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EVALUATING THE INFRARED TECHNIQUE AS A NOVEL DRYING METHOD OF THE TURKISH PASTIRMA

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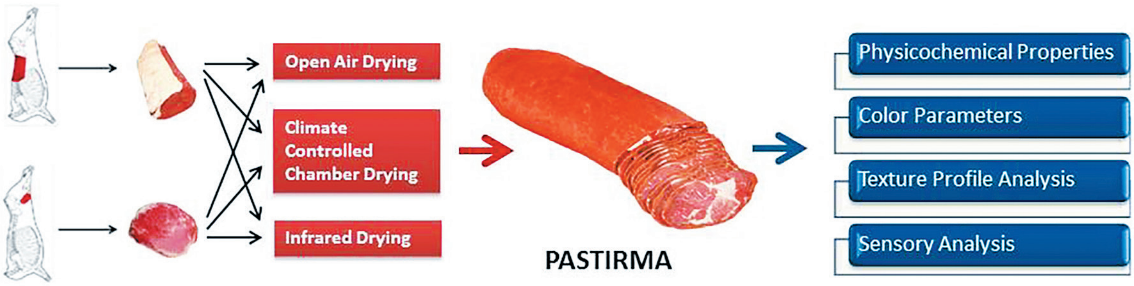
Keywords: *dry-cured meat, meat drying, microbial quality, pastirma, physicochemical quality, traditional meat product*

Abstract
Pastirma, a traditional dry-cured meat product from Turkey, is manufactured after a long drying process. In the study, we aimed to expedite the primary drying process, which is the lengthiest phase in pastirma production, by implementing the innovative infrared drying method, while preserving the sensory attributes of traditionally dried pastirma. Various physicochemical, microbiological and sensory characteristics of pastirma samples from two different muscles obtained by three various drying methods: traditional open-air (OA), climate-controlled chamber (CC) and infrared (IR) drying, were studied. The findings showed that IR drying, which reduced the drying time from 7 days to 2 days, produced the best quality in terms of sensory properties. Also, the lowest TBA values (0.07–0.13 mg/kg) were observed in IR dried samples. IR and CC drying solved the problem of uneven drying process of pastirma which was often encountered during the OA drying process. With the use of IR, the drying process of pastirma was rapid and the product quality was equivalent or even better than that of the other methods used in this research. This innovative approach of using IR drying can be adopted by the pastirma industry to facilitate the production of traditional products.

Graphical abstract



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Introduction

Pastirma, a traditional dry-cured meat product consumed for centuries in Turkey, epitomizes the intersecting historical and cultural heritage of the Middle East, Central Asia, the Mediterranean, the Balkans, and Europe as a significant gastronomic artifact; its name derives from the Turkish word 'bastırma,' meaning 'pressing' [1]. According to the Turkish Food Codex standards, pastirma is a meat product that has been cured and dried, but not thermally processed. It is made from various cuts of beef, such as loin, rib, and round, to achieve a tender texture desired by consumers [2].

The production process of pastirma involves several steps. It begins with curing the meat using a combination of salt, nitrite, sucrose, and glucose as curing agents. After curing, the meat is rinsed and pre-dried, and then it undergoes pressing, primary drying, and finally coating with a cemen paste. The cemen paste is prepared by mixing garlic, paprika and fenugreek seed powder (*Trigonella foenum-graecum*) with water. This paste is applied to the dried meat and plays a crucial role in enhancing the characteristic aroma of pastirma. Additionally, the cemen coating helps preserve the dried meat due to the antimicrobial properties provided by its ingredients [3]. For example, it acts as a barrier against oxygen and prevents mold growth on the surface. Traditionally, the production of pastirma takes place under natural weather conditions (open-air) and ambient temperatures [4]. This method allows the meat to dry and cure naturally, resulting in the desired flavor and texture.

In pastirma water activity (a_w) governs both microbial safety and structural integrity. Inadequate drying during ripening accelerates spoilage microorganism growth, causing degradation prior to product stabilization. Achieving target a_w levels (e. g., 0.84–0.92 as reported by Akköse et al. [5] and İnat et al. [6]) is thus vital to inhibit pathogens, extend shelf life, and permit safe raw consumption while preserving traditional quality [7]. According to the Turkish Food Codex, pastirma should possess a maximum moisture content of 50 %, pH of 6, salt up to 10 % (dry basis), and the coated cemen should not exceed 10 % by weight [2]. Furthermore, the pastirma must be free from rancidity and *Salmonella* contamination, and the presence of coagulase-positive *Staphylococci* and sulfite-reducing bacteria should not exceed 10^4 CFU/g [8].

The drying process reduces free water in pastirma to a very low level, resulting in a stable product with an extended shelf life of about 1 year at room temperature [9]. Low a_w inhibits physicochemical changes, biochemical reactions, and microbiological growth [10]. However, uneven drying can cause cracks in the cemen-coated surface, making these open areas susceptible to mold growth and maggot infestation from hatched fly eggs [11,12]. As pastirma is traditionally air-dried in the shade for about a month, climatic conditions such as temperature, air currents and humidity affect its quality [9]. The final drying phase is extensive, lasts for 5–12 days and poses several disadvantages [13]. The laborious processing of pastirma slows down its availability on the market and exposes it to microbial contamination during production [14]. Open-air drying, with its susceptibility to variable weather conditions, is challenging to regulate. For instance, rapid drying due to excessive air circulation, can lead to case hardening, leaving the meat core too moist [15]. Therefore, slower drying in climate-controlled chambers may resolve this issue, resulting in a more uniformly dried product.

Water removal, one of the oldest preservation techniques, is commonly used for meat and other food products. Recently, alternative drying methods using convective or radiant heat transfer have emerged. Infrared (IR) radiation, used in the food industry for heating, drying, roasting, cooking, thawing, surface pasteurization and packaging sanitization, is energy efficient. In IR drying, the food absorbs electromagnetic energy directly, unlike conventional drying where heat is transferred by convection. Fast, uniform heating and easily controllable process parameters make IR drying preferable to conventional methods. In addition, IR radiation is safe for heating food and is not harmful to human health or the environment [16].

The lengthy drying process has created logistical challenges for modern food production facilities, prompting the search for innovative techniques to speed up this stage while maintaining the traditional sensory characteristics that consumers associate with pastirma. The duration of the initial drying phase in pastirma production depends on climatic conditions and often exceeds five days in an open-air environment. However, the duration of the drying phase could be reduced by the use of IR energy or climate-controlled chambers. Neither infrared nor climate-controlled chamber drying has been investigated as part of the pastirma production process before. This innovative approach to meat drying could benefit the pastirma industry. Therefore, this research aimed to evaluate the effects of OA, CC, and IR drying techniques on some physicochemical and sensory characteristics of pastirma made from two types of beef muscles, loin and round. In addition, this research represents a pioneering effort to harness the potential of IR drying techniques to produce pastirma.

Materials and methods

Selection of meat for pastirma

The beef used in the study was sourced from a commercial meat processing company (Saray Meat Processing Co., Kayseri, Turkey). For the production of pastirma, two types of muscle were used, loin (*longissimus thoracis et lumborum*) and round (vastus group), 24 hours after slaughter. The meat was from 2-year-old steers of the Charolais breed. The steps of the pastirma production process, starting with meat selection and preparation, are detailed in Figure 1. The loin and round sections, meticulously removed from the carcass from an animal slaughtered the day before, were divided into three equal parts, each weighing approximately 1 kg. Thus, six pieces of pastirma grade meat of the same thickness and length were obtained from two sides. The meats were then trimmed to remove excess fat, tendons, and nerves. Each piece of meat was prepared to have the same length and thickness [17]. The temperature of the environment in which the samples were prepared was around 12 °C. An identification tag was attached to each of the pastirma-grade meat samples after the preliminary preparations were completed.

Preparation of curing salts and cemen paste

In the preparation of pastirma, a selection of curing agents was incorporated, including medium grain salt, sodium nitrite, and sucrose. These agents serve dual purposes in food preservation: inhibiting the growth of pathogenic microorganisms, thus enhancing food safety, and contributing to the flavor enhancement of the product.

Furthermore, an integral component of the pastirma preparation process involves the use of a spicy coating referred to as "cemen paste". The formulation of this paste involves the integration of fenugreek seed powder (50 % of the mixture), garlic (35 %), and paprika powder (15 %). These components were procured from local markets located in Kayseri, Turkey. The process of paste formation was carried out according to the methodology proposed by Gökalp et al. [9]. Specifically, an aqueous mixture was prepared by adding 1.2 L of tap water to 1 kg of the dry ingredient mixture. The result of this procedure is a homogeneous paste, which is essential for the production of pastirma. The use of this paste not only enriches the sensory appeal of the final product, but also improves its preservation properties.

Pretreatment of meat slabs for pastirma production

Pastirma samples were prepared at Saray Meat Processing Co. (Kayseri, Turkey) in accordance with the procedure described by Gökalp et al. [9] and Oz and Kaya [18]. The loin and round muscles removed from the carcass were divided into three equal parts weighing approximately 1 kg each. The excess fat, nerves and tendons were removed from six slabs of meat, each 25 cm long, 10 cm thick and 6 cm wide. To facilitate salt absorption, the slabs were stabbed twice on both sides with a knife, not penetrating more than 2/3 of the thickness of the slab. The meat slabs were cured in a stainless-steel tank containing 65 g NaCl, 80 mg $NaNO_3$ and 2 g of sucrose per kg of meat. The slabs were rubbed manually with the curing mixture and left in the tank for 1 day. The following day, the meat slabs were rinsed twice with cold fresh water to remove excess salt and hung on a metal trolley for pre-drying. All meat slab samples were dried under the same conditions for 1 day. Pre-drying was performed in the climate-controlled chamber (Kerres Anlagensysteme GmbH, Backnang, Germany) at 20 ± 2 °C and 75 % relative humidity at 1.5 ± 0.5 m s^{-1} air velocity. A period of 2 days of pre-drying was found to be effective in removing residual water that was absorbed during the rinsing process. Moisture was further removed using a custom-made press (Yıldızer Ltd., Istanbul, Turkey) manufactured for pastirma production, which applied a pressure of 1.0 kg/cm^2 for a period of 1 day. Pastirma samples were prepared in two batches to replicate the production.

Primary drying

Three different drying treatments were tested to perform primary drying, which is the longest drying stage in pastirma production. Since, it is common practice to carry out primary drying of pastirma in open air, the processing parameters for other drying methods were determined to produce a pastirma sample similar to open-air dried pastirma in terms of sensory properties. These parameters, which include drying temperature, RH, air velocity and drying time were determined as a result of preliminary studies. The similarity of controlled chamber and infrared dried samples to open-air dried samples was evaluated by traditional pastirma masters.

The meat slabs hung on a trolley were dried in the open air (OA) in the shade to avoid direct sunlight. The final drying process took 7 days and was carried out at a temperature of 37 ± 3 °C and a relative humidity of 55 ± 5 % with the air velocity of 1.5 ± 0.5 m s^{-1}. CC drying was carried out in a chamber at a temperature of 38 ± 3 °C and a relative humidity of 75 % with the air velocity of 1.5 ± 0.2 m s^{-1} for 5 days. The dimensions of the climate-controlled chamber (Kerres Anlagensysteme GmbH, Backnang, Germany) were 9 × 4 × 3 m^3. Infrared (IR) drying was performed in a custom-built drying chamber. Drying took 2 days at 38 ± 3 °C and 75 % relative humidity with 1.5 ± 0.2 m s^{-1} air velocity. An IR lamp (250-Watt, wavelength of 1100 nm) was installed in a stainless-steel cabinet (40 × 50 × 34 cm^3) to form the IR drying system. A temperature data logger (Model 174T, Testo, Lenzkirch, Germany) was used to monitor the temperature and a fan was installed to circulate the air inside the cabinet. The cabinet contained a horizontal bar on which slabs of meat were hung for drying. Ambient relative humidity (RH) and airflow velocity were measured periodically every 15 min using an anemometer (Model 410–2, Testo Co., Lenzkirch, Germany).

Application of cemen paste and final drying

To produce a traditional pastirma, dried and cured meat slabs were coated with cemen paste. The dried slabs of meat were left in the paste for 1 day and then uniformly coated with the paste. The thickness of the paste should not exceed 3–5 mm. The application of the cemen paste was followed by a final drying step in which the samples were dried at 20 ± 2 °C and 60 ± 5 % relative humidity with 1.5 ± 0.5 m s^{-1} air velocity for 1 day. This step was performed in a climate-controlled chamber (Kerres Anlagensysteme GmbH, Backnang, Germany) for all samples in one session.

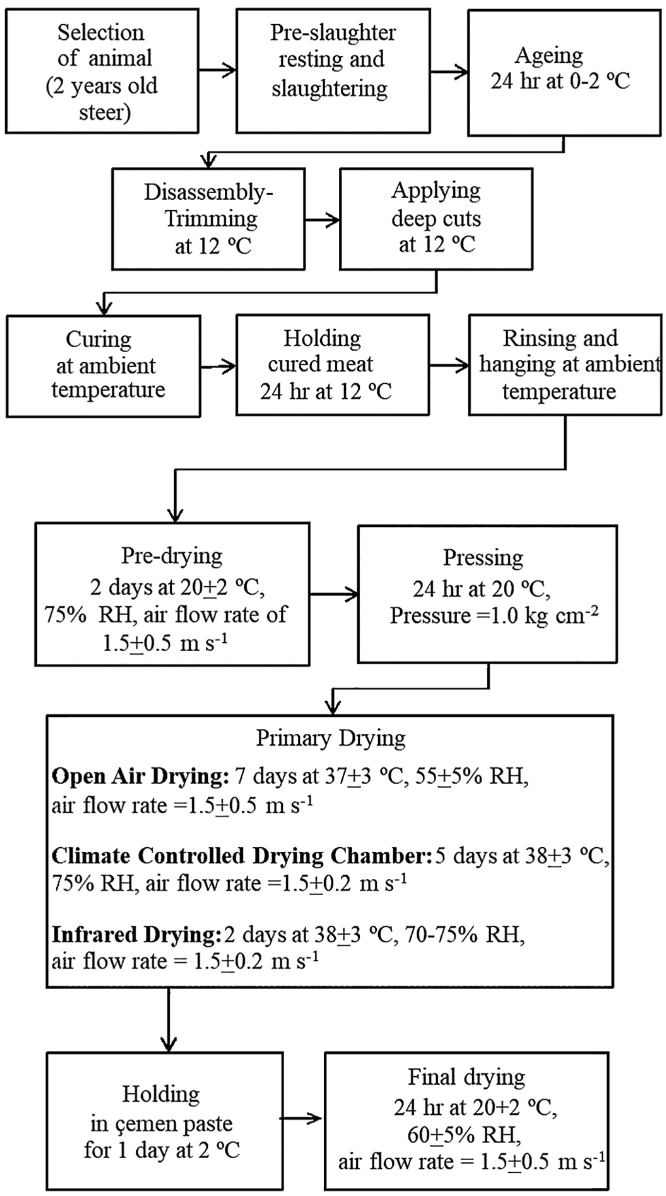

Figure 1. Flow chart of pastirma production

Physicochemical, microbiological and sensory analysis of fresh meat and pastirma

The fresh meat and pastirma samples were stored at 4 °C until analysis. Physicochemical analyses of fresh meat and pastirma included pH (Hanna HI 2211, Hanna Instruments Ltd., Bedfordshire, UK), water activity (a_w) (Aqua Lab 3TE, Meter Group Inc., Pullman, WA, USA), moisture (MA30, Sartorious AG, Göttingen, Germany), fat (B-811, Büchi Labortechnik AG, Flawil, Switzerland) and protein contents (FP, LECO Co., St. Joseph, MI, USA). Color (CIE L* a* b* color space values) was measured with a Minolta colorimeter (CR-300, Konica Minolta Sensing Inc., Osaka, Japan) with a 50 mm aperture size, D65 illuminant and 10° standard observer [19]. Residual nitrite content was determined by the AOAC method [20]. For the TBA test, the method described by Ulu [21] was used. Salt was measured by the Mohr method [22]. A texture analyzer was used to perform the TPA analysis (Microstable TA. XT Plus, Stable Micro Systems Ltd., Surrey, UK). This included hardness, adhesiveness and springiness of pastirma. The samples of pastirma were prepared by cutting 3.5 × 3.5 × 1 cm pieces. A cylindrical P25 probe of 25 mm diameter was used. Analysis was performed by compressing pastirma samples to 35 % strain at a rate of 1 mm/s. The trigger force was set to 0.01 N with a total test time of 10 s. Test samples were taken from the central part of the pastirma slabs. Fresh meat was analyzed for *Escherichia coli* O157: H7 using the ISO 16654 [23] standard method and for *Staphylococcus aureus* by the ISO 6888-1 [24] standard method. Samples of pastirma were analyzed for the presence of *Salmonella* [25], coagulase-positive *Staphylococci* [24], and sulfite-reducing bacteria [26].

The sensory analysis of pastirma was carried out by 10 expert panelists. They scored the pastirma samples according to taste, color, appearance and texture. The panelists were selected from among the pastirma masters working at Saray Meat Processing Co., Kayseri, who routinely evaluate pastirma products as a part of their job. The panelists were informed of the objectives of the study and signed an informed consent form before tasting. Furthermore, the factory management also approved the study. Pastirma samples were cut into 1.5–2 mm thick slices. The samples were labeled with 3-digit random numbers. The age of the panelists ranged from 20 to 55 years. The panelists all had a great deal of experience with pastirma. They were provided water between the samples to clear their palate. Analyses used a 5-point scale for descriptive testing, where 1 is reject, 2 is acceptable, 3 is good, 4 is very good and 5 is excellent. The test was conducted on both production batches but it was not replicated. The panelists tested a total of 12 samples in four sessions.

Statistical analysis of data

Pastirma production was replicated twice and, analysis was replicated three times. Minitab software was used for General Linear Model (GLM), as 3 different drying methods were tested on 2 different muscle types (Minitab version 16, Minitab Inc., PA, USA). One-way ANOVA with post hoc Tukey test ($P < 0.05$) was used for separation of means according to the results obtained from the GLM. The results of the sensory analysis were interpreted using Mood's median test, as the analysis was not replicated.

Results and discussion

Physicochemical and microbiological properties of fresh meat and pastirma

The pH of fresh loin and round ranged from 5.80 to 5.90. The moisture content was between 75 and 77 %. The a_w of fresh meat was between 0.965–0.998. The protein contents varied between 19.2–21.3 %. The fat content of the meat samples analyzed in this study was 5.6 % for loin and 6.3 % for round cuts. The fat content of the muscles from different parts of the carcass is often not similar [27].

Some physicochemical properties of pastirma are provided in Table 1. pH, a fundamental parameter in meat quality assessment, has an impact on the functional attributes, palatability, and meat product shelf life. The pH of dried meat products is significantly influenced by the drying process [28]. The pH of the pastirma samples

Table 1. Physicochemical properties of pastirma

Physicochemical properties	OA	CC	IR
pH			
L	5.73 ± 0.00^{bA}	5.78 ± 0.01^{aA}	5.78 ± 0.00^{aA}
R	5.68 ± 0.01^{bB}	5.72 ± 0.00^{aB}	5.74 ± 0.01^{aB}
Moisture (%)			
L	35.69 ± 0.63^{bA}	42.61 ± 0.39^{aA}	41.17 ± 0.37^{aA}
R	37.57 ± 1.82^{bA}	42.61 ± 0.27^{aA}	39.00 ± 0.32^{aA}
Water activity (aw)			
L	0.842 ± 0.003^{bA}	0.852 ± 0.002^{aA}	0.867 ± 0.003^{aA}
R	0.846 ± 0.001^{bA}	0.871 ± 0.001^{aA}	0.867 ± 0.002^{aA}
Salt (%)			
L	9.08 ± 0.15^{aA}	8.42 ± 0.12^{aA}	7.82 ± 0.10^{bA}
R	8.67 ± 0.04^{aA}	8.95 ± 0.11^{aA}	8.25 ± 0.09^{bA}
Fat (%)			
L	5.38 ± 0.39^{aB}	4.21 ± 0.37^{aB}	4.14 ± 0.20^{aB}
R	7.06 ± 0.22^{aA}	5.54 ± 0.39^{aA}	8.07 ± 0.56^{aA}
Protein (%)			
L	36.88 ± 0.06^{cA}	37.08 ± 0.09^{bA}	38.70 ± 0.02^{aA}
R	36.50 ± 0.07^{cA}	37.15 ± 0.06^{bA}	38.70 ± 0.02^{aA}
Nitrite (mg/kg)			
L	18.76 ± 0.13^{aA}	17.64 ± 0.12^{bA}	17.67 ± 0.23^{bA}
R	18.75 ± 0.10^{aA}	17.54 ± 0.13^{bA}	17.34 ± 0.06^{bA}
TBA (mg malondialdehyde/kg)			
L	0.29 ± 0.00^{bA}	0.31 ± 0.01^{aA}	0.07 ± 0.01^{cA}
R	0.16 ± 0.01^{bA}	0.32 ± 0.01^{aA}	0.13 ± 0.01^{cA}

Data are means and standard deviation of six replicates. All data were calculated on a dry weight basis. $^{a, b, c}$ Means on the same line that do not have a common superscript are different ($P < 0.05$). $^{A, B, C}$ Means within the same column that do not have a common superscript are different ($P < 0.05$). OA — Open-air drying, CC — Climate-controlled chamber drying, IR — Infrared drying. Muscle type: L — loin, R — round.

ranged from 5.68 to 5.78. Open-air (OA) dried samples had a significantly lower but comparable pH to the other samples ($P < 0.05$). The influence of drying techniques on pH dynamics in pastirma production is highlighted by this observation. The pH values of the pastirma samples in this study were in accordance with the Turkish Food Codex [2]. In other studies, the pH was found to be 5.69 to 5.92 by Karabıyıklı et al. [3] and 5.86 by Kaban [12]. In a study on the effect of salt types and drying methods, the pH was reported to be 5.72 and 5.75 for samples cured with NaCl and dried naturally or under controlled conditions, respectively [29]. Their results were similar to those obtained in the present study.

Moisture is a critical determinant of product characteristics, including texture, shelf life and sensory attributes, making it a key parameter in meat preservation and quality assessment [30]. The moisture content of the pastirma samples dried with the OA method was significantly lower than that of the pastirma dried with the other drying methods for both types of muscle ($P < 0.05$). The moisture contents of CC and IR dried samples were not significantly different. The drying process in CC and IR chambers was completed when the samples matched the sensory properties of OA dried pastirma samples. When visually inspected, the central part of the OA dried samples was wetter than the parts close to the surface in this study. The inner part of traditional pastirma is often wetter than the outer part. A pastirma product with an almost raw meat appearance in the center, although not considered to be of premium quality, is traditionally acceptable to consumers. In this study, IR and CC dried samples were observed to have a more uniform moisture distribution throughout the cross section of the sample. When infrared radiation is used to heat or dry a substance, the radiation falls on and penetrates the surface of the material and is then converted into thermal energy [31]. Therefore, infrared drying may have the potential to improve the uniformity of drying with a more homogeneous moisture distribution through the cross section of the pastirma. It was observed that IR dried samples had a more homogeneous moisture distribution when compared visually with OA dried pastirma samples. The drying time was significantly reduced from 7 days to 2 days by using IR drying instead of OA drying. The energy losses in IR drying are lower compared to conventional drying methods as the energy is absorbed directly by the food. This not only improves energy efficiency but also increases the heating rate. In addition, IR heating can promote better product quality due to a more uniform temperature distribution.

Muscle types are inherently different in their composition, which includes variables such as intramuscular fat content, connective tissue distribution and water-binding capacity [32]. Muscles with different fat content may have different moisture retention capabilities, which will affect the overall moisture content of the pastirma product. Pastirma moisture content was not significantly affected by using different muscle types. Dried OA loin pastirma had the lowest moisture content (35.69 %). Both types of muscle dried with the CC method had the highest moisture content (42.61 %). The moisture contents observed in this study were in accordance with the Turkish Food Codex [2]. The moisture contents of pastirma were determined as 47.56–48.23 % by Çakıcı et al. [33] and 45.84 % by Uğuz et al. [34].

Water activity profoundly impacts microbial stability, as microorganisms require available water for growth and metabolic activity. In addition, moisture content, which is closely linked to a_w, directly affects the texture, tenderness and mouthfeel of the product [32]. A previous study reported the effect of drying temperature and time on meat product moisture and a_w [35]. The a_w of pastirma samples in this study was between 0.842–0.871. In another study, the a_w of pastirma samples produced under controlled or natural air-drying conditions were determined as 0.91–0.92; moisture contents were 51.94–53.43 %, respectively [29]. The a_w for OA dried samples was considerably lower (0.842 to 0.846 for loins and rounds, respectively) than for other samples ($P < 0.05$). This observation may be associated with the circumstance that samples dried with the OA method exhibited the least moisture content. The lower water activity levels observed in our samples suggest the potential for all drying methods to contribute to microbial stability and extended shelf life. Furthermore, the results emphasize the importance of carefully managing moisture content to achieve the desired water activity range in pastirma production. The results also indicate that, within the parameters of this study, the choice of meat type did not significantly affect the change in water activity of pastirma.

The most important function of salt in pastirma production is its role in microbial control and preservation. The application of salt directly affects the water activity (a_w) of the meat, reducing it to a level that inhibits the growth and proliferation of spoilage microorganisms and pathogenic bacteria [36]. Salt also plays a crucial role in defining the texture, tenderness and sensory attributes of pastirma. It acts as a water-binding agent, promoting moisture retention within the meat matrix. This contributes to the characteristic chewiness and juiciness of the product, enhancing its palatability and sensory appeal. In our study, the salt content of the samples was determined between 7.82–9.08 %. These values were in accordance with the Turkish Food Codex [2]. The lowest levels of salt were found in IR dried loin (7.82 %) and round (8.25 %) samples ($P < 0.05$). The observed differences in salt content may be due to minor inconsistencies in the rinsing of pastirma slabs after the curing process to remove excess salt. Variability in rinsing practices could result in residual salt levels contributing to the observed differences in salt content between samples. In addition, the drying and pressing steps inherent in the pastirma production process exert a concentration effect on salt. As the moisture content decreases due to drying and pressing, the salt concentration in the meat matrix naturally increases. According to Hastaoğlu and Vural [29], the drying method of pastirma did not have a significant effect on salt content. In this study, OA and CC chamber dried samples had similar salt content, while IR dried sample had slightly lower salt content (Table 1). The salt content of pastirma was determined as 6.32–7.92 % by Çakıcı et al. [33], 7.83 % by Abdallah et al. [17], and 5.96 % by Uğuz et al. [34].

Fat acts as a moisture retention agent in pastirma, helping to reduce moisture loss during the curing and drying processes. This moisture retention is crucial for maintaining the juiciness of the product and preventing undesirable drying [37]. Furthermore, the lipid content in pastirma acts as a natural barrier to microbial growth, enhancing its preservation attributes and shelf life. Fat also plays a role in controlling lipid oxidation, a critical consideration in pastirma production. The presence of fat in meat products helps mitigate the effects of lipid oxidation, ensuring the product maintains its intended flavor and sensory characteristics [38]. Fatness varied between 4.14–8.07 % depending on the muscle type but not on the drying process. The elevated fat content observed in pastirma samples derived from round could be attributed to the inherent higher fat content in fresh round compared to the fresh loin utilized in the production of pastirma. Fat content of pastirma was not substantially changed by the choice of drying method. This result suggests that the fat content remains relatively stable and consistent regardless of the drying method used. In some other studies, the fat content of pastirma samples was determined between 8.80–5.05 % by Çakıcı et al. [33], and 4.65–4.71 % by Hastaoğlu and Vural [29].

The relationship between protein content and the drying process in pastirma production is a multifaceted interplay that encompasses texture development, flavor creation, preservation and nutritional aspects. The dynamic changes in protein structure and composition during drying are crucial in shaping the sensory attributes and overall quality of the pastirma. The protein levels of the samples ranged from 36.50 to 38.70 % were affected by the type of drying but not by the type of muscle. The protein content was highest in the IR dried pastirma samples, while the OA dried samples had the lowest protein content. However, the differences between the samples were negligible. As a result, IR drying contributed to the textural and structural properties by creating a denser protein network in the product with its higher protein content. Uğuz et al. [34] reported the protein content of pastirma as 27.06 % in their study where they tested the effect of different salts on the quality of pastirma. Our results are similar to those of Uğuz et al. [34], which is considerably higher than the result.

The nitrite concentration of pastirma samples was between 17.34–18.76 mg/kg. It was influenced by the drying method ($P < 0.05$). Samples dried by the OA method had higher nitrite levels than those dried by other methods. In another study, the nitrite concentration of pastirma was reported as 9.45–14.79 mg/kg [33].

The study reveals notable differences in the levels of lipid oxidation, as measured by the TBA values, among pastirma samples prepared using different drying techniques. TBA values represent the concentration of malondialdehyde, a secondary product of lipid oxidation, and therefore serve as a measure of the oxidative rancidity in food products. The drying process plays a critical role in modulating the extent of lipid oxidation, with certain methods potentially promoting higher TBA levels due to prolonged exposure to oxidative conditions. In the samples examined, TBA values ranged between 0.07–0.32 mg malondialdehyde/kg, indicating varied degrees of lipid oxidation. The CC chamber dried samples exhibited the highest TBA values. In contrast, IR dried samples showed the lowest TBA values, with 0.07 mg/kg for loin and 0.13 mg/kg for round cuts. These differences suggest that the drying method can significantly influence the rate of lipid oxidation in pastirma. The lower TBA values observed in IR dried samples can be attributed to their likely limited exposure to oxygen due to the shorter primary drying phase. The rapid and uniform drying facilitated by the IR method may have minimized the time that lipids in the pastirma were exposed to oxygen, thus limiting the potential for oxidation reactions to occur. Oxidative rancidity is primarily driven by the reaction of lipids with oxygen, forming peroxides and ultimately secondary oxidation products such as malondialdehyde. Therefore, methods that limit oxygen exposure can effectively reduce lipid oxidation. To put the TBA values into context, it is generally accepted that TBA values of 0.5 mg/kg may indicate the onset of noticeable oxidation, while values above 1 mg/kg may indicate an unacceptable level of oxidation in meat products [27]. Notably, Abdallah et al. [17] reported a TBA value of 0.81 mg/kg for uncoated pastirma, demonstrating the potential benefits of novel preservation methods such as chitosan coating in reducing lipid oxidation. The drying method has a significant effect on the degree of lipid oxidation in pastirma, as evidenced by the differences in TBA values among samples prepared by different techniques. Among the methods studied, IR drying appears to be particularly effective in minimizing lipid oxidation, probably due to its ability to reduce oxygen exposure. These results provide valuable insights for pastirma manufacturers wishing to optimize the oxidative stability of their products, thereby enhancing their shelf-life and sensory qualities.

Microbiological characteristics are key determinants of the safety and shelf life of pastirma. The drying process, especially when combined with salting, helps to create an inhospitable environment for undesirable microorganisms, thereby extending the shelf life of the product [39]. In the study, *E. coli* O157: H7 and *S. aureus* were absent in the fresh meat samples. Catalase-positive cocci and lactic acid bacteria predominated in the pastirma microflora. *Salmonella* was not detected in any of the sample during microbiological analysis of the pastirma. There were less than 10 CFU/g of both coagulase-positive *Staphylococci* and sulfite reducing bacteria. According to the Turkish Food Codex, *Salmonella* should not be present in pastirma while low levels of *Staphylococci* and sulfite-reducing aerobic bacteria are allowed [8]. *Salmonella* was also not detected in another study by Karabıyıklı et al. [3]. They observed that the coagulase-positive *Staphylococci* and sulfite-reducing bacteria in the pastirma ranged from 4.37 to 7.55 log CFU/g and from 1.00 to 4.18 log CFU/g, respectively.

Color parameters of pastirma samples

The color parameter of pastirma represents a fundamental aspect of its sensory and aesthetic properties, contributing to consumer acceptance and quality perception. Color is a sensory attribute that profoundly influences the consumer's perception of the quality and palatability of pastirma. The bright red color, traditionally associated with well-cured and well-preserved meat products, is emblematic of the visual appeal of pastirma. Consumers often equate a rich, even color with freshness and superior quality, making it an important determinant of product acceptance. The choice of drying method in the production of pastirma can have a noticeable effect on its color properties. Traditional open-air drying, characterized by prolonged exposure to environmental conditions, can lead to color variations in pastirma due to factors such as oxidative reactions and microbial activity. Controlled drying techniques, including climate-controlled chambers or infrared (IR) drying, are designed to speed up the drying process and can result in a more consistent and visually appealing color. No significant effect of muscle type on the color parameter of pastirma samples was found in this study (Table 2). However, the drying method played a critical role in determining these parameters, including lightness (L*), redness (a*), and yellowness (b*). In terms of lightness (L*), open-air (OA) dried samples were the darkest, displaying values between 25.02–27.48 for loin and round cuts, respectively. Conversely, the samples dried in the CC chamber had the lightest color ($P < 0.05$). Infrared (IR) dried samples, with L* values of 30.15 and 30.94 for loin and round respectively, were intermediate between the OA and CC dried samples in terms of lightness. An intriguing correlation was observed between moisture content and color intensity among the pastirma samples. Notably, the OA dried samples, which exhibited the darkest color, also possessed the lowest moisture content. This connection raises the possibility that reduced moisture content may contribute to increased color intensity in pastirma. On the other hand, the CC dried pastirma samples exhibited the lightest color of all the samples tested. This observation is consistent with the effect of controlled drying conditions, where reduced exposure to environmental factors may contribute to a lighter color profile. While IR dried samples resulted in a color profile falling between the extremes of OA and CC drying, lending a balanced visual appearance to the pastirma. Prior studies have demonstrated a range of L* values for pastirma, with values of 40.47–42.64 by Çakıcı et al. [33], 37.88 by Abdallah et al. [17], and 42.94–44.75 by Hastaoğlu and Vural [29]. These variations in L* values between the present study and previous research may be attributed to differences in the moisture content of pastirma samples.

Table 2. Color properties of pastirma

Color parameters		OA	CC	IR
L*				
	L	25.02 ± 0.15^c	32.88 ± 0.17^a	30.15 ± 0.48^b
	R	27.48 ± 0.29^c	34.26 ± 0.68^a	30.94 ± 0.42^b
a*				
	L	9.47 ± 0.23^c	14.01 ± 0.46^a	11.99 ± 0.17^b
	R	10.40 ± 0.28^c	15.45 ± 0.21^a	13.30 ± 0.12^b
b*				
	L	4.49 ± 0.17^a	1.73 ± 0.20^c	2.51 ± 0.06^b
	R	3.58 ± 0.16^a	1.37 ± 0.36^c	2.27 ± 0.18^b

Data are means and standard deviation of six replicates. [a, b, c] Means on the same line that do not have a common superscript are different ($P < 0.05$). OA: Open-air drying, CC: Climate-controlled chamber drying, IR: Infrared drying. Muscle type: L — loin, R — round. L* — Lightness, a* — Redness, b* — Yellowness.

In the context of pastirma, the analysis of the a* values revealed notable differences associated with the choice of drying method. As for the redness (a*) of pastirma, this study found it to range between 9.47–15.45. The CC dried samples exhibited the highest a* values, indicating increased redness, while the OA dried samples had the lowest a* value, indicating decreased redness. This result suggests that controlled drying conditions that limit environmental exposure may contribute to the development of a richer red color profile. A brighter red color is often associated with premium quality fresh pastirma, whereas a darker hue might suggest an older, potentially inferior quality product [40]. The a* values of the IR dried samples were close to those of the CC chamber dried samples. Pastirma a* values reported in prior research show a wide range, with values of 30.22–27.45 by Çakıcı et al. [33], 16.13 by Abdallah et al. [17], and 12.72–14.79 by Hastaoğlu and Vural [29].

Yellowness (b*) of pastirma was highest for OA dried samples. In contrast, CC chamber dried samples showed b* values ranging between 1.37–4.49, indicating a lower degree of yellowness compared to the other drying methods A darker red color with pronounced yellowness, as seen in OA dried pastirma, may be less desirable given the traditional preference for a lighter, pinkish-red color. The b* values reported in previous studies vary, with values of 16.50–17.53 by Çakıcı et al. [33], 4.98 by Abdallah et al. [17], and 42.94–44.75 by Hastaoğlu and Vural [29].

In summary, while muscle type does not significantly affect the color parameters of pastirma, the drying method used does. IR dried samples were intermediate between OA and CC dried samples for all color parameters.

The results of this study underline the importance of the drying method in shaping the color parameters and, consequently, the perceived quality of pastirma. These findings provide valuable insights for pastirma manufacturers seeking to optimize the color characteristics and overall quality of their products.

Texture profile analysis of pastirma samples

Texture is a fundamental attribute that significantly influences the palatability and overall sensory experience of food products [41]. One of the important factors in the consumer's perception of dried meat product quality is the texture of the dried meat. Compared to alternative drying methods like air and oven drying, sun-dried meat exhibits comparatively elevated textural and flavor ratings. Nevertheless, high temperatures can lead to the denaturation of essential proteins that play a role in shaping the texture and quality of the dried meat product [28]. In this study, there was no major effect on textural parameters of muscle types (Table 3). Hardness is defined as the peak force that occurs during the first compression cycle. The hardness of the pastirma samples ranged between 16.33–33.21 N. OA dried samples had the lowest hardness ($P < 0.05$) while CC and IR dried samples were similar. Despite OA dried samples had lower moisture content than IR dried samples, they displayed lower hardness values. This observation might be attributed to the fact that the texture analyses were conducted around the central part of the pastirma samples, which had a higher moisture content compared to the outer parts in the OA dried samples. In contrast, the moisture was evenly distributed throughout the cross section of the IR and CC dried samples, contributing to their relatively higher hardness values.

The results of this study show that the muscle type does not significantly affect the textural parameters of pastirma, as shown in Table 3. However, the drying method used have an effect on the textural properties of the final product, specifically on hardness, adhesiveness, and springiness. Hardness, defined as the peak force occurring during the first compression cycle, varied between 16.33–33.21 N among the pastirma samples. Surprisingly, despite having lower moisture content, open-air (OA) dried samples had the lowest

Table 3. Texture profile characteristics of pastirma

Texture parameters	OA	CC	IR
Hardness (N)			
L	16.33 ± 0.61^{b}	32.21 ± 0.70^{a}	25.53 ± 1.71^{a}
R	18.46 ± 0.44^{b}	28.49 ± 1.39^{a}	27.91 ± 0.35^{a}
Adhesiveness (J)			
L	82.58 ± 1.86^{a}	65.90 ± 0.73^{b}	64.10 ± 0.38^{b}
R	84.84 ± 1.32^{a}	67.39 ± 1.21^{b}	64.79 ± 0.09^{b}
Springiness (mm)			
L	1.52 ± 0.03^{b}	1.68 ± 0.01^{ab}	1.70 ± 0.01^{a}
R	1.64 ± 0.01^{b}	1.61 ± 0.04^{ab}	1.68 ± 0.01^{a}

Data are means and standard deviation of six replicates. [a, b, c] Means on the same line that do not have a common superscript are different ($P < 0.05$). OA: Open-air drying, CC: Climate-controlled chamber drying, IR: Infrared drying. Muscle type: L — loin, R — round.

hardness values ($P < 0.05$). A plausible explanation for this is the moisture distribution within the pastirma samples. The texture analyses were performed around the central part of the pastirma samples, which in the case of the OA dried samples, retained a higher moisture content than the outer parts. In contrast, both the climate-controlled (CC) chamber and the infrared (IR) dried samples exhibited a uniform moisture distribution throughout their cross section, resulting in comparable hardness values.

Adhesiveness, recorded as the area of the negative force curve, was highest for OA dried pastirma. Adhesiveness, as a textural characteristic, delineates the effort required to overcome the cohesive forces between the surface of food and the contacting materials. The highest adhesiveness observed for OA dried pastirma may be linked to the higher moisture content in the center of these samples, which may promote greater interaction and adhesion. As with hardness, CC chamber and IR dried samples showed similar adhesiveness, possibly due to their uniform moisture distribution. Springiness was found to be significantly higher in the IR dried pastirma samples. These samples displayed values between 1.68–1.70 mm, while the OA dried samples demonstrated lower springiness values between 1.52–1.64 mm ($P < 0.05$). Springiness is desirable in sliced pastirma, as consumers typically prefer elastic slices to inelastic ones. The uniform moisture distribution in IR dried samples may contribute to their enhanced springiness. Drying conditions, including time, temperature, and humidity, are variables that control the textural quality of the final product [4]. IR drying conditions may provide a more favorable balance of these variables to maintain the springiness of the product. Pastirma dried in the CC chamber showed a springiness comparable to both IR and OA dried samples.

Our study reveals the pivotal role of drying methods in determining the texture properties of pastirma. Drying method influenced the hardness, adhesion and springiness of the final product, while muscle type had no discernible effect on texture. The results highlight the importance of carefully controlling drying conditions, including time, temperature, and humidity, to ensure the textural quality of the final product that is in line with consumer preferences. Further research could explore the underlying mechanisms of these drying methods on moisture distribution and their consequent effects on pastirma texture.

Sensory parameters of pastirma samples

Sensory characteristics are an integral part of pastirma quality and consumer satisfaction. These properties are significantly influenced by the drying process. A drying mechanism should be chosen with a temperature that does not affect meat sensory quality and with sufficient drying time [42]. In the exploration of factors influencing the sensory parameters of pastirma, a type of cured and dried meat product, our findings revealed that the muscle type had no significant effect (Table 4). Instead, the drying method was found to be a more decisive factor in determining these parameters, including the color, odor, texture, and flavor of the product. Our study showed that the highest sensory scores for all parameters were obtained from samples dried using the infrared technique ($P < 0.05$). This radiant heating method allows the heat to be transferred directly from the IR source to the product in the form of electromagnetic waves. When absorbed, this energy is converted into heat, facilitating a more uniform and faster drying process when compared to conventional drying methods. IR drying is characterized by its specificity in targeting water molecules for evaporation, as well as its effective and rapid heat transfer [31]. Together, these attributes enable rapid and uniform removal of the moisture from the product. This uniformity, in turn, prevents localized overheating, thereby reducing the risk of scorching and associated adverse changes. Such changes can include unwanted color changes, structural deformation or onset of oxidative problems that can negatively impact product quality. It was observed that the sensory scores given by the panelists to the pastirma samples ranged from 2.00 to 3.50. A score of 2 corresponded to an acceptable product, while a score of 3 indicated a good product. In general, the sensory scores were low, probably reflecting the high-quality standards of the trained panelists.

Table 4. Sensory properties of pastirma

Sensory parameters	OA	CC	IR
Taste			
L	2.20 ± 0.20^b	2.20 ± 0.29^b	3.10 ± 0.23^a
R	2.00 ± 0.21^b	2.00 ± 0.20^b	3.30 ± 0.37^a
Color			
L	2.20 ± 0.36^b	2.60 ± 0.33^b	3.40 ± 0.3^a
R	2.60 ± 0.34^b	2.80 ± 0.20^b	3.40 ± 0.34^a
Appearance			
L	2.30 ± 0.26^b	2.20 ± 0.20^b	2.90 ± 0.31^a
R	2.10 ± 0.18^b	2.40 ± 0.13^b	2.80 ± 0.29^a
Texture			
L	2.10 ± 0.23^c	2.40 ± 0.16^b	2.70 ± 0.37^a
R	2.00 ± 0.15^c	2.20 ± 0.25^b	3.50 ± 0.37^a

Data are means and standard deviation of scores of ten panelists. $^{a, b, c}$ Means on the same line that do not have a common superscript are different ($P < 0.05$). OA: Open-air drying, CC: Climate-controlled chamber drying, IR: Infrared drying. Muscle type: L — loin, R — round.

It can be inferred that the IR dried samples that showed superior sensory scores were more consistent in texture, color and overall quality. This consistency in the sensory qualities is consistent with the results of another research. Cherono et al. [43] found that IR dried biltong had lower hardness scores compared to air-dried samples. Similarly, Kate and Sutar [44] reported superior texture in IR dried ginger rhizome samples as revealed by Scanning Electron Microscopy (SEM) images.

Moreover, the superior sensory evaluation of IR dried pastirma may also be due to the preservation of heat-sensitive flavor and aroma compounds. Traditional drying methods can result in the loss or alteration of these compounds, whereas the rapid and uniform drying characteristic of IR is likely to aid their retention. This could result in a product that is more appealing and acceptable to the trained panelists, as evidenced by the higher sensory scores.

In summary, our results highlight the central role of IR drying in improving the sensory parameters of pastirma. Its drying efficiency, rapidity and uniformity help to maintain the product quality in terms of color, texture and flavor while avoiding the negative effects of overheating and oxidation [45]. Future research directions could include extending the application of IR drying to other food products to further exploit the benefits of this technology in the food industry.

Conclusions

It can be concluded that a standard compliant pastirma product can be produced by using the three drying methods investigated in this study. This research clearly showed that the application of IR drying is capable of reducing the primary drying time from 7 to 2 days in pastirma processing while maintaining product quality. Indeed, for all sensory characteristics, including taste, color, appearance and texture, IR dried samples were found to be superior to other samples. The TBA values of the IR dried samples were the lowest, indicating less lipid oxidation and therefore a more acceptable flavor. Uneven drying can occur as a result of OA drying, resulting in a product with excessive central moisture and a raw appearance. It was shown that IR and CC chamber drying can help to avoid this problem and deliver a better product. The CC chamber dried pastirma samples had the highest L^* and a^* values, followed by the IR dried samples. The OA dried samples had the darkest color, hence poor color quality. To further shorten the drying process of pastirma without negatively affecting the product quality, it could be suggested that the IR drying method could be enhanced.

Within the scope of this study, IR and CC drying methods were tested together. Both methods have different advantages. While the drying time was reduced with IR drying, color parameters were better with CC drying. By using both drying methods together, it is possible to produce pastirma in a shorter time and with better quality parameters. It is acknowledged that the shortcoming of this study was that these two processes were not tried simultaneously.

The scientific significance of this study lies in its successful application of IR drying to substantially reduce the drying period of pastirma, from 7 days (as conventionally observed) to a mere 2 days. Such a remarkable reduction in processing time holds substantial implications for the food industry, particularly within the pastirma manufacturing sector. This work represents a notable innovation in food science, mainly by using IR drying technique to produce pastirma. Traditionally, the pastirma drying process has been time-consuming, necessitating prolonged open-air exposure. This research provides an approach that significantly reduces drying time while preserving the sensory qualities cherished by consumers. Furthermore, IR drying mitigates the issue of inconsistent drying encountered during the open-air drying process, ensuring uniform product quality. Importantly, the study highlights that the utilization of IR drying not only expedites the pastirma production process but also enhances the final product's quality.

In conclusion, this study has explored the experimental implementation of IR drying technology in the manufacturing process of pastirma, an esteemed cured meat product with cultural significance. The findings demonstrate that IR drying can substantially reduce the drying period while simultaneously improving sensory characteristics and product quality. This approach holds considerable promise for the pastirma industry, offering a viable means to streamline production processes and meet consumer demands for high-quality, traditionally inspired food products. As such, this research represents a remarkable contribution to food science and technology, exemplifying how modern methods can harmonize with the production of traditional foods.

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