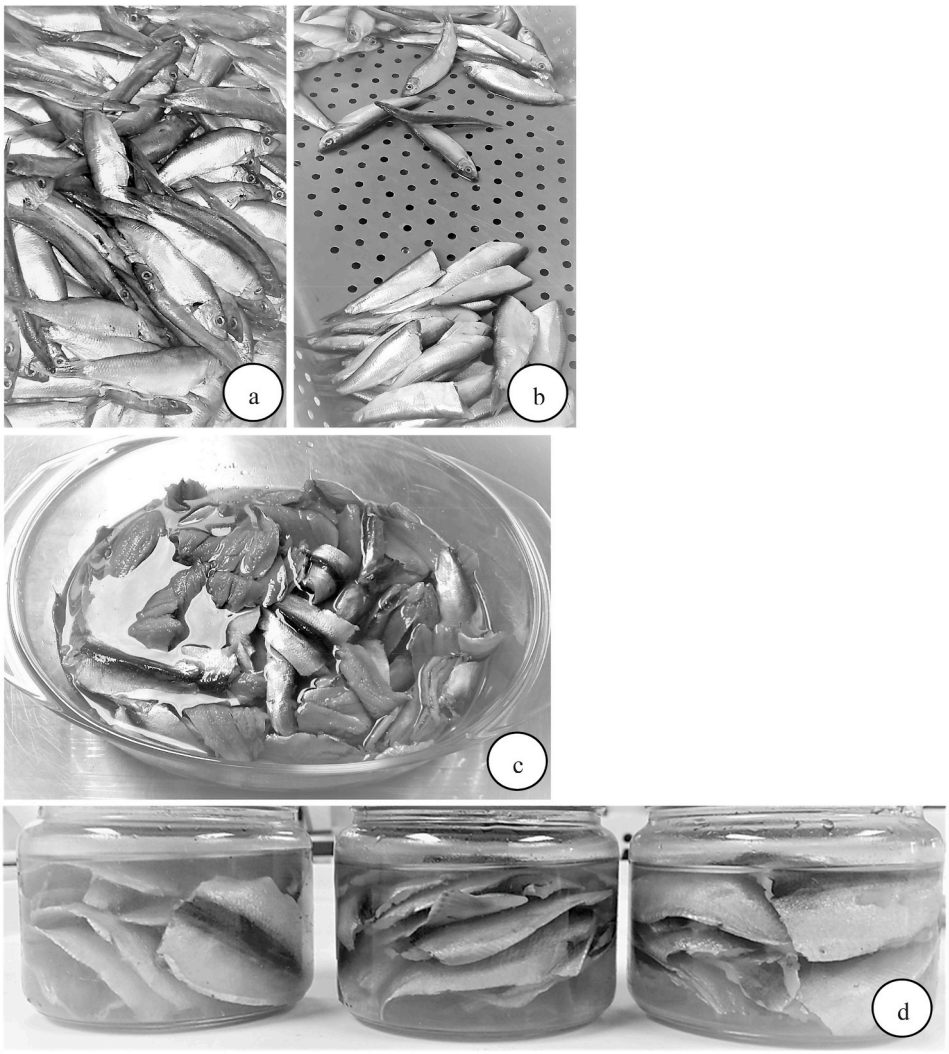

Fig. 2. Marinating process of *Sprattus sprattus*: (a) thawed sprat, (b) heading, gutting, and filleting, (c) brining and (d) marinating.

determined by a solvent extraction method in the Soxhlet apparatus according to AOAC 991.36 (1995). The protein was determined from the salt/alkaline protein extraction by bicinchoninic acid (BCA) colorimetric detection Protein Assay (Thermofisher, n.d.). The salt/alkaline protein extraction was performed and kept at −24 °C until analyses according to Mæhre et al. (2018). The absorbance was determined at 562 nm.

Physical and chemical analyses

For pH measurements the fish was homogenized with distilled water 1:2 (w/v), and measured with calibrated pH meter (Eutech Instruments, pH 150, Singapore).

The sodium chloride content was determined by the method developed by Zhang and Xia (2008) from salt extraction and measuring turbidity of standard and unknown samples six times with a Shimadzu UVmini-1240 spectrophotometer (Shimadzu, Kyoto, Japan) at 385 nm. This was performed an all treatments apart from THAWED.

Water activity (A_w) was theoretically calculated from the measured moisture and salt content (Mostafa and Salem, 2015) (Equation (1)). This was performed an all treatments apart from THAWED.

$$Aw = 1.0014 - 0.6039\,\frac{NaCl\%}{Moisture\,\%} \qquad \text{(Equation 1)}$$

(when NaCl%/Moisture% < 0.1775).

The colorimetric values of fish samples were measured using a CR-400 chroma meter (Konica Minolta, INC. Osaka, Japan) with Ø8/Ø11 lens opening. The colour measurements were performed by positioning the instrument on the surface of the flesh at three locations (top, middle and bottom).

Texture was measured by Warner-Bratzler shear force F(N) using a TA.XT2 Texture Analyzer (Stable Micro Systems, Godalming, UK)

Table 1
Details and ingredients list of the products used, including MAN (Mediterranean) NSP (Nordic) and ISP (Irish) marinated fish.

Code	Product	Brand	Sample	Ingredients
MAN	Filets D'anchois Marinés	Miceli, Turkey		Anchovy fillets with skin, vinegar, salt, citric acid, sunflower oil
NSP	Grebbestad Ansjovis	Abba, Sweden		Sprat fillets, sugar, salt, vinegar, preservatives (sodium benzoate), spices (muscat flower, cinnamon), flavourings.
ISP	Marinated Sprat	GMIT, Ireland		Sprat fillets, sugar, salt, white vinegar, cider vinegar, rapeseed oil

equipped with a rectangular flat ended knife with a 3 mm wide blade edge. The cutting speed was 2 mm/s and the distance 20.0 mm. Texture measurements were performed three times for each sample, totalling 60 measurements per batch. The mean values were expressed in terms of peak force (N).

Microbiological analysis

For all microbiological analysis, 10 g of diced sample was transferred into 90 ml of sterile buffered ¼ strength Ringer's solution (Oxoid, BR0052G, England) and homogenized by Stomacher 400 (Laboratory blender, SEWARD, UK) for 2 min. A series of decimal dilutions were prepared and inoculated on appropriate media.

For the purpose of microbiological analysis, the Total Viable Bacterial Count (TVBC), Total Psychrophilic Aerobic Bacteria (TPBC), Total yeast and mould, and Total Coliform Count (TCC) were determined.

Total Viable Bacterial Count (TVBC) and Total Psychrophilic Aerobic Bacteria (TPBC) were determined by using surface cultivation method and Plate Count Agar as a medium (PCA, Fannin, W11203). Plates were incubated at 37 °C for 48 h (Kocatepe et al., 2019) and at 7 °C for 10 days respectively (Kilinc and Cakli, 2004).

Total yeast and mould were cultivated on Sabouraud Dextrose Agar (SDA, Fannin, W11235) at 30 °C for 48 h (Ndaw et al., 2008). Total Coliform Count (TCC) were incubated on Mc Conkey at 37 °C for 48 h (Kilinc and Cakli, 2004).

Microbiological data were expressed as a logarithm of the number of colonies forming units (log cfu) per gram of sample. All experiments were conducted in three batches, duplicate samples per batch.

TVBC shows the presence of pathogenic and non-pathogenic, yeast and moulds. TPBC indicates bacteria able to grow at refrigerated temperature ≤5 °C. TCC shows lactose-fermenting coliforms at 35–37 °C, highlighting suitable circumstances for growing pathogens and generally performed as an index of food sanitation (Ray and Bhunia, 2013; Robinson, 2014).

Sensory analysis

For sensory analysis three marinated fish products were assessed. Sensory attributes of Irish sprat (ISP) were evaluated and compared with commercially available samples of Nordic (NSP) and Mediterranean (MAN) marinated products (Table 1).

Fillets were trimmed by removing the belly flap, the edge of the nape, and the tail. The rest of each fillet was cut into approximately 1 cm diamond shaped pieces. Two pieces per portion were chilled and served randomly in open white trays coded with random 3-digit numbers.

Sensory evaluation of the fish samples was performed by a panel of 87 consumers in the laboratory facilities in GMIT, in conformance with ISO 8589 (ISO, 2010). The consumer group included 31% males and 69% females. The age ranges were: 18–30 years (57%), 31–40 years (14%), 41–54 years (23%) and 55 or older (6%). Individuals were selected on the basis of being regular consumers of fish products.

Consumers were asked to examine three food samples monadically. The samples were served randomized on a sample-by-sample basis. Fresh water and crackers were provided to rest the palate between samples.

The consumers were asked to indicate their degree of liking of each sample on a 9-point scale, with neutral point at 5. In this instance, the 9-point hedonic rating scale ranged from 1 = "dislike extremely" to 9 = "like extremely" in order to determine the likability or acceptance of appearance, colour, aroma, texture, taste and overall attributes of each fish product. Appearance and colour were evaluated by visually assessing the product, then evaluated the aroma, and finally the fish samples were tasted for texture and flavour liking. Taste intensities, such as acidity, saltiness, sweetness, and flavours, such as fishiness, fatty/oil were examined by 5-point rating JAR scale from 1 = "not nearly enough" to 5 = "too much" and 3 neutral point.

The second part of the questionnaire included 10 short questions on age, gender, consumer perception of fish and purchasing motivation. The aim of the questionnaire was to identify factors that might influence the decision to buy a newly developed fish product, to establish previous experience of small oily fish products, and the willingness to choose small oily fish in restaurant settings. Some of these questions were adapted from (Alexi et al., 2018; Kulikowski and Mytlewski, 2016; Carlucci et al., 2015; Cosmina et al., 2012).

Statistical analysis

All sprat production was carried out in triplicate. All physicochemical data from the seven treatments and the sensory data for the three compared products were expressed as a mean ± standard deviation (SD) and were analysed using XLSTAT ® software (Addinsoft 2020.1.3, New York, USA). The data from the sensory analysis was captured using Compusense (Compusense Inc., Guelph, Ontario, Canada).

Comparisons of variable means were conducted by one-way ANOVA to test for any significant differences ($p < 0.05$) for physico-chemical attributes, and for consumer hedonic responses to sensory attributes of the three different samples (ISP, MAN and NSP). Pairwise comparisons were evaluated by Tukey's test at a 95% confidence level.

Distribution of responses for JAR attributes were analysed, and Penalty Analysis was conducted to quantify the effect of each taste attribute on overall liking.

For the consumers survey, the respondents were clustered according to overall liking using Agglomerative Hierarchical Clustering (AHC). AHC was performed by Ward's method on centred and standardised "Overall liking" data obtained from hedonic test.

Descriptive statistics and tests of independence (chi-square) at the 95% confidence level were performed to describe and differentiate panel clusters according to demographics and attitudes towards the tested products.

Results and discussion

Physico-chemical analysis

Proximate analysis

The changes in the nutrient composition of sprat used in the study

Table 2
Proximate composition, sodium chloride, pH and aw of the *Sprattus sprattus* fillet in different stages of the curing process.

	Water g/100 g<	Protein g/100 g	Ash g/100 g	NaCl g/100 g	pH g/100 g	a_w
Thawed fillet	67.20 ± 2.29^b	16.85 ± 0.86^a	6.22 ± 3.27 ^{c}	–	6.87 ± 0.07^a	–
Brining fillet	72.77 ± 1.77^a	10.28 ± 0.93^b	16.01 ± 1.99^a	4.07 ± 0.49^b	6.62 ± 0.04^b	0.968
M12	54.90 ± 1.88^c	18.32 ± 2.22^a	10.67 ± 0.42^{bc}	5.35 ± 0.36^a	3.96 ± 0.04^c	0.943
M24	53.63 ± 1.31^c	16.26 ± 0.47^a	12.44 ± 4.37^{ab}	5.48 ± 0.42^a	3.69 ± 0.03^d	0.940
M168	55.40 ± 1.86^c	19.02 ± 1.63^a	13.29 ± 2.66^{ab}	5.76 ± 0.35^a	3.69 ± 0.03^d	0.939
Pr > F	<0.0001	0.000	<0.0001	<0.0001	<0.0001	–

^{a}g. 100^{-1} of wet fish sample; and ^{b} g. 100^{-1} of fish solids. M12, 24, 168- marinated fish sample in 12 h (M12), 24 h (M24) and 168 h (M168). Factor levels with different letters in the same column are significantly different at $p < 0.05$.

Table 3
Values of the physical parameters of *Sprattus sprattus* fillet in different stages of the curing process.

	L*	a*	b*	F (N)
Thawed Fillet	54.56 ± 3.19[bc]	3.94 ± 2.78[a]	13.76 ± 1.74[a]	18.37 ± 5.23[c]
Brining fillet	53.35 ± 2.45[c]	1.83 ± 2.29[b]	9.89 ± 1.81[c]	13.90 ± 5.23[c]
M12	58.24 ± 2.45[a]	1.36 ± 1.77[b]	10.62 ± 1.85[c]	42.41 ± 9.49[a]
M24	58.78 ± 1.98[a]	1.26 ± 1.61[b]	10.51 ± 1.37[c]	45.65 ± 12.25[a]
M168	56.14 ± 2.60[b]	1.88 ± 1.59[b]	12.58 ± 1.73[b]	30.88 ± 6.85[b]
Pr > F	<0.0001			<0.0001

M12, 24, 168- marinated fish sample in 12 h (M12), 24 h (M24) and 168 h (M168). Factor levels with different letters in the same column are significantly different at $p < 0.05$.

were examined in the raw material and during each stage of the process. The results obtained from the research are shown in Table 2.

During the brining stage, a moderate increase in moisture content was observed, which can be attributed to brine absorption. However, during the marinating stage, the moisture content significantly decreased ($p < 0.05$). This reduction could be due to dehydration of fish tissues due to salt action, and by reduced water absorption resulting from protein denaturation in the presence of acetic acid (Kolakowski and Bednarczyk, 2002).

Loss of moisture from the fish flesh caused by acetic acid decreased the total water content of sprat fillets, similar to results by Ray and Bhunia (2013). According to Capaccioni et al. (2011), water activity of marinated anchovies (*Engraulis anchoita*) was reduced from 0.99 to 0.94. The calculated Aw of Irish marinated sprat in the present study was similar (0.94) suggesting that marination is a critical hurdle to microbial growth.

During the curing process a gradual increase of NaCl content was observed in sprat fillets accompanied by decreasing water content. These changes resulted from the diffusion of salt into the fish tissue and osmotic release of water (Kolakowski and Bednarczyk, 2002).

The protein content of Irish sprat during all curing stages was 19.02% in the final product. This was similar to marinated anchovies (18.32%) and sardines (15.4%) in previous reports by Yeannes and Casales (2008), and Kilinc and Cakli (2004), respectively. However, the lipid content of raw Irish sprat was 13%, which was significantly higher than that of raw anchovies (2.9%) and raw sardines (3.6%) reported in the same studies. The average lipid content of Baltic sprats caught in autumn 2009 and 2010 reported by Timberg et al. (2014a, 2014b) was 9.4% and 12.1% respectively, in line with the current study findings. Therefore, the difference in reported lipid content could be explained by the differences existing across species, feeding behaviour and habitat (Šimat and Bogdanović, 2012).

In marinated anchovies (*Engraulis anchoita*), as reported by Yeannes and Casales (2008), and in marinated sardines (*Sardina pilchardus*), in a study by Kilinc and Cakli (2004) the ash content was significantly lower than that observed in Irish sprat. This may be due to differences in composition of the species studied and in recipe formulation. In this study, the ash values rapidly increased from 3.91 g/100 g in THAWED to 15.85 g/100 g in BRINED and then gradually decreased to 10.82 g/100 g M168. Increasing ash content during the brining stage can be explained by salt penetration into fish, thereby increasing mineral content. Decreasing ash content of marinated fish could be the result mineral migration into the marinating solution, caused by denaturation of protein in acidic media. According to Cabrer et al. (2002), the most important changes occurred in the "variable grade period", i.e. the first 24 h of marinating, which proceeds into the "constant grade period" for the remainder of the process.

pH analysis

Initial pH of THAWED was close to neutral pH 6.87. There was rapid decline of pH from 6.62 in BRINED to 3.96 in M12 and finally the pH reached 3.69 in M24. This value remained constant throughout the rest of the process (M168). Cabrer et al. (2002) also observed a decrease in pH resulting from the diffusion of the acid into the fish tissue.

Colour and texture analysis

Changes in the L*, a* and b* values during the process are shown in Table 3. In this study, lightness (L*) did not show a significant change from THAWED (54.56) to M168 (56.14). However, marinated sprat fillet lightness increased and achieved the maximum value of 58.78 during the "variable grade period". Addition of acid in marinade had a lightning effect on the colour in the fish flesh. This was also observed by Kolakowski and Bednarczyk (2002); Kilinc et al., (2008a), and Kilinç and Yavuz (2011).

Red colour intensity of THAWED significantly decreased ($P < 0.05$) from 3.94 to 1.88 (M168) during the brining process and reached a minimum of 1.26 at the end of the "variable grade period" (M24). Based on the findings of Chow et al. (2009), acidic conditions greatly affect discoloration, due to increasing autooxidation of myoglobin in the fish meat. Discolouration can be explained by poor handling practice during defrosting, processing and storage (Šimat et al., 2011).

Brining before the marination decreased yellowness in sprat fillets from 13.67 ± 1.74 (THAWED) to 9.89 ± 1.81 (BRINED). However, it was increased during the marination process and reached 12.58 ± 1.73 in M168. Kilinc et al. (2008a, 2008b) and Kilinc (2009) reported lower yellowness in raw sardines ($b^* = 8.12 \pm 1.06$) and in raw anchovy ($b^* = 8.18 \pm 1.00$) respectively. Freezing not only transforms the protein and lipids in fish muscle but it has also been reported to affect pigments. Szymczak (2011) observed increasing yellowness in marinated fish produced from frozen compared to fresh, and attributed this result to lipid oxidation during freezing and frozen storage. The increased yellowness observed during these steps could also be partially contributed by pigments from the of apple cider vinegar used in the formulation.

Shear force hardness results indicated that marination significantly changed the texture of sprat (Table 3). The hardness increased with increasing acidity. In THAWED hardness was 18.37 ± 5.23 N, whereas in M168 it was 30.88 ± 6.85 N ($P < 0.05$). Kolakowski and Bednarczyk (2002) also described reduced elasticity and succulence in marinated herring flesh along with an increase in the acid concentration.

A direct relationship between pH, moisture content and textural changes was observed. The softest texture of 13.90 ± 5.23 N was detected after the brining stage, which corresponded to the highest

Table 4
Changes in microbiological analysis of *Sprattus sprattus* during marination process (log CFU/g). Total Viable Bacterial Count (TVBC), Total Psychrophilic Aerobic Bacteria (TPBC), Total yeast and mould, and Total Coliform Count (TCC) were determined.

Sample stage	TVBC	TPBC	YEAST/MOULDS	TCC
Thawed Fillet	6.4 x 10	2.7 x 10^2	6.0 x 10	1.2 x 10
Brining fillet	<10	1.3 x 10^2	<10	<10
M12	<10	<10	<10	<10
M24	<10	<10	<10	<10
M168	<10	<10	<10	<10

M12, 24, 168- marinated fish sample in 12 h (M12), 24 h (M24) and 168 h (M168).

Table 5
Mean consumer's liking scores for ISP (Irish), MAN (Mediterranean), and NSP(Nordic) marinated samples and p-value of pairwise comparisons (Tukey's).

Variable	Mean ± Std. deviation			Pr > Diff		
	ISP	MAN	NSP	ISP vs MAN	MAN vs NSP	ISP vs NSP
Appearance	4.98 ± 2.1	6.40 ± 1.6	5.09 ± 2.3	**0.001**	**0.014**	0.693
Colour	5.00 ± 2.0	6.54 ± 1.6	5.40 ± 2.2	**0.001**	0.108	0.283
Aroma	5.45 ± 1.9	5.90 ± 1.8	5.66 ± 1.8	0.992	0.661	0.582
Texture	5.94 ± 2.0	5.97 ± 1.9	4.67 ± 2.3	0.57	0.125	**0.009**
Taste	5.69 ± 2.4	5.88 ± 2.2	4.55 ± 2.5	0.356	0.053	**0.001**
Overall	5.71 ± 2.3	5.84 ± 2.00	4.60 ± 2.4	0.59	0.07	**0.004**

Table 6
Impact of the JAR variables on the overall liking (Spearman correlation coefficient of ISP (Irish), MAN (Mediterranean), and NSP(Nordic) marinated samples).

Variables	Overall liking		
	NSP	MAN	ISP
Fishiness	−0.090	**−0.386**	**−0.588**
Acidity	−0.079	**−0.283**	**−0.417**
Saltiness	−0.099	−0.107	**−0.378**
Sweetness	−0.199	0.149	**0.342**
Fatty/Oily	−0.141	**−0.230**	−0.164

*Values in bold are different from 0 with a significance level α = 0.05

water absorption (72.77% of water) and pH (6.62). The hardest texture at 45.65 ± 12.25 N corresponded to the 24 h of marination with the least moisture content (53.63%) and lowest pH (3.69). Increasing hardness could be attributed to protein denaturation and the resulting decreased water absorption, following the action of acid (Kolakowski and Bednarczyk, 2002; Bras and Costa, 2010). Over time the marination process improved texture as the hardness decreased in M168 compared to M12 and M24, respectively (Tables 2 and 3).

Microbiological analysis

The results in Table 4 show the mean values of the microbial flora CFU/g of Irish sprat throughout the curing process. The total aerobic viable, psychrotrophic bacteria count, yeast and mould counts, total coliform bacteria of thawed raw material were 6.4 × 10 CFU/g, 2.7 × 10^2 CFU/g, 6.0 × 10 CFU/g, 1.3 × 10 CFU/g, respectively. During the brining stage, the growth of all the microorganisms was inhibited. Further, the action of salt combined with acid during marination reduced the microbiological activity. This was also found in Kilinc and Cakli (2004) and Bilgin Fıçıcılar et al. (2018), who reported negligible microbial growth in marinated sardines and anchovies.

Sensory analysis

The results presented in Table 5 show the mean liking scores for each sample. MAN had the highest consumers' liking for all sensory attributes. However, no significant difference ($p > 0.05$) were found between MAN and ISP for taste, texture, aroma attributes and overall liking. Compared to NSP, ISP showed no significant difference for appearance, colour and aroma.

Most respondents (79%) showed strong liking of colour for MAN (6.54 ± 1.6). The MAN sample was lighter, perhaps due to extended and stronger acid treatment typical of marinated anchovies. However, this may also have negatively impacted the taste acceptance by panellists, as 53% of participants indicated MAN as "a little bit too acidic", compared to 36% and 29% for ISP and NSP, respectively (data not presented).

The NSP samples showed no significant difference from MAN in colour liking (5.40 ± 2.2 vs 5.00 ± 2.0). NSP had a light pink colour, which may be due to the colour contribution from some of the ingredients (nutmeg, cinnamon) in the product formulation. However, the spice intensity possibly impacted negatively on taste, since 57% panellist indicated a score below 5.

ISP received the lowest mean score for appearance (4.98 ± 2.1) and colour (5.00 ± 2.0). The main reason for dislike indicated by some panellists was the colour of the fish flesh. The acidic environment had a discolouring effect on a red pigment in the samples. Reduction in red (a*) corresponded to a more detectable green undertone, which, in combination with increased yellowness, resulted in a greying of the samples.

JAR variables had low impact on the overall liking of each product ($\alpha < 0.05$). However, "too much" fishiness, acidity, saltiness, 'fatty/oily' had greater impact than "too little" on overall liking of each product. At the same time, "too little" sweetness had higher impact than "too much" for MAN and ISP samples. Spearman's correlation coefficients of ISP, MAN, and NSP taste attributes and overall liking are presented in Table 6.

With regard to the ISP product, both fishiness and acidity strongly penalised product liking when they were considered "too much" by consumers (Table 7). Mean drops in overall liking in samples deemed to

Table 7
Penalty analysis of ISP (Irish sprat) product.

Variable	Level	% consumers	Mean Overall liking	Mean drops	Penalties	p-value
	Too little	6%	5.20	1.781		
Fishiness	JAR	62%	6.98		3.345	<0.0001
	Too much	32%	3.36	3.624		
	Too little	10%	5.56	1.189		
Acidity	JAR	54%	6.75		2.245	<0.0001
	Too much	36%	4.19	2.551		
	Too little	8%	6.71	−0.537		
Saltiness	JAR	71%	6.18		1.617	0.002
	Too much	21%	3.72	2.455		
	Too little	33%	4.41	2.198		
Sweetness	JAR	56%	6.61		2.060	<0.0001
	Too much	10%	5.00	1.612		
	Too little	17%	5.27	1.054		
Fatty/Oily	JAR	61%	6.32		1.556	0.002
	Too much	22%	4.37	1.952		

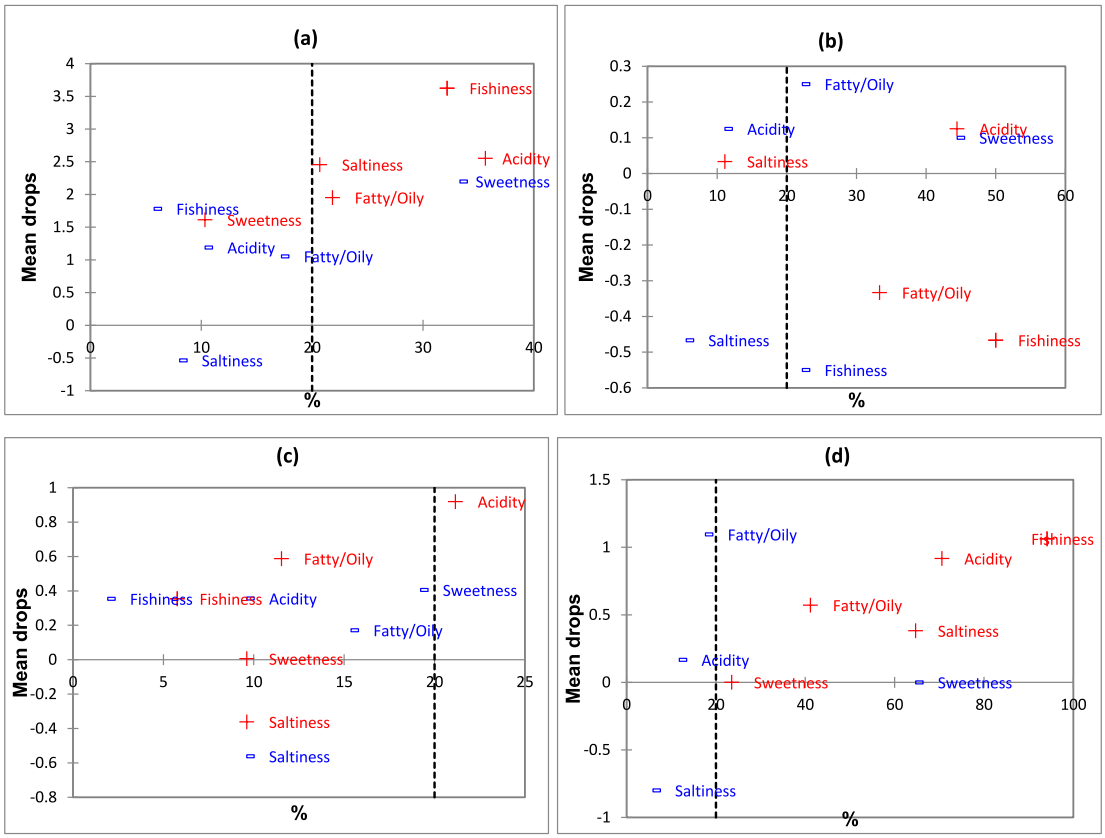

Fig. 3. Mean drop plot vs % of ISP (Irish sprat) product: (a) by all panellist, (b) by UPC (uncertain -potential customers) cluster panellists, (c) by HPC (high-potential customers) cluster panellists, (d) by LPC (low -potential customers) cluster panellists. The "too low intensity" is marked by "-", the "too hight intensity" is marked by "+". The dashed line represents the 20% of the consumers.

Table 8
Frequency of cluster differences; average age, gender, consumer liking for ISP (Irish sprat) product.

Variable\Statistic	Cluster_1	Cluster_2	Cluster_3
	UPC	HPC	LPC
% of observations	(n = 18) 21%	(n = 52) 60%	(n = 17) 19%
Age			
18–30	78	40	88
31–40	11	19	0
41–54	11	33	6
55+	0	8	6
Gender			
Female	78	60	88
Male	22	40	12
Overall liking			
Dislike	44	0	100
Like	0	100	0
Neutral	56	0	0

have "too much" of each attribute were 3.62 and 2.55 points, respectively. However, JAR scores were given by 61% and 52% of respondents, for fishiness and acidity, respectively. Sweetness caused a penalty on liking in 33% of panellist, when they considered it not sweet enough. ISP saltiness was described as JAR by 71% of panellists, which is in line with product development practice of not changing an attribute that receives 65% of JAR scores (Addinsoft, 2019).

Fig. 3a represents the mean drops plotted versus the percentage of respondents for ISP. Based on the Critical Corner (top right), product adjustments should aim towards reducing fishiness and acidity, and possibly increasing sweetness. Fishiness is strongly linked to the amount of trimethylamine (TMA) in the fish, which increases with storage time (Cardinal et al., 2004). This could be reduced by focusing on the sources being as fresh as possible prior to marination and production.

To investigate the potential customer profile and their reasons for rejecting a newly developed product an Agglomerative Hierarchical Clustering (AHC) test was applied. "Overall liking" criteria were chosen as they best represent product acceptance. AHC performed on "Overall liking" of ISP product showed three distinct groups among consumers which could be classified based on specific characteristics described in Kaimakoudi et al. (2013) research. The consumers' difference between the cluster was presented in Table 8.

The first cluster consisted of 18 (21% of total) consumers. Of this group, 78% were 18–30 years old and 22% were 31–54 years old. There were no consumers over 55 years old, and 78% of panellists were female. Analysis on hedonic responses indicated that 44% of these consumers disliked the ISP product while 56% neither liked nor disliked (4.56 ± 0.51). Based on these results, the consumers in this cluster was characterised as "uncertain potential customers" (UPC).

The second cluster of 52 consumers (60% of total) consisted of 40% 18–30 years old, 19% 31–40 years old, 33% 41–54 years old and 8% 55+ years old. Overall in this cluster 60% were female. Analysis of hedonic responses indicated 100% of product liking (7.33 ± 0.88). Thus, consumers from this cluster were considered "high-potential customers" (HPC).

The third cluster consisted of 17 consumers (19% of total). The majority were 18–30 years old (88%) and 6% were 41–54 years old and 6% 55+ years old, primarily female (88%). All panellists in this cluster disliked the ISP product (2.00 ± 0.94), and therefore were considered "low-potential customers" (LPC).

Penalty analysis was conducted to investigate the most critical taste attributes for ISP from panellists in each cluster. Fig. 3 (b, c and d) represents the mean drops plotted versus the percentage of respondents for the UPC, HPC and LPC clusters, respectively.

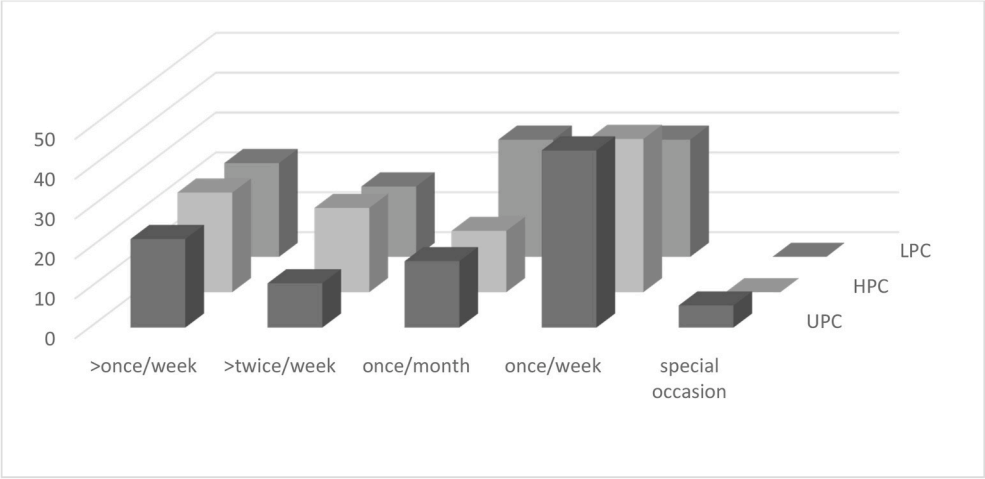

Fig. 4. Consumer responses to fish consumption frequency given in percentage for UPC (uncertain-potential customers), HPC (high-potential customers) and LPC (low-potential customers) clusters.

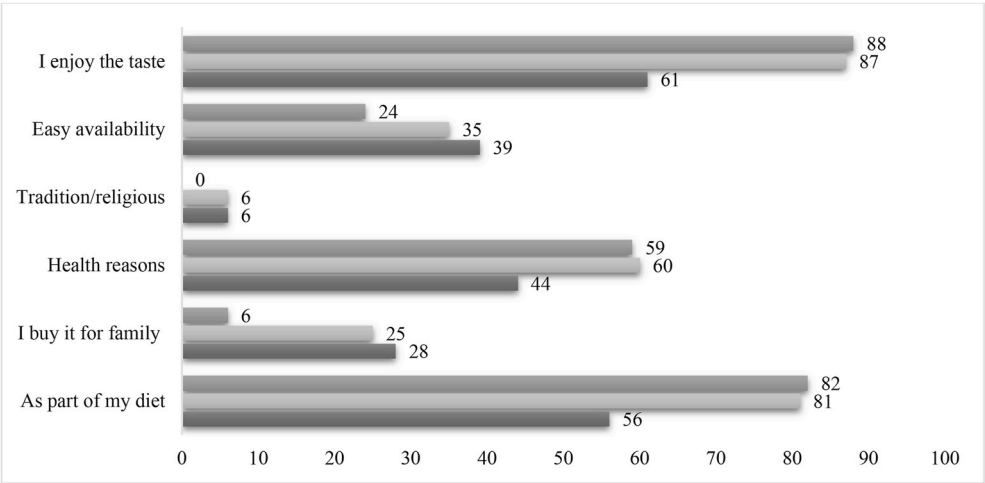

Fig. 5. Consumer responses to reason for consuming/purchasing fish product given in percentage for UPC (uncertain-potential customers), HPC (high-potential customers) and LPC (low-potential customers) clusters.

"Too much" acidity of ISP was penalised by panellists of each cluster to the degree of 21%, 44% and 71% from HPC, UPC and LPC groups, respectively. "Too little" sweetness was penalised by 44% of UPC consumers. In the LPC cluster, 94% reported "too much" fishiness, 71% too much acidity, 65% too much saltiness and 41% too fatty/oily in ISP samples, resulting in a strong penalty on liking. This result may reflect lack of familiarity with marinated fish flavour and a general preference for plainer fish products.

Consumer survey

The consumer survey showed that 38% of panellist purchased fish and fish products at least once a week, 24% more than once a week and 18% consumed fish more than twice a week or once a month. The remaining 2% consumed fish only in special occasions.

Within the UPC cluster, only 11% of panellist consumed fish more than twice a week, compared to 21% and 18% in HPC and LPC clusters, respectively. Within the LPC cluster, 29% consumed fish at least once a month (Fig. 4).

"Liking fish taste" and "normal part of the diet" were indicated as primary reasons for purchasing or consumption by more than 80% of respondents in LPC and HPC clusters and by around 60% of UPC respondents. Across the clusters, more than 50% respondents also valued the 'health and nutritional' properties fish. More than 25% of HPC and UPC respondents purchased fish for family members, significantly lower ($p < 0.05$) than in the LPC cluster (6%) (Fig. 5).

Analysis of consumer responses looked at a variety of fish products (Fig. 6). There was a significant difference ($p < 0.005$) in consumption of marinated fish products between HPC and LPC. Almost 40% of HPC respondents consumed marinated fish products, while only 17% of LPC consumers did.

More than 60% of respondents had previously tasted sardines, anchovies, and herrings. Within the age category there was a significant difference in responses. Respondents aged 18–30 years old had very limited experience of small pelagic fish, compared to other age groups. This result is also supported by the significant ($p < 0.05$) number of "None of the species have been tasted before" responses from this age category. This observation is supported by Kulikowski and Mytlewski (2016).

LCP respondents had limited experience of small pelagic fish, in marked contrast with HCP respondents. The survey showed that this type of product sits well with more experienced consumers, as 55% of respondents said they would choose this type of product in a restaurant (mainly as a starter), while preferring non-oily fish for their main course.

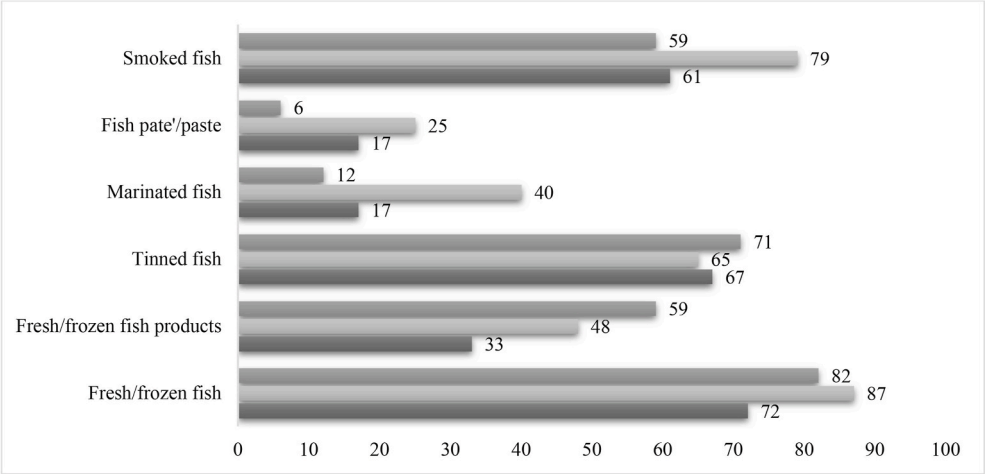

Fig. 6. Consumer responses to type of consumed/purchased fish product given in percentage for UPC (uncertain -potential customers), HPC (high-potential customers) and LPC (low-potential customers) clusters.

Cosmina et al. (2012) also reported similar attitudes of consumers towards small pelagic fish.

As reported by Kulikowski and Mytlewski (2016), the decision to purchase a newly developed product requires time, as consumers need to investigate attributes, the most important being price and fish species. However, for UPC respondents, "trusted brand" and "production method "were also important, while LPC and HPC respondents showed different views on 'use of preservatives'. LPC consumers did not rank this attribute highly.

When looking at age grouping, 31–40 year old consumers indicated "price", "Omega-3" and "country of origin" as top factors, followed by "locally produced", as highlighted by Bord Bia (2017). The current survey showed 18–30 year old respondents were more favourably disposed towards newly developed products from well-known brands, while 55+ year old respondents were more focused on 'less additives or preservatives'. These findings were in agreement with Kulikowski and Mytlewski (2016), which showed interest in less processed and more 'natural' food increased with consumer's age. Willingness to buy increased with age group, (60% of consumers in the 41–54 and 55+ group indicated they would buy the product, while 42% of 31–40 and 50% of 18–30 year old responded would not buy.

Conclusion

The present study indicates that the marinated product made from Irish sprat largely maintained the highly nutritious characteristics of the fresh fish, as the cold marination process did not substantially reduce the proportion of protein, fat, and minerals.

Some of the most important physico-chemical changes were shown to happen during the first 24 h of marination ("variable grade period"). Addition of salt and acid positively affected the physical characteristics of the product and showed strong preservative effect.

Overall, the product developed showed positive acceptance from consumers for most of the sensory characteristics, except for appearance and colour. Although the penalty analysis showed low impact of taste attributes on the overall liking, when acidity and fishiness were considered "too much" by consumers product liking was penalised. To improve product sensory characteristics, specific focus should be on raw material freshness, handling, and marinade formulation.

The results of this study could be valuable to the fish industry and contribute to increase the use of this small pelagic fish for direct human consumption in the Irish market.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

UPC (uncertain -potential customers) cluster panellists, HPC (high-potential customers) cluster panellists, LPC (low -potential customers).

Acknowledgments

This project was funded by GMIT Research and Innovation Strategic Endowment (RISE).

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