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Lumpfish (Cyclopterus lumpus) used as cleaner fish: Characterization and suitability for human consumption

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ABSTRACT

Farmed lumpfish (*Cyclopterus lumpus*) is frequently used as cleaner fish in Norwegian salmon aquaculture. During the period in the net cage, the lumpfish feed on salmon lice. After a time, the fish stop eating the lice and are then withdrawn from the net cage without further exploitation. In this study, the nutritional value of lumpfish was characterized to assess its suitability as a human food. The lumpfish were collected from two separate salmon aquaculture facilities and analyzed for proximate composition, amino acids, fatty acids, vitamins, minerals, environmental pollutants, and heavy metals. The water and protein content were approximately 90 and 6%, respectively. The protein contained all essential amino acids. The fat content ranged from 0.9 to 3.7% with a high level of the long chain polyunsaturated fatty acids EPA (eicosapentaenoic acid; 20:5n-3) and DHA (docosahexaenoic acid; 22:6n-3). Lumpfish may be a good source of B12 and D3 vitamins, however, the content of several minerals was low. The environmental pollutants and heavy metals were below the EU maximum levels, making the lumpfish safe for human consumption. Overall, our results indicate a potential to exploit the lumpfish, even after its time as a cleaner fish.

1. Introduction

In Norway, farmed lumpfish (Cyclopterus lumpus) is an important species to control sea lice (*Lepeophtheirus salmonis* (Krøyer 1837)) infestations on salmon in aquaculture. The sea lice parasite attaches to the skin and is considered both a health- and welfare problem for salmon. The lumpfish feeds on sea lice and thus reduces the problem of the infestation (Imsland et al., 2014a, 2018). Commonly, the lumpfish is transferred into the salmon net cage at an initial weight of about 25 g and stays there until the end of salmon production after reaching a weight of about 500 g (Powell et al., 2018). A net cage with about 200.000 salmon requires between 8.000 and 16.000 lumpfish (Nøstvold et al., 2016). The mortality of the lumpfish in the net cages is known to be high, but the survival rate is rapidly improving, close up to 80% in some facilities (Nøstvold et al., 2016). Re-use of the lumpfish as cleaner fish is not an option as it stops eating lice when it becomes mature at about 14 – 16 months (Brooker et al., 2018; Imsland et al., 2014b).

In 2019, about 43 million farmed lumpfish were used in the Norwegian salmon aquaculture industry as cleaner fish, representing a value of about 943 million Norwegian kroner (NOK) (Directorate of Fisheries, 2021). Apart from the purchasing costs of about 21 NOK per fish, additional charges are related to feeding and general care, which causes substantial expenses for the aquaculture industry. For instance, in 2016, these costs were estimated to 950 million NOK (Iversen et al., 2017). Still, there is no established procedures to utilize the lumpfish after use. Some salmon producers trade the lumpfish for ensilage purposes at a price of 2.5 NOK per fish, while some facilities pay to get rid of the fish (Nøstvold et al., 2016). The current practice may be questioned due to the social, economic, environmental, sustainability, and ethical aspects. In fact, a potential food resource is poorly utilized, and the ability to enhance value creation is lost. From a sustainability perspective, it is essential to exploit all available marine resources in the best way possible. From an ethical and social perspective, re-use of the lumpfish towards human consumption could be beneficial both for the Norwegian aquaculture industry and for the community (Nytrø et al., 2015; Nøstvold et al., 2016). Given the growing world population, alternative sources of proteins intended for human nutrition should be developed to meet future demand (Damodaran, 2008). Our hypothesis is that after being used as cleaner fish in salmon aquaculture, lumpfish can be used for alimentary purposes.

In general, risks associated with ingestion of seafood involve pathogens, toxins (i.e., algal toxins), and chemical contaminants (i.e., lead, mercury, cadmium, or PCBs) (Institute of Medicine of the National Academies, 2007). Seafood consumption also implies health benefits due to nutritional value, with omega-3 polyunsaturated fatty acids (PUFAs) as the most well-known (Chandra et al., 2019; Durmuş, 2018; Weinberg et al., 2021). Seafood can be a valuable source of fat-soluble vitamins (A, D, E), water-soluble vitamins (B12 and B6) (Lund, 2013),

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Table 1
Overview of examined sample types and analyses of lumpfish sampled. Batch 1 and 2.

Analysis	Batch 1	Batch 2	
	78 ± 39 g[1]	231 ± 67 g[1]	513 ± 84 g[1]
Proximate composition	Whole fish	Fillet Skin	Fillet Gutted with head
Fatty Acid composition	Whole fish		Gutted with head
Total Amino Acid composition	Whole fish		
Vitamins (except D3)	Gutted with head		
Vitamin D3			Gutted with head
Minerals	Whole fish		
Metals	Whole fish		
Environmental pollutants	Whole fish		

[1] Body weight (average weight ± standard deviation, SD).

and different minerals (phosphorus, selenium, zinc, potassium, magnesium, etc.) (Godswill et al., 2020; Ruxton, 2011).

To the best of our knowledge, papers describing lumpfish (pre-used as cleaner fish in salmon aquaculture) concerning proximate composition, vitamins, minerals, and pollutants, have not been published. Thus, in this paper, we aimed to screen and characterize the nutritional value of lumpfish after being used as a cleaner fish. Technological properties of lumpfish were also considered.

2. Materials and methods

2.1. Raw material

The lumpfish used in this study were sampled from salmon net cages during March 2020 (Batch 1) and September 2020 (Batch 2). For both batches, the lumpfish were supplied from Vangsvik (Senja, Troms, and Finnmark county, Norway).

Batch 1. In July 2019, the first group of lumpfish (body weight ≈ 30 g) was transferred to net cages with salmon at Karanes (Karlsøy, Troms, and Finnmark county, Norway). Additional groups of lumpfish (also body weight ≈ 30 g) were supplied to the same net cage about every 4th week until October 2019. During the period in the net cage, the lumpfish were supplementary fed (Lumpfish Grower 20 mg, BioMar, Norway) once a day. In March 2020, the lumpfish ($n = 83$) were randomly sampled from the net cage, stunned by a blow on the head, and exsanguinated by immediately cutting the ventral and dorsal aorta. The fish were then bled for 30 min in a container (100 L) with running seawater (≈ 5 °C), distributed and packed into plastic bags, and stored at -18 °C. The following day, the fish was shipped to Nofima, Tromsø, and transferred to -40 °C upon arrival.

Batch 2. In September 2020, the lumpfish were obtained from the net cage with salmon at Åbornes (Hansnes, Troms and Finnmark county, Norway). The first group of lumpfish (body weight ≈ 30 g) was added to the net cage in August 2019. Additional lumpfish (also body weight ≈ 30 g) were supplied approximately every 4th week during the net cage period. The fish were supplementary fed (Clean Lumpfish 2-4 mm, Skretting, Norway) once a day. Lumpfish ($n = 10$) were randomly sampled one by one from the net cage and slaughtered as described above. The fish were then packed in Styrofoam boxes with ice, transported to Nofima, Tromsø, within 40 min, and stored at 0 °C for about 16 h before being processed.

2.2. Preparation of samples

Batch 1. The frozen lumpfish in plastic bags were thawed in circulating tap water (3.4 °C), weighed, and sorted according to size. The fish were then divided into two weight groups: small ($n = 57$, 78 ± 39 g) and large ($n = 26$, 231 ± 67 g). Five fish from the large fish group were gutted, filleted, skinned, and the percentage proportion of the lumpfish' body fractions were determined (Table 1). Then, three groups were minced, namely (1) whole fish from the small fish group, (2) fillets from large fish, and (3) skin from large fish using a grinder (Kilia, TK 20 ltr, Dorfmark, Germany). The three minces were then packed in plastic containers (Kartell Labware, Noviglio, Italy) and frozen at -40 °C until analyzed.

Batch 2. The ten ice-stored lumpfish (body weight 513 ± 84 g) were weighted, gutted, and cut into head, skin, and fillets, followed by weight registration. Then, the body fractions (except the viscera) from five lumpfish were pooled, minced, and analyzed as gutted fish with head (Table 1). The skinned fillets from the remaining five fish were used to analyze proximate (Table 1). These two minces were packed in plastic containers and frozen at -40 °C, similarly to Batch 1, before being analyzed.

2.3. Analytical methods

The analytical methods applied are given in Table 2.

3. Results and discussion

The raw material variation due to size and fractions used for analyses is given in Table 1. In Batch 1, a wide weight range of lumpfish was obtained, as the fish were not sorted when taken out from the net cage. The small lumpfish' size varied between 22 - 150 g and of large lumpfish from 151 to 384 g. The total time in the net cage is not known as it could range from 4 weeks to 8 months as new fish were supplied in the net cage every 4th week. However, there were more small-sized fish than larger ones. During the processing of Batch 1, it was observed that some lumpfish had formulated feed residues in their stomachs. To avoid inaccuracies in the results due to feed remains, the lumpfish in Batch 2 were gutted (Table 1).

3.1. Technological properties of lumpfish

Lumpfish has a particular body shape, making processing (e.g., filleting) challenging. In profile, the body is longer than it is in circumference, but it is compacted anteriorly and posteriorly (Davenport, 1985; Powell et al., 2018). All fish in our study were filleted manually, and the smaller the fish, the more challenging the filleting became.

Table 3 shows the percentage distribution of the body fractions of lumpfish from both batches. All lumpfish were juvenile, as no mature gonads were detected. In Batch 1, the fractions of fillets and skin were slightly lower than the corresponding values for Batch 2. Challenges due to manual filleting and the size variations of lumpfish, may explain these differences. The fillet fractions obtained in this study (from 15 to 19%) were about the same as previously reported by Reykdal et al. (2012) and Ólafsson et al. (2009), 14 and 23% of lumpfish body, respectively. The fraction of the viscera in lumpfish from Batch 1 was twice as big as for Batch 2, 19 and 8%, respectively. Probably, the difference was caused by feed remains in the stomachs in fish from Batch 1.

The major fraction of all examined lumpfish consisted of head and skin together, about 47 and 53% in Batch 1 and Batch 2, respectively. This is higher compared to a fraction of about 40% as previously reported by Reykdal et al. (2012) and Ólafsson et al. (2009) but almost

Table 2
Methods for analyses applied.

Analyte	Principle	Refs.
Moisture	Gravimetric analysis	AOAC (2000) method 950.46
Ash	Gravimetric analysis	AOAC (2000) method 950.46
Fat	Pulsed NMR	Fiebig and Lüttke (2003)
Protein	N × 6.25, Leco TruMac N analyzer	Hamre and Mangor-Jensen (2006)
Total Amino acids	Ion exchange chromatography	EU, (2009)
Fatty acids	Transmethylation extraction and GC/FID	ISO 12966-2:(2011
Vitamin A	HPLC	ISO 14565:(2000)
Vitamin E	HPLC	ISO 6867:(2000)
Vitamin B1	HPLC	EN 14122:(2014)
Vitamin B2	HPLC	EN 14152:(2014)
Vitamin B3	HPLC	EN 15652:(2009)
Vitamin B6	HPLC	EN 14663:(2005)
Vitamin B9	SPR and HPLC	Mæland et al. (2000)
Vitamin B12	HPLC	Vyas et al. (2012)
Vitamin D3	HPLC	EN 12821:(2009)
Heavy metals	ICP-SFMS	ISO 17294-2:(2016)
PCDD/Fs + PCBs + dl-PCBs	HRGC/HRMS	CSN EN 16190 (2018)

GC/FID: gas chromatography/flame ionization detector.
HPLC: high performance liquid chromatography.
SPR: surface plasmon resonance.
ICP-SFMS: inductively coupled plasma sector field mass spectrometry.
HRGC/HRMS: high resolution gas chromatography/high resolution mass spectrometry.
PCDD/Fs: polychlorinated dibenzodioxins/furans; PCB, polychlorinated biphenyls; dl-PCBs: dioxin-like PCBs.

Table 3
Percentage distribution of the body parts of lumpfish, Batch 1, *n* = 5, and Batch 2, *n* = 10.

Fraction	Batch 1 264 ± 73 g[1]	Batch 2 513 ± 84g[1]
Head (%)	18 ± 2	18 ± 1
Skin (%)	29 ± 5	35 ± 3
Fillet (%)	15 ± 5	19 ± 2
Bones (%)	13 ± 3	15 ± 2
Viscera (%)	19 ± 5	8 ± 1

[1] Body weight (average weight ± SD).

similar to about 50%, which was reported by Paradis et al. (1975). The weights of the fish used in those three studies ranged from about 1 to 4.5 kg, while the weight of the fish in our study was relatively lower, which is assumed to be the source of differences. The large fractions of head and skin may be an issue when considering processing options for the lumpfish.

Traditionally, wild lumpfish have been harvested for their roe, which can be processed into a substitute for caviar, while the remained body fractions often are handled as waste (Davenport, 1985; Johannesson, 2006; Paradis et al., 1975; Powell et al., 2018). In some countries, however, the lumpfish body fractions are used for human consumption. For instance, Iceland exports frozen lumpfish to China (Þórðarson et al., 2018). In Russia, the wild lumpfish fillets are popular as hot-smoked products or canned food (Nord-West, 2021).

According to Nøstvold et al. (2016), the whole small-sized lumpfish could be exported to Asia, where consumption of portion-sized whole fish (with skin, bones, head, and viscera) is common. Another option is cutting the fish from the vent to the neck, across the stomach (commonly referred to as "Japanese cut" (Volda University College, Møreforsking Marine, Ålesund High School, SUROFI, The Norwegian Fishermen's Association, 2013). A Japanese cut simplifies the processing as traditional filleting of these fish is challenging and time-consuming. Apart from the Japanese cut, all fins (including caudal fin) and skin were removed, giving a skinned carcass yield of about 28 and 34% in Batch 1 and Batch 2, respectively. It is worth mentioning that the thickness and elasticity of the skin enabled easy manual removal. Besides, in our opinion, the skinned lumpfish carcass appears more appealing and similar to other fish species. If the lumpfish (after being used as cleaner fish) should be processed for other purposes than ensilage, this product might be considered.

3.2. Proximate composition

Several factors can affect fish species' proximate composition, for instance, body size, season, feed access, and feed composition (Ageeva et al., 2017; Breck, 2014; Jobling et al., 2008).

The proximate compositions of the feeds given to lumpfish during the net cage period and lumpfish samples from batches 1 and 2 are shown in Table 4. All samples of lumpfish had high water content (87.5–92.2%) and low ranges of protein (5.3–7.41%). Whole fish, skin, and gutted fish with head, had a higher ash content than fillets from both batches. This is expected as the contents of minerals and trace elements are higher in bones and skin than in muscle (Lorentzen et al., 2001).

The fat content in fillets from Batch 1 and 2 was 3.7 and 0.9%, respectively. Based on the fat content in the feeds applied, the differences are not likely to be linked to differences of the feeds as these are nearly similar. The results may indicate that the fish from Bach 2 was not fed sufficiently despite being offered feed daily. Other researchers registered an increase in fat content (from ≈ 2.8 to ≈ 4.2%) in farmed lumpfish after being kept in a net cage with salmon for about seven months (Espmark et al., 2020). During this period, the lumpfish gained weight from 30 to 50 g to 230 to 500 g. They concluded that the fish were fed sufficiently, not necessarily only cleaner fish feed but also plankton and salmon pellets, enabling them to build up the fat reserves. Our study shows that the proximate composition depends on the feeding regimen and general access to feed during the period in the net cage.

3.3. Fatty acid composition and nutritional evaluation

Table 5 gives an overview of the amounts of the primary fatty acids (FA) in lumpfish from Batch 1 (whole fish) and Batch 2 (gutted with head). Despite the difference in the type of samples, the total FA distribution was nearly similar in both batches. The percentage of saturated FA (SFA) ranged from 19.7 to 20.8%, monounsaturated FA (MUFA) from 34.5 to 37.1%, and polyunsaturated FA (PUFA) from 31.6 to 34.4%.

Table 4
Proximate compositions (%) of the feeds given to the lumpfish, Lumpfish Grower 20 mg and CLEAN Lumpfish 2 – 4 mm. Proximate compositions (%) and energy of sampled lumpfish, Batch 1, and Batch 2.

Element	Batch 1 Lumpfish Grower 20 mg^1	Whole fish	Fillet	Skin	Batch 2 CLEAN Lumpfish 2 – 4 mm^1	Gutted with head	Fillet
Ash	12	1.6	1.2	1.5	10.5	1.5	0.5
Water	8	91.5	87.5	92.1	n.a.	92.1	92.2
Protein	48	5.7	7.41	6.3	57	5.3	6.5
Fat	12	1.3	3.7	0.9	15	0.7	0.9
Energy (kcal/100g)		34	64	33		29	33
Energy (kJ/100g)		144	266	141		121	140

n.a. – not available.
^{1}Lumpfish Grower 20 mg (BioMar, 2019); CLEAN Lumpfish 2–4 mm (Skretting, 2021).

Table 5
Fatty acid (FA) fraction (% of total FA), and amount of FA (mg/g) in lumpfish, Batch 1 and Batch 2.

Fatty acid	Batch 1 (Whole fish)		Batch 2 (Gutted with head)	
	Fraction (%)	Amount (mg/g)	Fraction (%)	Amount (mg/g)
14:0	2.7	0.4	4.5	0.3
16:0	14.0	1.8	10.9	0.8
18:0	4.1	0.5	4.3	0.3
16:1n-7	5.1	0.7	4.4	0.3
18:1n-9	25.6	3.3	16.9	1.2
20:1n-9	2.5	0.3	8.8	0.6
22:1n-9	1.3	0.2	7.0	0.5
18:2n-6 (LA)	10.8	1.41	5.0	0.4
18:3n-3 (ALA)	1.8	0.23	2.2	0.2
18:4n-3	1.0	0.13	2.0	0.1
20:2n-6	0.3	0.04	0.3	0.02
20:5n-3 (EPA)	8.3	1.08	9.0	0.6
22:5n-3	1.3	0.16	0.9	0.1
22:6n-3 DHA)	10.9	1.42	12.2	0.9
ΣSFA	20.8	2.7	19.7	1.4
ΣMUFA	34.5	4.5	37.1	2.6
ΣPUFA	34.4	4.5	31.6	2.3
Σn-3	23.2	3.0	26.3	1.9
Σn-6	11.1	1.5	5.3	0.42
n-6/n-3	0.5		0.2	

LA: linoleic acid; ALA: alpha-linoleic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

Palmitic acid (16:0) dominated in the SFA in both batches, with a slightly higher level in Batch 1 than in Batch 2. The difference in content of palmitic acid could be explained by the lumpfish in Batch 1 not being gutted. It has been reported that palmitic acid is a dominant SFA in both wild and farmed cod (Jensen et al., 2013), salmon (Jensen et al., 2020), and other seafood species caught in the Northeastern Mediterranean coast (Durmuş, 2018).

Oleic acid (18:1n-9) was the primary FA and thereby the major contributor to the MUFA. Oleic acid is the most common MUFA in plants and animals (Lund & Rustan, 2020; Tvrzicka et al., 2011).

The fraction of EFA linoleic acid (LA, 18:2n-6) was twice as high in lumpfish from Batch 1 (10.8%) compared to Batch 2 (5%). The fish in Batch 1 was not gutted, which is assumed to explain the difference. The percentage of α-linoleic acid (ALA, 18:3n-3) was nearly the same in both batches, 1.8 and 2.2% in Batch 1 and Batch 2, respectively. LA is observed at low levels in fish oils (< 2%) while extensive in vegetable oils. Thus, LA and ALA can be used as markers to verify if the fish has been offered vegetable oils (Lund & Rustan, 2020; Olsen, 2017; Tvrzicka et al., 2011). The LA and ALA levels indicate elevated levels of vegetable oils in the feed. Nowadays, it is a standard procedure to apply vegetable oils when making fish feeds, and it is known that the dietary lipid composition of the feed reflects the total FA composition of fish (Jobling et al., 2008; Olsen, 2017; Ytrestøyl et al., 2015). For instance, the percentage of LA in farmed cod (4%) can be four times higher than in wild cod (1%) (Jensen et al., 2013).

The percentages of conditionally-EFA docosahexaenoic acid (DHA, 22:6n-3) were almost similar in both batches, about 11 and 12% in Batch 1 and Batch 2, respectively. Recommendations for minimum dietary intake of Eicosapentaenoic acid (EPA, 20:5n-3) and DHA (EPA+DHA) ranges between 250 and 450 mg/day (Tvrzicka et al., 2011). The results suggest that about 170 g of lumpfish (gutted with head) would provide 250 mg EPA+DHA and cover the recommended dietary daily intake. To improve the beneficial effects of the diet on human health, it is also recommended to reduce the n-6/n-3 FA ratio. The n-6/n-3 ratio of the western diet is about 15–17/1 (Jensen et al., 2013; Simopoulos, 2008). However, the ratio should be five or fewer (Olsen, 2017). The n-6/n-3 ratios were 0.5 in lumpfish from Batch 1 and 0.2 in lumpfish from Batch 2, respectively. Both ratios were low; hence, the consumption of lumpfish could contribute to a reduction of the n-6/n-3 ratio of the regular diet.

3.4. Amino acids (AA) profile and protein quality

Table 6 shows the total AA composition in the whole lumpfish from Batch 1.

The results indicate that lumpfish contains all essential amino acids (EAA), and the percentage of EAA is 36.0%. It is stated that a mean total protein reqirement consists of 27% EAA and 73% non-EAA, and healthy adults require approximately 0.66 g of protein per kg body weight per day to maintain body nitrogen homeostasis (FAO/WHO/UNU, 2007).

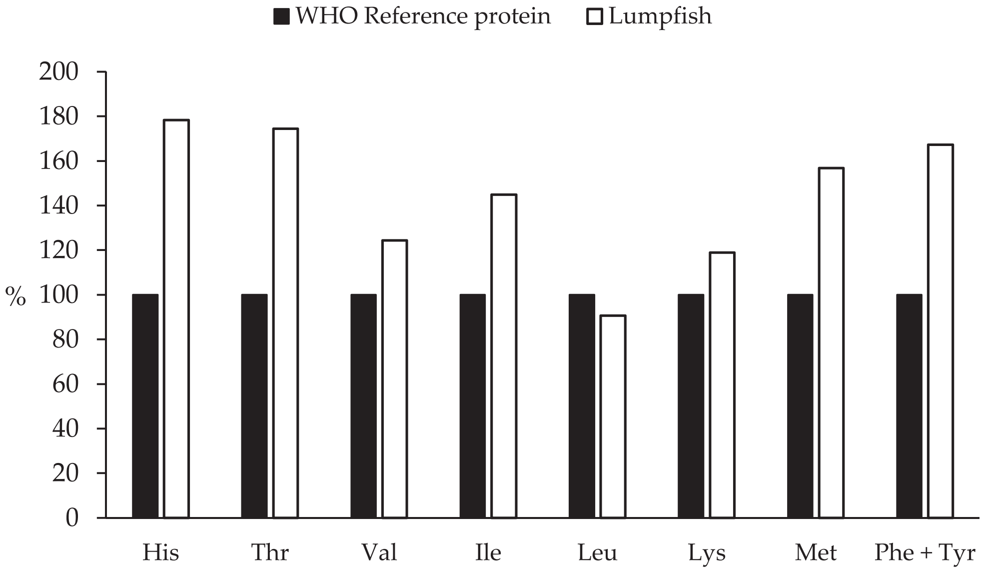

Fig. 1. Essential amino acids in protein of lumpfish relative to the estimated requirements in adults set by WHO when the reference level is set to 100%. His – Histidine, Thr – Threonine, Val – Valine, Ile – Isoleucine, Leu – Leucine, Lys – Lysine, Met – Methionine, Phe + Tyr – Phenylalanine and Tyrosine are summarized.

Table 6
Total amino acid composition in whole lumpfish, Batch 1.

Amino acid	Batch 1 (Whole fish) mg/g
Essential amino acids	
Histidine	1.6
Threonine	2.4
Valine	2.9
Isoleucine	2.6
Leucine	3.2
Lysine	3.2
Methionine	1.5
Phenylalanine	2.9
Tryptophan[1]	n.a.
Conditionally essential amino acids	
Tyrosine	0.9
Glycine	9.2
Arginine	4.9
Proline	4.0
Non-essential amino acids	
Serine	3.4
Alanine	4.2
Cysteine	0.5
Aspartic acid	4.6
Glutamic acid	6.9
Σ TAA	58.9
Σ EAA	21.2
% EAA	36.0

TAA: total amino acids.
EAA: essential amino acids.
n.a. – not analyzed.

[1] Tryptophan is decomposed during hydrolysis with 6M hydrochloric acid.

Among the EAAs, the levels of histidine (His) and methionine (Met) were the lowest (approximately 1.5 mg/g), threonine (Thr) and isoleucine (Ile) slightly higher (near 2.5 mg/g), valine, leucine, lysine, (Val, Leu, Lys) and phenylalanine (Phe) at the highest (approximately 3 mg/g).

To evaluate the dietary protein quality, a comparison with a "reference protein" for humans is suggested by the World Health Organization (WHO) (Damodaran, 2008; FAO/WHO/UNU, 2007). Reference protein includes the minimum required amount of EAAs. By calculating the ratio between each EAA both in a dietary protein and in the reference protein, a comparison is enabled. An AA giving the lowest value is the most limiting AA. High-quality proteins include all EAA at levels above the "reference" level of 100%.

Fig. 1 shows the percentage comparison of each EAA in lumpfish and the similar EAA in the WHO reference protein when the reference EAA level is set to 100%. Only Leu was slightly lower in lumpfish than the reference level, which is assumed to be related to the sampling method (see chapter 2.2.). However, lumpfish protein provides a sufficient amount of the remaining EAAs, especially His, Thr, Ile, Met, and Phe. The results suggest that lumpfish proteins are of good quality and can be applied for human consumption. However, more research is needed to obtain information about the digestibility and the quality of proteins, especially from lumpfish fillets.

3.5. *Vitamins*

Table 7 shows the levels of selected vitamins in lumpfish (Batch 1, gutted with head). Vitamins A and B9 were below the minimum detection limits, < 60.0 µg/100g and < 25.0 µg/100g, respectively (data not shown), while the remaining vitamins were above the detection limit. For comparison purposes, the EU recommended levels for Population Reference Intakes (PRIs) or the Adequate Intake (AIs) are added.

It appears that the analyzed lumpfish is a source of vitamin B12. For example, a daily intake of 220 g meets the vitamin B12 requirement for humans (Table 7). Vitamin B12 is mainly found in a diet of animal origin, and seafood is a particularly good source in the typical diet (Nordic Council of Ministers, 2014).

Vitamin D3 was analyzed in lumpfish (gutted with head) from Batch 2, which were older and had been fed with different feeds compared to lumpfish in Batch 1 (see chapter 2.1). Wild fish get vitamin D3 through diet (plankton or other fish), and farmed fish must be fed with feed containing adequate level of vitamin D (Waagbø et al., 2001). It seems that the analyzed fish could be a good source for vitamin D3, and based on the PRI, 160 g lumpfish could provide the daily requirement for a healthy person (Table 7).

The concentrations of vitamin B1 and vitamin B3 in lumpfish were higher than the corresponding AIs (Table 7), the latter was still lower than the tolerable upper intake level (ULs) (EFSA NDA Panel, 2014). Regarding vitamin B1, there are no reports of adverse effects, even at daily doses up to several hundred milligrams (EFSA, 2006). Due to the lack of scientific reports on dose-response intake and extremely low toxicity, no UL of vitamin B1 was endorsed (EFSA, 2006).

Table 7
Vitamins in lumpfish (gutted with head, Batch 1) accompanied with EU recommended intake-levels, Population Reference Intakes (PRIs) and Adequate Intakes (AIs), for males and females (≥18 years old). PRIs are in plain and AIs in bold type.

Vitamin	Batch 1(Gutted with head)	Unit	PRI / AI[1] Males	Females	Unit
E	1.26	mg/100g	**13**	**11**	mg/day
B1[2]	1.2	mg/MJ	**0.1**	**0.1**	mg/MJ
B2	0.2	mg/100g	1.6	1.6	mg/day
B3 (total) [2]	5.3	mg/MJ	**1.6**	**1.6**	mg/MJ
B6	0.05	mg/100g	1.7	1.6	mg/day
B12	1.8	µg/100g	**4.0**	**4.0**	µg/day
D3[3]	9.2	µg/100g	**15**	**15**	µg/day

[1] PRI is the daily dietary intake level that is sufficient to meet the nutrient requirement of 97.5% of healthy individuals in a particular stage of life and gender group (EFSA, 2017). AI is the average observed or experimentally determined estimates of nutrient intake by a group of healthy people assumed to be satisfactory. AI is used when there is no sufficient information to establish a PRI.

[2] For vitamin B1 and vitamin B3, the PRIs are expressed as amounts per MJ of calories consumed. MJ = megajoule = 239 kcal. Vitamin B3 (niacin) 0.64 mg/100 g = 5.3 mg/MJ. Vitamin B1 0.14 mg/100 g = 1.2 mg/MJ.

[3] Vitamin D3 was analyzed in lumpfish (gutted with head), Batch 2. Vitamin D3 3.68 IU/g = 9.2 µg/100g. Under conditions of assumed minimal cutaneous vitamin D synthesis. In the presence of endogenous cutaneous vitamin D synthesis, the requirement for dietary vitamin D is low or can be even zero.

Table 8
Minerals in lumpfish (whole fish, Batch 1) accompanied by Population Reference Intakes (PRIs) and Adequate Intakes (AIs), for males and females (≥18 years old). PRIs are in plain and AIs in bold type, respectively.

Mineral	Batch 1 (Whole fish)	Unit	PRIs and AIs[1] Males	Females	Unit
Macrominerals					
Na	324	mg/100g	n.d.	n.d.	
P	292	mg/100g	**550**	**550**	mg/day
Ca	232	mg/100g	1000[2]	1000[2]	mg/day
K	150	mg/100g	**3500**	**3500**	mg/day
Mg	21.8	mg/100g	**350**	**300**	mg/day
S	81.5	mg/100g	n.d.	n.d.	
Microminerals					
Se	22.5	µg/100g	70	70	µg/day
Mo	3.35	µg/100g	65	65	µg/day
V	0.755	µg/100g	n.d.	n.d.	
Zn	0.695	mg/100g	16.3	12.7	mg/day
Fe	0.348	mg/100g	11	16	mg/day
Mn	0.101	mg/100g	**3.0**	**3.0**	mg/day
Cu	0.048	mg/100g	**1.6**	**1.5**	mg/day

n.d. – not determined.

[1] PRI is the daily dietary intake level that is sufficient to meet the nutrient requirement of 97.5% of healthy individuals in a particular stage of life and gender group (EFSA, 2017). AI is the average observed or experimentally determined estimates of nutrient intake by a group of healthy people assumed to be satisfactory. AI is used when there is no sufficient information to establish a PRI.

[2] Age group ≥ 18-24 years. For age group ≥25 years the PRI of Ca is 950 mg/day both for males and females.

Table 9
Environmental pollutants and heavy metals in whole farmed lumpfish.

Compound	Batch 1 Whole lumpfish	EU maximum levels Wet weight fish[1]	Unit
Sum ICES-6 PCBs[2]	1.1	75	ng/g
Sum TEQ 12 dl-PCBs[3]	0.22	6.5[5]	pg/g
Sum TEQ 17 PCDD/Fs[4]	0.25		pg/g
Hg	0.00438	0.5	mg/kg
Pb	0.0161	0.3	mg/kg
Cd	0.00692	0.05	mg/kg
As	0.255		mg/kg

[1] Where fish are expected to be eaten whole, the maximum level applies to the whole fish EU, 2006, EU, 2011).

[2] Sum ICES-6 PCB includes PCB 28, 52, 101, 138, 153, and 180.

[3] Sum TEQ 12 dl-PCB includes PCB 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189.

[4] Sum TEQ 17 PCDD/PCDF includes 2378-TCDD, 12378-PeCDD, 123478-HxCDD, 123678-HxCDD, 123789-HxCDD, 1234678-HpCDD and OCDD; 2378-TCDF, 12378-PeCDF, 23478-PeCDF, 123478-HxCDF, 123678-HxCDF, 123789-HxCDF, 234678-HxCDF, 1234678-HpCDF, 1234789-HpCD, OCDF.

[5] Sum of PCDD/Fs and dl-PCBs. Sum of PCDD/Fs is 3.5 pg/g wet weight.

4. Minerals

Table 8 shows the content of macrominerals and microminerals in lumpfish from Batch 1 (whole fish). Like vitamins, the contents of different minerals were evaluated based on PRIs and AIs. Nickel (Ni), Cobalt (Co), and Chromium (Cr) were below the detection limits, < 0.02, < 0.004 and < 0.02 mg/kg, respectively (data not shown). Sodium (Na) was the major constituent in the lumpfish. According to European Food Safety Authority (EFSA) (EFSA NDA Panel EFSA Panel on Nutrition, Novel Foods and Food Allergens, 2019), no sufficient data to endorse Na's recommended level intake is given. However, the EFSA panel considered that the Na intake of 2.0 g/day was sufficient to reduce risk of cardiovascular diseases and to maintain the Na-balance for most adults, including pregnant and lactating women. In that context, a lumpfish of 250 g may contribute with only 0.8 g Na and could thereby be considered suitable for low-sodium diets. This is not surprising, as in general, the Na content in fish muscle is relatively low (Huss, 1995).

Assuming a consumption of a 100 g lumpfish, the contents of the macrominerals phosphorus (P), calcium (Ca), potassium (K), and magnesium (Mg) were all below the correspondent PRIs or AIs (Table 8). However, by consuming a whole lumpfish of 250 g, the contribution of P (730 mg) is higher than the corresponding value for AI (550 mg/day). There is no established UL for P, but it is indicated that normal healthy individuals tolerate up to at least 3000 mg P per day avoiding adverse effects (EFSA, 2006). P is commonly found in food as phosphates, especially in protein-rich foods like fish (200 mg/100g) (EFSA, 2006). Sulfur (S) is abundant in nature and is often not included as a required micromineral in human diet. The most important sources of S are two sulfur-containing amino acids, methionine, and cysteine, which are used to synthesize most proteins in the body (Lorentzen et al., 2001).

As regards the microminerals, the contents of all compounds in 100 g lumpfish were lower than corresponded PRIs or AIs. Still, it seems that if lumpfish of about 250 g is eaten as whole fish, the contribution of selenium (Se) (56.25 µg) is more than half of the corresponded AI (70 µg/day), which is encouraging. Vanadium (V) is not considered essential for humans and has no nutritional value, and thus, recommended intake levels are not established (EFSA, 2004).

4.1. *Environmental pollutants and heavy metals*

The environmental pollutants and heavy metals detected in lumpfish from Batch 1 (whole fish) are shown in Table 9. The levels of environmental pollutants were low, and in some cases, below the detection limit. In fact, the SUM ICES-6 PCBs and the SUM TEQ12 and 17, were 68 and 30 times below the EU maximum level for fish muscle (EU, 2011).

The levels of the heavy metals mercury (Hg), lead (Pb), and cadmium (Cd) in the lumpfish samples were 116, 18, and 7 times lower than the EU maximum levels (EU, 2006). The arsenic (As) analyzed refers to the total level, not distinguishing between organic and inorganic. Approximately 97-99% of the total amount of arsenic found in fish and seafood is found as organic compounds. This form is not harmful for human or fish health (Cubadda et al., 2017).

5. Conclusions

To evaluate the usability of a new food resource, a screening of potential positive and negative properties is considered valuable. Positive attributes include a prevalence of vitamins, essential amino acids, and fatty acids, while negative attributes are commonly associated with PCBs and heavy metals. Also, the technical aspects and the ability to process are relevant. The lumpfish investigated had high water content and low protein content. However, the protein was of good quality and a good source for all essential amino acids. The fat content varied between the batches in this study, indicating a variation dependent on the handling and feeding regimen during the net cage period.

The fatty acid composition is considered beneficial concerning the EPA and DHA content. Provided a daily consumption of 170 g lumpfish, the recommended daily dietary intake of 250 mg of EPA+DHA will be covered. Furthermore, it appears that lumpfish could be a good vitamin source. For instance, 160 - 220 g lumpfish could supply the daily requirement for humans of vitamins D3 and B12. The contents of several minerals were low, and the fish could be considered suitable for low-sodium diets. The contents of environmental pollutants and metals were lower than the established EU maximum levels, making the lumpfish a safe product for human consumption.

The processing of lumpfish may be challenging as the lumpfish have an almost spherical body shape, with a large fraction of head and skin. If the lumpfish (after being used as cleaner fish) should be processed for purposes other than ensilage, small lumpfish could be used as a whole or as a product skinned carcass. In our opinion, the latter has a more ordinary and attractive appearance.

However, it is essential to mention that the results presented covers two batches and should thereby be considered as indicative. Corresponding analyses from several aquaculture facilities should be performed aiming at the big picture of variation. Also, the screening and characterization of lumpfish should be conducted both on individual fish and pooled samples. In addition, if the fish is to be considered for consumption as a whole fish, feed deprivation before slaughter must be considered. The results presented in this study are considered promising in view of possibilities for improved after-use as an alternative to the use today.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Tatiana N. Ageeva: Conceptualization, Methodology, Validation, Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing. **Grete Lorentzen:** Supervision, Validation, Investigation, Writing – original draft, Writing – review & editing. **Heidi A. Nilsen:** Supervision, Validation, Investigation, Writing – original draft, Writing – review & editing. **Kjersti Lian:** Conceptualization, Methodology, Validation, Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing.

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