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RESEARCH ARTICLE

Determination of Quality Changes in Traditional and Liquid Smoked Fish Pastirma Prepared from Meagre (*Argyrosomus regius* Asso, 1801)

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Abstract: In this study, the nutritional composition and the physicochemical, microbiological, and sensory quality parameters of traditional and liquid smoke-treated meagre pastirma were investigated under refrigerated storage conditions at +4 °C. For this purpose, analyses were conducted over a 120-day storage period on four different sample groups: traditional pastirma with fenugreek paste (FMP), traditional pastirma without fenugreek paste (MP), liquid smoke-treated with fenugreek paste (LSFMP), and liquid smoke-treated without fenugreek paste (LSMP). Moisture content in fresh fish, originally 71.63%, decreased to approximately 42–44% in all pastirma groups. Despite this notable reduction, statistical analysis revealed no significant differences in moisture levels among the processed groups ($p > 0.05$). Protein content increased to 30–33% following pastirma processing, and significant differences were observed between traditionally and smoke-treated samples ($p < 0.05$). Crude fat content, initially 4.07% in fresh fish, ranged between 11% and 17.99% in the final products. Significant differences were found between fenugreek-coated and non-coated groups in terms of lipid content ($p < 0.05$). Ash content increased significantly in all processed groups ($p < 0.05$). pH values exhibited irregular fluctuations over time; the most stable pH trend was observed in the LSFMP group. Lower pH levels were associated with enhanced microbial and chemical stability. Salt content was initially around 10% in all groups and varied between 9% and 11% throughout storage. Thiobarbituric acid (TBA) values, indicative of lipid oxidation, increased over time in all groups and exceeded the 5 mg MDA/kg threshold in some samples (MP, FMP, LSMP). Trimethylamine nitrogen (TMA-N) values fluctuated but remained below the 4 mg/100 g acceptability limit, while total volatile basic nitrogen (TVB-N) levels increased throughout storage yet stayed well below the 25 mg/100 g threshold considered indicative of high quality. The findings demonstrated that both liquid smoke and fenugreek paste contributed positively to quality stabilization. Total viable counts increased significantly over the storage period across all groups ($p < 0.05$), but the lowest microbial load was observed in the LSFMP group, processed with both liquid smoke and fenugreek paste. No growth of yeasts, molds, coliforms, or *Staphylococcus spp.* was detected in any group. Sensory evaluation scores (appearance, color, odor, taste, texture, and overall acceptability) declined gradually in all groups during storage; however, all samples remained within the "acceptable quality" range by day 120. Notably, liquid smoke treatment provided improvements in aromatic profile, microbial stability, and taste characteristics. In contrast, fenugreek paste negatively affected sensory quality in some cases. In conclusion, the combined use of liquid smoke and fenugreek paste was found to be effective in extending the shelf life and preserving the quality of *meagre pastirma* during cold storage.

Anahtar kelimeler:

Kaya levreği
Balık pastirması
Sıvı duman
Besin değeri
Kalite değişimi

Kaya Levreği (*Agyrosomus regius* Asso, 1801) Kullanılarak Hazırlanan Geleneksel ve Sıvı Dumanlı Balık Pastırmalarının Kalite Değişimlerinin Belirlenmesi

Öz: Bu çalışmada, geleneksel ve sıvı duman ilaveli kaya levreği pastırmalarının besin değerleri ve +4C°'deki depolama koşullarında meydana gelen fiziko-kimyasal, mikrobiyolojik ve duyusal kalite parametreleri araştırılmıştır. Bu amaçla geleneksel çemenli (FMP), geleneksel çemeni sıyrılmış (MP), sıvı duman ekstraktı ilaveli çemenli (LSFMP) ve sıvı duman ekstraktı ilaveli çemeni sıyrılmış (LSMP) 4 grup üzerinden 120 günlük depolama süresi boyunca analizler yapılmıştır. Taze balıkta %71,63 olan nem oranı tüm pastırma gruplarında %42–%44 değerlerine düşmüş ve bu düşme sonrasında pastırma gruplarındaki nem oranları değişimi istatistiksel olarak anlamlı bulunmamıştır ($p>0,05$). Protein oranı pastırma işlemi sonrasında tüm gruplarda %30–%33 seviyelerine ulaşmış, dumanlı ve geleneksel yöntemler arasında anlamlı farklar tespit edilmiştir ($p<0,05$). Yağ oranı ise taze balıkta %4,07 iken pastırmalarda %11–%17,99 arasında değişmiştir; çemenli ve çemeni sıyrılmış gruplar arasında farklar önemli bulunmuştur ($p<0,05$). Kül oranı tüm pastirma gruplarında anlamlı şekilde artmıştır ($p<0,05$). pH değerleri zamanla düzensiz dalgalanmalar göstermiş olup en stabil grup LSFMP olmuştur. Düşük pH seviyeleri, ürünün mikrobiyal ve kimyasal stabilitesiyle ilişkilendirilmiştir. Tuz oranı başlangıçta tüm gruplarda %10 civarında olup depolama süresince %9–11 aralığında değişmiştir. Lipid oksidasyonunu gösteren TBA değerleri tüm gruplarda zamanla artmış ve bazı gruplarda (MP, FMP, LSMP) 5 mg MA/kg sınırını aşmıştır. TMA-N değerleri dalgalı seyir göstermiş, ancak kalite sınırlarının altında kalmıştır (<4 mg/100g). TVB-N değerleri de depolama boyunca artmış ancak tüm gruplarda "çok iyi" kabul edilen 25 mg/100g sınırının oldukça altında kalmıştır. Bulgular, sıvı duman ve çemenin kalite stabilitesini olumlu etkilediğini göstermektedir. Tüm gruplarda depolama süresince toplam bakteri sayısında istatistiksel olarak anlamlı artışlar gözlenmiş ($p<0,05$), en düşük mikrobiyal yük sıvı duman ve çemen kombinasyonuyla işlenen LSFMP grubunda tespit edilmiştir. Maya-küf, koliform ve *Staphylococcus spp*. tespit edilmemiştir. Duyusal analizlerde tüm gruplarda görünüş, renk, koku, tat, kıvam ve genel beğeni skorları zamanla azalmış olsa da 120. gün sonunda tüm gruplar hâlâ "iyi kalite" sınırında kalmıştır. Özellikle sıvı duman uygulamasının aromatik yapı, mikrobiyal stabilite ve tat parametrelerine olumlu etkiler sağladığı belirlenmiştir. Çemenin bazı durumlarda duyusal kaliteyi olumsuz etkileyebileceği gözlemlenmiştir. Sonuç olarak, sıvı duman ve çemen uygulamalarının balık pastirmalarının raf ömrünü uzatmada etkili olduğu ortaya konmuştur.

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Introduction

In contemporary times, significant changes have been observed in traditional dietary habits as a result of socio-economic transformations, urbanization, and shifts in individual lifestyles. The intensification of work schedules, time constraints associated with urban living, and the prevalence of individualized modes of life have led to increased consumption of convenience foods. Consequently, the food industry has been compelled to develop products that are more practical, have extended shelf life, and are perceived as healthier (Şimşek, 2011). The health implications of dietary patterns are now better understood, and due to the association of red meat consumption with cardiovascular diseases, there is a growing preference for more balanced protein sources rich in unsaturated fatty acids. In this context, seafood—particularly fish—has gained prominence owing to its high nutritional value, high-quality protein content, low fat levels, and richness in omega-3 fatty acids (Ormancı, 2005; Kaban & Kaya, 2006; Dursun et al., 2010; Babur, 2017). Processing fish into various forms for consumption is significant both for extending shelf life and for meeting diverse consumer demands. Among the processed seafood products, one of the notable items in recent years is fish pastirma. This product is manufactured using fish meat by adapting traditional pastirma production techniques originally developed for red meat. Traditional pastirma is a meat product typically made from beef or water buffalo, involving salting, drying, and fenugreek paste application processes, and is defined under the TS 1071 standard (Anonymous, 2002). Fish pastirma, on the other hand, represents a modified version of this traditional method, tailored to the delicate structure of fish. Historically, pastirma production was transferred from Central Asia to Anatolia and has since become a significant element of Turkish food culture. Traditionally produced in many cities, particularly in Kayseri, pastirma today shows similarities to products made using comparable techniques in other countries (Ekmekçi, 2012).

Liquid smoke is a natural derivative of smoke condensate, commonly utilized to impart a characteristic smoky flavor without the need for conventional smoking methods. It offers several advantages, including ease of application, cost-effectiveness, precise dosage control, and the ability to minimize the presence of undesirable compounds. Most notably, it presents a significantly lower environmental impact compared to traditional smoking systems. However, its antimicrobial and preservative efficacy remains relatively limited. Liquid smoke applications are generally performed by immersing the product in liquid smoke, spraying it onto the surface, or exposing it to its vapor. In this way, only the smoke flavor and aroma are imparted to the product (Ayvaz vd., 2010; Racioppo vd., 2023).

In conclusion, fish pastirma production constitutes an important alternative food product that not only meets the increasing demand for healthy food but also preserves traditional flavors (Baygar et al., 2002; Babur, 2017). Studies in this field contribute to the valorization of Turkey's rich aquatic resources and offer significant opportunities for the development of new products within the food industry.

In this study, in addition to the use of a different fish species (meagre, *Argyrosomus regius*) to contribute to fish pastirma production, the effects of incorporating liquid smoke treatment alongside the traditional fish pastirma process were investigated in terms of sensory properties and other quality parameters.

Material and Methods

Material

In this study, meagre (*Argyrosomus regius*, Asso, 1801) was used as the raw material. The fish were obtained from a private aquaculture facility located in İzmir, Türkiye. All specimens were transported to the processing technology laboratory under cold chain conditions to ensure freshness and minimize quality degradation.

The water-based liquid smoke extract used in the study was procured from a local food additive supplier.

Preparation of meagre (Argyrosomus regius) pastirma samples

The average weight and length of the meagre fish brought to the laboratory ranged from 1.5 to 2.2 kg and 42 to 64 cm, respectively. After removal of the heads and internal organs, the fish were thoroughly washed and drained. The fillets were then separated and skinned. Skinless fillets were rinsed again, patted dry, and subjected to the salting process. For salting, coarse commercial salt with a particle size of 1–2 mm was used, and the process was carried out over a period of three days. Following salting, the samples were washed to remove excess salt and subsequently dried.

The dried samples were then pressed under weights for two days. After pressing, the samples proceeded to the fenugreek paste coating stage. The fenugreek paste was prepared by proportionally mixing 450 g of *Trigonella foenum-graecum* (fenugreek) flour, 300 g of ground red pepper, and 225 g of dried garlic (processed in a blender). These dry ingredients were homogenized in a container, and water was gradually added to form a paste with the desired consistency.

Two types of fenugreek paste were prepared for coating the pastirma:
(1) Traditional fenugreek paste, composed of fenugreek flour, red pepper powder, blended dried garlic and water.

(2) Liquid smoke-enriched fenugreek paste, which included the same ingredients as the traditional formulation, with the addition of 5 mL of liquid smoke extract (diluted at a 1:2 ratio) per 1 kg of fenugreek paste.

During the coating phase, the fish fillets were divided into two groups. Half of the fillets were coated with the traditional fenugreek paste and the other half with the

liquid smoke-enriched fenugreek paste, with a uniform thickness of 1–2 mm. All coated samples were then subjected to a 15-day ripening process.

After ripening, the pastirma samples were vacuum-packed and stored at refrigerated conditions of +4 ± 2 °C. The storage period lasted for 120 days, and sampling was conducted at specific intervals beginning on day 0.

The samples were categorized into four analytical groups:

1. MP (Meagre Pastirma): Pastirma samples from which the fenugreek paste was removed before analysis; only the fish meat was evaluated.

2. FMP (Fenugreek paste-Coated Meagre Pastirma): Pastirma samples analyzed together with the fenugreek paste, without separation.

3. LSMP (Liquid Smoke-Treated Meagre Pastirma): Samples coated with liquid smoke-enriched fenugreek paste, with the paste removed prior to analysis; only the fish meat was analyzed.

4. LSFMP (Liquid Smoke-Treated Fenugreek paste-Coated Meagre Pastirma): Samples coated with liquid smoke-enriched fenugreek paste, analyzed together with both fish meat and coating material.

Methods

Moisture analysis

The moisture content of both fresh fish and pastirma samples was determined in accordance with the oven-drying method outlined by AOAC (2000). For each analysis, 5 grams of homogenized sample were accurately weighed into pre-dried and tared petri dishes. The samples were then dried in a convection oven maintained at 105 °C for a period of 16 to 18 hours to ensure complete removal of moisture. Upon completion of drying, the samples were cooled in a desiccator and reweighed. Moisture content was calculated based on the weight loss of the samples and expressed as a percentage of the initial sample weight.

Protein analysis

Protein content was determined using the Kjeldahl method in accordance with AOAC (2000). Approximately 1 gram of homogenized sample was transferred into Kjeldahl digestion tubes, to which 20 mL of concentrated sulfuric acid (H_2SO_4) and a Kjeldahl catalyst tablet were added. The samples were subjected to digestion for 2.5 hours until a clear solution was obtained. Following digestion, 50 mL of distilled water was added to each tube, and the samples were transferred to a distillation unit. During distillation, the liberated ammonia was captured in a receiving flask containing 25 mL of boric acid solution and 3–5 drops of Toshiro indicator. The distillate was then titrated with 0.1 N hydrochloric acid (HCl), and protein content was calculated based on the volume of acid consumed during titration.

Fat analysis

The lipid content of fresh and pastirma samples was determined according to the method described by Bligh and Dyer (1959). For each analysis, 10 grams of homogenized sample were mixed with 50 mL of a methanol/chloroform solution (1:2, v/v). The resulting homogenate was rinsed with an additional 10 mL of the same solvent mixture and filtered through filter paper into a pre-weighed round-bottom flask. The filtrate was allowed to stand in a dark environment for 24 hours to ensure complete extraction. Subsequently, the flask was placed in a rotary evaporator (IKA, RV 10 basic) to remove the solvent under reduced pressure. After the evaporation process and separation of lipids, the flask was transferred to an oven at 105 °C and dried for 1 hour. It was then cooled in a desiccator to room temperature and reweighed to determine the lipid content gravimetrically.

Ash analysis

Ash content of the samples was determined using the dry ashing method in accordance with AOAC (2000). Approximately 2 grams of each sample were weighed into pre-ashed crucibles and incinerated in a muffle furnace at 550 °C until a uniform light gray (cigarette ash-like) residue was obtained. After ashing, the crucibles were cooled in a desiccator to room temperature and reweighed. The ash content was calculated based on the weight of the inorganic residue remaining after combustion.

pH analysis

The pH values were determined by mixing the homogenized samples with an equal volume (1:1) of distilled water. The pH was then measured using a calibrated pH meter (Hanna Instruments, HI2211 Basic).

Salt

Salt content was determined using the Mohr titration method. For each analysis, 10 grams of sample were mixed with 90 mL of distilled water and thoroughly homogenized. The mixture was then filtered into a volumetric flask using filter paper. A 10 mL aliquot of the filtrate was taken, and 1 mL of potassium chromate (K_2CrO_4) indicator was added. The solution was titrated with 0.1 N silver nitrate ($AgNO_3$) until a persistent color change was observed. The amount of titrant consumed was recorded and used to calculate the salt content (Vural & Öztan, 1996).

TVB-N analysis

The determination of total volatile basic nitrogen (TVB-N) was carried out in accordance with the European Commission (2005) method. For each analysis, 10 grams of sample were homogenized with 90 mL of 6% perchloric acid solution and then filtered into a volumetric flask. A 50 mL aliquot of the filtrate was transferred into a distillation tube, followed by the addition of 3 drops of antifoaming agent and 3 drops of phenolphthalein indicator. The sample was then subjected to distillation. The distillate was collected in 25 mL of boric acid solution containing 8 drops of Toshiro indicator. The resulting

distillate was titrated with 0.01 N hydrochloric acid (HCl), and the volume of acid consumed was used to calculate the TVB-N content (Maghraby et al., 2013).

TMA-N analysis

Trimethylamine nitrogen (TMA-N) analysis was performed according to the method described by Schörmüller (1968). For each analysis, 10 grams of sample were homogenized with 7.5% trichloroacetic acid (TCA) and then filtered. From the filtrate, 4 mL was transferred into clean glass tubes. Subsequently, 1 mL of 20% formaldehyde, 10 mL of toluene, and 3 mL of 50% potassium hydroxide (KOH) were added. The mixture was vortexed for 2–3 minutes to allow for phase separation. After phase separation, 5 mL of the upper organic phase was collected and mixed with 0.02% picric acid solution. The absorbance of the samples was then measured against a blank at a wavelength of 410 nm using a spectrophotomete.

TBA analysis

TBA analysis was conducted according to the method described by Tarladgis et al. (1960). For each analysis, 10 grams of homogenized sample were combined with 50 mL of distilled water. The mixture was homogenized using an Ultra-Turrax and transferred into a Kjeldahl flask. An additional 47.5 mL of distilled water, 2.5 mL of hydrochloric acid (HCl), and a boiling chip were added. The sample was then distilled until 50 mL of distillate was collected in a round-bottom flask. From the distillate, 5 mL of the sample was mixed with 5 mL of a 0.02 N 2-thiobarbituric acid solution prepared in 90% glacial acetic acid. The mixture was then heated in a water bath at 100 °C for 40 minutes. After cooling, the absorbance was measured at 538 nm against a blank sample.

Microbiological analysis

Total viable count (TVC)

From the prepared serial dilutions, 1 mL of each sample was transferred using an automatic pipette onto sterile glass petri dishes containing Plate Count Agar. The samples were spread using the spread plate technique. For the enumeration of total psychrotrophic bacteria, the plates were incubated at 37 °C for 24–48 hours. After incubation, the formed colonies were counted, and the results were expressed as colony-forming units per gram (cfu/g) (FDA/BAM, 2009)

Total yeast and mold count

For the enumeration of total yeast and mold, 0.1 mL of the prepared dilution was transferred using an automatic pipette onto sterile glass petri dishes containing Plate Dextrose Agar (PDA). The samples were inoculated using the spread plate method. The inoculated plates were incubated at 25 ± 2 °C for 5 days. After incubation, the number of colonies formed was counted and recorded (FDA/BAM, 2009).

Total coliform bacteria count

For the determination of total coliform bacteria, appropriate dilutions of the samples were spread onto Violet Red Bile Agar (VRBA) plates using the spread plate method. The inoculated plates were incubated at 37 ± 1 °C for 24–48 hours. After incubation, the resulting colonies were counted, and the total coliform bacteria count was calculated (FDA/BAM, 2009).

Halophilic bacteria count

Halophilic bacteria enumeration was carried out according to the method described by Anonymous (2018). From the prepared serial dilutions, 1 mL of each sample was transferred using an automatic pipette onto glass petri dishes containing Plate Count Agar supplemented with 7% NaCl. The samples were inoculated using the spread plate method. The plates were incubated at 37 °C for 24–48 hours, after which the resulting colonies were counted to determine the total halophilic bacteria count (Ormancı, 2013).

Total Staphylococcus sp. count

For the enumeration of total *Staphylococcus spp.*, 0.1 mL of the prepared dilutions was spread-plated onto Baird-Parker (BP) agar. The plates were incubated at 35 ± 1 °C for 48 hours. During incubation, colonies exhibiting circular, smooth, convex, and moist characteristics with opaque zones were counted, and the total number of *Staphylococcus spp.* was calculated (FDA, 1998).

Sensory analyses

Sensory evaluations were conducted using a modified version of the Torry Scheme scale. The sensory analyses were performed by a trained panel of five experienced assessors. The products were evaluated based on color, appearance, odor, taste, texture, and overall acceptability, using a 5-point scale. According to Martinsdottir et al. (2009), the products were classified based on the given scores as follows: "5" = very good, "4" = good, "3" = moderate, "2" = poor, and "1" = very poor.

Statistical analyses

The data obtained were transferred to Microsoft Excel, where means and standard deviations were calculated. To evaluate differences between storage days and treatment groups, one-way ANOVA was performed using the SPSS version 21 statistical software package. Following the ANOVA, Duncan's and Tukey's multiple comparison post hoc tests were employed to determine statistically significant differences among the groups.

Results and Discussion

Proximate composition

Table 1 shows the proximate composition of meagre-based pastirma samples.

Table 1. Proximate composition values of meagre pastirma

Proximate	Fresh	MP	FMP	LSMP	LSFMP
Moisture (%)	71.63±1.60^{B}	43.09±1.20^{A}	44.51±1.72^{A}	42.20±0.83^{A}	43.58±3.09^{A}
Protein (%)	23.55±0.11^{A}	30.79±0.46^{B}	30.66±1.40^{B}	33.56±0.89^{C}	31.68±0.62B^{C}
Fat (%)	4.07±0.93^{A}	17.99±0.26^{D}	11.64±1.73^{BC}	15.00±2.38^{CD}	11.10±0.97^{B}
Ash (%)	1.22±0.03^{A}	9.49±0.27^{B}	9.03±0.92^{B}	9.32±0.80^{B}	9.26±1.00^{B}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

As a result of the proximate composition analyses, moisture content in the fresh material was determined as 71.63%. Following salting and fenugreek paste application processes, the moisture contents in the respective groups MP, FMP, LSMP, and LSFMP were found to be 43.09%, 44.51%, 42.20%, and 43.58%, respectively. Although a substantial decrease in moisture was observed compared to the fresh material, the moisture levels among all groups did not differ significantly (p> 0.05). The protein content of the fresh material was recorded as 23.55%. Due to water loss following the salting, pressing, and fenugreek paste treatments, protein contents increased in the respective groups to 30.79% (MP), 30.66% (FMP), 33.56% (LSMP), and 31.68% (LSFMP). While the protein levels of the liquid smoke-treated and traditionally prepared groups were relatively close, statistically significant differences were detected among them (p <0.05). Regarding crude fat content, fresh material had a fat ratio of 4.07%, whereas the values in MP, FMP, LSMP, and LSFMP groups were 17.99%, 11.64%, 15.00%, and 11.10%, respectively. The lowest fat content was found in the fresh material, and the highest in the MP group. Statistically significant differences were observed in fat content between groups with and without fenugreek paste (p <0.05), whereas no significant difference was found between smoked and unsmoked groups (p>0.05). Ash content in the fresh material was 1.22%. This value increased following salting, pressing, and paste application, and was determined to be 9.46% (MP), 9.03% (FMP), 9.32% (LSMP), and 9.26% (LSFMP). Although the ash content showed significant differences between the fresh material and pastirma groups (p <0.05), there were no statistically significant differences among the pastirma groups themselves (p>0.05). Studies on fish-based pastirma products remain scarce and are limited in number. The proximate composition of fish meat is known to vary substantially depending on a range of biological and environmental factors, including the geographical origin of the fish, season of capture, dietary habits, reproductive cycle, and environmental conditions, as well as post-harvest factors such as transportation, storage, and processing methods (Kök & Arslan, 2001; Arslan et al., 1997; Nizamlıoğlu et al., 1998). Babur (2017) reported the proximate composition of fresh seabass (*Dicentrarchus labrax*), with moisture, lipid, ash, and protein contents measured as 72.82%, 5.85%, 1.29%, and 18.42%, respectively. In the resulting pastirma products, these values shifted to 24.22% (moisture), 9.54% (lipid), 36.83% (ash), and 16.64% (protein). At the end of the storage period, protein contents in groups A (pastirma with fenugreek paste) and B (pastirma without fenugreek paste), C (extra-spiced pastirma with fenugreek paste), and D (extra-spiced pastirma without fenugreek paste) were determined as 36.42%, 36.10%, 35.29%, and 32.68%, respectively, while lipid levels were 10.20%, 9.74%, 9.00%, and 10.18%, and ash contents were 15.97%, 16.80%, 18.14%, and 19.74%, respectively. Arslan et al. (1997a) investigated vacuum-packaged mirror carp pastirma stored under refrigerated conditions and reported protein levels of 55.24–62.32%, fat contents of 4.55–10.64%, ash contents of 5.29–8.65%, and moisture levels of 23.06–30.98%. In non-vacuum-packaged samples, these ranges were 39.53–61.11% for protein, 6.48–21.59% for fat, 5.05–12.87% for ash, and 15.19–39.17% for moisture. In a subsequent study, Arslan et al. (1997b) evaluated mirror carp pastirma stored at 20 °C and recorded fat contents of 6.33–8.42% (vacuum-packed) and 7.77–14.88% (non-vacuum), ash contents of 9.75–11.94% and 5.51–15.60%, and moisture levels of 32.48–36.81% and 15.96–38.13%, respectively. Yapar (1993), in his study employing four distinct fenugreek paste formulations in pastirma production, found protein levels ranging from 23.24% to 55.99%, fat levels from 13.12% to 18.22%, and ash levels from 8.07% to 11.01%. Arslan and Kök (2001) investigated sliced, vacuum-packed barbel pastirma stored under refrigeration and observed fat contents of 36.81–38.87%, protein levels of 21.18–24.63%, and moisture contents of 36.31–37.86%. According to Yapar (1993), a proportional decrease in moisture content was observed during processing, while protein, fat, and ash contents increased accordingly. Gürbüz (1994) stated that salting, drying, and other processing methods applied during the conversion of raw meat into final products led to the partial removal of free water in the tissue, thereby significantly lowering the moisture levels compared to fresh meat. In a study conducted by Yapar (1993) on trout *pastirma* prepared using various fenugreek paste formulations, the moisture content decreased gradually throughout the ripening period, ranging between 14.71% and 50.62%. In line with these findings, the current study

demonstrated that moisture content decreased in all treatment groups following *pastirma* processing, whereas the contents of protein, fat, and ash increased proportionally due to water loss. Although some variations in protein and fat values were recorded in the liquid smoke-treated groups, these differences are thought to result from the natural variability among the fish fillets used. Overall, the results obtained in this study are consistent with those reported by previous researchers.

Physicochemical analysis

pH

The pH values of pastirma produced from meagre (*Argyrosomus regius*) are presented in Table 2.

Table 2. pH values of meagre pastirma

pH	MP	FMP	LSMP	LSFMP
Fresh		6.49 ± 0.01^{f}		
Day 0	5.90 ± 0.50^{Ae}	5.78 ± 0.01^{Bb}	5.79 ± 0.01^{Bbc}	5.70 ± 0.02^{Ca}
Day 15	5.91 ± 0.05^{Ae}	6.00 ± 0.05^{Ad}	5.93 ± 0.20^{Bg}	5.99 ± 0.01^{Be}
Day 30	5.89 ± 0.05^{Ade}	5.97 ± 0.03^{Ac}	5.87 ± 0.02^{Bfg}	5.97 ± 0.01^{Bde}
Day 45	5.85 ± 0.05^{Acd}	5.93 ± 0.01^{Bc}	5.87 ± 0.01^{Cf}	5.96 ± 0.01^{Dde}
Day 60	5.85 ± 0.45^{Acd}	5.84 ± 0.05^{Ac}	5.85 ± 0.01^{Ade}	5.94 ± 0.01^{Bd}
Day 75	5.79 ± 0.01^{Ab}	5.87 ± 0.25^{Bc}	5.86 ± 0.06^{Be}	5.89 ± 0.01^{Bc}
Day 90	5.87 ± 0.05^{Bcde}	5.56 ± 0.20^{Bc}	5.85 ± 0.02^{Aa}	5.98 ± 0.03^{Cde}
Day 105	5.73 ± 0.10^{Ba}	5.75 ± 0.30^{Aa}	5.63 ± 0.03^{Cb}	5.66 ± 0.04^{ABa}
Day 120	5.83 ± 0.25^{Bbc}	5.82 ± 0.20^{ABb}	5.80 ± 0.02^{Bcd}	5.76 ± 0.02^{Ab}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

In the present study, the pH value of the fresh product was determined to be 6.49 ± 0.01. Irregular increases and decreases in pH values were observed in all pastirma groups throughout the storage period. These fluctuations between the beginning and end of storage were found to be statistically significant in all groups ($p < 0.05$). At the beginning of storage, the pH values of the pastirma groups were recorded as 5.90 (MP), 5.78 (FMP), 5.79 (LSMP), and 5.70 (LSFMP), while on the 120th day of storage, these values were 5.83, 5.81, 5.80, and 5.76, respectively. Statistically significant differences were observed between fenugreek paste-coated and non-coated groups on certain days ($p < 0.05$). Similarly, significant differences in pH values were also observed between traditionally processed and liquid smoke-treated groups ($p < 0.05$). Among the groups, LSFMP was the most stable in terms of pH, while MP exhibited the greatest decrease in pH values over time.

According to Gram and Dalgaard (2002), pH variation in fish meat is an indirect indicator of several biochemical processes, including protein degradation, amino acid deamination, microbial fermentation, and organic acid production. The statistically significant differences observed on certain days between groups may be related to the effects of processing methods on quality parameters such as microbial activity, enzymatic reactions, and lipid oxidation. The findings of this study indicate that the combined use of smoke and fenugreek paste plays a crucial role in maintaining product quality and stability during storage. In a study investigating the effects of different fenugreek paste mixtures on pastirma quality, Nizamlıoğlu et al. (1998) reported that these mixtures influenced microbial growth and led to a gradual decrease in pH over time. Similarly, Kök and Arslan (2003) studied the effect of different fenugreek paste coating durations on pastirma made from Barbus esocinus and found that the pH values ranged between 5.70 and 5.96 over a 90-day storage period. They concluded that longer exposure to fenugreek paste helped maintain pH stability. Doğruer et al. (1998) emphasized the bacteriostatic effect of garlic in fenugreek paste, stating that it inhibited mold and yeast growth, thereby indirectly contributing to pH stability. These researchers collectively suggest that microbial growth, amino acid deamination, and the accumulation of organic acids over time are key contributors to pH variation. Kılınç and Sürengil (2016) reported that the pH values in a pastirma-like product made from whiting (Merlangius merlangus) fluctuated between 6.1 and 6.4 during a 15-day dry salting process. Following the coating phase of the product, the pH was recorded at 6.2 at the beginning of storage at 15–20 °C, subsequently decreasing to 5.6 by the fifth day of storage. The authors also indicated that lactic acid bacteria counts showed a strong

correlation with pH levels throughout processing, and that increases in lactic acid bacteria were associated with corresponding decreases in pH values. Furthermore, the decrease in pH values is generally considered an indicator of bacterial fermentation and the onset of spoilage (Gram & Dalgaard, 2002). The pH findings of the current study are consistent with the observations reported by these researchers. Although fluctuations in pH values were observed across all groups during storage, the magnitude of change remained relatively small (around 0.30). The low pH values in the products are likely attributed to the positive microbial and chemical effects of fenugreek paste and the added liquid smoke used in the coating process.

Salt: The salt contents of pastirma produced from meagre (*Argyrosomus regius*) are presented in Table 3.

Table 3. Salt content of meagre pastirma

Salt	MP	FMP	LSMP	LSFMP
Fresh		1.01 ± 0.04^{a}		
Day 0	10.06 ± 0.12^{Ae}	10.16 ± 0.06^{ABe}	10.00 ± 0.06^{Ag}	10.40 ± 0.06^{Cf}
Day 15	9.75 ± 0.08^{Bc}	10.21 ± 0.02^{Ce}	9.55 ± 0.04^{Ae}	10.50 ± 0.14^{Df}
Day 30	9.42 ± 0.03^{Cb}	9.24 ± 0.03^{Ab}	9.23 ± 0.05^{Ac}	9.33 ± 0.06^{Bb}
Day 45	9.93 ± 0.04^{Cd}	9.43 ± 0.05^{Bc}	9.08 ± 0.05^{Ab}	9.42 ± 0.06^{Bb}
Day 60	9.81 ± 0.02^{Cc}	9.64 ± 0.05^{Bd}	9.36 ± 0.06^{Ad}	9.35 ± 0.08^{Ab}
Day 75	10.34 ± 0.07^{Cf}	10.90 ± 0.08^{Df}	9.89 ± 0.03^{Ag}	10.19 ± 0.05^{Be}
Day 90	11.61 ± 0.03^{Bı}	11.51 ± 0.10^{Bg}	10.34 ± 0.16^{Ah}	10.34 ± 0.25^{Aef}
Day 105	11.23 ± 0.09^{Ch}	10.85 ± 0.06^{Bf}	9.99 ± 0.04^{Ag}	9.93 ± 0.07^{Ad}
Day 120	10.85 ± 0.06^{Bg}	10.85 ± 0.06^{Bf}	9.70 ± 0.08^{Af}	9.61 ± 0.05^{Ac}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

The salt content of the fresh material was determined as 1.01%. Following the salting and fenugreek paste treatments, the initial salt values in the pastirma groups at the beginning of storage were found to be 10.06% (MP), 10.16% (FMP), 10.00% (LSMP), and 10.40% (LSFMP), respectively. Throughout the storage period, salt contents in all pastirma groups showed statistically significant variations ($p<0.05$). During storage, salt levels ranged between 9.42–11.61% in the MP group, 9.24–11.51% in the FMP group, 9.08–10.34% in the LSMP group, and 9.33–10.50% in the LSFMP group. In a study conducted by Yapar (1993) on trout pastirma, the salt content at the beginning of maturation was reported as 10.03%, while on the 30th day it ranged between 10.44% and 11.34% among groups. The researcher noted that salt changes over time were significant ($p<0.05$), whereas differences among formulations were not statistically significant ($p>0.05$). Similarly, Babur (2017) reported that the salt content in sea bass pastirma was 10.01% in groups A (pastirma with fenugreek paste) and B (pastirma without fenugreek paste), and 9.08% in groups C (extra-spiced pastirma with fenugreek paste) and D (extra-spiced pastirma without fenugreek paste) at the beginning of storage, while at the end of storage, values were 9.91%, 9.51%, 9.02%, and 9.19%, respectively. Arslan et al. (1997a) reported that salt values in mirror carp pastirma ranged from 6.92% to 10.50% in vacuum-packed samples, and from 7.25% to 12.31% in non-vacuum samples. In another study, Arslan et al. (1997b) found that during storage at market temperature, the salt content ranged between 8.33–12.91% in vacuum-packed and 7.75–14.68% in unpacked samples. Arslan et al. (2001), in their study on pastirma made from *Barbus esocinus*, reported salt contents between 6.59% and 9.30%. Gürbüz (1994) indicated that salt content in pastirma may vary over time depending on the type and amount of salt used, the processing method, degree and duration of drying, environmental temperature, and storage conditions. According to the Turkish Food Codex, the maximum permitted salt content is 8.5%, while for meat pastirma specifically, it should not exceed 6%. In the current study, these values were exceeded, which is attributed to the use of higher salt concentrations aimed at better microbiological preservation of the product. Nevertheless, the salt contents observed in most fish-based pastirma studies are consistent with the findings of this study.

Thiobarbituric Acid (TBA)

The findings related to the TBA values of pastirma produced from meagre (*Argyrosomus regius*) are presented in Table 4.

Table 4. TBA (Malondialdehyde/kg) values of meagre pastirma

TBA MA/kg	MP	FMP	LSMP	LSFMP
Fresh			1.60 ± 0.06^{a}	
Day 0	1.64 ± 0.03^{Ba}	1.80 ± 0.16^{Bb}	2.31 ± 0.02^{Cb}	1.48 ± 0.05^{Aa}
Day 15	2.03 ± 0.03^{Ab}	2.46 ± 0.11^{Bd}	3.88 ± 0.03^{Cd}	2.35 ± 0.12^{Bb}
Day 30	2.60 ± 0.29^{Bd}	2.18 ± 0.13^{Ac}	3.41 ± 0.09^{Cc}	2.49 ± 0.07^{ABbc}
Day 45	3.00 ± 0.02^{Cf}	2.84 ± 0.08^{Be}	3.99 ± 0.04^{Dde}	2.73 ± 0.06^{Ad}
Day 60	3.03 ± 0.04^{Af}	2.89 ± 0.03^{Be}	4.76 ± 0.08^{Bg}	2.69 ± 0.26^{Ccd}
Day 75	2.26 ± 0.03^{Bc}	2.81 ± 0.06^{Ae}	4.10 ± 0.10^{De}	2.43 ± 0.11^{Cb}
Day 90	2.80 ± 0.10^{Ae}	3.19 ± 0.06^{Bf}	4.79 ± 0.06^{Cg}	2.76 ± 0.14^{Dd}
Day 105	3.74 ± 0.05^{Ag}	4.72 ± 0.11^{Dg}	4.42 ± 0.20^{Cf}	3.98 ± 0.07^{Be}
Day 120	6.18 ± 0.02^{Dh}	5.51 ± 0.02^{Bh}	5.83 ± 0.02^{Ch}	4.06 ± 0.03^{Ae}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

TBA (Thiobarbituric Acid) values were used in this study as an indicator of lipid oxidation occurring during the storage of pastirma products and to assess the level of deterioration in terms of product quality. According to the results obtained, TBA values showed statistically significant increases in all pastirma groups throughout the storage period (p <0.05). At the beginning of storage, TBA values in the MP, FMP, LSMP, and LSFMP groups were recorded as 1.64, 1.80, 2.31, and 1.48 mg MA/kg, respectively, and increased by day 120 to 6.18, 5.51, 5.83, and 4.06 mg MA/kg, respectively. Statistical analyses performed on the same days across different groups revealed that the applied processing methods and varying formulations had a significant influence on the TBA values (p <0.05). According to Schormüller (1968), TBA values exceeding 5 mg MA/kg indicate the onset of oxidative spoilage, while values above 7–8 mg MA/kg are considered beyond the threshold for consumption (Çorapçı, 2013). Based on these limits, it was observed that by the end of storage, all groups except LSFMP approached the critical threshold, with the MP group exceeding it. Babur (2017), in her study on sea bass pastirma, reported TBA values at the end of a 90-day storage period as 6.28, 3.29, 5.04, and 3.02 mg MA/kg for groups A (pastirma with fenugreek paste), B (pastirma without fenugreek paste), C (extra-spiced pastirma with fenugreek paste), and D (extra-spiced pastirma without fenugreek paste) respectively. The highest TBA value was found in the fenugreek paste-coated group. These findings indicate that the combination of liquid smoke and fenugreek paste exhibits a limiting effect on TBA formation and thus contributes positively to oxidative stability.

Trimethylamine Nitrogen (TMA-N)

The TMA-N values of pastirma produced from meagre are presented in Table 5**.**

According to the data obtained from the analyses, TMA-N values exhibited a fluctuating pattern across all pastirma groups from the beginning to the end of the storage period. The differences between the TMA-N values measured at the beginning and end of storage were found to be statistically significant (p <0.05). While statistically significant differences were observed between traditional and smoked groups at the beginning of storage (p <0.05), similar values were detected across all groups on days 45, 60, and 75 (p > 0.05). Compared to fresh fish meat, a significant increase in TMA-N values was observed in all pastirma groups starting from day 0 and continuing throughout the storage period (p <0.05). At the beginning of storage, TMA-N values in the MP, FMP, LSMP, and LSFMP groups were recorded as 1.93, 2.05, 2.73, and 2.48 mg/100 g, respectively, while by the end of storage these values had changed to 2.78, 2.67, 2.43, and 2.69 mg/100 g. Although irregular changes were noted during storage, an overall increase in TMA-N values was observed at the end of the storage period. Babur (2017), in his study on sea bass pastirma, reported fluctuating TMA-N values across all groups during storage. He identified a very low initial TMA-N value of 0.07 mg/100 g in fresh material, with all groups showing increases until day 15, followed by a decline. On day 90, TMA-N values in groups A (pastirma with fenugreek paste), B (pastirma without fenugreek paste), C (extra-spiced pastirma with fenugreek paste), and D (extra-spiced pastirma without fenugreek paste) were 0.52, 0.88, 0.61, and 0.76 mg/100 g, respectively. The differences between the fenugreek paste-coated and extra-spiced non-coated groups were statistically significant (p <0.05), while the differences

between non-coated and extra-spiced fenugreek paste-coated groups were not statistically significant ($p > 0.05$). According to international standards, acceptable TMA-N values range between 10 and 15 mg/100 g. In fish, TMA-N values of 12 mg/100 g and above indicate spoilage, values between 4–10 mg/100 g are considered marketable, and values of 4 mg/100 g or less are regarded as high quality (Gökoğlu, 1994). Although the TMA-N values obtained in the current study were higher than those reported by Babur (2017) (0.52–0.88 mg/100 g), they still fell within the "high quality" classification for all pastirma groups even on the 120th day of storage, as indicated by Gökoğlu's (1994) criteria (Table 5). It was observed that the presence or absence of fenugreek paste had no significant effect on TMA-N values in both traditional and liquid smoke-enriched groups. However, the groups treated with liquid smoke extract exhibited slightly lower TMA-N levels compared to their traditionally processed counterparts. The TMA-N values obtained in all groups remained below the consumption threshold reported by Gökoğlu (1994), indicating that the products fall within the good quality category.

Table 5. TMA-N (mg/100 g) values of pastirma produced from meagre

TMA-N mg/100g	MP	FMP	LSMP	LSFMP
Fresh		1.21 ± 0.16^{a}		
Day 0	1.93 ± 0.12^{Abc}	2.05 ± 0.17^{Ac}	2.73 ± 0.24^{Be}	2.48 ± 0.50^{ABcd}
Day 15	2.59 ± 0.12^{Bde}	2.71 ± 0.17^{Bf}	2.34 ± 0.06^{Acd}	2.49 ± 0.13^{ABcd}
Day 30	2.10 ± 0.66^{ABbc}	1.75 ± 0.09^{Ab}	2.87 ± 0.08^{Be}	2.10 ± 0.68^{ABbc}
Day 45	1.88 ± 0.03^{Ab}	1.95 ± 0.07^{Ac}	1.83 ± 0.08^{Ab}	1.84 ± 0.06^{Ab}
Day 60	2.01 ± 0.06^{Abc}	2.04 ± 0.04^{Ac}	1.99 ± 0.07^{Ab}	2.00 ± 0.02^{Abc}
Day 75	2.23 ± 0.06^{Abcd}	2.25 ± 0.06^{Ad}	2.18 ± 0.04^{Ac}	2.19 ± 0.03^{Abcd}
Day 90	2.34 ± 0.05^{Acd}	2.47 ± 0.06^{Be}	2.27 ± 0.04^{Acd}	2.33 ± 0.03^{Abcd}
Day 105	2.63 ± 0.07^{Bde}	2.59 ± 0.06^{Bef}	2.40 ± 0.06^{Ad}	2.38 ± 0.09^{Acd}
Day 120	2.78 ± 0.10^{Be}	2.67 ± 0.09^{Bf}	2.43 ± 0.11^{Ad}	2.69 ± 0.06^{Bd}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods ($p < 0.05$).

Additionally, the TMA-N levels determined in this study were higher than those reported by Babur (2017). This difference is presumed to be associated with the variation in fish species and the differences in processing methods applied.

Total volatile basic nitrogen (TVB-N)

The TVB-N values of pastirma produced from meagre (*Argyrosomus regius*) are presented in Table 6.

In our study, a significant increase in TVB-N values was observed in all groups from the beginning of storage throughout the entire storage period ($p < 0.05$). At the beginning of storage, TVB-N values were determined as 1.90 mg/100 g (MP), 2.09 mg/100 g (FMP), 2.06 mg/100 g (LSMP), and 2.29 mg/100 g (LSFMP). By the end of storage, these values had increased to 6.34, 5.64, 5.48, and 5.82 mg/100 g, respectively. In general, differences between fenugreek paste-coated and non-coated groups suggest that fenugreek paste has an effect on TVB-N levels. Regarding statistical differences between groups, significant differences were observed between MP and FMP, as well as between LSMP and LSFMP at the beginning of storage ($p < 0.05$), while TVB-N values in FMP and LSMP groups were found to be statistically similar ($p > 0.05$). At the end of storage, significant differences were detected between the MP group and the other three groups (FMP, LSMP, LSFMP) ($p < 0.05$). The increase in TVB-N values in the LSMP and LSFMP groups appeared to slow down after day 60. This trend is thought to be related to the delaying effect of liquid smoke and fenugreek paste on the accumulation of volatile nitrogen compounds. Babur (2017), in her study on sea bass pastirma, reported a TVB-N value of 15.36 mg/100 g in fresh material and values ranging from 19.93 to 22.02 mg/100 g at the beginning of storage in pastirma groups. Toward the end of storage, TVB-N values increased in all pastirma groups, reaching the consumption threshold on day 45 for group A (pastirma with fenugreek paste), day 30 for groups B (pastirma wihout fenugreek paste) and D (extra spiced pastirma without fenugreek paste), and day 60 for group C (extra spiced pastirma with fenugreek paste). According to Gökoğlu (1994), in fish and fishery products, a TVB-N value of up to 25 mg/100 g is considered "very good," up to 30 mg/100 g as "good," up to 35 mg/100 g as "marketable," and values above 35 mg/100 g are classified as "spoiled" (Kietzmann et al.,

1969; Ludorff & Meyer, 1973; Lang, 1979). The TVB-N values obtained in this study were significantly lower than those reported in the literature, and even at the end of storage, all values remained below the spoilage limit of 35 mg/100 g, falling within the "very good" quality category. This is thought to be due to the high freshness of the fish used in the study as well as species-specific differences.

Table 6. TVB-N (mg/100 g) values of pastirma produced from meagre

TVB-N mg/100g	MP	FMP	LSMP	LSFMP
Fresh		1.84 ± 0.04^{a}		
Day 0	1.90 ± 0.02^{Aa}	2.09 ± 0.03^{Bb}	2.06 ± 0.03^{Bb}	2.29 ± 0.02^{Cb}
Day 15	2.60 ± 0.02^{Ab}	2.84 ± 0.03^{Cc}	2.74 ± 0.02^{Bc}	2.86 ± 0.02^{Cc}
Day 30	3.49 ± 0.02^{Ac}	3.70 ± 0.02^{Cd}	3.61 ± 0.02^{Bd}	3.68 ± 0.03^{Cd}
Day 45	4.55 ± 0.10^{Ad}	4.43 ± 0.08^{Ae}	4.42 ± 0.02^{Ae}	4.49 ± 0.05^{Bea}
Day 60	4.66 ± 0.03^{Ae}	4.77 ± 0.02^{Cf}	4.63 ± 0.02^{Af}	4.71 ± 0.04^{Bf}
Day 75	4.87 ± 0.04^{Bf}	5.12 ± 0.02^{Cg}	4.79 ± 0.02^{Af}	4.87 ± 0.04^{Bf}
Day 90	5.09 ± 0.05^{Bg}	6.22 ± 0.02^{Dj}	4.98 ± 0.07^{Ag}	5.29 ± 0.03^{Cg}
Day 105	$6.43\pm0.03^{C\imath}$	$5.89\pm0.04^{B\imath}$	5.57 ± 0.04^{Ah}	5.70 ± 0.29^{ABh}
Day 120	6.34 ± 0.03^{Bh}	5.64 ± 0.29^{Ah}	5.48 ± 0.33^{Ah}	5.82 ± 0.01^{Ah}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

Microbiological Analysis

Total viable count

The total viable count (TVC log cfu/g) cvalues of pastirma produced from meagre are presented in Table 7.

Halophilic Microorganism Count

The halophilic microorganism (HBC log cfu/g) counts of pastirma produced from meagre are presented in Table 8.

Table 7. Total viable count (TVC log cfu/g) values of meagre pastirma

TVC (log cfu/g)	MP	FMP	LSMP	LSFMP
Fresh		2.30 ± 0.07^{a}		
Day 0	2.70 ± 0.04^{Bb}	2.48 ± 0.04^{Ab}	2.69 ± 0.09^{Bb}	2.53 ± 0.13^{ABb}
Day 15	2.73 ± 0.17^{Ab}	2.60 ± 0.04^{Ac}	2.77 ± 0.07^{Ab}	$2.65\pm.0.04^{Ac}$
Day 30	3.74 ± 0.01^{Cc}	3.03 ± 0.10^{Ad}	3.30 ± 0.04^{Bc}	3.02 ± 0.08^{Ad}
Day 45	4.07 ± 0.09^{Cd}	3.34 ± 0.05^{Ae}	3.74 ± 0.02^{Bd}	3.32 ± 0.05^{Ae}
Day 60	4.64 ± 0.03^{Ce}	4.62 ± 0.02^{Cf}	3.99 ± 0.09^{Be}	3.48 ± 0.04^{Af}
Day 75	4.74 ± 0.02^{Cef}	4.73 ± 0.02^{Cg}	4.18 ± 0.03^{Bf}	3.63 ± 0.03^{Ag}
Day 90	4.80 ± 0.01^{Cf}	4.79 ± 0.02^{Cgh}	4.27 ± 0.01^{Bfg}	4.21 ± 0.02^{Ag}
Day 105	4.84 ± 0.02^{Cf}	4.86 ± 0.02^{Ch}	4.68 ± 0.05^{Bg}	4.60 ± 0.02^{Ag}
Day 120	5.10 ± 0.01^{Cg}	5.06 ± 0.04^{Cj}	4.97 ± 0.03^{Bh}	4.85 ± 0.04^{Ah}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

PCA (Plate Count Agar) values serve as indicators of chemical spoilage or microbial activity increases during the shelf life of meagre pastirma. According to the data obtained, all pastirma groups exhibited statistically significant increases in total viable counts (TVC) throughout the storage period ($p < 0.05$). At the beginning of storage, total bacterial counts ranged from 2.48 to 2.70 log cfu/g, reaching 4.85 to 5.10 log cfu/g by day 120. Statistical comparisons performed between groups on the same days revealed that product formulation and processing techniques had a clear impact on microbial spoilage ($p < 0.05$). Notably, the liquid smoke–fenugreek paste combination (LSFMP) group had the lowest total bacterial count throughout the 120-day storage period. These findings demonstrate the effectiveness of both traditional and modern preservation methods in delaying microbial spoilage in delicatessen products derived from fish. The total bacterial count values observed under 7% salt concentration showed statistically significant increases across all groups depending on storage time ($p < 0.05$).

Table 8. Halophilic microorganism counts of meagre pastirma

HBC (log cfu/g)	MP	FMP	LSMP	LSFMP
Fresh		0.41 ± 0.01^{a}		
Day 0	0.66 ± 0.24^{Cb}	0.44 ± 0.24^{Ab}	0.90 ± 0.05^{Db}	0.51 ± 0.20^{Bb}
Day 15	0.69 ± 0.21^{Ab}	0.49 ± 0.20^{Ab}	0.89 ± 0.11^{Ab}	0.48 ± 0.44^{Ab}
Day 30	1.25 ± 0.06^{Ccd}	0.86 ± 0.12^{Ac}	0.99 ± 0.13^{Bb}	0.89 ± 0.14^{Ac}
Day 45	1.54 ± 0.08^{Dc}	1.39 ± 0.10^{Ccd}	1.28 ± 0.17^{Bc}	1.04 ± 0.08^{Acd}
Day 60	2.25 ± 0.02^{Ccd}	2.18 ± 0.08^{Cde}	1.72 ± 0.07^{Bcd}	1.33 ± 0.04^{Ade}
Day 75	2.32 ± 0.02^{Dd}	2.22 ± 0.04^{Cdf}	1.74 ± 0.06^{Bcd}	1.52 ± 0.05^{Aef}
Day 90	2.46 ± 0.02^{Dd}	2.36 ± 0.03^{Cdf}	1.81 ± 0.03^{Bde}	1.59 ± 0.02^{Aef}
Day 105	2.63 ± 0.03^{Dd}	2.41 ± 0.03^{Cdf}	2.24 ± 0.09^{Bde}	1.63 ± 0.02^{Aef}
Day 120	3.48 ± 0.01^{Dd}	3.44 ± 0.01^{Cf}	2.99 ± 0.09^{Be}	2.73 ± 0.02^{Af}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods ($p < 0.05$).

Generally, the highest microbial loads were observed in the MP and FMP groups, whereas the groups treated with liquid smoke showed lower microbial levels compared to traditional pastirma groups. At the end of the 120-day storage period, the group with the lowest PCA value was LSFMP (2.73 ± 0.02 log cfu/g), which was statistically significantly different from the other groups. These results highlight the protective effect of the liquid smoke–fenugreek paste combination and suggest that it could be a potential solution for extending the shelf life of meagre pastirma. In this study, total yeast–mold, total coliforms, and *Staphylococcus spp*. were not detected in any of the fresh or pastirma samples throughout the storage period. Özdemir et al. (1999) reported total aerobic mesophilic bacterial counts in meat pastirma between 10^5 and 10^7 cfu/g. Doğruer et al. (1995) recorded microbial loads between 2.8×10^7 and 7.0×10^7 cfu /g on day 1, and between 2.2×10^6 and 3.4×10^6 cfu /g on day 60. Arslan and Kök (2001) found aerobic counts between 4.0 and 7.7×10^4 cfu /g in vacuum-packed Barbus esocinus pastirma. Babur (2017) reported fluctuating total bacterial counts in pastirma with fenugreek paste, pastirma without fenugreek paste, extra-spiced pastirma with fenugreek paste, and extra-spiced pastirma without fenugreek paste sea bass pastirma groups, recording final values of 3.6, 6.7, 6.5, and 3.2 log cfu /g, respectively, after 90 days. Yeast and mold counts were reported as 2.3, 4.1, 4.5, and 0 log cfu/g, respectively. In another study, Arslan et al. (1997a) reported yeast–mold values in vacuum-packed mirror carp pastirma between 5.2×10^2 and 2.5×10^3 cfu /g. Yapar (1993), in a study testing different fenugreek paste formulations in trout pastirma, found yeast–mold counts between 10 and 2.2×10^3 cfu /g. Kılınç and Sürengil (2016) reported that in their study on a pastirma-like product prepared from whiting (*Merlangius merlangus*), the aerobic mesophilic bacterial count was 5.08 log CFU/g at the beginning of the drying process, which significantly decreased to 3.24 log CFU/g after 15 days of dry salting and drying. However, during the second phase—storage at 20 °C—they observed a rapid increase in total aerobic mesophilic bacterial counts. A similar trend was also noted for *Enterobacteriaceae*, coliforms, and lactic acid bacteria. Moreover, the authors stated that *Staphylococcus aureus*, *Escherichia coli*, and yeasts and molds were not detected in any of the samples throughout the study. Arslan and Kök (2001) also reported no yeast–mold growth throughout storage in their study. According to the Turkish Food Codex, the acceptable yeast–mold limit in pastirma

is 10^2 cfu /g. Some studies have also reported the presence of coliform bacteria during the pastirma production stages (Yapar, 1993; Babur, 2017). In addition to enhancing sensory attributes such as flavor, aroma, and color, the smoking process plays a crucial role in extending the shelf life of the product (Ledesma et al., 2016; Dışhan et al., 2021). Gürbüz et al. (1997) reported that the application of smoking before and after fenugreek paste coating significantly affected total aerobic mesophilic bacteria, *Staphylococcus–Micrococcus*, and yeast–mold populations in pastirma products. The total viable counts obtained in this study were notably lower than those found in meat pastirma studies and were similar to those in other fish pastirma studies. Although the general microbiological limit for consumption in food products is accepted as 10^6 cfu /g (6 log cfu/g), due to some values reaching 10^5 cfu /g by day 120, consumption beyond this point may pose a risk to human health. All pastirma groups were found to comply with criteria regarding yeast–mold, total coliforms, and *Staphylococcus spp*. Moreover, the application of liquid smoke was shown to have a significant effect on microbial inhibition.

Sensory analysis

Appearance

The appearance scores from the sensory evaluation of pastirma produced from meagre are presented in Table 9.

Table 9. Appearance scores of meagre pastirma

Appearance	MP	FMP	LSMP	LSFMP
Day 0	5.00 ± 0.10^{Af}	4.80 ± 0.45^{Af}	4.80 ± 0.45^{Ae}	4.80 ± 0.45^{Af}
Day 15	5.00 ± 0.11^{Af}	4.60 ± 0.55^{Aef}	4.60 ± 0.55^{Ade}	4.60 ± 0.55^{Aef}
Day 30	$4.60\pm0.55e^{Af}$	4.40 ± 0.55^{Adef}	4.40 ± 0.55^{Acde}	4.40 ± 0.55^{Adef}
Day 45	4.40 ± 0.55^{Ade}	4.20 ± 0.45^{Acdef}	4.20 ± 0.45^{Abcde}	4.20 ± 0.45^{Acdef}
Day 60	4.20 ± 0.45^{Acde}	4.00 ± 0.10^{Abcde}	4.00 ± 0.10^{Aabcd}	4.00 ± 0.15^{Abcde}
Day 75	4.00 ± 0.12^{Abcd}	$3.80\pm.45^{Aabcd}$	3.80 ± 0.45^{Aabc}	3.80 ± 0.45^{Aabcd}
Day 90	3.80 ± 0.45^{Aabc}	3.60 ± 0.55^{Aabc}	3.60 ± 0.55^{Aab}	3.60 ± 0.55^{Aabc}
Day 105	3.60 ± 0.55^{Aab}	3.40 ± 0.55^{Aab}	3.60 ± 0.55^{Aab}	3.40 ± 0.55^{Aab}
Day 120	3.40 ± 0.55^{Aa}	3.20 ± 0.45^{Aa}	3.40 ± 0.55^{Aa}	$3.20\pm.45^{Aa}$

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

Appearance, one of the key sensory quality parameters, plays a crucial role in forming the first impression for consumers. In meat products, appearance encompasses multiple dimensions such as color intensity, brightness, surface integrity, fat–membrane structure, moisture–dryness balance, and the uniformity of the fenugreek paste or surface coating. It also serves as a visual indicator of microbiological stability, signs of oxidation, and the effectiveness of processing conditions. In our study, appearance scores showed a statistically significant decline over time in all pastirma groups ($p < 0.05$). Although numerical differences in scores were observed among the groups, no statistically significant difference was found between them ($p > 0.05$). The MP group maintained a "very good quality" rating up to day 75, while the FMP, LSMP, and LSFMP groups remained in this category up to day 60. By day 120, appearance scores in all pastirma groups had decreased to between 3.20 and 3.40, which is still considered to reflect "good quality." Toward the end of storage, discoloration in the fenugreek paste and whitening on the meat surface were noted in all groups, contributing to the decline in appearance scores.

Color

The color scores from the sensory evaluation of pastirma produced from meagre are presented in Table 10. Color parameter scores showed a statistically significant decrease over time in all groups ($p < 0.05$). However, despite numerical differences in scores, no statistically significant differences were observed among the groups at the same time points ($p > 0.05$). At the beginning of storage, scores reached up to 5.00 (particularly in the LSMP group), but by day 120, they had declined to a range between 3.20 and 3.60.

Table 10. Odor scores of meagre pastirma

Color	MP	FMP	LSMP	LSFMP
Day 0	4.80±0.45^{Ad}	4.60±0.55^{Ae}	5.00±0.15^{Af}	4.80±0.45^{Af}
Day 15	4.60±0.55^{Acd}	4.40±0.55^{Ade}	4.80±0.45^{Aef}	4.60±0.55^{Aaf}
Day 30	4.40±0.55^{Abcd}	4.20±.45^{Acde}	4.60±0.55^{Adef}	4.40±0.55^{Adef}
Day 45	4.40±0.55^{Abcd}	4.00±0.10^{Abcde}	4.40±0.55^{Acdef}	4.20±0.45^{Acdef}
Day 60	4.20±0.45^{Aabc}	4.00±.15^{Abcde}	4.20±0.45^{Abcde}	4.00±0.10^{Abcde}
Day 75	4.00±0.10^{Aabc}	3.80±0.45^{Aabcd}	4.00±0.15^{Aabcd}	3.80±0.45^{Aabcd}
Day 90	4.00±0.15^{Aabc}	3.60±0.55^{Aabc}	3.80±0.45^{Aabc}	3.60±.0.55^{Aabc}
Day 105	3.80±0.45^{Aab}	3.40±0.55^{Aab}	3.60±0.55^{Aab}	3.40±0.55^{Aab}
Day 120	3.60±0.55^{Aa}	3.20±0.45^{Aa}	3.40±0.55^{Aa}	3.20±0.45^{Aa}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

Odor

The odor scores from the sensory evaluation of pastirma produced from meagre are presented in Table 11.

At the beginning of storage, odor scores in all pastirma groups ranged between 4.8 and 5.0, indicating that the products were classified as "very good quality." Odor scores declined to the "good quality" level by day 75 in the MP, FMP, and LSMP groups, and by day 45 in the LSFMP group. By day 120, only the LSFMP group was rated as "moderate quality" in terms of odor. A statistically significant decrease in odor scores was observed in all groups from day 0 to day 120 (p <0.05). However, although numerical differences were noted among the pastirma groups on the same days, these differences were not statistically significant (p> 0.05). The observed sensory changes in odor are thought to result from several factors, including the reduction of aromatic compounds during storage, the formation of undesirable odors due to secondary products from lipid oxidation, and a decline in aroma quality caused by microbial activity.

Table 11. Odor scores of meagre pastirma

Odor	MP	FMP	LSMP	LSFMP
Day 0	5.00±0.01^{Af}	5.00±0.01^{Af}	5.00±0.10^{Af}	4.80±0.45^{Af}
Day 15	4.80±0.45^{Aef}	4.80±0.45^{Aef}	4.80±0.45^{Aef}	4.40±0.55^{Aef}
Day 30	4.60±0.55^{Adef}	4.60±0.55^{Adef}	4.60±0.55^{Adef}	4.20±0.45^{Ade}
Day 45	4.40±0.55^{Acdef}	4.40±0.55^{Acdef}	4.40±0.55^{Acdef}	4.00±0.10^{Acde}
Day 60	4.20±0.45^{Abcde}	4.20±0.45^{Acde}	4.20±0.45^{Abcde}	3.80±0.45^{Abcde}
Day 75	4.00±0.01^{Babcd}	4.00±0.10^{Bcd}	4.00±0.10^{Aabcd}	3.60±0.55^{Babcd}
Day 90	3.80±045^{Aabc}	3.80±0.45^{Abc}	3.80±0.45^{Aabc}	3.40±0.55^{Aabc}
Day 105	3.60±0.55^{Aab}	3.40±0.55^{Aab}	3.60±0.55^{Aab}	3.20±0.45^{Aab}
Day 120	3.40±0.55^{Aa}	3.20±.045^{Aa}	3.40±0.55^{Aa}	3.00±0.10^{Aa}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

Flavor

The flavor scores from the sensory evaluation of pastirma produced from meagre are presented in Table 12.

According to the results of the sensory analysis, flavor scores decreased significantly over time in all groups ($p < 0.05$). Initially, the MP and LSMP groups received the highest scores (5). Although the liquid smoke-added groups (LSMP and LSFMP) received higher flavor scores than the MP and FMP groups throughout the storage period, these differences were not found to be statistically significant ($p > 0.05$). The MP and FMP groups were classified as "very good quality" up to days 30 and 45, respectively. Between days 45 and 105, they were rated as "good quality," with the FMP group dropping to "moderate quality" on day 105, and the MP group on day 120. In contrast, the "very good quality" classification for the liquid smoke groups lasted until day 75 in the LSMP group and day 60 in the LSFMP group. By day 120, both groups were still rated as "good quality." This trend reflects the expected sensory deterioration in product quality during storage. The decline in flavor scores is likely due to factors such as increased microbial load, lipid oxidation, protein degradation, and the breakdown of aromatic compounds. The application of liquid smoke had a positive effect on flavor, helping to preserve taste quality for a longer period. This effect was observed in both the traditional liquid smoke group (LSMP) and the fenugreek paste-coated version (LSFMP). Additionally, fenugreek paste appeared to have a negative impact on flavor scores over time. The FMP group, which had the lowest flavor scores, suggests that fenugreek paste may contribute to sensory deterioration either through oxidative or microbial mechanisms.

Table 12. Flavor scores of meagre pastirma

Flavor	MP	FMP	LSMP	LSFMP
Day 0	5.00 ± 0.01^{Bg}	4.40 ± 0.55^{Af}	5.00 ± 0.01^{Bf}	4.80 ± 0.45^{ABf}
Day 15	4.40 ± 0.55^{Af}	4.20 ± 0.45^{Aef}	4.80 ± 0.45^{Aef}	4.60 ± 0.55^{Aef}
Day 30	4.20 ± 0.45^{Aef}	4.00 ± 0.01^{Adef}	4.60 ± 0.55^{Adef}	4.40 ± 0.55^{Adef}
Day 45	4.00 ± 0.01^{Adef}	3.80 ± 0.45^{Acdef}	4.40 ± 0.55^{Acdef}	4.20 ± 0.45^{Acdef}
Day 60	3.80 ± 0.45^{Acde}	3.60 ± 0.55^{Abcde}	4.20 ± 0.45^{Abcde}	4.00 ± 0.01^{Abcde}
Day 75	3.60 ± 0.55^{Abcd}	3.40 ± 0.55^{Aabcd}	$4.00\pm.01^{Aabcd}$	3.80 ± 0.45^{Aabcd}
Day 90	3.40 ± 0.55^{Aabc}	3.20 ± 0.45^{Aabc}	3.80 ± 0.45^{Aabc}	3.60 ± 0.55^{Aabca}
Day 105	3.20 ± 0.45^{Aab}	3.00 ± 0.01^{Aab}	3.60 ± 0.55^{Aab}	3.40 ± 0.55^{Aab}
Day 120	3.00 ± 0.15^{Aa}	2.80 ± 0.45^{Aa}	3.40 ± 0.55^{Aa}	3.20 ± 0.55^{Aa}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods ($p < 0.05$).

Texture: The texture scores from the sensory evaluation of pastirma produced from meagre are presented in Table 13.

At the beginning of storage, texture scores in all groups ranged between 4.40 and 4.80, classifying the products as "very good quality." Throughout the storage period, a decrease in texture scores was observed in all pastirma groups over time. These time-dependent changes were found to be statistically significant ($p < 0.05$). The MP group was rated as having the most favorable texture throughout the storage period. By day 120, the FMP, LSMP, and LSFMP groups had declined to the "moderate quality" level. Texture differences between the MP group and the other groups on days 105 and 120 were statistically significant ($p < 0.05$). Texture defines the chew resistance, mouthfeel, and structural integrity of meat products. It is a critical parameter in terms of product acceptance, perceived quality, and shelf life. Particularly, moisture loss during storage can cause notable changes in texture characteristics.

Table 13. Texture scores of meagre pastirma

Texture	MP	FMP	LSMP	LSFMP
Day 0	4.60 ± 0.55^{Aa}	4.40 ± 0.55^{Af}	4.80 ± 0.45^{Af}	4.60 ± 0.55^{Af}
Day 15	4.40 ± 0.55^{Aa}	4.20 ± 0.45^{Aef}	4.60 ± 0.55^{Aef}	4.40 ± 0.55^{Aef}
Day 30	$4.20\pm.45^{Aa}$	4.00 ± 0.10^{Adef}	4.40 ± 0.55^{Adef}	4.20 ± 0.45^{Adef}
Day 45	4.00 ± 0.10^{Aa}	3.80 ± 0.45^{Acdef}	4.20 ± 0.45^{Acdef}	4.00 ± 0.10^{Acdef}
Day 60	4.40 ± 0.55^{Ba}	$3.60\pm.55^{Abcde}$	4.00 ± 0.10^{ABbcde}	3.80 ± 0.45^{ABbcde}
Day 75	4.00 ± 0.71^{Aa}	3.40 ± 0.55^{Aabcd}	3.80 ± 0.45^{Aabcd}	3.60 ± 0.55^{Aabcd}
Day 90	4.00 ± 0.71^{Aa}	3.20 ± 0.45^{Aabc}	3.60 ± 0.55^{Aabc}	3.40 ± 0.55^{Aabc}
Day 105	4.20 ± 0.45^{Ba}	3.00 ± 0.10^{Aab}	3.40 ± 0.55^{Aab}	3.20 ± 0.45^{Aab}
Day 120	4.20 ± 0.45^{Ba}	2.80 ± 0.45^{Aa}	3.20 ± 0.45^{Aa}	3.00 ± 0.10^{Aa}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

Overall Acceptability: The overall acceptability scores from the sensory evaluation of pastirma produced from meagre are presented in Table 14.

As storage progressed, a significant decrease (p <0.05) in overall acceptability scores was observed in all groups. While the initial scores (day 0) ranged between 4.60 and 4.80, by day 120 they had declined to between 2.80 and 3.20. The LSMP group maintained the highest overall acceptability scores. Particularly between days 0 and 60, the scores remained between 4.80 and 4.00, indicating a high level of consumer acceptance. It is believed that the application of liquid smoke enhanced the aromatic profile of the pastirma, contributing to greater consumer preference. Although the MP group showed a similar trend to the LSMP group, a noticeable quality decline was observed after day 75, with scores dropping to 3.20 by day 120—still within the sensory acceptability range. The LSFMP group remained at acceptable levels during the early storage period (0–60 days), but a decline in acceptability began after day 75, reaching 3.00 by day 120. Among all groups, the GPC group had the lowest overall acceptability score on day 120 (2.80 ± 0.45). Sensory characteristics are among the most critical factors determining the consumer appeal of a product. Particularly for highly perishable products such as seafood, determining freshness and optimizing sensory qualities are among the most reliable parameters for product marketing and quality assurance.

Table 14. Overall acceptability scores of meagre pastirma

Overall Acceptability	MP	FMP	LSMP	LSFMP
Day 0	4.80 ± 0.45^{Af}	4.60 ± 0.55^{Ae}	4.80 ± 0.45^{Af}	4.60 ± 0.55^{Ae}
Day 15	4.60 ± 0.55^{Aef}	4.40 ± 0.55^{Ade}	4.60 ± 0.55^{Aef}	4.40 ± 0.55^{Ade}
Day 30	4.40 ± 0.55^{Adef}	4.20 ± 0.45^{Ade}	4.40 ± 0.55^{Adef}	4.20 ± 0.45^{Ade}
Day 45	4.20 ± 0.45^{Acdef}	4.00 ± 0.10^{Acde}	4.20 ± 0.45^{Acdef}	4.00 ± 0.15^{Acde}
Day 60	4.00 ± 0.10^{Abcde}	3.80 ± 0.45^{Abcd}	4.00 ± 0.12^{Abcde}	3.80 ± 0.45^{Abcd}
Day 75	3.80 ± 0.45^{Aabcd}	3.40 ± 0.55^{Aabc}	3.80 ± 0.45^{Aabcd}	3.80 ± 0.45^{Abcd}
Day 90	3.60 ± 0.55^{Aabc}	$3.20\pm.45^{Aab}$	3.60 ± 0.55^{Aabc}	3.40 ± 0.55^{Aabc}
Day 105	$3.40\pm.0.55^{Aab}$	3.20 ± 0.45^{Aab}	3.40 ± 0.55^{Aab}	3.20 ± 0.45^{Aab}
Day 120	3.20 ± 0.45^{Aa}	2.80 ± 0.45^{Aa}	3.20 ± 0.45^{Aa}	3.00 ± 0.10^{Aa}

Groups: MP (Traditional pastirma without fenugreek paste), FMP (Traditional pastirma with fenugreek paste), LSMP (liquid smoke-treated without fenugreek paste), LSFMP (Liquid smoke-treated pastirma with fenugreek paste). Results are expressed as mean ± standard deviation. Statistically significant differences among treatment groups are indicated by uppercase letters, while lowercase letters represent significant differences across storage periods (p <0.05).

Results from sensory analyses indicate that when sensory quality is insufficient, the marketing and consumption of such products can pose significant risks. Although sensory evaluation is a key criterion for consumption, it is more effective when supported by physical and chemical analyses (Baygar et al., 2002). Babur (2017), in his study involving different formulations of sea bass pastirma, reported that although all groups A (pastirma with fenugreek paste), B (pastirma without fenugreek paste), C (extra-spiced pastirma with fenugreek paste), D (extra-spiced pastirma without fenugreek paste) initially displayed "very good quality" in terms of taste, odor, color, appearance, crispness, and overall acceptability, all groups experienced significant sensory quality declines after day 45. She noted that the extra-spiced pastirma with fenugreek paste group was the most favored in terms of taste and color, while fenugreek paste-coated samples (A, C) developed white spots due to salt crystallization by day 60, and non-coated samples (B, D) showed surface yellowing. Anıl (1988) reported that the pastirma he prepared had excellent sensory qualities in terms of appearance, color, taste, and texture, and that vacuum packaging and slicing allowed the product to retain its quality for three months at 20°C. Doğruer (1992) emphasized that both salting duration and pressing had significant effects on texture, appearance, taste, and color. Yapar (1993) reported that fish pastirma prepared with different fenugreek paste formulations retained their sensory quality for at least 30 days. Arslan et al. (1997a) stated that in non-vacuum-stored samples, excessive water loss caused the texture to become firmer and chewability to decline, suggesting that vacuum packaging prolongs the sensory acceptability of pastirma. Arslan and Kök (2001) concluded that fish pastirma prepared with high-quality raw material and stored under refrigeration in vacuum packaging could retain its quality for 90 days or more. Although the sensory quality parameters obtained in the present study align with findings from the literature, the products in this study retained their sensory quality within acceptable limits for a longer period up to 120 days. It is suggested that both fenugreek paste and liquid smoke contributed significantly to attributes such as flavor, aroma, and taste, while vacuum packaging, as recommended by previous researchers, had a substantial effect on maintaining color, texture, and appearance.

Conclusion

In this study, changes in the physicochemical, microbiological, and sensory properties of pastirma products produced from meagre (*Argyrosomus regius*) using traditional and liquid smoke-assisted methods were evaluated throughout their shelf life. The results demonstrated that the applications of liquid smoke and fenugreek paste were effective in preserving product quality. In particular, the LSFMP group, which was treated with both liquid smoke and fenugreek paste, stood out with the lowest microbial load and the highest sensory scores over the 120-day storage period. Furthermore, the fact that TVB-N, TMA-N, and TBA values in all pastirma groups remained within legal limits supports the products' suitability for consumption. Sensory evaluations also revealed that liquid smoke–treated groups exhibited superior performance in terms of taste, odor, and overall acceptability. It can be concluded that the application of liquid smoke may serve as an effective preservative and flavor-enhancing agent in the production of fish pastirma, contributing both to microbial stability and sensory quality. In addition, fenugreek paste provided positive contributions to taste and odor when used in certain combinations, although its potential to negatively affect sensory quality in some cases suggests that formulation optimization is necessary. The broader application of liquid smoke technology in fish pastirma production offers not only the potential to extend shelf life but also provides an alternative means of enhancing sensory attributes such as flavor, odor, and aroma.

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Conflict of Interest

The authors affirm that they do not have any conflicts of interest.

Ethics Approval

This study does not require ethical committee approval.

Author Contributions

Buminhan Burkay Selçuk: Sample collection, analyses, data gathering, laboratory work, writing, and data analysis. Fikret Çakır: Analyses, study design, statistical analysis and calculations, and manuscript editing.

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