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ANALYSIS OF A FUNCTIONAL PRODUCT FROM CARP (*Cyprinus carpio*) WASTE IN THE CONTEXT OF THE CIRCULAR ECONOMY

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Abstract

According to the data provided by the representative organization of the Romanian aquaculture sector, a production of 10,000 tons of fish is estimated for 2024. The fish processing industry is known for its high quantities of by-products, and in these circumstances, it is necessary to adopt the most correct approach to their disposal or recycling to prevent the challenges related to environmental management. The circular economy has been of increasing interest in recent years as the exploitation of fish waste represents a sustainable strategy for realizing a circular bio-economy by producing high-value-added compounds. This study aimed to obtain a concentrated soup from fish waste (bony skeleton, head, and skin) and to incorporate this concentrate into a paste obtained from processed fillets. Determinations were carried out to establish the gross chemical composition, color, and pH of the experimental batches, as well as the acceptability of this product to potential consumers.

Key words*: circular economy, concentrated soup, fish waste, value-added product.*

INTRODUCTION

With the global population expected to reach a staggering 8.5 billion people by 2030, there is a continuing concern about the need for food, and aquaculture is showing the highest growth globally.

The Food and Agriculture Organization of the United Nations (FAO) estimates that by 2030, aquaculture will account for 2/3 of all fish and seafood production (Venslauskas et al., 2021). Although fish is a quite popular food choice, globally, 7.2-12 million tons of fish waste is discarded annually, according to data presented by Manjudevi et al. (2024).

Increasing consumer demand for healthy food has initiated large-scale research and development of new products in the food industry (Anchidin et al., 2023). Adopting a more sustainable lifestyle requires the implementation of new methods capable of solving the problems related to the management of by-products resulting from fish processing. Thus, to meet industrial requirements as well as actions regarding environmental protection, different approaches have been conceived, among which the circular economy, being defined as "an economic system that replaces the end-of-life concept by reducing, reusing, recycling and recovering materials in production processes", (Fraga-Corral et al., 2022). Also, in recent years, more and more trends are pursuing the use of animal by-products as an integrated part in the realization of renewable material, which can then be used in different industries.

The search for new functional food ingredients from natural sources is one of the most important discussions in food science and technology (Olaniran et al., 2024).

More than 70% of all fish undergoes further processing before being placed on the market, resulting in the production of large quantities of between 20 and 80% of overproduced fish, depending on the level of processing (Coppola et al., 2021).

The by-products and waste resulting from fish processing are separated into by-products from eviscerating fish (gastrointestinal mass) and by-products from skinning, slicing, and filleting fish, resulting in by-products such as scales, skeletal remains, head, and fins.

According to statistics, the head represents between 9 and 12%, the viscera between 12 and 18%, the skin between 1 and 3%, the bones between 9 and 15% and the scales about 5% of the total weight of the whole fish (Olaniran et al., 2024).

The increase in meat production and consumption is due, in addition to the need to provide food for the ever-growing population, to its high nutritional and biological value, especially as a good source of complete proteins, with meat traditionally being associated with good health and prosperity (Ciobanu et al., 2025).

The meat we consume is an important component of the human diet. It contains essential nutrients that help to maintain normal physiological functions, improve immunity, and prevent certain diseases, including malnutrition (Ciobanu et al., 2023).

A fish-based diet has a positive nutritional impact, playing an important role in correcting unbalanced diets. As well as being an important source of high-quality protein containing all essential amino acids, fish provides essential fats (long-chain omega-3 fatty acids), vitamins (D, A and B), and minerals (Ca, I, Zn, Fe and Se) (Coppola et al., 2021).

Due to its chemical composition, but also its high consumption demand, fish accounts for about 17% of the animal protein intake of the global population and 6.7% of all protein consumed worldwide. Collagen is the most common structural protein found in the extracellular matrix of animal organisms.

It has been found that there are at least 29 distinct forms of collagen derived from animal tissues, each with its protein structure (Olaniran et al., 2024). Thus, fish by-products can be an excellent source in functional food ingredients manufacturing. With its unique sensory profile along with other qualities, meat and meat products play a significant role in human nutrition. The consumption of meat and meat products is increasing in parallel with the level of development and standard of living of society (Boiștearu et al., 2025).

MATERIALS AND METHODS

The current research was carried out at the Iasi University of Life Sciences, within the Department of Food Technologies.

The realization of the experimental samples was carried out in the Meat Processing and Processing Section, and the subsequent determinations were carried out in the Meat and Meat Preparations Laboratory and the Sensory Analysis Laboratory.

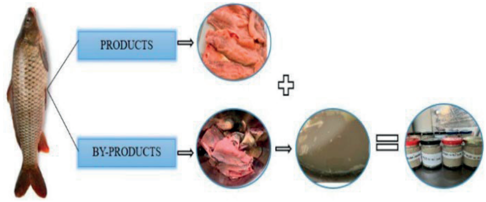

Figure 1. Methodology for obtaining experimental samples (original)

The biological material used consisted of fresh aquaculture carp and was purchased from a local supermarket under refrigerated conditions (2-4°C) for 2 hours, and then subjected to a first stage of splitting, removing the gastrointestinal mass, the second stage consisting of slicing the fish, removing the head, tail and lateral fins and then a final filleting stage removing the biologically valuable tissue from the skeletal structure.

The bony skeleton and the head were used to produce the concentrated fish bone soup.

The super pods were boiled for 4 hours for the most efficient extraction of collagen and other proteins until a concentrated liquid was obtained, and the mass of sub pods began to crumble.

The resulting broth was filtered and stored under refrigerated conditions for 24 hours to gel.

The remaining carp fillets were heat-treated for pasteurization as shown in Table 1.

Table 1. Heat treatment applied to fish fillets

	Drying I	Smoking	Boiling	Drying II
Time (minutes)	20	30		10
Cell temperature (°C)	45	60	76	72
Core temperature (°C)	50	55	72	69
Moisture (%)	10	10	99	10

To make the fish paste with concentrated bone broth, the heat-treated skin-on fish fillets were minced using a Volf machine with a 3 mm diameter sieve and then finely ground using a Cutter (Cutter Titane 45 V) at 3.500 rpm until a fine homogeneous paste was obtained. The resulting emulsion was blended with three different percentages of fish bone broth (10%, 15%, and 20%), the pre-weighed spice mix was added, and the composition was homogenized using a blender (La Felsinea). The resulting samples were filled into 220 mL glass jars and subjected to a sterilization heat treatment for 2 hours at 98-110°C in a pressure boiling kettle. These technological processes resulted in 4 experimental batches of fish paste, a control samples without the addition of concentrated bone soup, and three batches containing 10%, 15%, and 20% concentrated soup. Subsequently, the experimental samples were analyzed from physico-chemical and sensory points of view. The physico-chemical analysis consisted of pH determination using a digital pH meter for meat (Hanna HI98163) fitted with an FC2323 electrode. Texture determinations were carried out with the TA1Plus texture analyzer, applying tests for the determination of TPA parameters, using a Kramer shear cell. The color characteristics were determined using the Konica Minolta Chroma Meter CR-410, which employs a spectrophotometric measurement technology using CIE color coordinates (L*, a*, b*). The gross chemical composition was determined by using a Food-Check analyzer, which uses a non-invasive technology based on infrared spectrometry to determine the percentages of moisture, protein, collagen, and fat. A panel of 50 semi-experienced panelists (students in their fourth year of study, food industry profile), with an average age of 21 years, was formed to evaluate sensory characteristics. The panelists received the questionnaire in digital format (Google Forms) to centralize the data as accurately as possible, and they were instructed on the sample samples received and the content of the questionnaire. A hedonic test (9-point scale) was applied, evaluating the general appearance, smell, taste, color, and consistency of the experimental samples. Score 1 represents the expression "extremely unpleasant" and score 9 the expression "extremely pleasant".

RESULTS AND DISCUSSIONS

To compare the differences between the means of the experimental samples in the analysis of physico-chemical determinations, the ANOVA statistical method was used, using the one-factor ANOVA test followed by the Tukey HSD test. From the analysis carried out it can be seen, as shown in Table 2, that in terms of fat content of the samples analyzed, significant variations were evident between all pairs of groups ($p<0.05$), the control sample showed the highest fat content (10.2%) while the values decreased with increasing percentage of added concentrated soup. Compared to the control sample, the samples with added concentrated soup showed lower fat concentration values, with the addition of soup significantly decreasing the fat, especially in the samples with 15% and 20% added concentrated soup. As regards the moisture content of the samples, the p-value ($p<0.05$) showed statistically highly significant differences, with a significant increase in the moisture content of the samples with added concentrated soup compared to the control sample. This increase was mainly due to the amount of moisture contained in the concentrated soup. The percentages of protein and collagen did not differ significantly, as shown by the p-values ($p>0.05$) of the two indices measured, the values being almost equal between all groups. The average protein content values were very close between the samples, ranging from 20.22% in the control sample to 20.24% in the 10% added sample. The most significant mean difference was observed between the control (SM) lot (20.22%) and the L3 lot (20.32%). The mean percentages of collagen in the total mass of the sample showed slight variations in the mean percentage between sample L2 (18.4%) and sample L3 (18.6%). This high proportion of collagen in the total protein is due to the high content of skin that was not removed from the surface of the fillets used. In the literature, the collagen content in fish varies according to the species, age, and method of analysis. For example, according to the study conducted by Duan et al. (2009), the collagen extracted from crap fish was 41.3%/dw for skin and about 40%/dw for bones compared to other species. This would correspond in our study to a content of 12.7% collagen/dw. Thus, the values obtained in this study show that the high percentage of collagen results from the collagen found in the bone soup, but also from the collagen found in the skin and flesh of the fish.

Table 2. Physico-chemical composition of the experimental samples

Experimental groups		**Fat (%)**	**Moisture (%)**	**Protein (%)**	**Collagen (%)**
SM	**Count**	5	5	5	5
	Mean±SD	10.02^{b}±0.16	69.24^{a}±0.20	20.22^{a}±0.19	18.46^{a}±0.25
	Min.-Max.	9.74-10.29	69.10-69.37	20.07-20.36	18.27-18.64
L1	**Count**	5	5	5	5
	Mean±SD	9.64^{b}±0.24	69.62^{b}±0.13	20.24^{a}±0.16	18.48^{a}±0.16
	Min.-Max.	9.36-9.91	69.48-69.75	20.09-20.38	18.29-18.66
L2	**Count**	5	5	5	5
	Mean±SD	8.40^{a}±0.40	70.26^{c}±0.11	20.4^{a}±0.12	18.4^{a}±0.15
	Min.-Max.	8.12-8.68	70.12-70.39	20.25-20.54	18.21-18.58
L3	**Count**	5	5	5	5
	Mean±SD	8.62^{a}±0.31	70.14^{c}±0.11	20.32^{a}±0.13	18.6^{a}±0.17
	Min.-Max.	8.34-8.89	70.00-70.27	20.17-20.46	18.41-18.78
p-value		2.87884E-07**	1.76414E-08*	0.28^{ns}	0.43^{ns}

Superscript letters that differ within the same column denote statistically significant differences, as assessed by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$). SM - sample control, L1 - 10% concentrated soup L2 - 15% concentrated soup, L3 - 20% concentrated soup.

The mean values of the color parameters of the experimental samples show that the mean values of the brightness vary between 66.42 and 68.81, with a slight increase as the percentage of added concentrated soup increases. The red-green color component (a*) shows mean values ranging between 4.68 (L3) and 5.52c (L2), with sample L2 showing a slight increasing trend compared to the control sample, having a darker shade of the lot color, while lots L1 and L3 show a decreasing trend in color concentration. The yellow-blue color component (b*) shows mean values between 15.7a and 16.33c. However, there is a general trend of increasing b* value with increasing percentage of concentrated bone broth, suggesting an intensification of the yellow color tone The ANOVA results showed significant differences between groups for the parameters a* and b*, suggesting that the addition of concentrated bone broth significantly influences the color of the fish paste ($p<0.05$), with implications for visual perception and consumer acceptability of the product. One-factor ANOVA statistical analysis revealed significant differences in pH variation between the samples analyzed. The differences between the control sample and the samples with added concentrated soup are statistically significant ($p<0.05$), the pH evolution being altered due to the contribution of weakly acidic organic compounds or mineral salts present in the concentrated soup. The decrease in average values in the samples with added soup may have a positive influence on the microbiological stability of the product, increasing its shelf life. By correlating the results presented in Table 3, an inversely proportional relationship can be observed between color intensity and pH parameters. It can be observed that as the pH value decreases, the color intensity of the samples increases. pH may be a factor that can influence the color variations of the studied samples.

As for the textural profile analysis, significant differences were found between the control sample and the samples to which concentrated soup was added, according to the p-values ($p<0.05$), as shown in Table 4.

In terms of the hardness of the samples, it can be observed that the impact of the addition of concentrated soup from bones decreased the consistency of the samples, this parameter decreasing significantly from a mean value of 29.49 N in the control sample to a mean value of 16.85 N in the L3 sample.

Table 3. Physical parameters of the experimental samples

Experimental groups		L*	a*	b*	pH
SM	**Count**	5	5	5	5
	Mean±SD	66.42^{a}±0.24	5.12^{a}±0.07	15.70^{a}±0.06	6.67^{a}±0.02
	Min.-Max.	66.15-66.77	5.06-5.25	15.61-15.76	66.64-6.7
L1	**Count**	5	5	5	5
	Mean±SD	66.53^{a}±0.49	4.89^{b}±0.14	15.98^{b}±0.11	6.61^{b}±0.01
	Min.-Max.	65.66-66.91	4.65-5.02	15.86-16.16	6.59-6.63
L2	**Count**	5	5	5	5
	Mean±SD	67.71^{ab}±1.09	5.52^{c}±0.06	15.91^{ab}±0.20	6.58^{a}±0.01
	Min.-Max.	65.87-68.73	5.45-5.61	15.56-16.07	6.57-6.6
L3	**Count**	5	5	5	5
	Mean±SD	68.81^{b}±0.91	4.68^{d}±0.09	16.33^{c}±0.10	6.55^{b}±0.03
	Min.-Max.	67.71-70.19	4.58-4.78	16.26-16.51	6.51-658
p-value		0.00	4.06E-09	1.58E-05	3.2E-06

Superscript letters that differ within the same column denote statistically significant differences, as assessed by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$), SM - sample control, L1 - 10% concentrated soup, L2 - 15% concentrated soup, L3 - 20% concentrated soup.

Table 4. Textural parameters of experimental samples

Experimental groups		Hardness (N)	Adhesiveness (N x mm)	Springiness	Cohesiveness (N)	Gumminess (N)	Chewiness (J)
SM	**Count**	5	5	5	5	5	5
	Mean±SD	29.49^{d}±1.36	53.20^{d}±0.51	0.27^{d}±0.01	1.66^{d}±0.05	49.77^{b}±3.96	13.46^{b}±1.50
	Min.-Max.	28.47-32.14	52.69-53.99	0.26-0.28	1.60-1.73	45.59-55.74	11.85-15.60
L1	**Count**	5	5	5	5	5	5
	Mean±SD	26.52^{c}±1.24	4.53^{b}±0.40	0.24^{c}±0.01	0.52^{a}±0.05	13.96^{a}±1.94	3.36^{a}±0.60
	Min.-Max.	25.27-28.58	3.89-4.82	0.23-0.25	0.47-0.58	12.40-16.60	2.85-4.15
L2	**Count**	5	5	5	5	5	5
	Mean±SD	23.60^{b}±0.78	3.60^{a}±0.43	0.20^{b}±0.008	0.50^{a}±0.06	12.04^{a}±1.74	2.50^{a}±0.39
	Min.-Max.	22.17-24.47	3.38-4.37	0.2-0.22	0.40-057	9.28-14.02	1.85-2.94
L3	**Count**	5	5	5	5	5	5
	Mean±SD	16.85^{a}±0.99	6.28^{c}±0.03	0.17^{a}±0.008	0.81^{c}±0.06	13.81^{a}±1.79	2.45^{a}±0.32
	Min.-Max.	15.84-18.46	6.22-6.31	0.17-0.19	0.73-088	11.71-16.17	2.10-2.91
p-value		2.9048E-11	1.22461E-28	2.43506E-10	3.26292E-15	9.14E-14	7.12067E-13

Superscript letters that differ within the same column denote statistically significant differences, as assessed by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$), SM - sample control, L1 - 10% concentrated soup, L2 - 15% concentrated soup, L3 - 20% concentrated soup.

This is basically due to the increase in the amount of gelling components in the realized products. In terms of adhesion, it can be seen that although the mean values decrease in the 10% and 15% of the control sample, respectively, they increase in L3, which indicates a recovery of the binding properties due to the amount of collagen. However, fish concentrated soup additions affect the ability of the dough to return to its original shape after elastic deformation, as the samples analysed show lower values in the ados (0.17) than in the control (0.27). Internal consistency demonstrates that at high concentrations of concentrated soup addition, collagenous compounds contribute to the stabilization of the product. The results show that, although compared to the mean value of the control sample (1.66 N), the mean values decrease in L1 (0.52 N) and L2 (0.50 N), in L3 the mean value increases to 0.81 N. The foaminess and chewiness were also significantly influenced by the concentrated soup addition (p<0.05). The gumonized parameter showed low mean values, from 49.77 N in the control sample to 13.81 N in the 20%-added sample. Chewability showing values of the means from 13.56 J in the control sample to 2.45 J in L3, demonstrating a reduction in the mechanical forces required for product fragmentation and chewing.

According to Pogurschi et al. (2018), consumption behavior in a "Western" society has changed in terms of the type of food consumed, but it is still limited in relation to income level and food price. However, according to Ciobanu et al. (2024) consumers turn their attention to a clean label, still being guided by the sensory properties that the final product presents. As regards the experimental samples conducted, the sensory analysis revealed variations in the visual appearance and color of the samples studied. Batch L2 (15%) recorded the highest mean value, 8.96, which explains that this addition brings an improvement to the visual impression. In the case of color, there is an increase in the averages up to batch L2 (15%), then a sharp decrease in sample L3 (20%), which shows that the concentrated bone soup added in a higher percentage changes the pigmentation of the color of the product, making it more unattractive. The mean values did not vary significantly in terms of taste, with a slight decrease in batches L2 and L3, which may indicate a change caused by mineral compounds that negatively modified the taste profile. In samples with a high percentage of concentrated soup, the panelists also did not appreciate the odor, with low average values. Consistency was the most stable attribute, with similar values for the lots. From a statistical point of view, the *p*-value > 0.05, indicating that none of the differences observed between the experimental samples were statistically significant.

Table 5. Sensory parameters of the experimental samples

Experimental groups		**Overall Appearance**	**Consistency**	**Taste**	**Smell**	**Color**
SM	**Mean±SD**	8.54±2.21	7.68±2.25	5.85±2.92	7.36±2.16	6.28±1.75
L1	**Mean±SD**	8.66±1.89	7.56±2.34	5.98±2.89	6.34±2.11	7.05±1.46
L2	**Mean±SD**	8.96±1.94	7.62±2.37	5.16±3.03	5.26±2.30	7.36±1.61
L3	**Mean±SD**	8±2	7.68±2.54	5.24±3.05	5.4±2.30	3.28±1.52
p-value		0.600151	0.993281	0.917887	0.989985	0.804889

Superscript letters that differ within the same column denote statistically significant differences, as assessed by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$), SM - sample control, L1 - 10% concentrated soup, L2 - 15% concentrated soup, L3 - 20% concentrated soup.

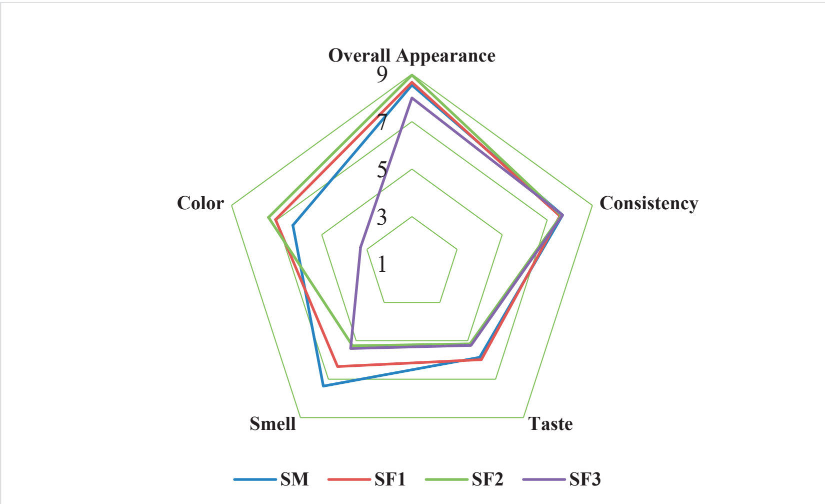

Figure 2. Diagram of the results of the sensory analysis of the experimental samples

The radar plot gives an overview of the values presented in the statistical table. Thus, from the diagram, it is confirmed that the experimental samples have a high score for general appearance, with L2 (SF2) in evidence. Overlapping lines are highlighted in the case of consistency, which denotes that there is uniformity among the experimental samples. Taste is affected by the percentages of soup added, which corresponds to the values in Table 5. At the same time, the downward trend of the L2 (SF2) and L3 (SF3) samples compared to the control sample is also observed. In the case of color, the diagram clearly shows a downward trend of the values presented in the statistical table for the experimental sample with 20% added bone broth.

CONCLUSIONS

The results obtained in this study showed that the addition of concentrated bone soup significantly influenced both the physico-chemical properties and the sensory profile of the experimental batches. Lot L2 (15%) provided a favorable balance between improved nutritional parameters and acceptable sensory characteristics. Therefore, the use of concentrated soups in moderate quantities may present a viable technological strategy for the valorization of animal-origin soups and the development of innovative food products with added value and improved functional profile.

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