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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

A Comparative Study on Quality and Nutritional Values of Rainbow Trout (*Oncorhynchus mykiss* Walbaum, 1792) Treated by Liquid Smoke and Traditional Smoking Methods

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Abstract: In this research, the physical, chemical, and sensory effects of liquid smoking and traditional smoking methods on rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) were examined and compared. Both groups obtained by these methods were found to have high nutritional value, while a decrease in moisture and lipid content was observed in the traditional smoking group due to the cooking method. Liquid smoking caused a greater reduction in pH compared to the traditional method, while the TVB-N value was higher in the liquid-smoked group. TBARs values were low in both methods, indicating good quality in terms of lipid oxidation. In sensory analyses, both smoked groups received high acceptance scores; traditional smoking stood out in appearance and texture, while liquid smoking was preferred for saltiness. Textural analyses revealed that products treated with liquid smoke exhibited a more elastic and cohesive structure. In conclusion, liquid smoking applied to rainbow trout emerges as a strong alternative to the traditional method in terms of both quality and health.

Keywords: Liquid smoking, traditional smoking, rainbow trout, sensory analysis, food safety.

Sıvı Dumanlama ve Geleneksel Dumanlama Yöntemleriyle İşlenen Gökkuşağı Alabalığında (*Oncorhynchus mykiss* Walbaum, 1792) Kalite ve Besin Değerleri Üzerine Karşılaştırmalı Bir Çalışma

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Öz: Bu araştırmada, sıvı dumanlama ve geleneksel dumanlama yöntemlerinin gökkuşağı alabalığı (*Oncorhynchus mykiss* Walbaum, 1792) üzerindeki fiziksel, kimyasal ve duyusal etkileri incelenmiş ve karşılaştırılmıştır. Bu yöntemlerle elde edilen her iki grupta da yüksek besin değeri bulunmuş, geleneksel dumanlama grubunda ise pişirme yöntemine bağlı olarak nem ve yağ içeriğinde azalma gözlemlenmiştir. Sıvı dumanlama, geleneksel yönteme kıyasla pH'da daha büyük bir azalmaya neden olurken, TVB-N değeri sıvı dumanlanmış grupta daha yüksek bulunmuştur. Her iki yöntemde de TBARs değerleri düşük olup, bu da yağ oksidasyonu açısından iyi kaliteyi göstermektedir. Duyusal analizlerde, her iki dumanlanmış grup da yüksek kabul puanları almıştır; geleneksel dumanlama görünüm ve doku açısından öne çıkarken, sıvı dumanlama tuzluluk bakımından tercih edilmiştir. Doku analizlerinde ise, sıvı duman ile işlenen ürünlerin daha elastik ve bütünleşik bir yapıya sahip olduğu ortaya çıkmıştır. Sonuç olarak, gökkuşağı alabalığına uygulanan sıvı dumanlama, hem kalite hem de sağlık açısından geleneksel yönteme güçlü bir alternatif olarak öne çıkmaktadır.

Anahtar kelimeler: Sıvı dumanlama, geleneksel dumanlama, gökkuşağı alabalığı, duyusal analiz, gıda güvenliği.

INTRODUCTION

Rainbow trout (*Oncorhynchus mykiss*) is one of the most important farmed fish species worldwide, with a production of 744,000 tons in 2021. Leading producers include Norway, Chile, and Türkiye (FAO, 2024). In recent years, the increase in rainbow trout production has paved the way for a rise in the number of value-added and nutritious products. According to Future Market Insights, which is one of the biggest companies that prepares global market forecasts and future projections, the smoked fish/seafood market, valued at $5.58 billion USD this year, is projected to reach $8.42 billion USD by 2035. Over the next ten years, the share of smoked fish/seafood produced from salmon/trout is expected to directly constitute 38% of the total market with an annual compound growth rate of 4.20% (Anonymous, 2025).

There are various smoking techniques in the food processing industry. However, the two preferred methods are liquid smoke and traditional hot smoking. In traditional hot smoking, wood chips from low-resin woods are slowly burned in an oven, and as a result, the generated smoke penetrates the food product with the heat, causing certain changes in the food. The most prominent of these are changes in flavor, aroma, smell, and color. When performed under correct and appropriate conditions, traditional smoking increases the product's value and demand, but when done under unsuitable conditions or without adhering to certain parameters, it may lead to products that are of low quality and lack food safety, both in terms of safety and sensory aspects. Because of some producers who use these poor practices, there are public health concerns regarding smoked products (Anonymous, 2020). Even though producers operating in controlled environments and adhering to high food safety standards take all necessary measures and are strictly monitored during traditional smoking, liquid smoke technology-developed as an alternative and rapidly gaining ground in recent years-is becoming prominent in the food sector to minimize these health concerns. Liquid smoke processing is based on condensing the smoke produced by controlled pyrolysis of wood chips and then converting it into liquid form after various purification processes. This makes it possible to significantly reduce the content of polycyclic aromatic hydrocarbons (PAHs) and other toxic compounds in the smoke (Nnenna & Oluebube, 2023).

The advantages of liquid smoking are particularly evident in terms of health and food safety compared to the traditional method. In products processed with liquid smoke, the levels of unwanted chemical compounds, especially PAHs, can be minimized in a controlled manner, which is a great plus for both regulations and consumer health. In addition, this method provides various flexibilities in industrial production due to its ease of application and standardizable quality parameters (EFSA, 2021).

However, both methods are known to have significant and different effects on the physical, sensory, and nutritional properties of the product. In particular, for a fish such as rainbow trout, which has high protein and fat content, the effect of the applied smoking method on sensory properties such as color, texture, flavor, smell, and overall acceptability is a decisive factor for consumer preferences. In addition to the commonly consumed and commercially popular fish species, carpet shell (*Ruditapes decussatus*) and cartilaginous fish (*Raja clavata*) can also be smoked quite conveniently. Applying the smoking process to these seafood variants not only enhances their sensory characteristics (by providing a distinctive smoky aroma, flavor complexity and attractive coloration) but also contributes significantly to their preservation (Çağlak et al., 2015; Karsli & Caglak, 2021). In particular, the smoking process reduces the microbial load by inhibiting the growth of spoilage and pathogenic microorganisms, while at the same time slowing down lipid oxidation and other harmful chemical reactions that typically compromise product quality. As a result, smoked shellfish and cartilaginous fish exhibit improved shelf life, greater stability during storage and transportation, and higher consumer acceptance compared to their non-smoked counterparts, increasing their potential in both domestic markets and international trade (Çağlak et al., 2015). However, the chemical and biochemical changes that occur during the smoking process directly affect the nutritional value of the product. Therefore, the smoking process should be applied in accordance with the species and purpose, and all process steps should be strictly controlled.

This study aims to provide data to the industry as well as contribute to literature by conducting a comparative analysis of liquid and traditional smoking methods specifically on rainbow trout. The physical, sensory, and nutritional changes caused by the applied liquid and traditional smoking processes were critically and comparatively evaluated considering the current literature. Especially, findings related to product quality and sustainable production were discussed, and projections regarding the future of the sector were presented.

MATERIAL AND METHOD

Materials

Rainbow Trout Used in This Study: The rainbow trout (*Oncorhynchus mykiss*) used in this study were harvested daily from the Sinop region and supplied in polystyrene boxes with ice from Mevsim Fisheries Company (Sinop, TR). The average length and weight of the fish were 29.53±0.91 cm and 782.26±30.47 g (n=12), respectively.

Liquid Smoke, Wood Chips, and Salt Used in This Study: A liquid smoke product derived from mixed woods, code 24TB/152.SMK.6501, manufactured by GMT Food Technologies Company (Business registration no: TR-16-K-000876), was used. For traditional smoking, beech and oak wood chips that each approximately 2 mm in size, were mixed in equal amounts. The salt used was unrefined, untreated brine rock salt obtained from Çankırı, Türkiye.

Methods

Processing Steps and Grouping: First, the viscera of all fish were removed, and the fish were washed under tap water. Then, fish were soaked for 15 minutes in iced water containing 3% salt to remove all residues. After this, four fish were set aside for fresh fish and sensory analyses, and the remaining eight fish were divided into two groups. For each 1 kg of fish to be treated with liquid smoke, a solution was prepared according to the instructions: one part liquid smoke concentrate to three parts pure water, resulting in 1 L solution per kg fish. Additionally, brine salt equivalent to 10% of the weight of the fish was added. The salt was fully dissolved using a magnetic stirrer for about 15 minutes at medium speed. Sliced fish (4 cm thickness) were immersed in the solution and left in refrigerated conditions for 30 minutes. After removal, the fish were drained and patted dry with paper towels. The fish were then cooked in a conventional home oven set to 120°C; a thermometer probe was inserted into the center of the slices, and once the core temperature reached 80°C at the 16th minute, they were cooked for another 15 minutes, turning the slices every 5 minutes. At the end, the final core temperature reached 85°C. For the traditional smoking group, all conditions were kept as similar as possible to those of the liquid smoke group, except for the use of liquid smoke extract and the step of slicing the fish. Brine containing 10% salt was also used for this group. However, because the fish needed to be hung by the spine with hooks during cooking for better penetration of brine and smoke, deep and wide incisions were made every 2-3 cm along the backbone and back. The smoking oven was set to 120°C, wood chips were placed in the burning chamber and slightly moistened to prevent flames. When the core temperatures of the fish reached 80°C at the 22nd minute, the upper and lower smoke covers of the oven were closed, and intense smoke was maintained throughout the cooking time. The core temperature reached 85°C at the 18th minute from the start of cooking. The oven temperature was then lowered to 90°C, and the fish were left in intense smoke for an additional 15 minutes at around 85°C. At the end of the period, the smoke covers were opened, the smoke inside the oven was vented out, and the power was turned off. The smoked rainbow trouts are shown in Figure 1.

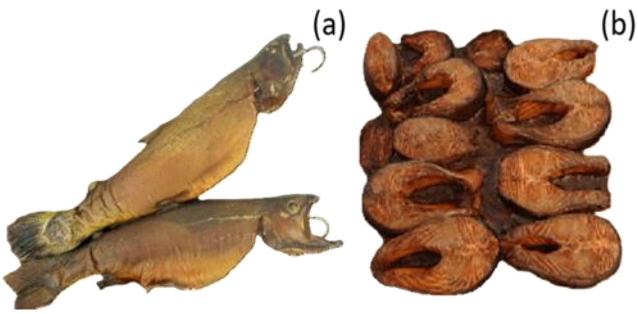

Figure 1. The traditional and liquid-smoked rainbow trouts (original) (a: traditional hot smoking method, b: liquid-smoking method).

Analyses

Salt Analysis: Salt analysis was performed according to the Mohr method (Yoder, 1919) with two repetitions and three parallels (n=6). Five grams of fish fillet were homogenized in 100 mL of pure water at 3000 rpm for approximately 90 seconds using an ultra-homogenizer. The resulting homogenate was filtered through Whatman No. 1 filter paper into an Erlenmeyer flask. Ten milliliters of the filtrate were transferred to another flask, and 2 mL of K_2CrO_4 solution was added until a slight orange color appeared. Then, titration was performed using 0.1 N $AgNO_3$ in a burette. The volume that consumed at that moment, the color turned brick red and remained so for at least 15 seconds was recorded as the endpoint. The calculation was performed using the following formula (*1*):

$$NaCl\ (\%) = [v \times N \times M(NaCl) \times 100] \div [A \times 1000] \quad (1)$$

v: Volume of $AgNO_3$ consumed (mL); **N:** Normality of $AgNO_3$ (0.1); **M(NaCl):** Molecular weight of NaCl (58.44); **A:** Amount of sample taken (g)

pH Analysis: pH analysis was performed by homogenizing 5 g of fish meat in 50 mL of pure water (1:10), using a Hanna pH meter (Model: HI 98100, Hanna Instruments Inc., Smithfield, RI, USA) equipped with an immersion probe (n=6) (Karsli et al., 2021).

Water Activity (aw) Analysis: Water activity (aw) was measured with a Lab Swift aw instrument (Novasina AG, Lachen, Switzerland) at an ambient temperature of 22.4°C. Approximately 10 g of homogenized fish flesh was placed into the instrument's measuring cups (n=3).

Proximate Composition Analyses: Protein (P), ash (A), moisture (M), and lipid (L) analyses were carried out according to AOAC (2005) methods (references: 925.04, 938.08, 954.01, and 991.36, respectively) (n=6). Total carbohydrate content (%) was calculated by subtracting the sum of the four basic nutrients from 100 (*2*) (FAO, 2003). Energy values (kcal) were calculated according to the Atwater conversion factor (*3*) (FAO, 2003).

$$Carbohydrate\ (\%) = 100 - (P + A + M + L) \quad (2)$$

$$Energy\ (kcal) = (lipid \times 9) + (protein \times 4) + (carbohydrate \times 4) \quad (3)$$

Color Analyses: Color parameters (L^*, a^*, b^*) were determined using a Konica Minolta CR-400 colorimeter (light projection tube model: A33a, Tokyo, Japan), set to a closed-cone aperture of 8.0 mm. Measurements were taken at six different locations (n=6) on each fillet, with at least 3 cm between points. For all analyses, the CIE *Lab** color space, as recommended by the Commission Internationale de l'Eclairage (CIE), was used (Hunter & Harold, 1987). In this system, L^* represents lightness (0 = black, 100 = white), a^* denotes the red-green axis, and b^* represents the yellow-blue axis (Hunter & Harold, 1987; Bekhit et al., 2019).

From these primary color coordinates, the following color indices were calculated: hue angle (*4*) ($h°$), chroma (*5*) (C^*), total color difference (*6*) (ΔE), whiteness index (*7*) (*WI*), and yellowing index (*8*) (*YI*) (Pathare et al., 2013). C^* expresses color saturation; $h°$ qualitatively defines the dominant color. *WI* and *YI* provide a more quantitative and in-depth interpretation of changes in whiteness and yellowness, which is important in the context of drying or spoilage (Škrlep & Čandek-Potokar, 2007). ΔE quantitatively reveals the total color change between experimental samples (smoked groups) and reference samples (fresh fillets). All calculations were performed based on L^*, a^*, and b^* parameters using the formulas given by Rhim et al. (1999) and Pathare et al. (2013).

$$h^{\circ} = tan^{-1}(b^*/a^*) \quad (4)$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (5)$$

$$\Delta E = \sqrt{(a^*_{smoked\ fillet} - a^*_{fresh\ fillet})^2 + (b^*_{smoked\ fillet} - b^*_{fresh\ fillet})^2 + (L^*_{smoked\ fillet} - L^*_{fresh\ fillet})^2} \quad (6)$$

$$WI = \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (7)$$

$$YI = 142.86 \times b^*/L^* \quad (8)$$

Total Volatile Basic Nitrogen (TVB-N) Analysis: TVB-N content in fish meat was determined according to Antonacopoulus & Vyncke (1989). Two grams of homogenized fish meat were transferred to a distillation tube; 100 mL pure water and 1 g magnesium oxide (MgO) were added. In a 250 mL Erlenmeyer flask, 5 mL of 3% boric acid, four drops of Tashiro indicator, and 50 mL of distilled water were added. After 10 minutes of distillation, the distillation was stopped and the distillate was titrated with 0.1 N HCl until the neutral point was reached. TVB-N content was calculated according to the following formula (n=6) (9):

$$\text{TVB} - \text{N (mg/100 g)} = (\text{a x 1.4 x 100}) \ / \ \text{m} \quad (9)$$

a: Volume (mL) of 0.1 N HCl consumed; **m:** Sample amount (g)

Thiobarbituric Acid Reactive Substances (TBARs) Analysis: TBARs analysis was carried out according to Weilmeier & Regenstein (2004) and Khan et al. (2006). Five grams of fish meat were combined with 50 µL butylated hydroxytoluene (BHT) and 45 mL trichloroacetic acid (TCA), then homogenized in an ultra-homogenizer for 3 minutes. The homogenate was filtered through Whatman No. 1 filter paper into flasks. Five milliliters of the filtrate were placed into test tubes, and 5 mL of thiobarbituric acid reagent (with 10% glacial acetic acid) was added. The mixture was incubated at 75-79°C on a hot plate for 30 minutes. After incubation, the test tubes were cooled in cold water and read against a blank at 532 nm on a spectrophotometer (n=6).

Texture Profile Analysis (TPA): Texture Profile Analysis was performed using a Brookfield CT3 texture analyzer (Middleboro, MA, USA), with slight modifications to the method described by Bourne (1978). A standard cylindrical probe with a diameter of 12.20 mm was used; trigger sensitivity, probe speed, compression ratio, recovery time, and load parameters were set to 0.05 N, 2 mm/s, 60%, 2 s, and 5 kg, respectively (n=8).

Sensory (Organoleptic) Analyses: Sensory analyses were conducted based on a slightly modified version of the form by Sallam et al. (2007). Seventeen individuals who had previously participated in at least one sensory panel took part (n=34). The widely used 9-point hedonic scale was employed for scoring. The sensory form included questions on "texture, appearance, flavor intensity, saltiness, smoke perception, umami perception, and overall acceptability."

Statistical Analyses: Data were analyzed using one-way analysis of variance (ANOVA) in Minitab (Windows Version 21.4, Minitab Inc., State College, PA, USA). Results were presented as mean ± standard error (mean±SE), and homogeneity of variance was evaluated at the P<0.05 significance level. Charts and graphics were created with OriginPro (Version 2025, Windows vers., Northampton, MA, USA).

RESULTS AND DISCUSSION

Proximate Composition: The proximate compositions of fresh, traditionally smoked, and liquid smoked rainbow trout are presented in Figure 2.

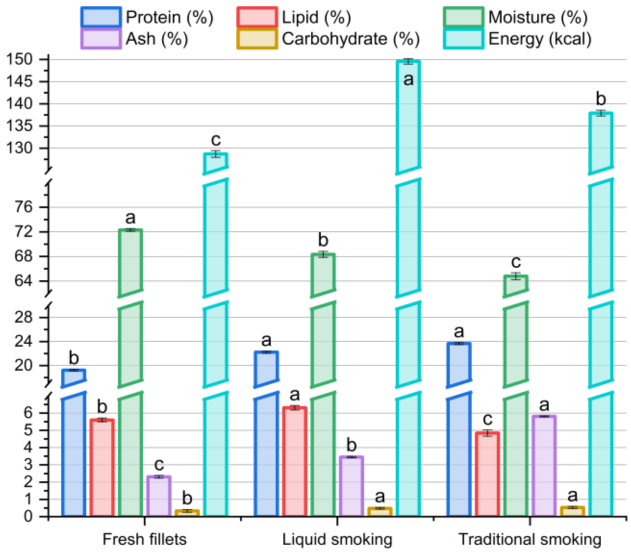

Figure 2. Proximate compositions of fresh trout fillets and smoked groups.

The moisture, protein, lipid, ash, carbohydrate content, and energy value of the fresh fish were found to be 72.31±0.22%, 19.24±0.13%, 5.60±0.11%, 2.31±0.08%, 0.43±0.05%, and 128.70±0.85 kcal, respectively.

Aberoumand et al. (2024) reported values for rainbow trout as 72.50±1.87% moisture, 13.59±1.26% protein, 8.09±0.78% lipid, 5.82±0.87% ash, and 133.13 kcal energy, while Cortes-García et al. (2025) determined 77.87±0.65% moisture, 16.55±0.07% protein, 2.64±0.22% lipid, and 1.19±0.00% ash in the same species. Altan (2020) found the values in broodstock-sized trout as 69.74±0.05% moisture, 20.52±0.02% protein, 7.12±0.00% lipid, 1.84±0.02% ash, 0.78±0.06% carbohydrate, and 149.28±0.15 kcal. As seen, some nutritional components are similar to the literature, while others vary. It is well-known that these differences in proximate composition are directly related to factors such as feeding regime, water parameters, gender, spawning season, size-weight parameters, harvest conditions, and transportation (Giacalone et al., 2010; Assan et al., 2021; Li et al., 2023). In addition to all of these, changes in nutritional composition can be observed in fish products due to differences in smoking methods. In particular, the smoking process can cause significant changes in the protein, fat, and moisture content of fish meat, depending on many factors such as the temperature-time relationship, the smoking method used, and the surface area of the fish meat exposed during the smoking process (Cardinal et al., 2001; Kjällstrand & Petersson, 2001; Stołyhwo & Sikorski, 2005; Gómez-Guillén et al., 2009).

In both smoked groups, heat treatment led to an increase in the relative content of protein, ash, carbohydrate, and energy, while a decrease in moisture was observed (P<0.05) (Figure 2). However, the moisture loss was higher in the traditional smoking group compared to the liquid smoking group (P<0.05). Although the cooking temperatures and durations were very similar, this difference is mainly attributed to the traditional method: fish were hung and cooked without surface contact, resulting in more surface moisture loss due to constant air and smoke circulation.

Regarding lipid content, an increase was observed in the liquid smoked group, while a decrease was seen in the traditional group. This difference is also attributed to the cooking technique, as with moisture loss. In the traditional group, fish hung without surface contact lost more fat due to gravity. Swastawati et al. (2022) reported that lipid content in traditionally smoked barracuda was 5.24%, while in the liquid smoked group it was 5.63%. Another notable point is that the ash content in the traditional group was much higher than in other groups, likely due to the transfer of inorganic substances from burning sawdust. Swastawati et al. (2022) similarly found ash content in the traditional group was more than three and a half times that of the liquid smoked group (P<0.05).

pH, aw & Salt: In fresh fillets, aw and pH values were 0.997±0.001 and 6.35±0.02, respectively. Kocatepe et al. (2015) reported pH and aw as 6.20±0.00 and 0.970±0.001, while Altan (2020) found values of 6.78 and 0.950. Both aw and pH are known to be affected by freshness, harvest method, and storage conditions (Varlık et al., 2004). Both smoking treatments caused a significant decrease in aw (P<0.05), especially in the traditional smoking group, due to the hanging cooking method and associated moisture loss, since moisture content and aw are directly related.

Analysis of pH changes (Figure 3) showed a decrease in the smoked groups, with a more pronounced reduction in the liquid smoked group (P<0.05). The liquid smoke used had a pH of 2.74, within the manufacturer's specification of 2.50-3.50. The application of liquid smoke lowers the pH. Traditional smoking is also reported to reduce pH (Alcicek & Atar, 2010; Araújo et al., 2020; Amin & Ali, 2021), consistent with our findings.

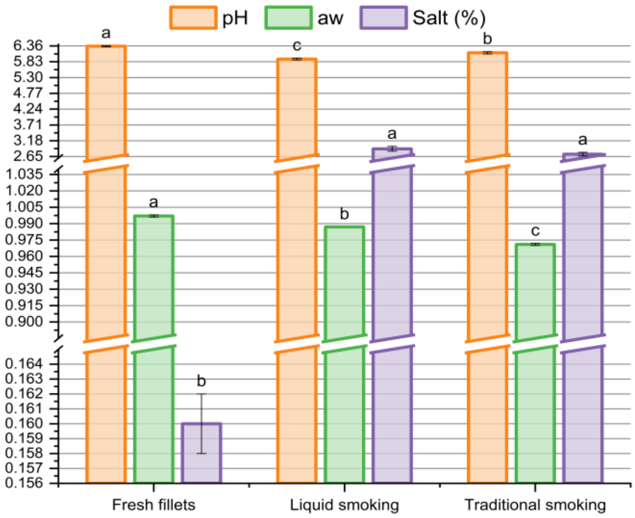

Figure 3. pH, aw & salt (%) changes of fresh trout fillets and smoked groups.

According to salt analysis, the salt content of fresh fish was found to be 0.16±0.01%. Most of this salt likely came from the 3% salt wash used during cleaning. After brining (10% salt by weight) for 30 minutes in refrigerated conditions, the salt contents in the liquid smoked and traditional smoked groups were 2.91±0.08% and 2.73±0.05%, respectively (P>0.05). The desired salt content in smoked seafood, both sensory and microbiologically, should be between 2% and 3% depending on species (Göğüş & Kolsarıcı, 1992; Ünlüsayın et al., 2001; Can, 2018), and the values found in this study are appropriate.

Total Volatile Basic Nitrogen (TVB-N) & Thiobarbituric Acid Reactive Substances (TBARs): TVB-N in fresh trout fillets was 6.56±0.06 mg N/100 g. After smoking, both groups showed an increase in TVB-N (P<0.05), but the increase was higher in the liquid smoked group (Figure 4) (about double that of fresh fillets, P<0.05). This suggests the transfer of nitrogenous compounds from the liquid smoke to the flesh. Huong (2013) reported that liquid smoke decreased TVB-N in mackerel, while Alcicek & Atar (2010) found that it increased TVB-N in trout. Amin & Ali (2021) found increases in both traditional and liquid smoked tilapia, similar to our findings. Differences between liquid smoke types and fish species play a significant role in TVB-N variation.

TBARs in fresh trout were 0.44±0.06 mg MDA/kg. Varlık et al. (2004) state that TBARs in fish should not exceed 8 mg MDA/kg. In our study, all TBARs values were well below this limit (Figure 4). Amin & Ali (2021) reported TBARs values in fresh, liquid smoked, and traditional smoked tilapia as 0.52±0.05, 0.95±0.11, and 1.01±0.15 mg

MDA/kg, respectively. Dang et al. (2024) also found TBARs values as fresh < liquid smoked < traditional smoked in mackerel, similar to our results. All groups in our study had TBARs below 1 mg MDA/kg, indicating very high quality in terms of lipid oxidation. However, compared to the literature, the TBARs values determined in our research were slightly higher. These differences are due to the variety of liquid smoke and wood chips used, as well as the treatment time, temperature applied, and pre-treatment processes (Stołyhwo & Sikorski, 2005).

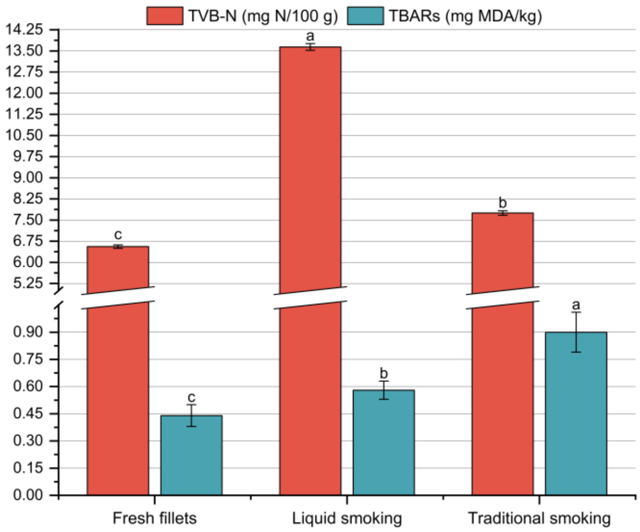

Figure 4. TVB-N & TBARs changes of fresh trout fillets and smoked groups.

Texture Profile Analysis (TPA): The TPA results of fresh, traditional and liquid smoked trout are shown in Figure 5.

In fresh fish, hardness, adhesive stickiness, springiness, elasticity, cohesive stickiness, and chewiness values were 13.04±0.54 N, 0.50±0.06 mJ, 0.081±0.005, 4.29±0.30 mm, 0.122±0.003, and 8.03±0.41 N×mm, respectively. Both smoked groups showed increased hardness due to water loss and protein denaturation (P<0.05). Dang et al. (2024) reported similar shear force values for both smoking techniques in mackerel. Birkeland & Skåra (2008) and Araújo et al. (2020) found no significant difference in hardness between the two methods, which is consistent with our results. Adhesiveness decreased in the liquid smoked group compared to fresh fillets, while it increased in the traditional smoked group (P<0.05). This is related to cooking characteristics and the formation of a smoke layer. Cohesive stickiness, representing the integrity and resistance to deformation, was highest in the liquid smoked group (P<0.05), likely due to higher moisture (Figure 2) and matrix formation during cooking. Springiness and elasticity were also higher in the liquid smoked group (P<0.05), indicating better maintenance of structure and greater tendency to return to the original form. Chewiness, which is a formulated result of hardness, cohesion, and elasticity, was also highest in the liquid smoked group (P<0.05). Overall, the liquid smoked group better retained fillet integrity.

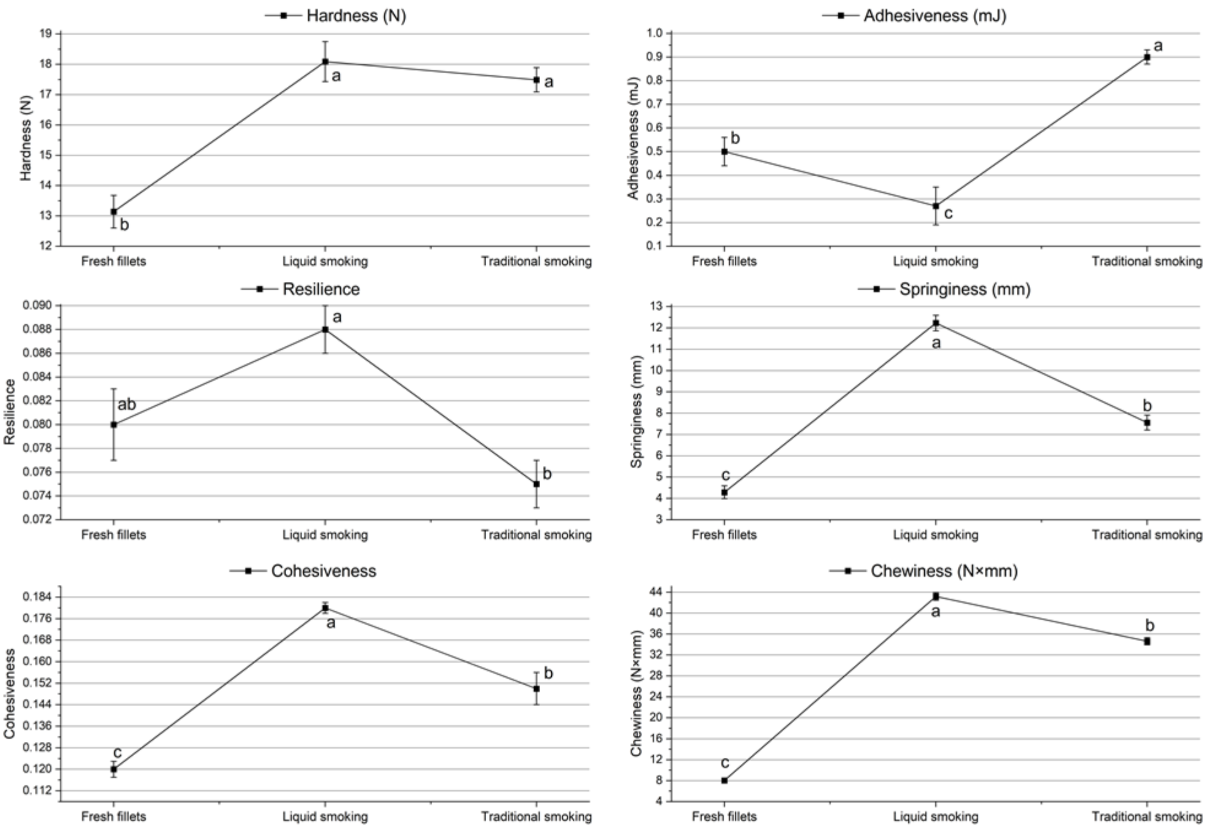

Figure 5. TPA results of fresh trout fillets and smoked groups.

Color Analyses: Color results of fresh, traditional and liquid smoked trout are shown in Figure 6.

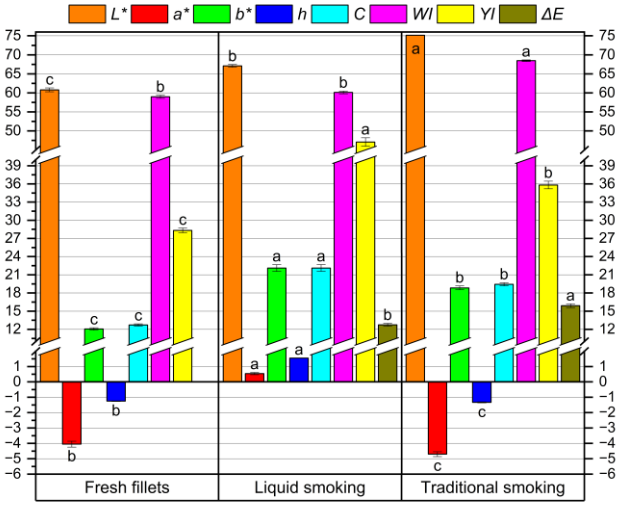

Figure 6. Color parameters of fresh trout fillets and smoked groups.

*L** (lightness), *a** (red-green), *b** (yellow-blue), *h* (hue angle, rad), *C* (chroma), *WI* (whiteness index), and *YI* (yellowness index) values in fresh fillets were 60.8±0.50, -4.05±0.19, 12.06±0.20, -1.25±0.02, 12.72±0.19, 58.98±0.43, and 28.33±0.38, respectively. Altan (2020), reported the rainbow trout burgers' *L**, *a**, and *b** values as 58.23±0.95, 1.35±0.33, and 4.13±0.49, respectively. Cortes-García et al. (2025) found *L**, *a**, and *b** values in commercial-feed trout as 55.91, -0.14, and 13.04, and in alternative-feed trout as 56.81, -2.65, and 8.40. As with previous findings, feeding regime, water temperature, stress, and spawning period all affect color parameters. In this research, both smoking treatments increased *L** and *b** values compared to fresh fillets (P<0.05). Regarding *a**, an increase was seen in the liquid smoked group, while a decrease was observed in the traditional group (P<0.05). Dang et al. (2024) reported a greater increase in *a** with liquid smoke compared to traditional smoking. However, some studies observed no difference between methods (Birkeland & Skåra, 2008; Araújo et al., 2020). An increase in *b** is common in smoked products (Astruc et al., 2022), and in this study, the highest *b** value was found in the liquid smoked group (P<0.05). Hue angle (*h*, rad) provides more holistic and sensitive information than just *a** or *b** values. In this study, the fresh and traditional smoked groups were close to the blue tone, while the liquid smoked group was closer to the yellow tone. Chroma (*C*) indicates color saturation, and both smoked groups showed increased values compared to fresh fillets, with the highest C value in the liquid smoked group (P<0.05). *WI*, a more quantitative indicator of whiteness than *L**, was similar in fresh fillets and the liquid smoked group (P>0.05), while higher in the traditional group (P<0.05). *YI* (yellowness index), which is more descriptive for yellowness than *b**, was higher in both smoked groups than in fresh fillets (P<0.05), with the highest *YI* in the liquid smoked group (P<0.05). *ΔE* represents the total color difference compared to the control (fresh fillets). The *ΔE* value was 12.75±0.24 for the liquid smoked group and 15.89±0.31 for the traditional smoked group (P<0.05), indicating a greater total color change in the traditional group compared to fresh fillets.

Sensory Analyses: The sensory evaluation results for oven-cooked fresh, traditionally smoked, and liquid smoked trout are shown in Figure 7.

Panelists scored texture, overall acceptability, appearance, flavor intensity, smoke perception, saltiness, and umami perception. For texture, the traditional smoked group scored highest, although the liquid smoked group was close. For appearance, the traditional smoked group also had slightly higher scores (P<0.05). For saltiness, the liquid smoked group scored highest. Panelists noted that the salt balance in the liquid smoked group was ideal, while the traditional group was somewhat under-salted. In contrast to our findings, Birkeland & Skåra (2008) reported higher salt preference scores in traditional smoked Atlantic salmon. Smoke perception scores showed that both smoked groups had an appropriate smoke level, with no need for adjustment. Umami perception was not reported by panelists in the smoked groups.

Flavor intensity scores were similar in both smoked groups (P>0.05) and higher than in the unsmoked group (P<0.05). Overall acceptability was also higher in both smoked groups compared to unsmoked fish. Araújo et al. (2020) reported higher sensory scores for all parameters in catfish sausages made with liquid smoke, while Amin & Ali (2021) found higher scores for all parameters in traditionally smoked tilapia fillets. These findings show that species, processing, smoke intensity, and other parameters can result in considerable variation in sensory analysis results.

CONCLUSION

In this study, the physical, chemical, and sensory changes resulting from both traditional and liquid smoking processes of rainbow trout were investigated. According to the findings, both smoked groups were found to be highly nutritious in terms of proximate composition, with only a slight decrease in moisture and lipid content in the traditional smoked group due to the cooking method. As a result, the aw value of the traditional smoked group was lower than that of the liquid smoked group. However, due to the very low pH of the liquid smoke extract, a similarly low pH was observed in the liquid smoked group as well. In terms of TVB-N levels, the liquid smoked group had higher values, but even this level (13.54 mg N/100 g) indicated very good fish quality. For TBARs, all groups showed very low values—below 1 mg MDA/kg—

indicating high quality in terms of lipid oxidation, although the highest TBARs was found in the traditional smoked group (0.90 mg MDA/kg). Regarding sensory parameters, both smoked groups received very high panelist scores. The traditional smoked group scored higher for appearance and texture, while the liquid smoked group was more preferred in terms of saltiness. When overall acceptability scores were considered, both smoked groups had high and equal scores. The highest L^* value was observed in the traditional smoked group, while only the liquid smoked group had a positive a^* value. The highest b^* value was also observed in the liquid smoked group. Generally, the liquid smoked group was superior in TPA parameters; although hardness and adhesive stickiness were similar to the traditional group, elasticity, cohesive stickiness, springiness, and chewiness were higher in the liquid smoked group. Higher cohesive stickiness and elasticity contributed to firmer yet more elastic flesh. When all these parameters are considered together, it can be concluded that while both smoked groups were similar nutritionally and chemically, their distinguishing features were sensory and textural parameters. The liquid smoked group stood out slightly both in instrumental and sensory analyses, making it preferable. Furthermore, the health risks associated with traditional smoking are much higher than those for liquid smoking, further supporting this preference.

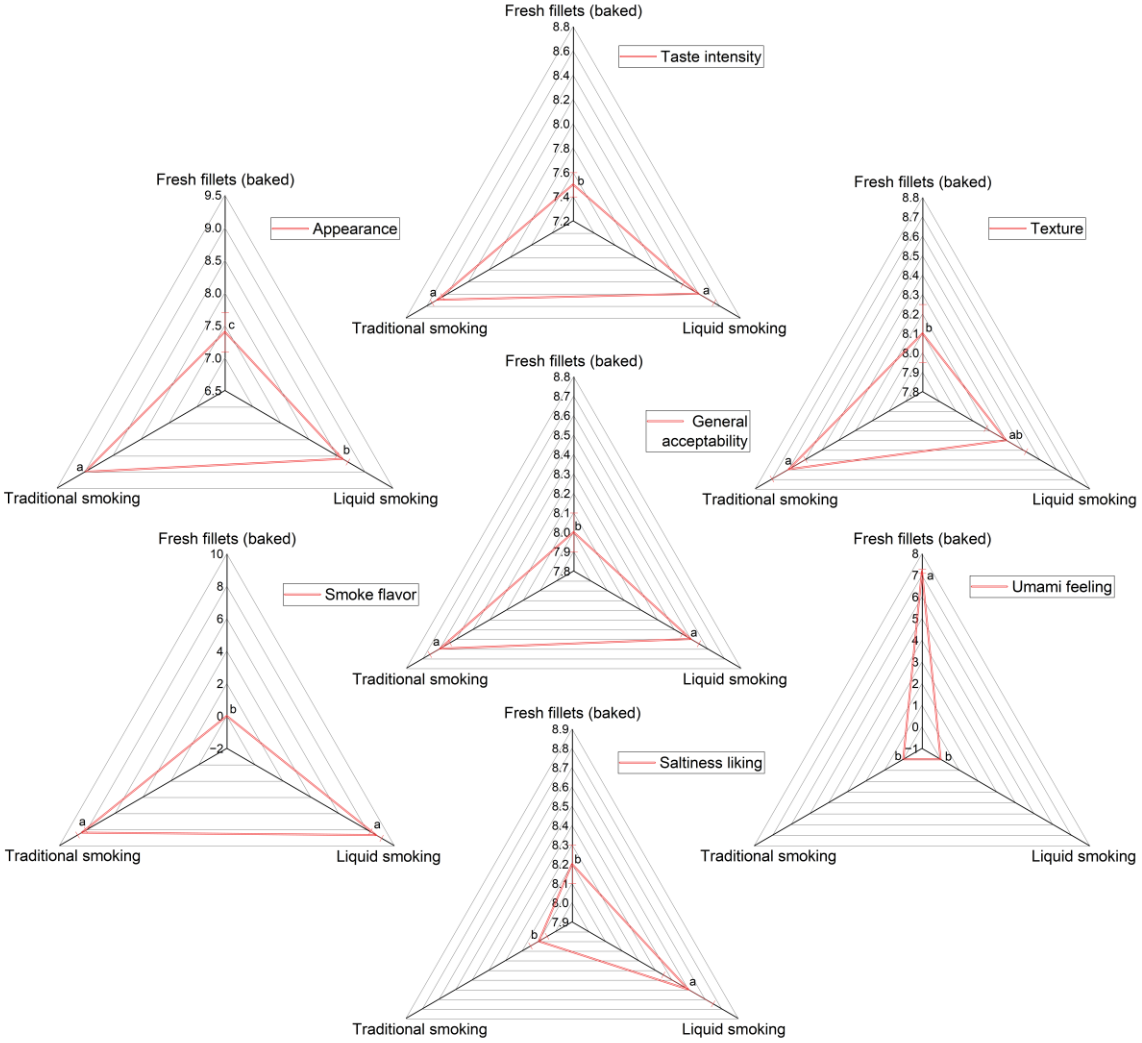

Figure 7. Sensory evaluation results of baked fresh trout fillets and smoked groups.

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