[Turkish Journal of Veterinary & Animal Sciences](https://journals.tubitak.gov.tr/veterinary)

Volume 45 | Number 6 Article 8

1-1-2021

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Recommended Citation

SHAVIKLO, AMIR REZA; GHAMSARI, AMIR HOSSEIN ALIZADEH; ETEMADIAN, YASAMAN; and RAFIPOUR, FEREIDOON (2021) "The effects of dietary fish protein hydrolysate-based supplementation on sensoryproperties and meat quality of broiler chicken," *Turkish Journal of Veterinary & Animal Sciences*: Vol. 45: No. 6, Article 8. https://doi.org/10.3906/vet-2104-80
Available at: https://journals.tubitak.gov.tr/veterinary/vol45/iss6/8

Turkish Journal of Veterinary and Animal Sciences

http://journals.tubitak.gov.tr/veterinary/

Research Article

Turk J Vet Anim Sci
(2021) 45: 1041-1051
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doi:10.3906/vet-2104-80

The effects of dietary fish protein hydrolysate-based supplementation on sensory properties and meat quality of broiler chicken

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Received: 24.04.2021 • **Accepted/Published Online:** 25.10.2021 • **Final Version:** 13.12.2021

Abstract: The aim of the present study was to determine the effect of supplement fish protein hydrolysate-based to broiler feed on sensory properties and meat quality. A total of 400 pieces of 1-day-old male broiler chicks (Ross 308) received 4 dietary levels (0, 2.5, 5.0, 7.5%) of fish protein hydrolysate-based supplement (FPHS) in the basal diet mix for 42 days. Quality index-derived method (QIM) was used for assessment of chicken carcass. Quantitative descriptive analysis method was applied to study sensory properties of the chicken fillets. Water holding capacity (WHC), cook loss, color, meat texture were also determined. The carcass odor and flavor in broilers received 2.5, 5.0, and 7.5% FPHS were significantly different from those of control. The highest intensity of darkness, reddish pink, and yellowness of the legs and breast was observed in the carcass of control treatment. The highest fat content (1.34%) and WHC (70.36%) were reported in treatments received 7.5% FPHS. The umami taste was detected in chicken broth and cooked fillets of broilers fed received FPHS, which was not detected in the control treatment. The umami (a pleasant savory taste) was sensed more strongly in the cooked fillet followed by chicken broth. Breast fillet of birds received FPHS had a better texture, which was confirmed by shear stress measurement. The results could be helpful in application of FPHS in the poultry farming especially in the countries looking for local feed protein products as soybean meal replacement.

Key words: Broiler chicken, fish protein hydrolysate, meat quality, quality index method, sensory attributes, umami taste

1. Introduction

Chicken meat is one of the most popular livestock products consumed in the human diet, and it is known all over the world as a nutritious, healthy, and available animal food [1-2]. With a total production of more than 2.5 million tons in 2020, Iran is an important country producing chicken meat in the region and the world [3]. Like many chicken meat producing countries, poultry farming in Iran depends on the import of feed items such as corn and soybeans meal. Replacing these food items with local raw materials is one of the priorities of all poultry producers in the countries importing these items. Therefore, in order to reduce the dependence on imports and also the optimal use of fishery and agricultural wastes, it is necessary to move towards the production of local protein supplements such as fishery-based feed. This approach can solve the problems of commercial poultry production, which include high feed costs and limited feed resources [1,4].

Generally, poultry feed prices are about 60%–75% and more than 15% of the total cost of feed is protein [4]. The biggest challenge in the livestock industry is the need for protein-rich feeds. The production of these protein sources has more environmental effects than animal husbandry. Dependence on soybean imports from major producer countries for animal farming including broilers husbandry, has led many livestock producers to replace local protein products with soy protein. The use of local protein products, including fish protein ingredients from fishery by-products, is the best alternative to soybean meal in animal husbandry [1,5].

Fish protein hydrolysate (FPH) is the product of the breakdown of fish proteins into smaller peptides with a balance of amino acids and bioactive peptides have several functions, including antioxidant, antihypertensive, immune modulators, and antimicrobial in the body [6]. It has been recommended as an alternative to animal feed protein sources [6,7]. The annual production of FPH is

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not known because the domestic production statistics of the countries have not been reported in this regard. But the size of the FPH market exceeded USD 420 million worldwide in 2019 and is projected to grow by more than 5% by 2026. The FPH is developed in powder, paste and liquid forms. The FPH powder is widely used in the production of pharmaceutical industry. The FPH in liquid and paste forms are used in livestock, poultry, aquaculture, and pet food industries. The price of FPH varies from 1 US$ for a liter liquid FPH to 20 US$ for a kg high quality FPH powder [8].

The fish protein hydrolysate-based supplement (FPHS) is a new functional feed ingredient that can be introduced to the animal farming industry. This product, which is produced from fishery and agricultural by-products, may replace soybean protein in the livestock diet. The production method is such that the fish by-products or low value fish is enzymatically hydrolyzed, and then the liquid protein solution is mixed and codried with agricultural waste/ by-products. The protein content of this product is lower than fish meal but higher than soybean meal, with a higher nutritional value. This product is environmentally friendly as well as contributing to the greater independence of the local agricultural and animal farming industries [9].

Successful application of FPH in aquatic feed has been noted [10–12]. The use of marine-based protein hydrolysate has had a significant effect on the growth performance of broilers, especially at a young age, can promote intestinal and physiological growth and improve the growth and function of broiler chicken [7,13-16].

In the application of FPH in animal farming, the sensory quality of farmed animal meat has never been studied precisely. Therefore, the objectives of this work were a) to study the effect of using FPHS on the sensory characteristics of raw skinless chicken carcass using quality index-derived method (QIM) and b) to study sensory properties of the cooked samples (breast meat broth and fillets) with the focus on umami taste detecting by application quantitative descriptive analysis (QDA) method. The results of this study can be applicable for the industrial application of FPHS in poultry feed formulations.

2. Materials and methods

This work was implemented at the ASRI farms and laboratories (Animal Science Research Institute of Iran, Karaj, Alborz, Iran), based on the National Veterinary Organization recommendations to protect animals considered for scientific researches and the animal ethics committee of ASRI (Certificate No. 47-13-13-083-990566-22 Sep. 2020).

2.1. Bird breeding conditions and sampling

A total of 400 pieces of 1-day-old male broiler chicks (Ross 308) were obtained from a local hatchery (Karaj, Alborz, Iran). The chickens were weighed and allocated to 20-floor pens with 3m^3 spaces for each 20 chicks' treatment. The primary temperature of the farm was held at 32 ± 2 °C and slowly decreased to have a permanent temperature (21±1 °C) at the age of 42. Water and feed were supplied for the broilers use within the whole period of farm study.

Fish protein hydrolyzed-based supplement (FPHS) was obtained from Guilan Science and Technology Park (GSTP), Rasht, Iran. Chemical characteristics of the FPHS are given in Table 1. One-day-old male broiler chicks were randomly grouped into 4 treatments with 5 replicates of 20 birds. The basal diets were included 4 levels of FPHS (0, 2.5, 5.0, and 7.5%) in the main feed mix (starter, grower, and finisher phases) (Table 2).

At 42 day old, four birds were selected and slaughtered from each replicate based on the European Union legislation on the protection of animals used for scientific purposes (Directive 2010/63/EU). The carcasses of each slaughtered bird were used for sensory assessment. The chicken breasts were cut in 2 pieces and each half was labeled. The samples were put in plastic pouches and kept at –24 °C until further measurements.

2.2. Physico-chemical characteristics

Proximate compositions were measured using AOAC methods [17]. A texture Analyzer (Stable Micro Systems, TA.XTplus, Surrey, UK) was applied for Shear force analysis using Zhuang & Savage method [18]. Frozen samples were defrosted at room temperature overnight, and then they were cut into 100 mm^2 (10×10 mm) pieces. The thickness of each piece was 10 mm. A knife blade (72 mm long×68 mm wide×3 mm thick) was used for the experiment. The texture analyzer software reported the shear force values (N) in triplicate for the samples.

The method used by Ryoichi et al. [19] was applied to measure water holding capacity (WHC). Initially, about 2 g of the minced breast sample was wrapped in a filter paper (No. 4, Whatman Ltd. Kent, UK). Then, it was placed into a centrifuge tube followed by centrifugation at 6,700×g for 10 min (Hitachi Koki Co., Ltd. Fukuoka, Japan). The extracted and adsorbed water on the paper was weighed and measured as the primary moisture content of the chicken meat.

The color of chicken breast was assessed on the surface of the fillets using a colorimeter (Minolta Spectrophotometer, CM-3500d, Japan). The amount of lightness (L*), yellowness (b*) and redness (a*), were reported.

Boiling method was used to measure cooking loss. An Erlenmeyer flask containing 10 g of chicken breast and 50 g of distilled water was placed in a bain-marie laboratory water bath (1092, GFL Gesellschaft Für Labortechnik GmbH, Burgwedel, Germany) at 85 ± 5°C for 60 min. After leaving the Erlenmeyer flask, the broth and cooked

Table 1. Chemical compositions of FPHS*.

Compositional profile (g/100g)		**Amino acid profile (g/100g)**				**Fatty acid profile (% of total fatty acids)**	
Moisture	6.34	Aspartic acid	3.72	Methionine	0.82	C14:0 (Myristic acid)	1.83
Crude protein	45.72	Glutamic acid	6.74	Valine	2.47	C14:1 (Myristoleic Acid)	0.31
Crude fat	21.65	Histidine	0.92	Phenylalanine	2.14	C16:0 (Palmitic acid)	16.83
Ash	9.75	Serine	2.80	Isoleucine	1.89	C16:1 (Palmitoleic acid)	1.50
Fibre	1.0	Arginine	3.17	Leucine	3.57	C17:0 (Margaric acid)	0.50
Carbohydrate	15.54	Glycine	2.91	Lysine	2.34	C18:0 (Stearic acid)	5.36
Calcium	1.49	Threonine	1.67			C18:1 (Oleic acid)	26.70
Available phosphorus	0.89	Alanine	2.56			C18:2 (linoleic acid)	46.94
Metabolizable energy (KCal)	3527	Tyrosine	1.63			SFA	9.50
		Tryptophane	0.42			PUFA	72.64

*The product consisted of 50% FPH and 50% agricultural by-products.

Table 2. Broilers diets formula*.

Item	**Days 1–10**				**Days 11–24**				**Days 25–42**			
	FPHS (%)**				**FPHS (%)**				**FPHS (%)**			
	0	**2.5**	**5**	**7.5**	**0**	**2.5**	**5**	**7.5**	**0**	**2.5**	**5**	**7.5**
Ingredients(g/kg)												
Maize grain	544.5	541.6	536.9	532.1	615.2	614.5	608.2	603.4	656.9	657.8	653.3	650.3
Soybean meal (44%crudeprotein)	399.9	374.0	348.0	320.0	330.0	305.0	280.0	253.0	290.0	263.0	237.0	210.0
Soybean oil	11.0	10.0	10.0	10.0	11.0	9.5	9.5	9.5	12.7	10.5	10.5	9.5
Fish protein hydrolysate	-	25.0	50.0	75.0	-	25.0	50.0	75.0	-	25.0	50.0	75.0
Limestone	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	11.5	11.5	11.0	11.0
Dicalcium phosphate	18.5	18.5	18.5	18.5	17.8	17.8	17.8	17.8	16.5	16.5	16.5	16.5
Sodium chloride	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.3	2.5	2.5	2.2	2.5
Bicarbonate sodium	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Vitamin-mineral premix	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
DL- Methionine 99%	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.1	2.1	2.1	2.1
L- Lysine HCL	1.4	1.7	2.1	2.6	1.3	1.6	2.0	2.5	1.2	1.2	1.2	1.7
L- Threonine	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
Washed sand (inert filler)	-	4.5	9.8	17.1	-	1.9	7.8	14.3	-	3.3	9.6	14.8
Nutrient composition												
Metabolizable energy (MJ/kg)	12.0	12.0	12.0	12.0	12.4	12.4	12.4	12.4	12.6	12.6	12.6	12.6
Crude protein	225.2	225.8	225.9	225.3	200.3	201.0	201.5	201.2	185.6	185.3	185.0	185.0
Calcium	9.1	9.4	9.7	10.0	8.8	9.1	9.4	9.7	7.8	8.1	8.2	8.5
Phosphorus	4.5	4.6	4.7	4.8	4.3	4.4	4.6	4.7	3.8	3.9	4.1	4.2
Sodium	1.9	1.9	2.0	2.0	1.9	1.9	2.2	2.5	1.7	1.7	1.7	1.8
Lysine	13.7	13.7	13.7	13.7	11.9	11.9	11.9	11.9	10.8	10.5	10.2	10.3
Cystine +Methionine	9.5	9.6	9.7	9.7	8.8	9.2	9.6	9.9	8.2	8.5	8.9	9.2

* All diets of the tested chickens were adjusted to contain the same levels of protein and energy to meet the nutritional needs of Ross 308.
.** The protein content of fish protein hydrolysate was 45.72%.

meat were separated. The cooked meat was drained and cooled to room temperature. The samples were then weighed to determine the cooking loss as a percentage of the total weight loss. Chicken broth was kept for sensory evaluation.

2.3. Sensory assessment

For sensory assessment of the chicken carcass and chicken meat trained and skillful expert panel consisting of 6 (3 females) assessors with the average age of 30 were used. The panelists were trained during 4 sessions to evaluate raw chicken carcass, and chicken broth, and cooked chicken fillet using QIM and the QDA, respectively. To evaluate fresh skinless chicken carcass a sensory criterion with 14 attributes was used (Table 3). During training sessions, 17 attributes were detected to evaluate the cooked samples (chicken broth and chicken fillet). These attributes are presented in Table 4.

Sensory evaluation of the samples was carried out according to the ISO guidelines [20,21]. This evaluation was performed separately on:

- raw skinless chicken carcass
- chicken broth, and
- cooked chicken fillet

Initially, the QIM was used to assess the sensory quality of the broilers' skinless carcass samples including appearance, odor, color, and texture (Table 3). Then, the sensory attributes of the chicken broth were studied. The procedure for making chicken broth was mentioned in Section 2.2. About 20 ml of chicken broth was poured into a plastic container and it was given to the assessors in random order in 2 different sessions for evaluation together with a glass of warm water for palate cleansers, a spit cup for expectoration, and a paper napkin.

Finally, to evaluate cooked chicken fillets, the breast meat samples were grilled in a kitchen oven for 40 min at 190 ± 5 °C with a core temperature of 75 °C. Cooked fillets were divided into 7 pieces with vertical slices (Figure 1). Sections 1 and 7 (the end pieces) were not used for sensory evaluation. Each piece was considered for a panelist. The panelists were asked to use the left part of each piece to evaluate the odor, the middle part to evaluate the texture, and the right part to evaluate the taste.

Table 3. Sensory criteria for evaluation of fresh skinless chicken carcass*.

Appearance	Definitions	Scales
Leg color (yellowness)	Color severity.	Light = 0, yellow = 100
Leg color (redness)	Color severity.	Light = 0, pink = 100
Leg color (darkness)	Color severity.	Light =0, dark = 100
Breast color (yellowness) Leg skin color (pinkish)	Color severity.	Light =0, yellow = 100
Breast color (redness)	Color severity.	Light =0, pink = 100
Breast color (darkness)	Color severity.	Light =0, dark = 100
Abdominal cavity		
Fat		
Fat color (yellowness)	Color intensity.	Light = 0, yellow = 100
Odor of fat	Intensity of chicken odor.	None = 0, much = 100
Fat texture	After pressing with fingers.	Very soft = 0, firm = 100
odor		
Rancid odor	Rancid odor can remind oxidation.	None = 0, much = 100
Metallic odor	Metallic odor can remind iron odor.	None = 0, much = 100
Unusual odor	Unusual odor like sourness.	. None = 0, much = 100
Meat texture		
Thigh	After pressing the thigh tissue with the index and thumb fingers, it comes back to the previous position.	Irreversible = 0, fast reversible = 100
Breast	After pressing the breast tissue with the index and thumb fingers, it comes back to the previous position.	Irreversible = 0, fast reversible = 100

*adapted from Shaviklo et al. [47].

Table 4. Vocabulary used for sensory characteristics of cooked chicken breast*.

Attribute	Definitions	Scale (0–100)
Odor		
Chicken	How intense is the odor of fresh chicken meat?	none | much
Fish	How intense is the odor of fresh fish meat?	none | much
Off-odor	How intense is the off-odor?	none | much
Metallic	How intense is the odor of iron?	none | much
Flavor/ Taste		
Chicken	How intense is the flavor of fresh chicken meat?	none | much
Fish	How intense is the flavor of fresh fish meat?	none | much
Off-odor	How intense is the off-flavor?	none | much
Metallic	How intense is the flavor of iron?	none | much
Umami	How intense is the of umami taste?	none | much
Sweet	How intense is the of umami taste?	none | much
Salty	How intense is the of umami taste?	none | much
Bitter	How intense is the bitterness taste?	none | much
Astringency	How intense is the astringency?	none | much
Texture**		
Tenderness	How tender is the sample until the fourth chew?	firm | soft
Elasticity	How 'elastic-like' is the sample until the fourth chew?	little | much
Juiciness	How juicy is the sample until the fourth chew?	dry | juicy
Acceptance		
Liking	How do you like it?	none | much

*adapted from Horsted et al. [46] & Shaviklo et al. [47]).
** Texture attributes were evaluated for cooked chicken fillet.

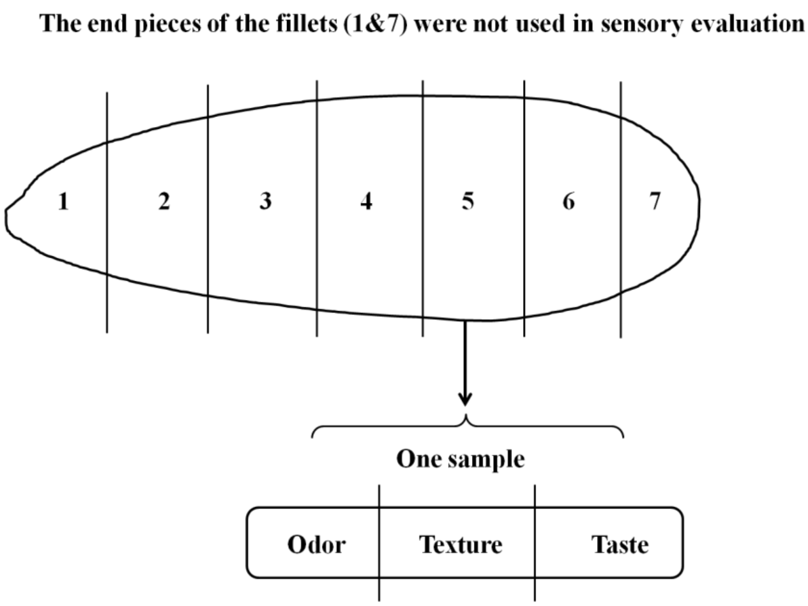

Figure. 1 Chicken fillet slicing image for sensory evaluation*.
* adapted from: Horsted et al. [46]

Sensory attributes of chicken broth and cooked chicken fillets were assessed on an unstructured and unmarked 15 cm line scale ranging from 0 (no cognition) to 100 (intense cognition). All test specimens were numbered accidentally with 3-digit numbers and given to the panelists separately. How to present the sample to the panelists in two replications was completely random [22].

2.4. Statistical analysis

Sensory data was analyzed, and the performance of the panelists was controlled by the software (PanelCheck version V1.3.2, Matforsk, Ås, Norway). The NCSS statistical program (NCSS, Statistical Software, Kaysville, UT) was used to assess the variance (ANOVA) of physicochemical data. A principal component analysis (PCA) was used for the visualization of the results. The PCA plot was organized by a statistical program (Unscrambler V 9.7, CAMO Software AS, Oslo, Norway). The program calculated multiple comparisons using Duncan's test to indicate if treatments were different. All differences were considered statistically significant when $p < 0.05$.

3. Results

3.1. Physicochemical characteristics

The assessment of physicochemical properties indicated that the diet containing FPHS influenced the quality of the chicken meat (Tables 5 and 6). Across the treatments, control and chickens received FPHS had equal protein (21.11%–22.33%), moisture (74.74%–75.76%) and ash content (1.16%–1.78%), and in breast fillet. Control had the lowest fat content (0.88%) and pH (5.67). The highest fat content (0.99%–1.34%) was reported for the chickens, which received the FPHS diet. The highest of WHC was observed in the treatment received 7.5 and 5% FPHS (70.36 and 68.20%). The highest cook loss (39.78%–41.23%) was found in the control and treatments received 2.5 and 5% FPHS. The pH values among treatments showed significant differences. The control sample had the lowest pH value (5.67). Birds fed with FPHS had the same level of pH (5.80–5.91). Lightness values (41.21–51.14) were equal for the broilers that received the FPHS diet. The highest redness (b*) and yellowness (a*) value was observed in

Table 5. Proximate analysis (%), pH, WHC (%) and cook loos (%) of chicken fed with different level of FPHS in the diets for 42 days

Samples	C0	C1	C2	C3	P value
Protein	22.24±1.21	22.33±1.15	21.29±1.21	21.11±1.25	p>0.05
Moisture	74.74±0.30	74.91±0.21	75.76±0.32	75.16±0.14	p>0.05
Ash	1.78±0.03	1.19±0.29	1.18±0.10	1.16±0.32	p>0.05
Fat	0.88^{b}±0.05	0.99^{ab}±0.03	1.10^{a}±0.18	1.34^{a}±0.26	p<0.01
pH	5.67^{b}±0.01	5.80^{ab}±0.04	5.88^{a}±0.01	5.91^{a}±0.03	p<0.0001
WHC	61.02^{b} ±0.40	63.25 ^{b}±0.39	68.21 ^{a}±0.44	70.36^{a}±0.50	p<0.0001
Cook loss	41.23^{a}±0.31	40.34^{a}±0.30	39.78^{a}±0.29	37.78^{b}±0.34	p<0.001

Values are mean of 3 analyses. The numbers with different superscript letters in a row are significantly different. C0: control sample, C1: broilers received 2.5% FPHS, C2: broilers received 5.0% FPHS; C3: broilers received 7.5% FPHS.

Table 6. Color evaluation values and shear force of broilers received different level of PHS in the diets for 42 days

Treatment	**C0**	**C1**	**C2**	**C3**	**P value**
L* (Lightness)	35.14^{a}±4.01	41.21^{b}±2.02	46.18^{b}±1.58	51.14^{c}±2.36	p<0.001
a* (Redness)	16.04^{a}±2.02	10.94^{b}±1.07	08.50^{b}±1.25	05.16^{c}±1.50	p<0.01
b* (Yellowness)	15.75^{a}±2.01	10.50^{b}±1.52	07.75^{bc}±1.42	05.10^{c}±0.83	p<0.001
Shear force (N)	87.92^{b}±11.09	102.09^{ab}±14.53	123.60^{a}±15.23	134.78^{a}±13.46	p<0.01

Values are mean of 3 replicates. The numbers with different superscript letters in a row are significantly different. C0: control sample, C1: broilers received 2.5% FPHS, C2: broilers received 5.0% FPHS; C3: broilers received 7.5% FPHS.

the control samples. The lowest a* and b* values were observed for the birds that received 5.0 and 7.5% FPHS (Table 6). The chicken breast samples had different levels of shear force values. The broilers received FPHS had the highest shear force (102.09–134.78 N) comparing to the control (87.92 N) (Table 6).

3.2. Sensory evaluation

Feeding broilers containing FPHS played a significant role in the sensory quality of their meat. Sensory results of fresh skinless chicken carcass showed only a difference in the color attribute (Table 7). Leg and breast meat of control birds had the highest intensity of darkness, yellowness, and redness. The yellowness of fat color was more recognized in the control. Abnormal odor in the abdominal cavity and adipose tissue and meat were not observed in any of the samples and they had a similar texture.

Feeding broilers with FPHS affected the sensory quality of chicken broth and cooked chicken fillets. No significant differences were found for chicken odor and flavor, within the chicken broth of the treatments. Umami taste and liking in the chicken broth was only detected in the birds that received FPHS and these treatments were more liked comparing to the control. Attributes like odor and flavor, metallic odor and flavor, off-odor/ flavor, and bitterness were not detected in the treatments. The same results with the higher severities were observed in the evaluation of cooked chicken fillets. Chicken fed with FPHS was more liked by the expert panel due to detecting umami taste in these treatments. The control treatment had the lowest scores for elasticity like texture, tenderness and juiciness, and liking. The highest texture scores and liking were reported for treatments received 7.5% FPHS.

An overview of multivariate analysis of the interaction between physicochemical and sensory characteristics data shows that FPHS plays an important role in characterizing meat quality, whether physicochemical or sensory. This interaction between sensory and quality properties of the raw skinless carcass, chicken broth, and cooked chicken fillet data was visualized on PCA plots (Figure 2). Birds received FPHS and control samples were classified individually. The control samples (C0) are on the left side and birds received 2.5, 5 and 7.5% FPHS (C1, C2, C3) are on the right side of the chart. The features on the right part of the chart show that the birds that received FPHS have similarities in terms of sensory quality. FPHS-fed treatments were mostly characterized by the taste of umami, juiciness and acceptance, high WHC, and shear stress values. The intensity of umami taste and liking scores were increased in the broilers fed with higher levels of FPHS in their diet as shown by the circle.

4. Discussion

A review of the literature indicates that only a few works studied sensory and quality changes of broiler meat fed with marine-based protein hydrolysate in their diet. Hardini & Djunaidi [16] studied the influence of incorporating

Table 7. Sensory scores for evaluation raw skinless chicken carcass

Attribute	C0	C1	C2	C3	P value
Leg color: yellowness	68.3	43.2	42.0	39.3	p<0.01
Leg color: redness	65.5	51.3	47.5	42.2	p<0.01
Leg color: darkness	64.4	44.5	37.6	36.5	p<0.001
Breast color: yellowness	60.2	46.6	45.2	39.6	p<0.01
Breast color: redness	65.6	45.1	49.3	43.4	p<0.001
Breast color: darkness	75.3	44.0	33.1	31.3	p<0.001
Fat color: yellowness	63.6	41.2	38.0	40.0	p<0.01
Fat odor: chicken odor	27.1	31.6	27.1	27.3	p>0.05
Fat texture	45.3	39.2	37.4	42.4	p>0.05
Abdominal cavity: rancidity odor	16.0	19.5	17.3	11.1	p>0.05
Abdominal cavity: metallic odor	16.3	15.7	21.5	13.3	p>0.05
Abdominal cavity: unusual odor	15.2	29.4	22.2	23.5	p>0.05
Chicken leg texture	84.5	84.0	82.6	84.6	p>0.05
Chicken breast texture	85.6	85.3	83.3	84	p>0.05

Broilers received different levels of FPHS in the diets and were slaughtered at the day of 42. Values are mean of 10 analyses. C0: control sample, C1: broilers received 2.5% FPHS, C2: broilers received 5.0% FPHS; C3: broilers received 7.5% FPHS.

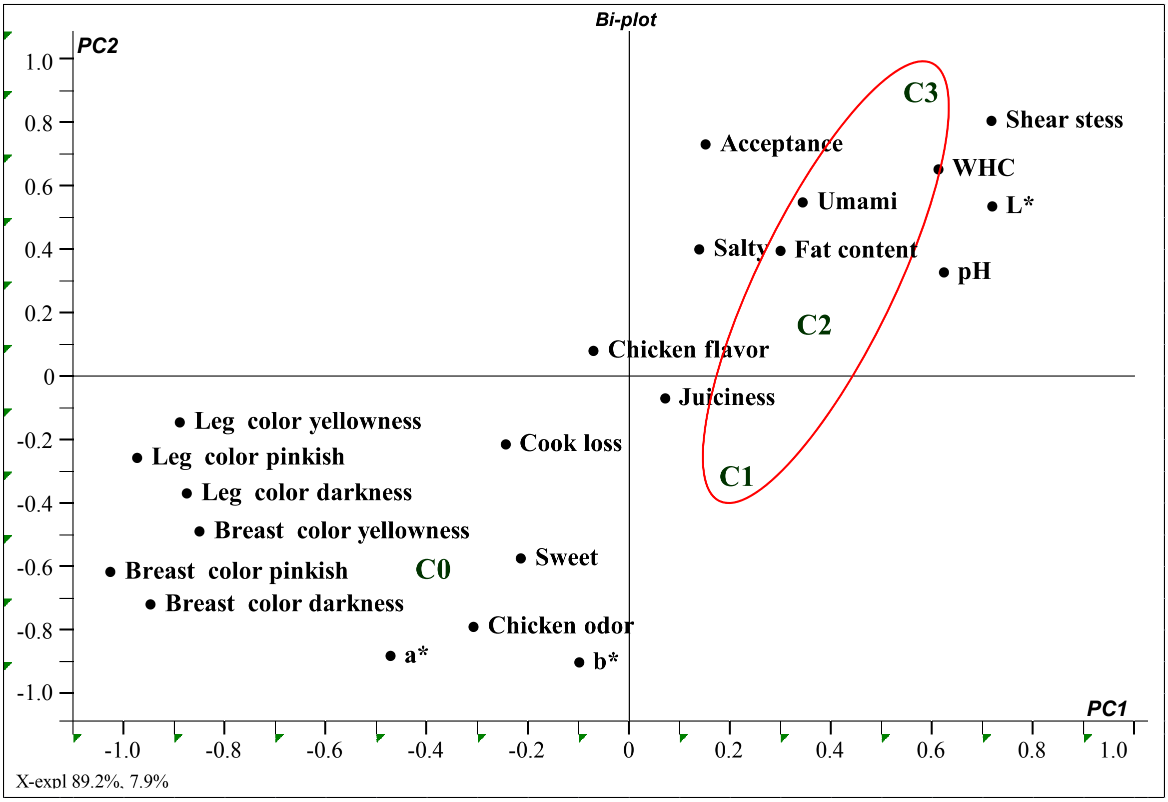

Figure. 2. PCA scheme describes sensory scores of 42-day-old cooked chicken carcasses and breast fed with FPHS evaluated by an expert panel. C: control sample, C1: broilers received 2.5% FPHS, C2: broilers received 5.0% FPHS; C3: broilers received 7.5% FPHS.

shrimp waste hydrolysate in broiler feeding and reported that the inclusion of hydrolyzed shrimp waste improved texture, cooking loss, and WHC of broiler meat. The shrimp waste hydrolysate inclusion did not affect the pH value, ash, and protein content of broiler meat, but it was significantly affected the water and lipid content of broiler meat. The pH value and ash content of meat were similar to control, and the fat and protein content were significantly decreased by treatments.

In our study, feeding broilers with FPHS increased the fat content possibly due to the high-fat content of FPHS (21.65%). The pH value of meat mostly depends on the level of glycogen in the muscle. The WHC, texture, and color of raw meat are affected by the pH value [5]. Birds fed with 5.0 and 7.5% FPHS had the highest WHC because chicken meat with higher pH value has higher WHC and cook-loss.

FPHS content significantly affected meat color (Table 6). The control sample was darker than the samples fed the FPHS diet. The higher yellowish and redness values were observed for the control treatment. It has been noted that texture properties of meat are influenced by the pH value, and it is the main cause of chicken meat color [5].

The functional and physicochemical properties of chicken meat influence the lightness (L*) of raw and cooked meat [18]. Accordingly, chicken meat at pH = 6.0 has the least protein changes and a clear lightness. However, at pH value below 6.0, more protein denaturation occurs, resulting in more light dispersion and clarity. The shear force was higher in the FPHS treatment compared to the control. Muscle fat content and meat moisture can affect the quality of broiler meat [23].

Wu et al. [14] evaluated the effect of feeding 4 types of FPH meals on broiler performance and carcass sensory quality. They reported no significant differences among the treatments in total moisture, cooking time, total cooking losses, and juiciness. According to their results, the fish odor may be detected in the carcass if FPH is included at a higher level in the diet. Therefore, the use of FPH in poultry diets should be carefully adjusted to prevent adverse changes in the sensory quality of the meat.

Odor and flavor compounds play an important role in the sensory properties of muscle foods [24–26]. More than 350 volatile compounds have been found in various chicken meats with a content range of hundreds of micrograms (μg) or nanograms (ng) per kg [2, 27–31].

These compounds affect sensory attributes of chicken meat [10,32]. The volatile compounds in fresh or cooked chicken meat have been reported to depend on a variety of factors, including genetic factors, sex, age, diet, as well as various processing factors [2,33]. Ayseli et al. [2] evaluated volatile compounds in chicken breast meat. They identified 33 volatile compounds in the chicken breast extracts which contained volatile acids (8), esters (4), alcohols (8), ketones (4), aldehydes (4), volatile phenols (4), and terpene (1). Acids and esters were found as the major compound classes. They concluded that in terms of odor contribution to raw chicken breast meat hexanal and 4-vinyl-2-methyoxyphenol were more prominent based on odor activity value.

In sensory evaluation, the meat odor is detected faster than the flavor and taste and may influence the product's acceptance [22]. Sensory assessment of skinless raw chicken carcasses fed FPHS showed significant differences in thigh/breast meat and fat color and meat texture. The chicken meat color is affected by the pH value and protein denaturation, and the level of lipid-soluble pigments in the feed ingredients [34]. Furthermore, FPH containing sarcoplasmic pigments that may affect the color of the final product. The off-odor/ flavor, fishy and metallic odor and flavor, and bitterness are sensory attributes that are undesirable in meat products and hurt consumer liking [22]. These attributes were not detected among the treatments. It may explain that the protein supplement did not have the pungent odor and flavor of fish, and the amount of supplement in the diet was appropriate.

Cooking influences the acceptance and flavor of poultry meat [11]. Because the thermal process causes a reaction between amino acids and lipids, oxidation and decomposition of thiamine create many volatile compositions. Most of the meat-specific flavors are related to these volatile compounds [34]. Accordingly, carbonyl compounds are known the main cause of flavoring compounds in cooked chicken. These compounds are formed by the peroxidation of unsaturated acyl lipids and are one of the most important causes of *chicken-like* odor. If they are removed from the volatile part, it leads to the disappearance of *chicken-like* odor and enhancing of meat odor [35]. On the other hand, saturated and unsaturated aldehydes containing 6–10 carbons are the major volatile compounds in cooked meat. Therefore, they may play an important role in creating the aroma of meat. The odor threshold values of aldehydes are usually lower than those of volatile compounds. Therefore, they have a potentially important effect on chicken meat flavor [29, 36, 37] cited by Ayseli et al. [2].

Several scientific studies have reported flavor development in marine-based protein hydrolysates [38,39]. In our study, we observed umami taste as dominant sensory attributes in broilers fed with FPHS. However, little information is available on the sensory attributes of broiler chicken (carcass/ meat) fed with FPHS. Detecting umami taste in chicken broth and cooked fillets are positively associated with FPHS in broilers' diet. Umami, the fifth basic taste, has a meaty, broth-like, or savory taste and is used to describe the taste of meat products [40]. Among all free amino acids, only aspartic acid and glutamic acid or a combination of them contribute to the characteristic umami/ palatable taste [41-43].

Several peptides in various fermented foods and protein hydrolysates have been known to have umami taste due to free amino acids and various-sized peptides [44]. Noguchi et al. [23] reported that several dipeptides and tripeptides based on glutamic acid and aspartic acid are responsible for umami taste in FPH even in low threshold concentration (150–300 mg/100g). It is reported that FPH consists of free amino acids like glutamic acid and glutamic acid-rich oligopeptides, which play as a natural flavor enhancer and create umami taste [44]. Unlike Park et al. [45], which stated a combination of glutamic and aspartic acids in the absence of NaCl in fish sauce taste sour and umami, we observed that in the absence of NaCl chicken broth and cooked fillet tasted salty and umami. This is in line with Shimono & Sugiyama, [44] who reported that FPH increases the salty taste in food and Youn et al. [43], who investigated the intensifying effect of saline taste by enzymatically hydrolyzed Anchovy protein. This positive effect of these amino acids had a significant effect on improving the palatability of chicken meat. In our study, glutamic acid (6.75 g/100g) and aspartic acid (3.72 g/100g) were the higher values among amino acids profile of FPHS.

Meat texture, especially juiciness, is one of the most important sensory qualities related to consumer acceptance of poultry meat [34]. WHC of meat affect the juiciness attribute [31], and this may explain why birds fed 5% and 7.5% FPHS more liked and accepted by the panelists.

5. Conclusion

Dietary supplementation of FPH indicated a favorable impact on sensory attributes and quality characteristics of the carcass and chicken meat. Meat sensory improvement of the chickens received FPHS can be attributed to the breakdown of proteins and the release of peptides that have a taste-enhancing property and umami taste produced by glutamic and aspartic acids, which improved the palatability of the meat. In general, FPH seems to be an acceptable source of dietary protein for broilers as a substitute for a part of soybean meal in their diets and quality enhancement of poultry meat. Therefore, in countries that have less access to sources of soy and fishmeal, the use of fishery and agriculture by-products in animal feed can be a way to solve this problem with potential benefits.

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