Journal of Aquatic Food Product Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/wafp20

Sensory Properties and Chemical Composition of Fish Solubles Obtained from Upcycling of Fish Filleting Side Streams

Tone Aspevik, Tor Andreas Samuelsen, Mari Øvrum Gaarder & Åge Oterhals

To cite this article: Tone Aspevik, Tor Andreas Samuelsen, Mari Øvrum Gaarder & Åge Oterhals (2023): Sensory Properties and Chemical Composition of Fish Solubles Obtained from Upcycling of Fish Filleting Side Streams, Journal of Aquatic Food Product Technology, DOI: 10.1080/10498850.2023.2217165

To link to this article: https://doi.org/10.1080/10498850.2023.2217165

JOURNAL OF AQUATIC FOOD PRODUCT TECHNOLOGY
https://doi.org/10.1080/10498850.2023.2217165

Taylor & Francis
Taylor & Francis Group

Sensory Properties and Chemical Composition of Fish Solubles Obtained from Upcycling of Fish Filleting Side Streams

Tone Aspevik[a], Tor Andreas Samuelsen[a], Mari Øvrum Gaarder[b], and Åge Oterhals[a]

[a]Department of Nutrition and Feed Technology, Nofima, Bergen, Norway; [b]Department of Consumer and Sensory Sciences, Nofima, Ås, Norway

ABSTRACT
The whitefish processing industry igenerates large amounts of food-grade side streams consisting of trimmings, head-backbone-skin (HBS), and viscera. Several factory fishing vessels have fishmeal plants to utilize the residues after onboard processing of the fish, however, at present, the protein-rich solubles is discarded. . In this study, fish solubles based on side streams from cod, saithe, haddock, and golden redfish were produced based on cooking, mechanical dewatering, centrifugation, and membrane filtration. All products had high flavor intensity, and only minor differences between fish species on sensory attributes were observed, suggesting a potential application as broth and flavor enhancer.

KEYWORDS
Whitefish side streams; upcycling; stickwater; sensory properties; fish solubles

Introduction

The global fishing industry results in large quantities of side stream products, including heads, backbones, viscera, gonads, trimmings, bones, and scales, after processing the fish into the main edible products gutted and beheaded fish or fish fillet (FAO 2022). In Norway, one of the main contributions to marine side streams comes from the whitefish sector. Of the total catch of 718.000 tons in 2021, as much as 315.200 tons were considered as residuals (Myhre et al. 2022). Only 56% of these were utilized, mainly caused by processing onboard factory fishing vessels without bringing the residual material ashore, leaving more than 140.000 tons of side stream materials discarded back to the sea. A factory trawler typically operates for 4 weeks at sea before returning to the harbor for delivery of fish products and exchange of crew. Space is a limiting factor onboard a fishing vessel, and without economic incentives, the motivation for allocation of resources to conserve and transport such side stream materials ashore is likely to be low (Hjellnes et al. 2020). Onboard processing is therefore the most feasible valorization route.

Several large Norwegian industry trawlers have installed a fishmeal processing plant to enable the manufacture of a commodity presscake fishmeal based on residual products after beheading and gutting or filleting operations. A standard fish meal process is based on thermal coagulation of the raw material ($T = 90–95°C$) followed by mechanical dewatering to obtain a press cake and press liquid. The press liquid is further separated to remove excess oil and to obtain stickwater (fish solubles). (Schmidtsdorff 1995). The obtained fish solubles typically represent 20–25% of the total dry matter and protein in a fishmeal process and have a high nutritional value, including essential amino acids, minerals, and vitamins, and bioactive properties (Bechtel 2005; Liaset and Espe 2008; Oterhals and Samuelsen 2015). However, the fish solubles are not included in the final presscake fishmeal due to limited space and lack of evaporator capacity onboard the fishing vessels, and the present practice is to

CONTACT Tone Aspevik tone.aspevik@nofima.no Department of Nutrition and Feed Technology, Nofima, Kjerreidviken 16, Bergen N-5141, Norway

pump this back to the sea. Thus, the development of new product concepts is essential to establish economic incentives for complete valorization of side stream products onboard trawlers.

A prerequisite for successful implementation of fish solubles in food applications is acceptable taste, flavor, and smell. Water-soluble molecules and metabolites present in the raw material will follow the aqueous phase and influence the overall product sensory properties. These components include protein, peptides, and free amino acids, NaCl, and other mineral salts, nucleotides, non-protein amino acids, trimethylamine (TMA), and small amounts of lipids and lipid oxidation products (Kirimura et al. 1969; Sarower et al. 2012; Steinsholm et al. 2020). Several studies have assessed the sensory properties of fish solubles; however, most relevant studies are based on protein hydrolysates, where enzymes are added to the raw material to increase the yield of water-soluble protein (Aspevik et al. 2016, 2021; Dauksas et al. 2004; Idowu and Benjakul 2019; Remme et al. 2022; Steinsholm et al. 2020). In general, the products are rich in fishy and salty tastes and flavors and are often perceived as bitter due to the presence of small hydrophobic peptides. In comparison, fish solubles manufactured based on direct thermal treatment only have been perceived as less bitter and more salty tasting, compared with corresponding protein hydrolysates (Aspevik et al. 2016). The separation of solubles in a fishmeal process is comparable to the traditional manufacture of fish broth, which is based on prolonged simmering of fish or fish residues to extract a flavor rich, savory solution (Zhang et al. 2013). Some scientific studies have assessed the sensory properties of fish broths and soups without information about generic sensory attributes (Lekjing et al. 2021; Morita et al. 2003; Zhang et al. 2013). Morita et al. (2003) evaluated the sensory properties of fish broth based on 16 different fish species and, in general, the whitefish-based product had high intensity of cooked fish flavor and sweet aroma.

Limited information is available with relevance to fish solubles based on fish species caught by factory trawlers in the North-East Atlantic. Information about both species-specific properties and side stream fractions in processing and handling of the raw material is important for future upcycling of this material. Based on a standard filleting processing line onboard a factory trawler, three main side streams can be defined: 1) trimmings, 2) head, backbones, and skin (HBS), and 3) viscera (intestines, liver, and gonads). The two former fractions are rich in muscle proteins and/or bones and are regarded as relatively stable, whereas the viscera is more prone to degradation due to the high content of endogenous enzymes (Prabhakar et al. 2020; Rustad et al. 2011).

The objective of this study was to assess the sensory properties and chemical composition of fish solubles obtained after heat treatment, mechanical pressing, and separation and purification of the liquid phase from trimmings, HBS, and viscera of different whitefish species (cod, haddock, and saithe) and golden redfish, and to evaluate their potential as food ingredients.

Materials and methods

Materials

Cod (*Gadus morhua*), saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), and golden redfish (*Sebastes norvegicus*) were captured outside Lofoten, north of Norway, at the end of March 2019 by the industry trawler Granit (Halstensen Granit AS, Bekkjarvik, Norway) and directly frozen at −30°C onboard the fishing vessel. Fishes from each species were thawed overnight at Nofima and manually beheaded, gutted, and filleted. Pooled head, backbone, and skin (HBS) were coarsely ground, mixed, and refrozen in portions of approx. 2 kg for later processing. The fillet fraction was considered complementary to the trimmings and used as model raw material in the study. Both fillet/trimmings and viscera fractions were refrozen without further processing.

Methods

Thermal processing

Frozen fish residues were thawed overnight at 4°C, and fillet/trimmings and viscera fractions were coarsely cut. The fish residuals were added to water (4:1 on weight basis) before heating to 85°C under continuous stirring and kept at this temperature for 10 min. The heat coagulated raw material was mechanically dewatered in a Hafico tincture press (Fischer Maschinenfabrik GmbH, Neuss, Germany). The press liquid was separated at 15,000 × g for 20 min in a Sorvall, LYNX 6000 centrifuge (Thermo Scientific, Waltham, MA, USA) to remove excess oil and suspended solids and further processed on a Centramate™ 500 S Tangential Flow Filtration System (Pall Corporation, Port Washington, NY, US) using a T-series Centramate™ cassette with 300 kDa molecular weight cutoff (MWCO) (Pall Corporation) to remove trace amounts of residual lipids and fine particles. All products were stored at −80°C until analysis and further use.

Chemical analysis

Nitrogen was analyzed by the Kjeldahl method (ISO 2009), and crude protein was estimated based on N × 5.3 (Steinsholm et al. 2020). Ash was determined by combustion of raw material at 550°C (ISO 2002). Dry matter was determined by drying at 103°C (ISO 1999). Peptide size distribution was measured by high performance liquid chromatography (HPLC) size-exclusion chromatography (SEC) (1260 series HPLC Agilent Technologies) using a Superdex Peptide 10/300GL column (GE Healthcare, Uppsala, Sweden), acetonitrile with trifluoroacetic acid (TFA) as eluent, and UV detection at 190–600 nm (Oterhals and Samuelsen 2015). Free amino acids were measured by HPLC using Waters Pico-Tag method and UV-detection at 254 nm (Bidlingmeyer et al. 1987). Sodium chloride (NaCl) was determined based on ion chromatography of chloride ions (Sánchez-Faure et al. 2020).

Sensory evaluation

The sensory properties of the fish solubles were assessed by a panel of 10 assessors, trained according to ISO 8586 (2012) at Nofima (Ås, Norway). A generic descriptive analysis was performed as described by Lawless and Heymann (2010) and in accordance with ISO (2016). The fish solubles were diluted in tap water at 1.0% dry matter concentration and served in plastic glasses (20 ml) with a lid at room temperature (18 ± 2°C). In a pre-test session before the main session, the assessors were calibrated on samples that were considered the most different on the selected attributes typical for the samples to be tested. All products were coded with a three-digit number in a full balanced design (ISO 2007), and red light was used in the sensory laboratory to masque differences in appearance between samples. Relevant product attributes (Table 1) were evaluated at individual speed on an unstructured 15 cm line scale with labelled end points from ‘no intensity’ (1) to ‘high intensity’ (9) and registered on a computer system for direct recording of data (EyeQuestion, Software Logic8 BV, Utrecht, Netherlands). Tap water and unsalted crackers were available for palate cleansing during the assessment.

Statistical analysis

Analysis of variance (ANOVA) of the sensory-profiling data was performed using Minitab (v19.2, Pennsylvania State University, State College, PA, USA). First, a two-way mixed factorial model was used to identify significant differences between sensory attributes of the individual products. Product was set as a fixed variable, whereas assessor and interaction effects were set as random variables (Næs and Langsrud 1998). Mixed-effects ANOVA was used to evaluate the individual-fixed effects of species and fraction on sensory attributes, still treating assessor as a random variable. Tukey’s pairwise comparison was applied where significant ($p < .05$) differences were found. The dominant structure of the sensory and chemical properties of the solubles was assessed by the use of principal component analysis (PCA) (Martens and Martens 2001) using Unscrambler v.10.4.1 (Camo, Oslo, Norway). Prior

Table 1. Attributes and description of the sensory attributes evaluated by the sensory panel. Descriptions are based on the Norwegian standard NS-ISO 5492.

Attribute	Description
Smells	
Total intensity of smell	The intensity of all different smell present in the sample
Sourness smell	Organoleptic attribute of pure substances or mixtures which produces the sour sensation
Trimethylamine smell	The smell of TMA, ammonia, and a sharp sensation
Pungent smell	Describes a product causing a sharp sensation of the nasal mucous membrane
Sour/Fermented smell	A fermented and unpleasant sour smell related to a complex sensation generally due to the presence of organic acids.
Fish smell	The smell of white fish (i.e. cod, pollock, haddock, redfish)
Process smell	The smell related to a burned, mechanical and exhaust like smell
Rancid smell	The intensity of all rancid smells (i.e. grass, hay, stearin, paint)
Tastes and flavor	
Total flavor intensity	The intensity of all different flavors presents in the sample
Sour flavor	Organoleptic attribute of pure substances or mixtures which produces the sour sensation
Sweet taste	Describes the basic taste produced by diluted aqueous solutions of various substances such as sucrose
Salty taste	Describes the basic taste produced by diluted aqueous solutions of various substances such as sodium chloride
Acid taste	Describes the basic taste produced by diluted aqueous solutions of most acid substances (i.e citric acid)
Bitter taste	Describes the basic taste produced by diluted aqueous solutions of various substances such as quinine and caffeine
Umami taste	Describes the basic taste of umami
Trimethylamine flavor	The taste of TMA, ammonia and a sharp sensation
Pungent flavor	Describes a product causing a sharp sensation of the buccal mucous membrane
Sour/fermented flavor	A fermented and unpleasant sour flavor related to a complex sensation generally due to the presence of organic acids.
Fish flavor	The flavor of white fish (i.e. cod, pollock, haddock, redfish)
Process flavor	The flavor related to a burned, mechanical and exhaust like smell
Rancid flavor	The intensity of all rancid flavors (i.e. grass, hay, stearin, paint)
Fullness	Mechanical texture property related to the flow resistance, a rich sensation of the sample in the mouth
Astringent	A complex feeling, followed by contractions, dryness sensation, puckering of the skin or mucous membranes in the mouth
Aftertaste	Aftertaste after ½ minute without rinsing the mouth

to analysis, each variable was mean centered and standardized by subtracting the mean and dividing each entry by the standard deviation of the variables.

Results and discussion

Chemical composition of the fish solubles

The fish species included in this study represents some of the most important commercial fish species caught by Norwegian industry trawlers in the Northeast Atlantic. Combined, these species represent almost 300,000 tons of side stream materials annually, with potential for improved valorization. The obtained soluble fractions after cooking and mechanical dewatering of the respective fish fractions, followed by centrifugation and membrane filtration of the collected aqueous phase, were essentially fat-free and contained 49–69% protein and 12–38% ash (Table 2). Protein was estimated based on a nitrogen-to-protein factor of 5.3, representative for cod fillet (Steinsholm et al. 2020) and may be inaccurate for the samples included in this study. Interestingly, the NaCl content was notably higher in all HBS products compared to the trimmings and viscera, contributing to 60–74% of the ash content. This may be partly attributed to uptake of salt by gills and skin exposed to saltwater (Evans et al. 2005) and displacement of the protein-to-salt ratio after membrane filtration due to retention of high molecular weight peptides (Aksnes et al. 2006; Steinsholm et al. 2021). The molecular weight distribution of the products (Table 2) demonstrates that the viscera-based products contained

Table 2. Chemical composition (g/kg dry matter), NaCl relative to ash (%), peptide size distribution (% of peptides) of fish solubles based on trimmings (Trim), heads, backbones, skin (HBS) and viscera from cod, haddock, saithe, and golden redfish.

	Cod			Haddock			Saithe			Redfish		
	Trim	HBS	Viscera	Trim	HBS	Viscera	Trim	HBS	Viscera	Trim	HBS	Viscera
Protein (N × 5.3)[a]	685	489	574	624	489	594	566	525	642	674	541	563
Ash	308	294	207	333	294	167	320	316	123	381	250	176
NaCl	54	194	107	75	200	71	52	189	54	43	185	97
NaCl/Ash	18%	68%	52%	23%	68%	43%	16%	60%	44%	11%	74%	55%
Peptide distribution												
>20 kDa	9.6	10.1	2.6	4.4	8.7	0.6	1.1	10.5	0.3	0.4	15.9	0.4
20–15 kDa	1.6	2.4	1.0	1.2	1.9	0.5	0.5	3.3	0.3	0.2	4.5	0.4
15–10 kDa	1.8	3.1	2.3	2.1	2.2	2.0	0.7	4.1	0.8	0.3	5.8	1.2
10–8 kDa	0.8	1.6	2.0	1.6	1.1	2.2	0.4	2.0	0.8	0.2	3.7	1.0
8–6 kDa	0.8	1.7	3.8	2.4	1.3	3.9	0.5	2.1	1.8	0.3	4.1	1.8
6–4 kDa	0.7	1.7	6.8	3.1	1.4	7.2	0.6	2.3	4.8	0.4	4.1	3.5
4–2 kDa	0.6	2.1	10.7	4.3	1.7	14.4	0.7	2.5	12.0	0.6	4.3	7.3
2–1 kDa	0.3	1.2	7.4	2.9	0.8	12.1	0.4	1.3	13.4	0.4	2.3	6.6
1–0.5 kDa	0.4	1.0	4.9	2.5	0.8	8.6	0.6	0.9	10.9	0.4	1.5	5.7
0.5–0.2 kDa	17.6	3.0	5.4	16.4	5.6	7.0	19.2	3.1	9.0	4.1	2.7	9.1
<0.2 kDa	65.7	72.2	53.2	58.9	74.5	41.5	75.2	67.9	45.9	92.7	51.1	63.0

[a] Based on Steinsholm et al. (2020).

a lower percentage of large molecules (>20 kDa) and a more balanced peptide distribution compared with the trimmings- and HBS-derived solubles. The latter two were mostly composed of large peptides (>20 kDa) and small molecules (<0.2 kDa). However, the levels of peptides >20 kDa were significantly less than numbers reported by others (Kousoulaki et al. 2012; Oterhals and Samuelsen 2015) and may be a consequence of the applied filtration step with the removal of high molecular weight fractions in addition to fat and particles by the applied filtration step (Steinsholm et al. 2021). The aim of the filtration step was to remove remnant fat and suspended particles with possible negative impact on flavor and to obtain a completely water-soluble product. However, this step inevitably will also give some product loss in the form of high molecular weight water-soluble protein.

The molecular fraction <0.2 kDa, which includes all free amino acids given in Table 3, except tryptophan (204 Da), comprised a large proportion of the samples. All viscera-based solubles were richer in free amino acids, compared with products based on HBS and trimmings, possibly explained by endogenous enzyme activity in the digestive tracts, adding to a release of free protein amino acids. The visceral products were especially rich in free glutamine (36–72 g/kg DM), followed by leucine (14–28 g/kg DM) and lysine (17–25 g/kg DM). For both trimmings and HBS products, the dominant-free amino acids were glutamic acid (5–16 g/kg DM), glycine (6–12 g/kg DM), and alanine (5–12 g/kg DM). The distribution of free non-protein amino acids was comparable between species and fraction, except for anserine, where especially solubles based on cod, haddock, and saithe trimmings were rich in this amino acid. All products were rich in taurine (30–100 g/kg DM), an important amino acid for human physiology (Wu 2020).

Sensory properties of the fish solubles

Generic descriptive analysis was performed to compare the effect of different whitefish species and fractions of the fish on taste, flavor, and smell attributes of the products. The average sensory intensities for the fish solubles are listed in Tables 4 and 5 for smell and taste/flavor, respectively. All tested attributes varied significantly between products, except for sweet taste and aftertaste. Although acid taste was significant, based on the ANOVA model, the Tukey Post Hoc test did not provide differences between the products. Regardless, the average intensity scores for this attribute were low and regarded as not relevant for the overall organoleptic properties of the products. On average, the total intensity of smell (Table 4) was high and >5 for all products, except cod trimmings (4.5) and was a consequence of the high volatiles content found in fish products (Wang et al. 2022).

Table 3. Levels of free amino acids and dipeptides (g/kg dry matter) in fish solubles based on trimmings (Trim), heads, backbones, skin (HBS), and viscera from cod, haddock, saithe, and golden redfish.

	Cod			Haddock			Saithe			Redfish		
	Trim	HBS	Viscera	Trim	HBS	Viscera	Trim	HBS	Viscera	Trim	HBS	Viscera
Protein-AA												
Aspartic acid	<1	<1	10	<1	<1	12	<1	5	18	<1	5	12
Glutamic acid	15	12	24	8	12	17	16	16	19	5	5	12
Hydroksyproline	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Serine	4	6	10	4	6	12	4	5	16	5	5	12
Asparagine	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	3
Glycine	8	6	7	8	6	10	12	11	12	10	10	9
Glutamine	8	12	72	8	12	36	8	11	51	<1	10	38
Histidine	<1	<1	<1	<1	<1	5	<1	<1	4	<1	<1	6
Threonine	4	06	7	4	6	12	4	5	14	<1	5	9
Alanine	12	12	14	8	12	17	12	11	21	5	10	18
Arginine	<1	<1	14	<1	6	21	<1	<1	21	<1	5	15
Proline	4	<1	7	<1	<1	7	04	5	9	5	5	9
Tyrosine	<1	<1	7	<1	<1	10	<1	<1	12	<1	<1	9
Valine	<1	<1	7	4	6	12	4	5	14	<1	5	12
Methionine	<1	<1	7	4	<1	10	<1	<1	12	<1	<1	9
Cysteine	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Isoleucine	<1	<1	7	<1	<1	10	<1	<1	12	<1	<1	12
Leucine	<1	6	14	4	6	24	4	5	28	<1	5	21
Phenylalanine	<1	<1	7	<1	<1	10	<1	<1	14	<1	<1	9
Tryptophan	<1	<1	<1	<1	<1	2	<1	<1	4	<1	<1	3
Lysine	4	6	17	4	6	19	4	5	25	14	5	21
Sum free protein-AA	**58**	**65**	**231**	**58**	**76**	**245**	**72**	**84**	**305**	**43**	**75**	**235**
Non-protein AA												
Creatinine*	8	<1	<1	8	<1	<1	4	<1	<1	10	<1	<1
β-alanine	8	6	3	4	6	<1	12	16	2	<1	<1	<1
Taurine	62	71	86	33	71	52	52	74	40	100	85	68
4-aminobutanoic acid	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Citrulline	<1	<1	<1	<1	<1	2	<1	<1	2	<1	<1	<1
Carnosine*	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	3
L-Ornithine	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	3
Anserine*	69	<1	<1	92	6	2	56	<1	<1	<1	<1	3
Sum non-protein AA	**146**	**76**	**90**	**138**	**82**	**57**	**124**	**89**	**46**	**110**	**85**	**77**

*dipeptides.

Table 4. Mean sensory intensity values of smells in fish solubles based on trimmings, heads, backbones, skin (HBS) and viscera from cod, haddock, saithe, and redfish. Different letters indicate statistical difference ($p < .05$) within each attribute based two-way mixed factorial model and Tukey's post hoc test.

		Total smell	Sourness	TMA	Pungent	Fermented	Fish	Process	Rancid
Cod	Trimmings	4.5^{e}	1.9^{ab}	2.6^{d}	3.6^{de}	2.2^{c}	2.6^{d}	1.4^{b}	1.1^{c}
	HBS	6.5^{abc}	1.1^{c}	5.3^{a}	6.2^{abc}	4.2^{ab}	5.1^{ab}	2.2^{ab}	2.7^{bc}
	Viscera	6.8^{ab}	1.1^{c}	4.9^{ab}	6.7^{a}	5.1^{a}	4.1^{abcd}	2.0^{ab}	3.0^{bc}
Haddock	Trimmings	5.1^{de}	2.0^{a}	2.9^{cd}	3.3^{e}	2.2^{c}	2.9^{d}	1.5^{b}	1.2^{c}
	HBS	6.0^{abcd}	1.3^{bc}	4.6^{ab}	5.4^{abcd}	3.6^{abc}	3.9^{abcd}	1.9^{ab}	1.6^{bc}
	Viscera	6.6^{abc}	1.2^{c}	4.5^{abc}	5.9^{abc}	3.5^{abc}	3.9^{abcd}	2.5^{ab}	3.5^{b}
Saithe	Trimmings	5.4^{cde}	1.4^{abc}	3.4^{bcd}	4.4^{cde}	2.8^{bc}	3.1^{cd}	2.1^{ab}	1.3^{c}
	HBS	5.6^{bcde}	1.3^{bc}	3.9^{abcd}	5.2^{abcde}	3.6^{abc}	3.4^{bcd}	1.8^{ab}	1.5^{c}
	Viscera	6.1^{abcd}	1.1^{c}	4.2^{abcd}	5.1^{abcde}	2.6^{bc}	4.1^{abcd}	2.8^{ab}	2.9^{bc}
Redfish	Trimmings	6.9^{a}	1.0^{c}	4.2^{abcd}	6.7^{ab}	3.1^{bc}	5.4^{a}	3.1^{a}	5.9^{a}
	HBS	6.1^{abcd}	1.4^{abc}	4.6^{ab}	5.5^{abc}	2.8^{bc}	4.7^{abc}	1.8^{ab}	2.3^{bc}
	Viscera	5.7^{abcde}	1.3^{bc}	4.2^{abcd}	4.8^{bcde}	3.2^{bc}	4.0^{abcd}	2.0^{ab}	1.9^{bc}
p-value		<.001	<.001	<.001	<.001	<.001	<.001	0.017	<.001

Further, the total intensity of flavor scores (Table 5) varied between 5.1 and 6.9, implying a strong organoleptic sensation of all tested products.

Of the tested attributes, total smell and flavor intensities, pungent smell and flavor, and aftertaste had high scores, whereas the intensity scores for sourness, sour taste, process smell, and flavor and

Table 5. Mean sensory intensity values of taste and flavor in fish solubles based on trimmings, heads, backbones, skin (HBS) and viscera from cod, haddock, saithe, and redfish. Different letters indicate statistical difference ($p < 0.05$) within each attribute based two-way mixed factorial model and Tukey's post hoc test.

		Total flavor intensity	Sour	Sweet	Salty	Acid	Bitter	Umami	TMA	Pungent	Sour/ Fermented	Fish	Process	Rancid	Fullness	Astringent	Aftertaste
Cod	Trimmings	5.1^{c}	1.8^{abc}	3.1	3.7^{bc}	2.5	3.3^{c}	4.5^{ab}	3.1^{b}	4.1^{bc}	1.6^{c}	3.2^{b}	1.3	1.2^{c}	4.2^{a}	3.4^{bc}	5.2
	HBS	6.3^{ab}	1.2^{bc}	2.9	4.4^{ab}	2.5	4.0^{bc}	3.3^{c}	5.1^{a}	6.0^{ab}	3.4^{ab}	4.8^{ab}	1.8	2.5^{bc}	4.0^{ab}	3.5^{abc}	6.0
	Viscera	6.9^{a}	1.0^{c}	3.0	3.4^{c}	2.7	5.6^{a}	3.6^{bc}	5.2^{a}	6.4^{a}	4.2^{a}	4.8^{ab}	2.5	2.7^{bc}	3.8^{ab}	4.2^{ab}	5.9
Haddock	Trimmings	5.6^{bc}	2.1^{a}	2.9	3.7^{bc}	2.8	3.7^{c}	4.6^{a}	3.3^{b}	3.5^{c}	2.0^{bc}	3.9^{ab}	1.4	1.2^{c}	4.1^{ab}	3.5^{abc}	5.2
	HBS	6.2^{abc}	1.2^{bc}	2.8	4.7^{a}	2.6	3.8^{bc}	3.7^{abc}	4.2^{ab}	5.5^{ab}	2.8^{abc}	3.7^{b}	2.2	1.6^{bc}	4.1^{ab}	3.1^{c}	5.4
	Viscera	6.2^{abc}	1.3^{bc}	2.8	3.4^{c}	2.6	4.4^{abc}	4.1^{abc}	4.7^{ab}	5.3^{abc}	2.9^{abc}	4.8^{ab}	1.9	2.8^{bc}	3.7^{ab}	3.8^{abc}	5.7
Saithe	Trimmings	5.5^{bc}	1.5^{abc}	2.8	3.3^{c}	2.4	3.4^{c}	4.0^{abc}	3.3^{b}	4.3^{bc}	2.1^{bc}	3.3^{b}	1.7	1.5^{bc}	3.7^{ab}	3.4^{bc}	5.3
	HBS	6.0^{abc}	1.2^{bc}	2.7	3.9^{abc}	2.4	3.6^{c}	3.4^{c}	4.5^{ab}	5.7^{ab}	3.1^{abc}	3.9^{ab}	1.6	1.6^{bc}	3.7^{ab}	3.4^{bc}	5.4
	Viscera	6.2^{abc}	1.4^{bc}	2.7	3.2^{c}	2.8	5.1^{ab}	3.5^{bc}	4.3^{ab}	4.8^{abc}	2.1^{bc}	4.3^{ab}	2.1	2.1^{bc}	3.4^{b}	4.4^{a}	5.6
Redfish	Trimmings	6.6^{ab}	1.1^{c}	2.8	3.6^{bc}	2.8	3.9^{bc}	3.8^{abc}	4.6^{ab}	6.4^{a}	2.6^{abc}	5.5^{a}	2.5	4.9^{a}	3.8^{ab}	3.9^{abc}	5.8
	HBS	5.7^{bc}	1.4^{bc}	2.9	4.1^{abc}	2.3	3.6^{c}	3.9^{abc}	4.2^{ab}	4.9^{abc}	2.3^{bc}	4.3^{ab}	1.4	2.2^{bc}	3.8^{ab}	3.4^{abc}	5.4
	Viscera	6.0^{abc}	1.4^{bc}	2.7	3.4^{c}	2.8	4.7^{abc}	3.6^{bc}	4.2^{ab}	4.6^{abc}	2.3^{bc}	4.2^{ab}	1.6	1.5^{bc}	3.6^{ab}	3.9^{abc}	5.3
p-value		<.001	<.001	.8	<.001	.004	<.001	<.001	<.001	<.001	<.001	<.001	.03	<.001	.02	.001	.2

rancid flavors were low (Tables 4 and 5). Except for redfish trimmings, all products had low scores for rancid smell (<3.5) and flavor (<2.8), which implies little or negligible oxidation of the raw material and/or processing steps. Whereas cod, haddock, and saithe are considered as lean fish with low levels of fat in the trimmings fraction, the redfish is a considerably fattier fish species (Institute of Marine Research Seafood Database 2022). The higher level of rancid flavor of the redfish trimmings solubles indicates lipid oxidation during storage and/or processing of the raw material (Karlsdottir et al. 2014)

To assess the individual effects of fish species and side stream fraction on the sensory attributes, a mixed model ANOVA was performed (Figures 1 and 2). Only small differences between fish species on sensory attributes were found; however, products based on redfish were perceived as significantly more fish and rancid tasting (Figures 1a and 2a), explained by the high levels of rancid flavor in the redfish trimmings (Table 5). The viscera fractions include liver with high fat level, which may explain the significantly higher rancid smell of this fraction compared to HBS (Figure 1b). However, no

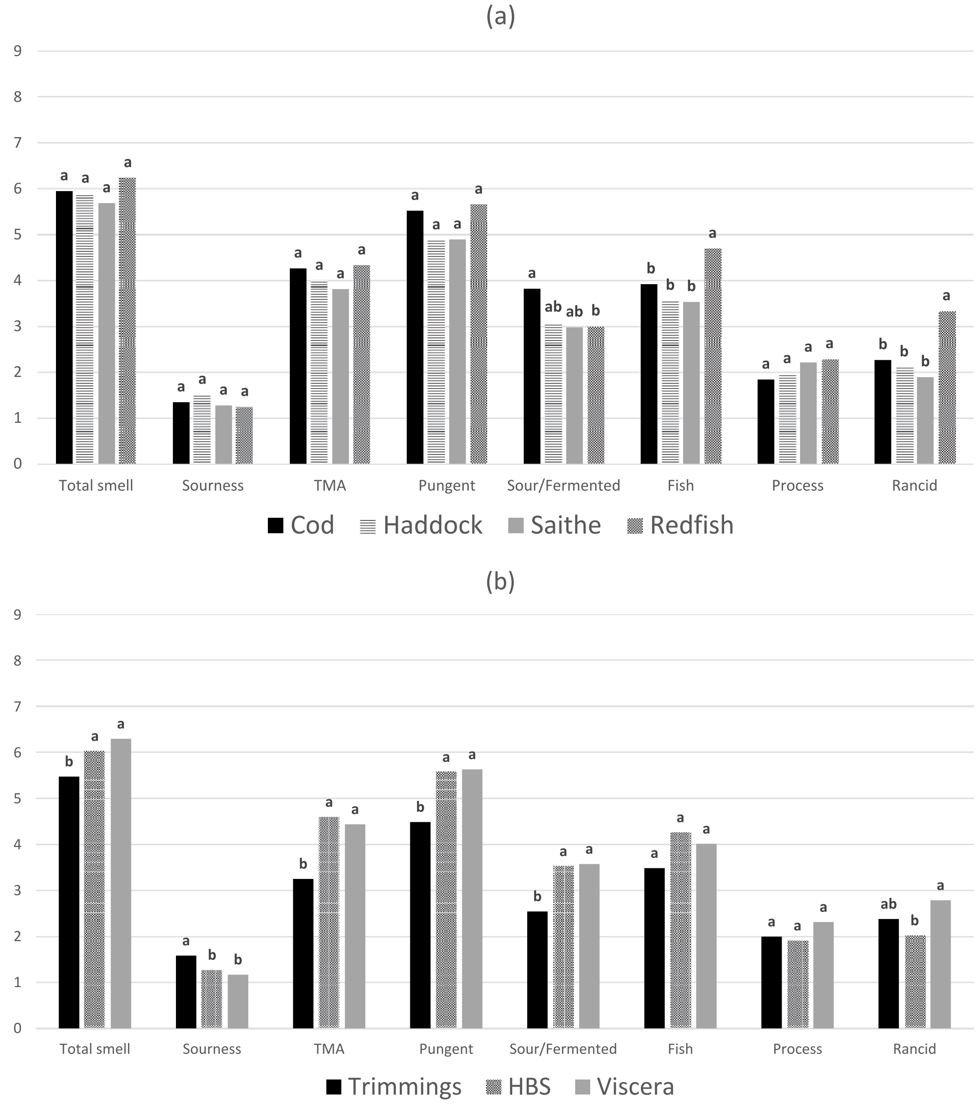

Figure 1. Mean intensity of smell sensory attributes for cod, haddock, saithe, and golden redfish (a) and trimmings, head-backbone-skin (HBS) and viscera (b). Different letters for each parameter within each attribute indicate significant differences ($p < 0.05$) based on ANOVA and Tukey's post hoc test.

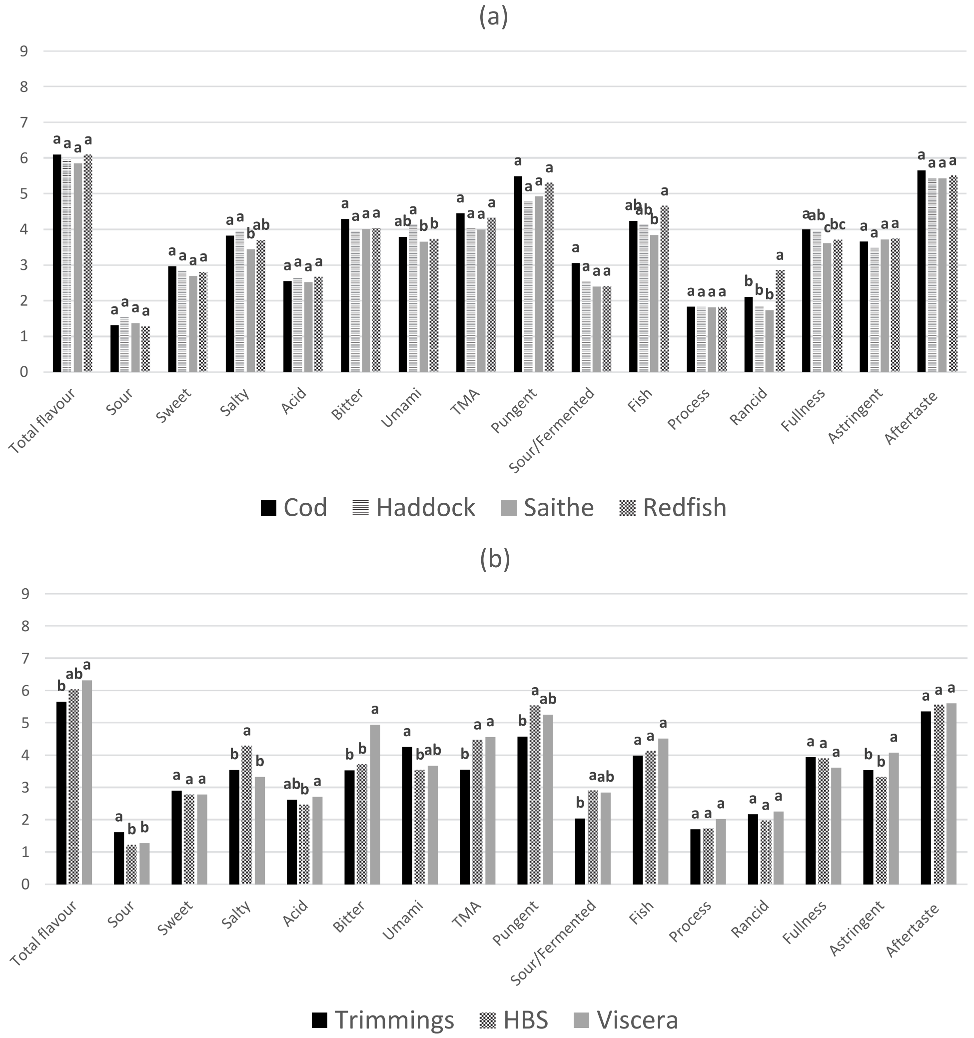

Figure 2. Mean intensity of taste and flavour sensory attributes for cod, haddock, saithe, and golden redfish (a) and trimmings, head-backbone-skin (HBS) and viscera (b). Different letters for each parameter within each attribute indicate significant differences ($p < 0.05$) based on ANOVA and Tukey's post hoc test.

significant difference was observed for rancid flavor (Figure 2b). In general, products based on HBS and viscera had higher sensory intensity scores than products based on trimmings, except for sourness smell and umami taste, where the trimmings solubles had the highest average scores (Figures 1b and 2b). Umami is defined as the fifth basic taste and is generally related to high content of glutamate (Kurihara 2015). All products had relatively high content of free glutamic acid (Table 3) with only small differences between species and fraction, not explaining this observation. However, umami taste has also been related to other components, including valine, alanine, anserine, and tyrosine (Kurihara 2015; Steinsholm et al. 2020), and particularly the trimmings solubles were rich in anserine (Table 3). TMA, caused by bacterial degradation of trimethylamine oxide (TMAO), is an important quality indicator of fish and has a distinctive stale and unpleasant 'fishy' smell and flavor (Wu and Bechtel 2008). The trimmings products had the lowest intensity values of this attribute (Tables 4 and 5; Figures 1b and 2b), compared with HBS and viscera solubles. No significant difference was observed as a function of species (Figures 1b and 2b), and the highest overall level was found in the cod HBS product.

Products based on viscera were perceived as more bitter compared with the trimmings- and HBS-solubles, within each species (Table 5; Figure 2b). High intensity of bitter taste in the viscera-based fish solubles has also been found in previous research (Aspevik et al. 2021) and may be explained by high endogenous proteolytic activity of the digestive tract causing a release of small bitter-peptides (Idowu and Benjakul 2019). Further, the viscera contained bile that may add to the bitter taste sensation (Dauksas et al. 2004). The HBS-products were significantly saltier compared with trimmings- and viscera-solubles, ascribed to the high content of NaCl in these products (Table 2).

Association between sensory and chemical properties

One of the most important challenges for successful utilization of fish-based solubles for food applications is the development of processes giving acceptable sensory properties. Principal component analysis (PCA; Figure 3) was used to evaluate the association between free amino acid composition, peptide molecular weight distribution, and sensory properties. Based on the score plots, products

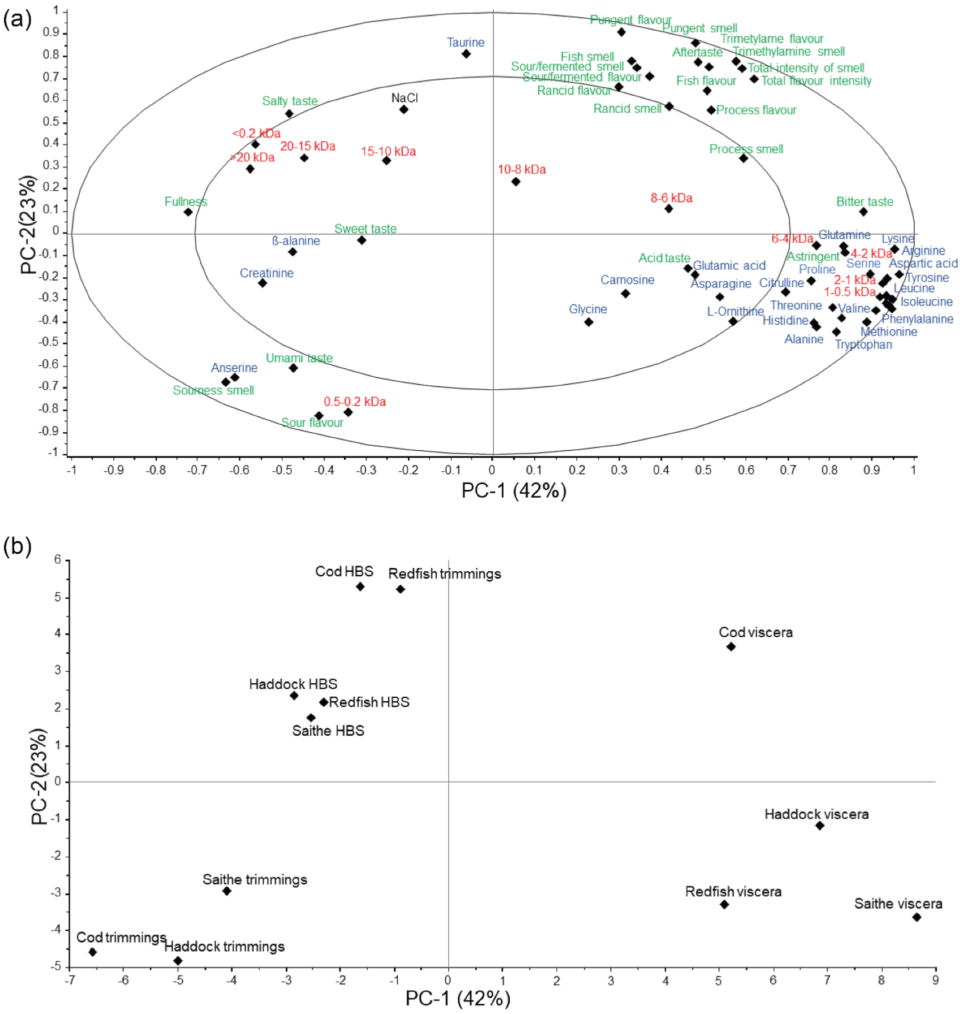

Figure 3. (a) Principal component analysis loading plot based on NaCl (black; Table 2), peptide molecular weight distribution (red; Table 2) distribution of free amino acids (blue; Table 3) and sensory attributes (green; Tables 4 and 5). The two ellipses represent 50% and 100% of explained variance. (b) Principal component analysis score plot showing similarities and differences between the fish solubles based on cod, haddock, saithe and redfish trimmings, head-backbone-skin (HBS), and viscera.

with similar or different properties could be identified. Two principal components (PCs) were found to be relevant for the interpretation of results. The first and second PCs explained 42% and 23%, respectively. The third and fourth PCs explained 12% and 6%, respectively (not shown).

The loading plot (Figure 3a) shows the association between tastes and flavors with the distribution of free amino acids, peptide molecular weight, and NaCl. Most of the free amino acids were found on the right side of the plot, positively associated with bitter taste and peptides of 0.5–4 kDa. These attributes were negatively correlated with NaCl and salty taste and peptides >10 kDa. Umami taste and sourness smell and flavor were positively correlated with anserine and peptides 0.2–0.5 kDa and negatively correlated with aftertaste, total, pungent, trimethylamine, fish, sour/fermented, rancid, process tastes, and flavors.

The PC score plot (Figure 3b) shows the similarity and difference among the products. Three distinct groupings can be observed, representing HBS, trimmings, and viscera. However, redfish trimmings deviate from the remaining and were mostly associated with cod HBS. This may partly be ascribed to the high level of taurine found in this product (Table 2). Not surprisingly, the products based on viscera were found on the right side of the PCA plot, associated with high intensity of most of the assessed attributes (Figure 3a).

Altogether, the relatively high flavor intensities of the fish solubles indicate a potential as flavor enhancers and protein-rich broths, being rich in savory fishy, umami, and salty tastes and flavors. Thermally processed ready-to-eat meat extract soup or essence soup is currently very popular worldwide, especially in Southeast Asia (Lekjing et al. 2021). At present, ready-to-eat commercial essence soups in the market are mostly made based on chicken and/or vegetables; however, increasing recognition of health benefits of marine products may pave the way for whitefish solubles within this market. Still, more work should be done to optimize the filtration process in order to increase the yield and retain larger peptides and solubilized proteins in the product. Assessments of the suitability of solubles as food ingredients should be performed in future studies.

Conclusion

The whitefish fisheries discard significant amounts of food-grade side streams and/or protein-rich solubles with the potential for upcycling for human consumption and value creation. Fish solubles based on cod, haddock, saithe, and golden redfish trimmings, HBS, and viscera all had high flavor intensities and were rich in savory tastes and flavors. The variance between fish species was small. The viscera-based solubles were perceived as more flavor intense and bitter, compared with HBS and trimmings, but were also the richest in free amino acids. Solubles obtained from golden redfish had a higher rancid score and might be a less suited raw material. The high flavor intensities of the solubles indicate potential use as broth and/or flavor enhancer, which could potentially pave the way for increased utilization and value creation for solubles manufactured from whitefish residuals. In a commercial perspective, the minor differences observed in this study between solubles based on HBS and trimmings fractions from whitefish species will be of advantage and make it possible to base a commercial product on mixed raw materials.

Acknowledgments

We want to thank the skillful and accurate laboratory personnel at Nofima BioLab, the technical staff in the sensory panel at Nofima, and Oscar Martínez-Alvarez for delivery of NaCl analyses in the solubles. Halstensen Granit AS is thanked for the kind contribution of fish caught and frozen onboard the industrial trawler Granit.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by funding from the Research Council of Norway under Grant numbers [280498 and 245883].

ORCID

Tone Aspevik http://orcid.org/0000-0002-8921-347X

References

Aksnes A, Hope B, Jönsson E, Björnsson BT, Albrektsen S. Size-fractionated fish hydrolysate as feed ingredient for rainbow trout (Oncorhynchus mykiss) fed high plant protein diets. I: Growth, growth regulation and feed utilization. Aquaculture. 261:305–17.

Aspevik T, Thoresen L, Steinsholm S, Carlehög M, Kousoulaki K. 2021. Sensory and chemical properties of protein hydrolysates based on Mackerel (*Scomber scombrus*) and Salmon (*Salmo salar*) side stream materials. J Aquat Food Prod T. 30(2):176–87.

Aspevik T, Totland C, Lea P, Oterhals Å. 2016. Sensory and surface-active properties of protein hydrolysates based on Atlantic salmon (*Salmo salar*) by-products. Process Biochem. 51(8):1006–14.

Bechtel PJ. 2005. Properties of stickwater from fish processing byproducts. J Aquat Food Prod T. 14(2):25–38.

Bidlingmeyer BA, Cohen SA, Tarvin TL, Frost B. 1987. A new, rapid, high-sensitivity analysis of amino acids in food type samples. J Assoc Off Anal Chem. 70(2):241–47.

Dauksas E, Slizyte R, Rustad T, Storro I. 2004. Bitterness in fish protein hydrolysates and methods for removal. J Aquat Food Prod T. 13(2):101–14.

Evans DH, Piermarini PM, Choe KP. 2005. The multifunctional fish gill: dominant site of gas exchange, osmoregulation, acid-base regulation, and excretion of nitrogenous waste. Physiol Rev. 85(1):97–177.

FAO. 2022. The state of world fisheries and aquaculture 2022. Towards blue transformation. Rome. doi:10.4060/cc0461en.

Hjellnes V, Rustad T, Falch E. 2020. The value chain of the white fish industry in Norway: history, current status and possibilities for improvement – a review. Reg Stud Mar Sci. 36:101293.

Idowu AT, Benjakul S. 2019. Bitterness of fish protein hydrolysate and its debittering prospects. J Food Biochem. 43(9): e12978.

Institute of Marine Research Seafood Database. 2022. [accessed 2022 Dec 22]. https://sjomatdata.hi.no/.

ISO 13299. 2016. Sensory analysis - methodology - general guidance for establishing a sensory profile. Geneva (Switzerland): International Organization for Standardization.

ISO 5983-2. 2009. Animal feeding stuffs - determination of nitrogen content and calculation of crude protein content. Part 2: block digestion and steam distillation method. Geneva (Switzerland): International Organization for Standardization.

ISO 5984-2. 2002. Animal feeding stuffs - determination of crude ash. Geneva (Switzerland): International Organization for Standardization.

ISO 6496-2. 1999. Animal feeding stuffs - determination of moisture and other volatile matter content. Geneva (Switzerland): International Organization for Standardization.

ISO 8586. 2012. Sensory analysis - general guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors. Geneva (Switzerland): International Organization for Standardization.

ISO 8589. 2007. Sensory analysis - general guidance for the design of test rooms. Geneva (Switzerland): International Organization for Standardization.

Karlsdottir MG, Sveinsdottir K, Kristinsson HG, Villot D, Craft BD, Arason S. 2014. Effects of temperature during frozen storage on lipid deterioration of saithe (*Pollachius virens*) and hoki (*Macruronus novaezelandiae*) muscles. Food Chem. 156:234–42.

Kirimura J, Shimizu A, Kimizuka A, Ninomiya T, Katsuya N. 1969. Contribution of peptides and amino acids to the taste of foods. J Arg Food. 17:689–95.

Kousoulaki K, Olsen HJ, Albrektsen S, Langmyhr E, Mjøs SA, Campbell P, Aksnes A. 2012. High growth rates in Atlantic salmon (*Salmo salar* L.) fed 7.5% fish meal in the diet. Micro-, ultra- and nano-filtration of stickwater and effects of different fractions and compounds on pellet quality and fish performance. Aquaculture. 338–341:134–46.

Kurihara K. 2015. Umami the fifth basic taste: history of studies on receptor mechanisms and role as a food flavor. Biomed Res Int. 2015:1–10.

Lawless HT, Heymann H. 2010. Sensory evaluation of food. 2nd ed. New York (NY): Springer. p. 596.

Lekjing S, Venkatachalam K, Wangbenmad C. 2021. Biochemical evaluation of novel seabass (*Lates calcarifer*) fish essence soup prepared by prolonged boiling process. Arab J Chem. 14(10):103365.

Liaset B, Espe M. 2008. Nutritional composition of soluble and insoluble fractions obtained by enzymatic hydrolysis of fish-raw materials. Process Biochem. 43(1):42–48.

Martens H, Martens M. 2001. Multivariate analysis of quality. An introduction. 2nd ed. West Sussex: John Wiley & Sons., Ltd. p. 466.

Morita K, Kubota K, Aishima T. 2003. Comparison of aroma characteristics of 16 fish species by sensory evaluation and gas chromatographic analysis. J Sci Food Agric. 83:289–97.

Myhre M, Richardsen R, Nystøyl R, Strandheim G. 2022. Analyse marint restråstoff 2021. SINTEF 2022:00501. Trondheim (Norway).

Næs T, Langsrud O. 1998. Fixed or random assessors in sensory profiling? Food Qual Prefer. 9(3):145–52.

Oterhals Å, Samuelsen TA. 2015. Plasticization effect of solubles in fishmeal. Food Res Int. 69(0):313–21.

Prabhakar PK, Vatsa S, Srivastav PP, Pathak SS. 2020. A comprehensive review on freshness of fish and assessment: analytical methods and recent innovations. Food Res Int. 133:109157.

Remme JF, Tveit GM, Bondø M, Slizyte R, Ólafsdóttir A, Jónsdóttir R, Geirsdóttir M, Carvajal AK. 2022. Valorisation of frozen cod (*Gadus morhua*) heads, captured by trawl and longline by the oceanic fleet, by enzymatic hydrolysis. J Aquat Food Prod T. 31(5):483–95.

Rustad T, Storrø I, Slizyte R. 2011. Possibilities for the utilisation of marine by-products. Int J Food Sci Technol. 46 (10):2001–14.

Sánchez-Faure A, Calvo MM, Pérez-Jiménez J, Martín-Diana AB, Rico D, Montero MP, Gómez-Guillén MDC, López-Caballero ME, Martínez-Alvarez O. 2020. Exploring the potential of common iceplant, seaside arrowgrass and sea fennel as edible halophytic plants. Food Res Int. 137:109613.

Sarower G, Hasanuzzaman A, Biswas B, Abe H. 2012. Taste producing components in fish and fisheries products: a review. Intl J Food Ferment Technol. 2(2):113–21.

Schmidtsdorff W. 1995. Fish meal and fish oil-not only by-products. In: Ruiter A, editor. Fish and fishery products, composition, nutritive properties and stability. Wallingford (UK): CAB International. p. 347–76.

Steinsholm S, Oterhals Å, Thoresen L, Underhaug J, Kousoulaki K, Aspevik T. 2021. Reduction in flavor-intense components in fish protein hydrolysates by membrane filtration. J Food Sci. 86(9):3855–67.

Steinsholm S, Oterhals Å, Underhaug J, Måge I, Malmendal A, Aspevik T. 2020. Sensory assessment of fish and chicken protein hydrolysates. Evaluation of NMR metabolomics profiling as a new prediction tool. J Agr Food Chem. 68(12):3881–90.

Wang Z, de Jager LS, Begley T, Genualdi S. 2022. Large volume headspace GC/MS analysis for the identification of volatile compounds relating to seafood decomposition. Food Sci Nutr. 10(4):1195–210.

Wu G. 2020. Important roles of dietary taurine, creatine, carnosine, anserine and 4-hydroxyproline in human nutrition and health. Amino Acids. 52(3):329–60.

Wu TH, Bechtel PJ. 2008. Ammonia, dimethylamine, trimethylamine and trimethylamine oxide from raw and processed fish by-products. J Aquat Food Prod Technol. 17(1):27–38.

Zhang J, Yao Y, Ye X, Fang Z, Chen J, Wu D, Liu D, Hu Y. 2013. Effect of cooking temperatures on protein hydrolysates and sensory quality in crucian carp (*Carassius auratus*) soup. J Food Sci Technol. 50:542–48.