Colegio de Postgraduados

Physicochemical evaluation of the meat of the American Bullfrog (*Lithobates catesbeianus*)

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Citation: Ortiz-Ortiz, C., Valencia-Cobos, M. C., Camacho-Carrasco, B., Pérez-Ruiz, Rigoberto V., Arce-Vázquez, María B., Aguilar-Toalá, J. E., Rosas-Espejel, M., & Cruz-Monterrosa, R. G. (2026). Physicochemical evaluation of the meat of the American Bullfrog (*Lithobates catesbeianus*). *Agro Productividad*. https://doi.org/10.32854/c73vrt46

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Juan Francisco Aguirre Medina

Received: October 5, 2025.
Accepted: December 5, 2025.
Published on-line: March XX, 2026.

Agro Productividad, 19(1). January. 2026. pp: 39-48.

ABSTRACT

Objective: To determine the physicochemical characteristics of bullfrog (*Lithobates catesbeianus*) meat.

Design/methodology/approach: Fifteen samples of bullfrog legs and fifteen samples of chicken meat were used. Subsequently, 50% of the meat was cooked in a water bath.

Results: Bullfrog meat had less protein and more fat ($P<0.05$) than chicken meat. The percentage of moisture and collagen was higher in bullfrog meat ($P<0.05$). The L*, a*, and b* values showed significant differences, with greater luminosity in cooked bullfrog meat, while a* showed a variation of 2.36 units in raw *vs.* cooked meat. b* was higher in cooked meat ($P<0.05$) compared to raw meat. The parameters water activity, water-holding capacity, and pH showed significant differences ($P<0.05$) between the two treatments analyzed.

Limitations/Implications of the study: The number of bullfrog samples was limited due to their cost and producers' distrust of institutional and governmental organizations.

Findings and Conclusion: Bullfrog meat is lean. The meat presented water activity values below the established limit for meat. This species is a viable alternative in the food sector.

Keywords: Meat, Bullfrog, raw meat, cooked meat, evaluation, physicochemical.

INTRODUCTION

The introduction of species outside their natural habitat occurs intentionally or accidentally as a result of human activities. This process generates adaptation mechanisms that allow species to survive in new environments. The absence of natural predators favors rapid population growth. This population increase facilitates the establishment of these species as pests and causes negative ecological effects (Casas *et al.*, 2001). In this context, the American bullfrog (*Lithobates catesbeianus*) is among the main drivers of the decline in amphibian populations worldwide (Laufer *et al.*, 2008).

Consuming frog meat is an age-old practice. In ancient Greece, frog meat was considered a delicacy. In Asian countries such as China, consumption of frog meat dates back more than 4,000 years. Currently, this meat remains widely recognized as a regional food. Rana catesbeiana is a species native to North America. Intensive frog farming began in the United States around 1915. Subsequently, during the 19th century, countries such as Mexico, Canada, Japan, and Brazil incorporated their production and consumption. Since then, frog meat has been introduced as an alternative food in industrialized Western countries and in various Latin American nations, such as Chile, Venezuela, and Argentina (Aragón, 2010). In Mexico, frog farming has gained importance in recent years. This activity responds to growing domestic demand and the export of specimens for research, teaching, and food. National production is concentrated mainly on the domestic market. Tourist areas account for the largest share of production (Ojeda, 2020). Likewise, population growth increases demand for food for human consumption. In this context, frog farming represents an activity with high productivity and economic potential. This potential is especially evident in the species *Lithobates catesbeianus* (Méndez, 2014).

Limited statistical data is available on bullfrog production and consumption. In 1980, aquaculture supplied approximately 3% of the global bullfrog market. By 2002, this proportion had increased to nearly 15%. Taiwan, Mexico, and Brazil led global production of this species during that period (Islas *et al.*, 2020; Islas *et al.*, 2021). In Mexico, the main bullfrog-producing states are the State of Mexico, Sinaloa, Nayarit, and Jalisco. Production in Jalisco reached approximately 20 tons in 2015. In 2016, production increased by 3.5 tons. In 2017, total production reached 26 tons. Bullfrogs have been successfully introduced to at least 16 states in the country. The State of Mexico stands out among the regions with a significant presence of this species. Official records indicate a sustained increase: national production rose from 5 tons in 2009 to 71 tons in 2014. This change represented a total increase of 66 tons over five years. The region's climate favors the development of the American bullfrog. The geographic location of the State of Mexico contributes to the establishment of the species. Physical and biological heterogeneity characterizes this region due to the diversity of physiographic, geographic, and hydrological regions, which increases the area's biotic richness (Aguilar *et al.*, 2009).

In the State of Mexico, the American bullfrog has gradually become established in various municipalities. Records indicate the species' presence in 39 municipalities. These include Almoloya de Juárez and Almoloya del Río. It is also found in Amatepec and Capulhuac, specifically in the town of San Miguel Almaya. Additionally, the species is present in Chicoloapan, in the town of San Vicente Chicoloapan, and in Chimalhuacán, Coatepec de Harinas, Ecatzingo, and Huehuetoca, in the town of Jorobas. The distribution includes Ixtapaluca, Ixtapan de la Sal and Jilotepec, Lerma, Malinalco, Metepec, Naucalpan, Nepantla, Ocoyoacac, Otzolotepec, San Antonio La Isla, San Mateo Atenco, San Simón de Guerrero, Santa María Rayón, Santo Tomás de los Plátanos, Sultepec, Tejupilco, Temascaltepec, Tenancingo, Tenango, Tepetlixpa, Tepotzotlán, Texcoco, Tlatlaya, Toluca, Valle de Bravo, Villa Victoria and Zumpahuacán (Casas *et al.*, 2001).

The American bullfrog adapts to temperate and warm zones with suitable aquatic systems. The species can thrive at altitudes up to 2,600 meters above sea level. Some reports indicate the species' ability to adapt to colder climates. In the Lerma region and along its river, a government-run breeding facility was established during the 1960s. The facility was located in the community of San Pedro Tlaltizapán, in the municipality of Tianguistenco. At this site, the American bullfrog exhibited a period of hibernation during the winter. This behavior was associated with the organism's poikilothermic nature. Generally speaking, the species thrives across a wide altitudinal range. Development occurs when water is available. It also requires adequate relative humidity. The species develops at ambient temperatures between 20 and 30 °C (Méndez Béjar, 2014). However, aquaculture activities in the region have declined. This decrease was due to the need to allocate the drinking water resource to supply other areas surrounding the Toluca Valley (Pillado and Viesca, 2013).

The culinary tradition of frog meat consumption has declined in recent years. Overexploitation of these species has contributed to this reduction. This process has led to frog meat currently being considered a high-value commercial product. In this context, frog farming presents significant production potential. This activity generates various byproducts for human consumption. The meat and its derivatives are the main products of interest. Frog legs represent the product with the highest export volume. Restaurants and supermarkets require this product to prepare gourmet dishes (Rodríguez, 2014; Vargas, 2015). The skin is another relevant byproduct; this material is mainly used in the manufacture of leather goods, such as wallets and belts. The byproduct represents approximately 11% of the animal's total weight. After harvesting, the skin must undergo sterilization before distribution. Other byproducts of interest include the viscera and liver. The viscera are used in the production of suture thread. The liver is used in the production of pâté. Additionally, the frog's body is used in cosmetic applications, such as the production of moisturizing creams (Rodríguez, 2014; Vargas, 2015).

The objective of this study was to perform a physicochemical evaluation of bullfrog meat. The meat of this species appears to have a high protein, mineral, and essential amino acid content for human consumption. It also contains mineral salts and is low in fat. The net meat yield represents approximately 60% of the animal's live weight. Frog legs constitute between 33% and 35% of the live weight (Vásconez and Rodríguez, 2003). However, the available scientific literature on the quality of bullfrog meat and the benefits associated with its consumption is limited.

MATERIALS AND METHODS

Meat quality is defined by its physicochemical characteristics. These characteristics include organoleptic and instrumental properties. Organoleptic properties include tenderness, juiciness, color, and flavor, among others (Guerrero, 2002). For the physicochemical analysis, the study used 15 bullfrog leg samples and 15 chicken meat samples, the latter serving as a positive control. The procedure involved defleshing the samples beforehand, followed by cooking 50% of the meat in a water bath at 60 °C for 20 minutes. Proximate chemical analysis was performed using a FoodScan™ Lab meat analyzer (Figure 1). Once the equipment was calibrated, the analysis was performed on 180 g samples placed in sample holders. The procedure avoided the formation of air

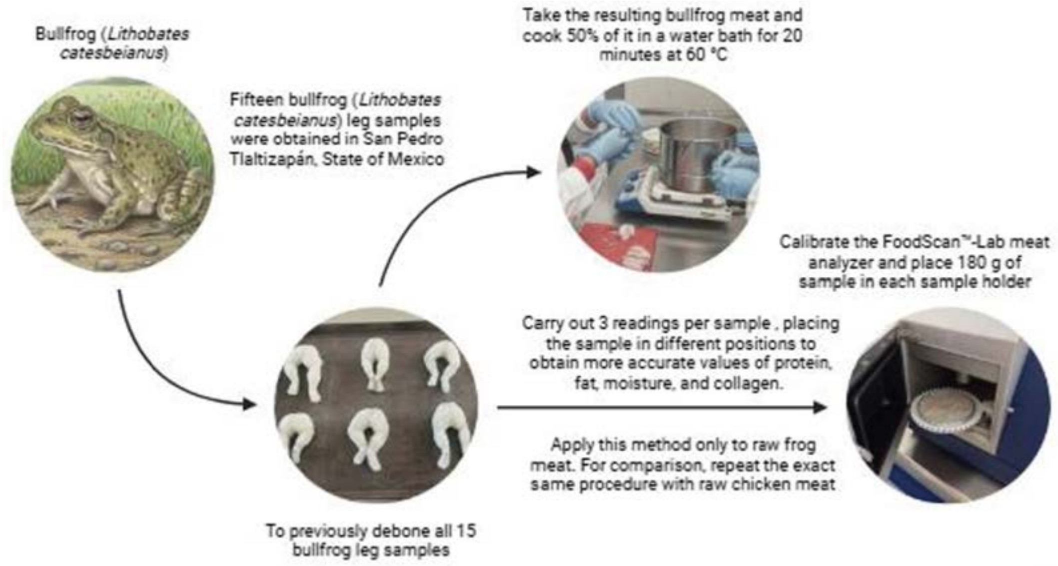

Figure 1. Procedure for the Proximate Analysis and Comparison of Raw Meat Using the FoodScan™-Lab Analyzer.

pockets and bubbles in the meat, thereby preventing alterations in the sample readings. The analysis included three readings per sample, taken at different positions. This procedure allowed for greater precision in determining the percentages of protein, fat, moisture, and collagen. The method was applied exclusively to raw meat. The study was compared to a positive control. The analysis used the same procedure for both treatments.

pH analysis was performed using potentiometry. The study employed a Beckman pH Φ 50 potentiometer (Palo Alto, California, USA). Color determination was performed using a Minolta portable colorimeter (Chroma Meter CR-400, Tokyo, Japan). The procedure used black-and-white standards for calibration. The analysis evaluated the color coordinates L*, a*, and b*. The meat was placed in the instrument's sample holder (Figure 2). The procedure involved rotating the sample 90°, allowing for four readings per repetition. Water activity (Aw) was determined using an Aqualab psychrometric instrument (Decagon CX-1, Washington, USA). The instrument exhibited a sensitivity of 0.001. Aw was expressed as $a_w = P/P_0$. In this equation, P represents the vapor pressure of the solution and P_0 the vapor pressure of the solvent, corresponding to pure water.

Finally, the study determined the meat's water-holding capacity (WHC). The procedure used 10 g samples. The analysis involved placing the samples in duplicate into centrifuge tubes. During the procedure, 16 mL of a 0.6 M NaCl solution was added to each tube. The samples were then incubated for 30 min in an ice bath. Subsequently, the samples were centrifuged at 5,000 rpm for 30 min. The study reported water-holding capacity as the milliliters of water retained per gram of meat (Figure 3).

RESULTS AND DISCUSSION

The chemical composition of bullfrog and chicken meat is shown in Table 1. The analysis identified differences between both treatments ($P<0.05$).

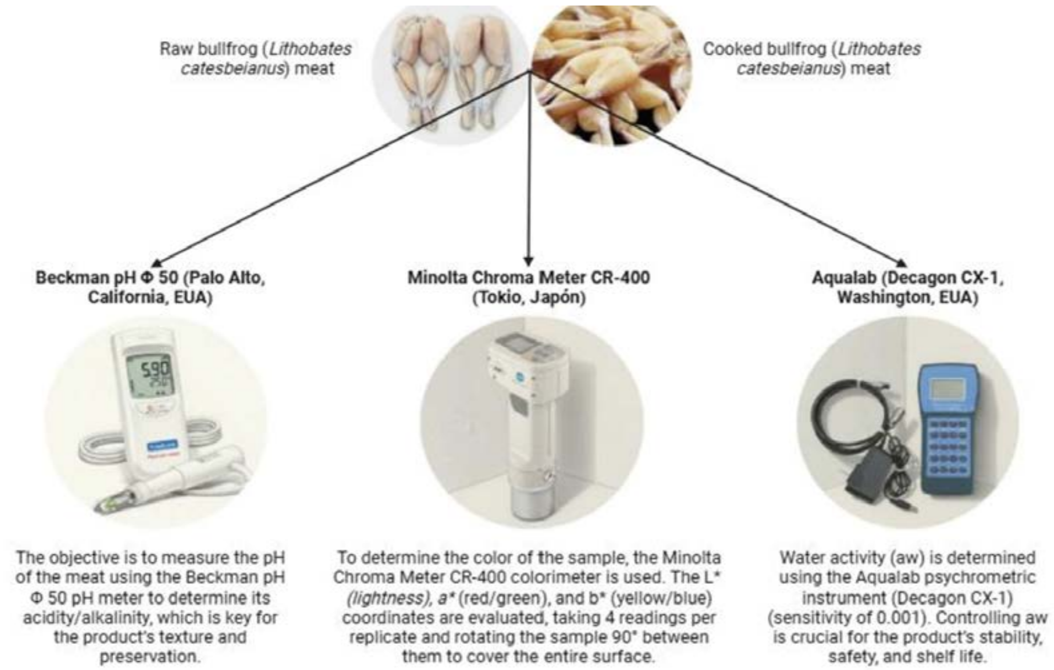

Figure 2. Determination of pH, color, and water activity in raw and cooked bullfrog (*Lithobates catesbeianus*) meat samples.

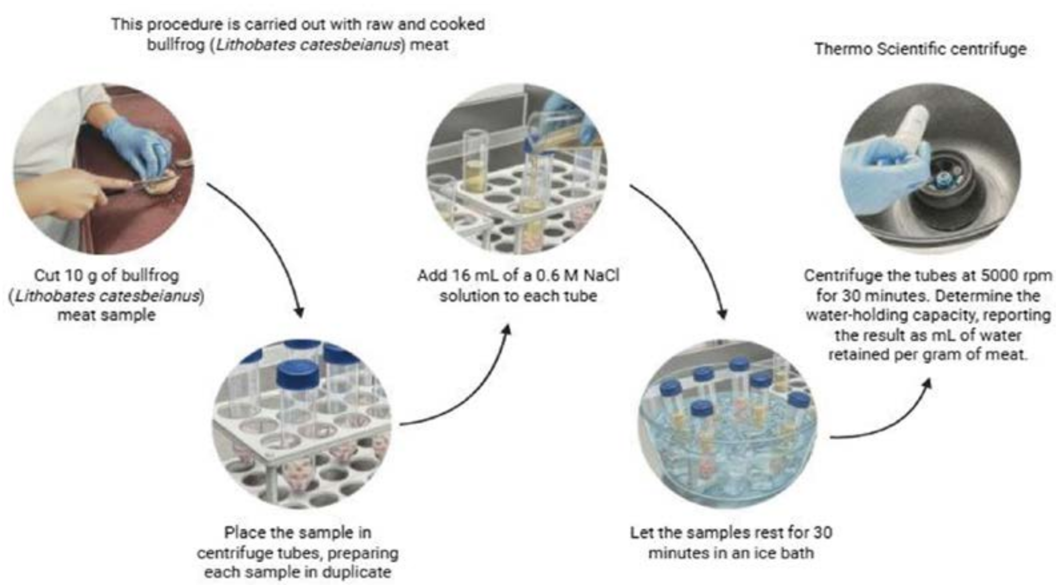

Figure 3. Analysis of water-holding capacity (WHC) by centrifugation method.

Table 1. Chemical composition of bullfrog meat (mean ± SD).

Meat	Protein	Fat	Moisture	Collagen
Bullfrog	16.84 ± 0.34[b]	0.71 ± 0.02[b]	81.39 ± 0.28[a]	1.03 ± 0.10[a]
Chiken	23.62 ± 0.03[a]	1.59 ± 0.01[a]	73.41 ± 0.06[b]	0.75 ± 0.24[b]

[a,b] Different letters in the same column indicate significant differences ($p<0.05$).

The protein content differed between bullfrog meat and chicken meat. Chicken meat showed a higher protein content than bullfrog meat. The values were 23.62% for chicken meat and 16.84% for bullfrog meat. This difference represented an approximate variation of 6.0 units. A study by Zhu *et al.* (2021) evaluated the nutritional composition of bullfrog meat in different parts of the animal. The authors reported protein values similar to those observed in the present study. The protein contents were 15.32±1.08% in the foreleg, 21.17±1.72% in the thigh, and 17.66±0.98% in the calf. The same study analyzed the amino acid content in different parts of the meat. The results identified glutamic acid, aspartic acid, and lysine as the most abundant amino acids. These results are consistent with those reported by Özden and Erkan (2011), who indicate that these amino acids predominate in aquatic organisms. The analysis also identified alanine, valine, glycine, arginine, and methionine in smaller proportions. Coura *et al.* (2016) evaluated the protein content of raw frog meat. They reported a value of 17.09%, which was lower than that observed in other species analyzed in the same study. Raw beef accounted for 21.09%. Indriana *et al.* (2023) described frogs and salamanders as the most common edible amphibians. They noted that frog legs are considered a culinary delicacy in Europe, the United States, Asia, Australia, and Africa. These authors also indicated that frog meat is consumed as an alternative to chicken. The flavor of frog meat was similar to that of poultry. Fat content showed statistically significant differences between the samples ($p<0.05$). Chicken meat had a higher fat content than bullfrog meat. Fat values were 1.59% in chicken meat and 0.71% in frog meat. Statistical analysis confirmed significant differences between the two treatments ($p<0.05$). Moisture content showed an opposite trend. Bullfrog meat had a higher moisture content than chicken meat. This difference represented an increase of 7.98 units ($p<0.05$). Collagen content showed a similar trend to that observed in moisture. Bullfrog meat had a higher collagen content than chicken meat ($p<0.05$). Quinto Mina (2021) indicated that frog meat has low levels of fat and carbohydrates. This nutritional profile is associated with higher protein and water content. These characteristics contribute to greater juiciness and lower acidity. These properties differentiate frog meat from that of other species, such as chicken, pork, and beef.

The results of the bullfrog meat color parameters are shown in Table 2. Statistical analysis identified significant differences between treatments ($p<0.05$). Meat color plays an important role in product quality. Color also influences consumer acceptance. This study evaluated bullfrog meat color using the parameters L* (lightness), a* (+red/−green), and b* (+yellow/−blue) in both raw and cooked meat. The L* parameter was higher in cooked meat than in raw meat ($p<0.05$). The L* value increased by 9.38 units after cooking. The a* parameter was lower in cooked meat than in raw meat ($p<0.05$). The difference between the two treatments was 2.36 units. The b* parameter showed a significant increase in cooked meat ($p<0.05$). The b* value was higher in cooked meat (14.15) than in raw meat (8.38).

Meat color results depend on the slaughter method used for bullfrogs. Ramos *et al.* (2005) evaluated meat color and muscle pigment levels in frogs subjected to electrical or thermal stunning, with and without exsanguination. The study reported lower myoglobin content in the muscles of electrically stunned frogs. This myoglobin content was similar to that observed in birds' white muscle. The analysis identified a correlation between muscle pigments and color parameters. Oxymyoglobin, reduced myoglobin, and metmyoglobin contents correlated with lightness (L*), redness (a*), and yellowness (b*). These results are consistent with those reported by Cori *et al.* (2014), who indicated that meat lightness depends primarily on the availability of hemoglobin and myoglobin. Additionally, Ramos *et al.* (2005) reported a lower content of muscle hemoglobin in the meat of frogs subjected to bleeding. This content was significantly lower than that observed in non-bleeding frogs ($p<0.05$).

A study by Padilla *et al.* (2022) evaluated the color parameters of raw frog legs from Jalisco and Morelos. The study reported L* values between 68 and 71, a* values between −0.80 and 0.90, and b* values between 8.00 and 9.40. All parameters showed statistically significant differences ($p<0.05$). These results indicated greater luminosity than that obtained for the raw meat analyzed. The production and consumption of bullfrog meat have increased steadily in recent years. However, the available information on its physicochemical properties remains limited. The composition of the meat is a relevant physicochemical property. Water loss during cooking is another important physicochemical property. These factors determine the intrinsic quality attributes and functional properties of the meat (Ssepuuya *et al.*, 2019).

Table 2 presents the results of pH, Aw, and WHC measured in bullfrog meat, both raw and cooked. The pH value was lower in raw meat than in cooked meat ($p<0.05$). The cooking process increased the pH by 0.14 units.

These results are consistent with those reported in the scientific literature. Several studies indicate that the pH values of meat increase during cooking; this increase is associated with the breaking of bonds involving imidazole, sulfhydryl, and hydroxyl groups. Other studies demonstrate that cooking processes at temperatures above 80 °C favor the formation of free hydrogen sulfide (Vasanthi *et al.*, 2007; Oz *et al.*, 2016).

Aw exhibited a similar behavior to that observed for pH. The Aw value was higher in cooked meat than in raw meat ($p<0.05$). The difference between the two treatments was 0.027 units. Increasing cooking temperature increases the energy of free water, thereby favoring an increase in water activity in food. Mendoza (2014) indicated that the Aw value in chicken meat should not fall outside the range of 0.98 to 0.99. The scientific literature establishes that Aw values in food range from 0.0 to 1.0. The values obtained in this study were 0.93 and 0.95. These values correspond to the ranges reported for meat products and for foods with high water availability, such as fresh meats, cured

Table 2. Analysis of color, pH and water functionality in bullfrog meat (mean±SD).

Type of meat	L*	a*	b*
Cooked frog	75.97 ± 2.93^{a}	2.41 ± 0.46^{b}	14.15 ± 1.06^{a}
Raw frog	66.14 ± 2.29^{b}	4.77 ± 1.03^{a}	8.38 ± 1.69^{b}
Type of meat	pH	Water activity	water-holding capacity
Cooked frog	7.14 ± 0.05^{a}	0.957 ± 0.007^{a}	14.97 ± 0.04^{b}
Raw frog	7.00 ± 0.15^{b}	0.930 ± 0.008^{b}	15.87 ± 0.69^{a}

[a,b] Different letters in the same column indicate significant differences ($p<0.05$).

meats, fresh fish, fermented sausages, soft cheeses, evaporated milk, fruits in syrup, and some vegetables. Foods with high Aw values are more likely to undergo microbiological spoilage. Consequently, the application of preservation technologies is necessary to control decomposition processes. These technologies help extend the product's shelf life (Inungaray and Reyes, 2013).

WHC showed significant differences between raw and cooked meat ($p<0.05$). Cooked meat exhibited a lower water-holding capacity than raw meat. The WHC value decreased from 15.87 to 14.97 units after cooking. This decrease represented a 0.9-unit reduction. Rengifo (2010) evaluated the water-holding capacity of chicken meat, reporting a value of 22.5% in fresh meat and 6.62% in cooked meat. León *et al.* (2017) analyzed the water-holding capacity of chicken meat and reported a value of $17.603 \pm 2.587\%$. These studies indicate that pH influences WHC, increasing as pH moves away from the proteins' isoelectric point.

The WHC of frog meat showed statistically significant differences compared to chicken meat. This difference was observed in both raw and cooked frog meat. However, the available scientific evidence on the physicochemical analysis of frog meat is limited. For this reason, the study used chicken meat as a reference. Both species share similarities in their organoleptic characteristics, including taste, color, and aroma. Nóbrega *et al.* (2007) analyzed the volatile compounds present in pressure-cooked bullfrog legs. The study used steam distillation and simultaneous solvent extraction. The authors identified compounds with high odorant activity, including (E,E)-2,4-decadienal, (E,Z)-2,4-decadienal, (E,Z)-2,6-nonadienal, 1-octanol, and (E)-2-nonenal. These compounds are commonly associated with the characteristic aroma of chicken, which explains the sensory similarity between bullfrog and chicken meat.

CONCLUSION

This study revealed differences in the nutritional quality of bullfrog meat compared to chicken meat. However, the scientific literature reports similarities in the organoleptic characteristics of the two species, including flavor, color, and aroma. Bullfrog meat is considered lean due to its low-fat content. This characteristic suggests that this species is more commonly associated with aquatic organisms than with terrestrial ones. Furthermore, bullfrog meat presented water activity values below the established limit for meat. However, these values approached 1.0, increasing the risk of microbiological spoilage. In this context, the application of preservation methods is necessary to guarantee product stability. Brine is a viable alternative, as it reduces the meat's water activity and limits the growth of microorganisms responsible for spoilage. The available scientific information on bullfrog meat in the State of Mexico is limited. This lack of evidence restricts a comprehensive evaluation of its quality and the benefits associated with its consumption. Therefore, this study provides relevant information from a general perspective and contributes to the physicochemical knowledge of bullfrog meat. The results obtained highlight the need to continue research into the nutritional, functional, and technological properties of this species to further strengthen its use as a viable alternative in the food sector.

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