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NUTRITIONAL, ANTIOXIDANT, AND MICROBIAL QUALITY OF TRADITIONAL BALOCHI DRIED MEAT (LANDHI) ENHANCED WITH POMEGRANATE SEED POWDER

Mushtaq Tariq[*1], Saeed Ahmad[2], Ansa Maqbool[3], Zafar Abbas[4], Ismail Anwar Siapad[5], Sulaim Lutafullah[6]

*[*1,6]Department of Food Technology, University of Agriculture Faisalabad*
[2]University of Lincoln UK, Lincoln Institute for Agri-food Technology
[3]Cholistan University of Veterinary and Animal Sciences Bahawalpur, Pakistan
[4]Food science and Technology, Sindh Agriculture University Tandojam
[5]Livestock and Dairy development Department Balochistan

[*1]mushtaqtariq2020@gmail.com; [2]ahmadsaeeduol@gmail.com; [3]ansamaqbool80@gmail.com; [4]zafaralizai700@gmail.com; [5]Ismailsiapad1234@gmail.com; [6]sulaimlutafullah05@gmail.com

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Corresponding Author: *
Mushtaq Tariq

Abstract

Traditional Balochi dried meat, known as Landhi, represents a culturally significant method of meat preservation in South Asia. This study aimed to evaluate the nutritional composition, microbiological stability, antioxidant potential, physicochemical attributes, and sensory properties of Landhi prepared with varying concentrations of pomegranate seed powder (PSP). Treatments included PSP levels of 0 g (T0), 5 g (T1), 10 g (T2), 15 g (T3), and 20 g (T4), while salt concentration remained constant across samples. Proximate analysis revealed that PSP incorporation enhanced protein retention, reduced lipid oxidation, and improved ash and phenolic content compared to control samples. Antioxidant assays (DPPH and FRAP) demonstrated increased radical scavenging activity with higher PSP levels, while microbiological analysis confirmed lower total plate counts in PSP-treated samples, particularly T4. Sensory evaluation indicated improvements in tenderness but reductions in juiciness and overall acceptability at higher PSP concentrations. The findings suggest that PSP serves as an effective natural preservative by improving nutritional quality, oxidative stability, and microbial safety of Landhi, thereby supporting its potential as a healthier alternative to synthetic additives in traditional meat preservation.

INTRODUCTION

Meat preservation played an important role in ensuring food security and taste enhancement in human history. Dissanayake et al. (2024) noted that drying, curing, fermentation and smoking were some traditional ways of preserving meat used still in different ancient societies. These processes ensured the nutritional composition and shelf life of meat. These practices are also closely connected with cultural identity and food heritage (Mathew, 2024). Meat spoilage refers to the decomposition of meat by bacteria and other microorganisms, which cause the meat to spoil in appearance, taste, and smell. Old

Methods Like salting, drying and smoking were effective controlling these processes and thus extending the shelf life of meat without losing its nutritional and sensory properties (Mutwakil, 2011). This was very important in history when fridges and modern preservation technology did not exist.

In addition, fermentation improves the flavor of meat, which is very important because taste plays an important role in traditional gastronomy. Microbial fermentation can assist in the reduction of harmful substances such as histamines. For example, it can be useful for the food industry; as mentioned by Dissanayake et al., 2024. Furthermore, essential oils from thyme and clove have antimicrobial and antioxidant properties, thus traditional practices are switching over to these natural preservatives as a natural and culturally relevant way to preserve meat (Ricardo-Rodrigues et al., 2024).

Research on meat preservation includes the amalgamation of age-old methods with cutting-edge ones. This serves to enhance both the flavors and safety of the meat without negating the past. This evolution indicates that traditional methods for preserving meat can continue to play an effective role in the future (Zhang et al., 2023).

Landhi is an essential part of the Balochi culture and food heritage, owing to its various preparations and cultural significance. Landhi is a common method of preserving meat, usually mutton or lamb, by marinating it in salt and spices and then drying in the open air (Dissanayake et al., 2024). This makes the meat delicious and allows it to be stored, without any need for a refrigerator, for a long period of time, which is very important in the dry area of Balochistan (Yang et al., 2017).

Landhi is a display of Balochi ingenuity and survival and hence carries significant cultural importance to the Baloch people. Because of the extreme environmental conditions in the region, it has been historically essential to preserve food efficiently. Landhi demonstrates the Balochi people's ingenuity and ability to improvise with whatever resources were available at any given time, especially when hunting was scarce or during long winters (Bakhsh & Khan, 2020).

In addition to cooking, Landhi is also used in social and cultural events. The Balochi people prepare and eat Landhi during special occasions and large gatherings. Landhi is a dish prepared by drying the meat of goat, sheep and camel through traditional methods. This culinary information is passed on generations. This allows younger generation to experience the culture and ways of the Baloch communities. Thus, it preserves their cultural identity (Ahangar et al., 2020).

Dried meat products are highly nutritionally and economically valuable to consumers and the meat industry. According to Mehta et al., 2013, dried meats are rich in low-cost protein along with containing essential fatty acids, vitamins, minerals and other bioactive products. The drying technique used in this process reduces the moisture content, which prevents the growth of microbes. Therefore, this method prolongs the shelf-life of the meat while maintaining its nutritional value (Mediani et al., 2022).

Dried meat products are economically significant, reducing the storage and transport costs (Mediani et al., 2022). Moreover, the incorporation of fiber sources into dried meat products not only reduces the cost of production but also enhances the functionality of these products (Singh et al., 2014). In actual practice, fibers are wastes derived from agricultural processes, which are inexpensive (Talukder, 2015). The economic value added as well as health-benefits enhanced through the incorporation of dietary fibers in meat processing enhances cooking yield, reduces unhealthy fat components as well as enhances further sensory properties of the finished products (Talukder, 2015). Dried meats can satisfy the growing consumer demand for ready-to-eat and convenient foods due to changing socio-economic factors (Mehta et al., 2013). Dried meats stay competitive in the marketplace due to their convenience and nutritional quality (Espinales et al., 2024)

The preparation of Landhi, a traditional dry meat product of South Asia, is done under certain objectives. This includes the quality assessment Landhi for food safety, nutritional and sensory properties. It is necessary to ensure that the product satisfies regulatory and consumer standards and that it is safe and palatable.

Making Landhi involves different steps of marination, drying and fermentation which contributes to its unique taste and texture. When

preparing the food, it is ensured that food is primarily safe for consumption, tasty and has an appealing texture. To avoid spoilage, careful selection of ingredients, appropriate control of fermentation conditions and ensuring the meat is dried to the required level is important.

The evaluation of chemical, microbiological and sensory properties of Landhi is important for its quality assessment. Chemical testing involves testing for moisture, salt, and protein levels, which affect taste and preservation. Microbiological assessments ensure unwanted bacteria are absent and the fermentation process has been successful. They promote beneficial bacteria, which improves taste and preserves meat. In conclusion, sensory evaluation, usually on a trained panel or using electronic nose and tongue technology, measures taste, aroma, and texture in line with consumer and industry expectations (Vanaraj et al., 2025).

Due to globalization, several traditional food practices and food varieties may disappear. In response to this, there have been attempts to safeguard local customs through educational initiatives and culinary tourism (Mathew, 2024). These initiatives help strengthen traditional practices on preserving meat, recognizing them as not only practical solutions for food-safe storage, but also as an important part of culinary culture.

With change in time culture and traditions are being changed. The traditional method of meat preservation, once culturally significant, is at risk of being abandoned with improvement in modern technology and globalization (Knorr & Augustin, 2023). Landi, Balochi traditional dried meat, face the challenges due to growing use of industrial processed food and erosion of local culinary practices. Despite its importance of being an effective method of food preservation in harsh environments, the research on its nutritional and sensory properties is limited. This research gap presents the opportunity to evaluate potential of this method (Ahangar et al., 2020).

This research focuses to evaluate the nutritional composition, microbiological safety, and sensory properties of Landhi. For assessment of nutritional composition assessment moisture, protein, fat, and mineral content were determined. Microbial activities were determined for safety and sensory properties such as taste and texture were analysed. Additionally, pomegranate seed power (PSP) was applied to analyse the effect on preservation quality of Landhi.

MATERIALS.AND METHODS

Study site

The site of study was the National Institute of Food Science and Technology (NIFSAT), University of Agriculture, Faisalabad, Pakistan. Making traditional Balochi dried meat (Landhi) and evaluating its quality. To boost the validity of the study, every analysis was completed in triplicate.

Procurement of raw material

Mutton meat, pomegranate seed powder and salt were procured from the supermarket of Turbat (Kech) Balochistan, Pakistan for the preparation of dried meat.

Sample preparation

The meat samples were washed and sliced into pieces and dipped into a brine solution with PSP for 2 minutes. Later meat samples were hung for sun drying. Samples were sun dried for 10 days. All the analysis was completed within 21 days after the drying process. The weight of mutton meat was 250g before the sun drying. After the sun drying process, the weight was (T^0- 90.20, T^1- 88.57, T^2= 86.47, T^3= 84.80, T^4= 82.36).

Experimental plan

In the present study, brine solution and raw mutton meat are same for all treatments and there is variation in PSP for all the treatments that is for T^0= 0g, T^1= 5g, T^2= 10g, T^3= 15g and T^4= 20g. Salt concentration is same for all the treatments; 20g of salt was dissolved into 500ml of water for the preparation of brine solution.

Table 0.1: Treatment plan for the preparation of traditional Balochi dried meat (Landhi)

Treatments	Brine solution (20g salt/500mL water)	Pomegranate seed Powder	Meat (Mutton)
T^0	4%	0 g	250 g
T^1	4%	5 g	250 g
T^2	4%	10 g	250 g
T^3	4%	15 g	250 g
T^4	4%	20 g	250 g

Proximate analysis of dried mutton meat

Determination of moisture content in dried meat

The accepted technique described in AOAC (2016) was followed to determine the moisture content of dried meat. Weighing out 10g of dried meat, we put it in a dry, clean porcelain dish. After that, the china dish containing the sample was baked for 24 hours at 105 °C in a hot air oven. The china dish was taken out after the allotted amount of time, and its ultimate weight was noted.

The moisture content was calculated using the provided formula given below:

$$\text{Moisturem}(\%) = \frac{W1 - w2}{W1} x100$$

Where

W_1= initial weight of sample

W_2= final weight of dried sample

Determination of crude protein in dried meat

The Kjeldahl method was used to ascertain the crude protein level of the beef sample, adhering to the protocol specified in AOAC (2016). 3-gram sample of meat and 30 milliliters of sulfuric acid were added to the digestion chamber along with a digestion pill for every replicate. The solution kept turning light green as the digestion process went on. After cooling the flask, 10 mL of distilled water was added to dilute the digested material. Ten milliliters of the diluted sample and ten milliliters of 40% NaOH were introduced to a distillation tube in the distillation assembly. 20 mL of a 2% boric acid solution and two to three drops of an indicator were placed in a different beaker. The boric acid solution turned into a brilliant hue during the distillation process. The computation made use of the findings of a titration using 0.1N H_2SO_4. The nitrogen percentage was multiplied by 6.25 to determine the protein proportion in the sample.

Formula is given below

$$\% \text{ Nitrogen} = \frac{\text{Volume of 0.1N Sulfuric acid x Volume of dilution x 0.0014}}{\text{Weight} - \text{of sample x} + \text{Volume of diluted sample}} \times 100$$

Determination of crude fat in dried meat

By utilizing the Soxhlet apparatus and following the protocol outlined in AOAC (2016), the fat content of the meat sample was determined. 5 g of moisture free samples were obtained and wrapped in filter paper before being pinned. After wrapping, the sample was weighed again and then placed in the thimble. To extract fat that was soluble in organic solvents, hexane was utilized as a solvent. The solvent was then heated and evaporated before being poured into the thimble chamber and the washing procedure was repeated 6 to 7 washings. After removal, the sample was heated to between 60 and 80 degrees Celsius for three to four hours, or until its weight remained constant. Use the formula to determine the fat percentage.

$$\text{Crude fat (\%)} = \frac{W1 - w2}{W1} x100$$

Where
W_1= Wt. of sample before extraction of fat
W_2= Wt. of after extraction of fat

3.4.4 Determination of mineral content in dried meat

Following the methodologies outlined in AOAC (2016). A 10 g sample of meat was dried at 105 °C in a hot air oven until the weight remained constant, indicating that the moisture had been removed. Mineral determination was then applied to the resultant dry samples. This started by adding 5mL of 65% HNO3 and slowly boiling the mixture for 15 minutes on a hot plate. After the liquid cooled, 2.5 mL of 70% $HClO_4$ was added, and it was then brought to a boil until dense white vapors emerged.

Physicochemical analysis of dried meat

Determination of color in dried meat

The assessment of color in dried meat was conducted employing a colorimeter, as previously detailed by (Nam et al., 2016). The procedure involved placing the sample beneath the photocell of the colorimeter, from which valve corresponding to a (redness), L (lightness), and b (yellowness) were derived.

Determination of pH of dried meat

The determination of the pH in dried meat samples was carried out utilizing a digital pH meter, in accordance with the procedure delineated by Serdaroglu et al., (2021). Using a homogenizer, 10 grams of beef sample were completely covered with 90 milliliters of distilled water to create a homogenous slurry. The pH meter was calibrated using a standard buffer solution before any readings were made. After being cleaned with distilled water, the electrodes were dried using tissue paper. For each measurement, the electrodes were immersed into the sample solution, ensuring continuous dipping. After noting the reading, the electrodes were again washed with distilled water before the subsequent measurement. The average mean reading derived from these measurements represents the pH of the dried meat sample.

Determination of TBARs valve

Using the methodology outlined by Nam et al., (2016), the amount of Thio barbituric acid reactive compounds (TBARs) in a dried meat sample was determined. Ten milliliters of cooled 20% trichloroacetic acid (TCA) were combined with a carefully weighed five-gram quantity of dried meat. After two minutes of homogenization, the mixture was allowed to stand for ten minutes before being filtered. After filtering, 3 mL of the filtrate and 3 mL of Thio barbituric acid (TBA) solution (0.1% v/v) were mixed. After cooling, the combined solution was immersed in boiling water for 35 minutes. Using a spectrophotometer, the optical density (OD) at 530 nm was determined. The results were compared to a blank sample that was run in parallel.

$$[\text{TBA Valve (mg MDA/kg)} = (50 \text{ x } (A - B) / M]$$

Where
A= The\test solution's absorbance
B= Blank reagent absorbance
m= Mass of the test sample
50 = A valid factor if the volumetric flash volume is 25mL, and the cuvette width is 10mm

Determination of WHC

Using the methodology outlined by Bowker et al., (2014), weigh exactly 5g of the meat sample using a precise weighing balance. Place the 5g meat sample into a pre-weighed centrifuge tube. Record the weight of the meat sample plus the centrifuge tube. Set the centrifuge to a specific speed, typically between 1500 to 3000 rpm, depending on the protocol. Centrifuge the sample for 10-20 minutes.

The exact duration and speed may vary based on the specific method you are following. A common setting is 3000 rpm for 20 minutes. After centrifugation, carefully remove the centrifuge tube without disturbing the sediment. Decant the supernatant (released water) carefully without losing any of the meat sample. Weigh the centrifuge tube with the meat sample after decanting the water. Record the weight of the meat plus the tube. Determine the amount of water released by subtracting the post-centrifugation weight from the pre-centrifugation weight. WHC can be expressed as the percentage of water retained relative to the original weight of the sample. Use the formula:

$$\text{WHC (\%)} = \frac{\text{Initial weight of sample} - \text{Weight of water released}}{\text{Initial weight of sample}} \text{x100}$$

Determination of TVBN

Procedure defined by (Xin et al., 2022) was used to determine Total Volatile Basic Nitrogen valve of dried meat. The basic nitrogen microtitration method was used to determine the total volatile nitrogen content. For this purpose, took 10g sample distributed it into 100 mL of distill water and was agitated for 30 minutes. Slurry was filtered once agitation was finished. Add 5 mL of MgO (10/1) to 5 ml of filtrate after taking a sip. The distillate was immersed in a 20 mL aqueous solution of boric acid (2%) that contains 0.1 g of methyl reduand 0.1 g of methylene blue. The filtrate runs into distillation assembly. After that, it is removed from assembly and titrated against 0.1 normal hydrochloric acids. Hydrochloric acid usage was considered while calculating the total volatile basic nitrogen valve.

Antioxidant assay of Pomegranate seed powder incorporated dried meat

Determination of total phenolic content in dried meat

Vareltzis et al., (2023) method was utilized to analyze the total phenolic content of dried meat. A 5-gram sample of meat from the patty was homogenized for 15 minutes at 5000g in an ice-filled beaker using 20mmL of 0.1M8phosphatelbuffer at pH87.4. The mixture was placed in a 100 mL polypropylene tube. The removal of connective tissue was accomplished by filtering with a Muslim cloth. Following this, a micropipette was used to extract 100 µL of the filtrate, which was then combined with 2.5 µ of distilled water, 250 µL of 50% Folin Coalter reagent, and 500 µL of 95% ethanol. Following a five-minute incubation period, 500 µL of 20% Na_2CO_3 was added, and after that, the mixture was incubated in a dark area for an hour. The absorbance at 725 nm was then measured using a spectrophotometer.

Determination of DPPH free radical scavenging activity of dried meat

Using a conventional protocol, the DPPH test was performed to evaluate the free radical scavenging activity. Three milliliters of a 0.004% DPPH solution made with methanol were combined with a 0.03-gram sample of meat, and the mixture was allowed to sit at room temperature for half an hour. After that, the sample was centrifuged for 10 minutes at 1430 rpm. The absorbance of the supernatant was measured at 517 nm using methanol as the blank. Using the approach outlined by Kim and Chin (2016), the results were represented in terms of absorbance, where lower values indicated stronger antioxidant activity.

DPPH free radical scavenging % = [Ac-As)/Ac] x 100

Where

Ac = Absorbance6of control

As = Absorbance6of test sample

Determination of FRAP of dried meat

It was measured using the method that (Kim and Chin, 2016) suggested. The sample's antioxidants cause ferric-tripyridyl triazine to be reduced to its colorful form from ferrous. The 2.5 mL of a 10 mmol/L TPTZ (2,4,6-tripyridy-s-triazine, Sigma) solution were dissolved in 40 mmol/L HCl, 20 mmol/L ferric chloride (2.5 mL), and 0.3 mol/L acetate buffer (25 mL) to create the FRAP reagent. A fresh preparation was carried out at 37°C and pH 3.6. To make a solution, a little 40 µL sample precipitate was combined with 1.8 mL of FRAP reagent, 0.2 mL of distilled water, and additional components. Subsequently, the mixture was incubated for 10 minutes at 37°C. The absorbance of this mixture was measured with a spectrophotometer at 593 nm. One millimole/liter of $FeSO_4$ serves as the standard solution when determining the antioxidant levels using FRAP. The

results obtained were represented as the antioxidants amount having the capacity to reduce ferric equal to that of standard solution 1mmol/L $FeSO_4$.

Microbial analysis of dried meat

Determination of Total plate count (TPC) of dried meat

The determination of total plate count (TPC) in dried meat sample was executed following the procedure outlined by (Lim et al., 2012). TPC serves as a vital indicator for assessing the microbiological profile of the samples. In each treatment, 5g of meat sample were dissolved in 45 mL of saline solution (0.85%) and homogenized for 2 minutes using stomacher. Following autoclaving at 121°C for 15 minutes, serial decimal dilution was prepared, and suitable dilution (0.1mL) were transferred to solidified plate count agar. For simpler colony counting, agar plates were employed after 48 hours of incubation at 37°C. To ensure precise colony counting, an automated colony counter was utilized. The measurements of microorganisms were expressed as log colony forming units (CFU) per gram, which was shortened to log CFU/g.

Sensory evaluation of dried meat

The sensory evaluation involved a comprehensive assessment of juiciness, tenderness and overall acceptability. Trained panelists conducted the evaluations utilizing a 9-point hedonic scale, in accordance with the methodology delineated by (Narsaiah et al., 2011). This meticulous approach ensures a systematic and detailed appraisal of the sensory characteristics, providing a nuanced understanding of the qualities associated with the evaluated samples.

Salt analysis

The method outlined by Bader et al., (2021) was used to ascertain the dried meat samples salt content. Two grams of dried sample (obtained after moisture content was calculated) are combined with 500 milliliters of chloride-free distilled water, and the mixture is heated on a water bath until all of the sod is dissolved. In water, chloride dissolves. After the filter has been placed inside a 500 ml conical flask, rinse it with distilled water to remove all of the chloride. Add enough standard silver nitrate (a known amount) and 200 milliliters of diluted nitric acid to make all of the chloride precipitate. Add one milliliter of ferric Talum indicator and titrate with ordinary potassium thiocyanate solution when a persistent light brown color appears.

Sodium chloride

(On dry basis) m/m= 5.85jx V_1N_1-V_2N_2/M

Where

V1= Volume of silver nitrate standard6solution

N1= Standard silver nitrate solution normality

V2= Standard pot volume. Thiocyanate solution

N2= Regularity of a normal pot. Solution containing thiocyanates

M= Weight of dried sample collected for analysis

Statistical analysis of the recorded data

The analysis's produced results were collected in duplicates and then put through a completely randomized design (CRD) two-way analysis of variance (ANOVA). Statistical parameters such as mean valves and standard deviations were calculated utilizing statistics 8.1 software Montgomery, 2017).

Results

Effect of treatment and storage on proximate analysis of dried meat (Figure ***0.1***)

Ash Content and Its Effect on Nutritional and Processing Quality

Ash content reflects the mineral composition of meat, which is vital for nutritional and processing quality, with fresh meat usually containing 0.8-1.5% and higher levels in processed meat are observed due to additives. In this study, ash content of processed dried meat was significantly affected by storage duration and treatments, ranging from 3.70% (T^0) to 4.24% (T^4), with PSP treatment showing the highest values, consistent with earlier findings (Hafizur Rahman et al., 2020).

Crude Protein Levels in Dried Meat and the Impact of Storage and Treatment

Crude protein is a key indicator of nutritional value, and dried meat generally has higher protein levels than fresh meat due to nutrient concentration during drying. In this study, crude protein content was significantly affected by both storage duration and treatments, ranging from 68.93% (T^0) to 69.57% (T^4), with pomegranate seed powder (PSP)

treatment showing the highest values, consistent with earlier findings (Shahamirian et al., 2019).

Changes in Crude Fat Content of Dried Meat Over Time

Crude fat content is an important quality parameter in dried meat, and additives like pomegranate seed powder may help reduce lipid oxidation during storage. In this study, crude fat content showed a declining trend over time, ranging from 9.39% (T^0) to 8.70% (T^4), with storage duration being the main influencing factor, while treatment differences were not significant; similar trends were also reported by Musa et al. (2019).

Effect of Storage and Treatments on Moisture Content of Dried Meat

Moisture content is a key factor influencing the stability and shelf life of dried meat, and additives such as pomegranate seed powder (PSP) can affect its retention. In this study, moisture content significantly decreased with storage time, ranging from 13.22% (T^0) to 11.76% (T^4), with both treatment and storage duration showing strong effects. These results are consistent with earlier findings of Aksoy et al. (2019).

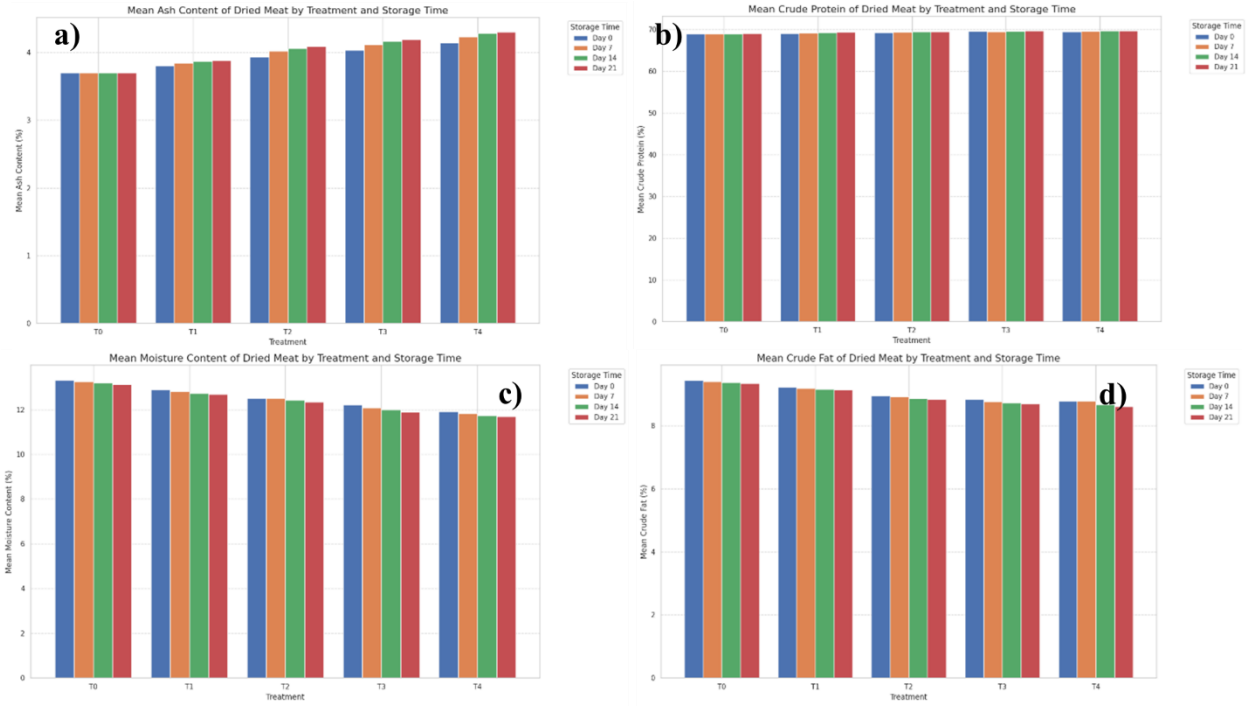

Figure 0.1: Proximate composition of dried meat (Landhi) showing changes in ash content (Panel a), crude protein (Panel b), moisture content (Panel c), and fat content (Panel d) across treatments (T0-T4) and storage durations

Effect of treatment and storage on antioxidant analysis of dried meat (Figure *0.2*)

Effect of Storage and Treatments on Total Phenolic Content of Dried Meat

Phenolic compounds are important dietary antioxidants that contribute to health benefits by scavenging free radicals. In this study, total phenolic content of dried meat increased slightly with storage and was significantly influenced by treatments, ranging from 17.33 (T^0) to 19.26 (T^4), with the highest levels under PSP treatment; these findings agree with earlier reports (Suryati et al., 2012).

Antioxidant Activity Evaluated Using DPPH Assay in Dried Meat

The DPPH assay is a widely used method to evaluate antioxidant activity, where higher scavenging capacity indicates better protection against oxidative damage in meat. In this study, antioxidant activity

was significantly influenced by treatments, ranging from 42.32 (T^0) to 43.49 (T^4), with PSP treatment showing the highest radical scavenging activity. These results are consistent with the findings of Kim and Chin (2016).

Influence of Storage and Treatments on FRAP Values of Dried Meat

The FRAP assay measures antioxidant potential by assessing the ability to reduce ferric (Fe^{3+}) to ferrous (Fe^{2+}) ions, with higher values reflecting stronger antioxidant capacity. In this study, both storage duration and treatments significantly influenced FRAP values, which increased over time and ranged from lower levels in the control (T^0) to the highest in PSP treatment (T^4); these findings are consistent with earlier results reported by Demir (2021).

Impact of Storage Duration and Treatments on Salt Content in Dried Meat

Salt content plays an important role in the preservation and flavor of dried meat, and factors such as storage duration and the addition of pomegranate seed powder (PSP) can influence its stability. In this study, salt content increased slightly over storage, ranging from 6.41 (T^0) to 7.03 (T^4), with significant effects of both treatments and storage duration; these results agree with Teixeira et al. (2011).

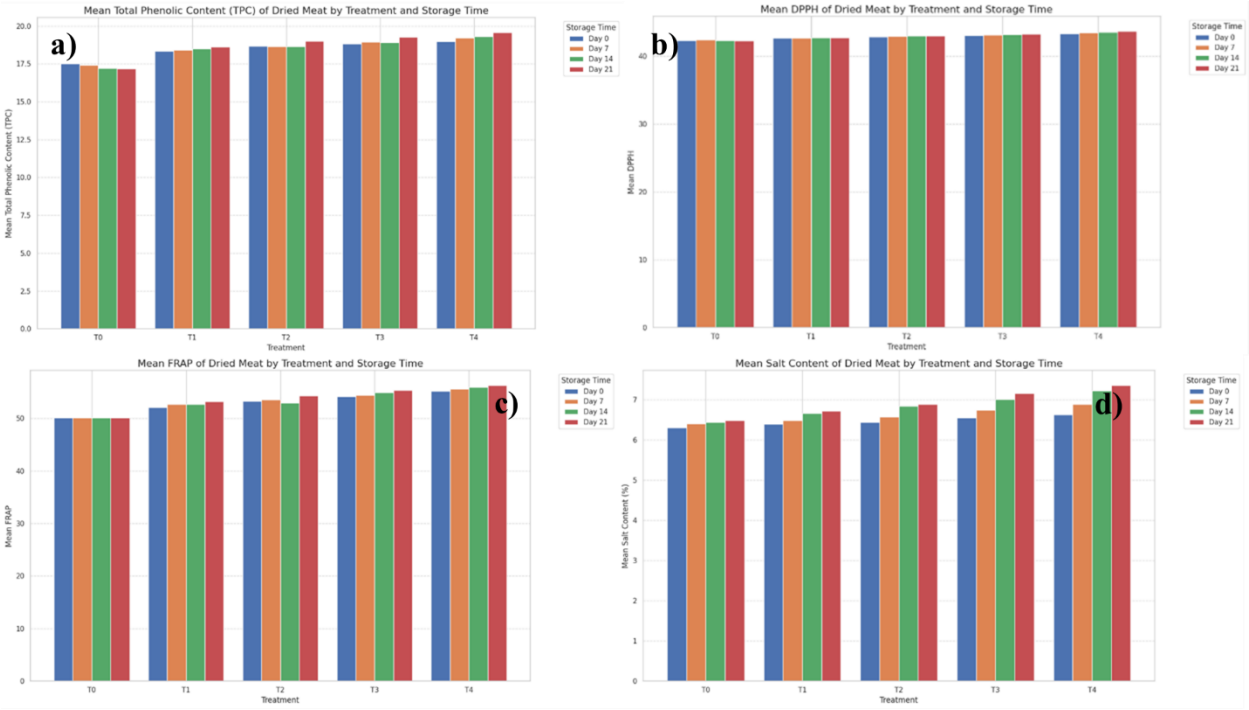

Figure 0.2: Proximate composition of dried meat showing changes in Total Phenolic Content (TPC) (Panel a), DPPH (Panel b), FRAP (Panel c), and Salt Content (Panel d) across treatments (T0-T4) and storage durations

Effect of treatment and storage on physicochemical analysis of dried meat (Figure *0.3*)

Effect of PSP Treatment on pH Levels in Dried Meat During Storage

pH is an important indicator of meat stability, as it influences microbial growth and oxidative changes, and the addition of pomegranate seed powder (PSP) can help lower and stabilize pH during storage. In this study, pH decreased slightly over time, ranging from 6.27 (T^0) to 5.64 (T^4), with the lowest values observed under PSP treatments; these results are consistent with the findings of Dhara et al. (2021).

Changes in Water Holding Capacity (WHC) of Dried Meat with Storage and PSP Treatments

Water holding capacity (WHC) is a key quality trait in meat, influencing texture, juiciness, and tenderness, and it generally declines with storage. In

this study, WHC decreased from 67.35% (T^0) to 64.39% (T^4), with PSP treatments showing lower values than the control These results are in line with Bowker et al. (2014).

Effect of PSP Treatment on TVBN Levels in Dried Meat During Storage

Total volatile basic nitrogen (TVBN) is an important indicator of meat spoilage, as higher values reflect protein breakdown and microbial activity. In this study, TVBN levels increased during storage but remained lowest in PSP treatment (10.87 in T^4) compared to the control (11.89 in T^0), indicating that PSP effectively slowed deterioration. These findings agree with Das et al. (2021).

Impact of PSP on Lipid Oxidation Measured by TBARs in Dried Meat

Thio barbituric Acid Reactive Substances (TBARs) are widely used to assess lipid oxidation, a major factor influencing rancidity, flavor, shelf life, and nutritional quality of meat products. The Mean values showed TBAR levels peaking at 0.30 on day 7 before decreasing to 0.27 by day 21, while the addition of pomegranate seed powder (T^1–T^4) consistently reduced lipid oxidation compared to the control (T^0). Treatment T^4, containing the highest PSP concentration, exhibited the lowest TBAR values, confirming its strong antioxidant effect in retarding lipid peroxidation, in agreement with findings reported by Alvarez-Parrilla et al. (2014).

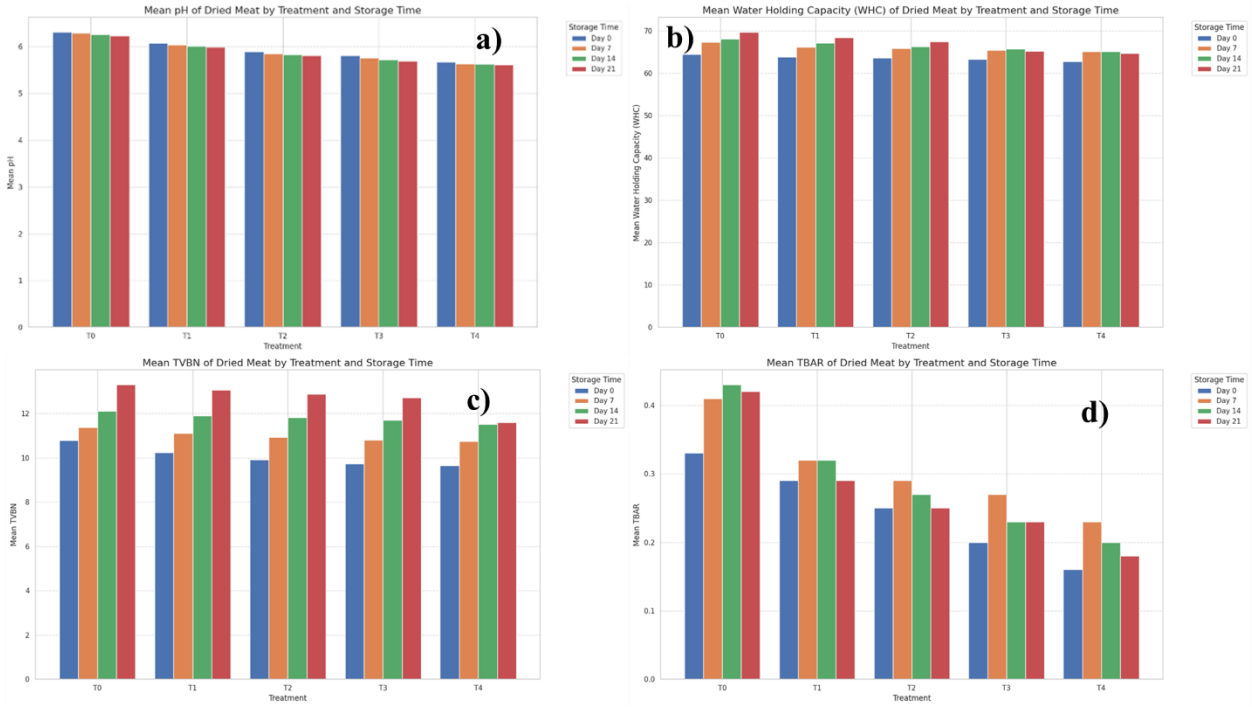

Figure 0.3: Mean pH (Panel a), Water Holding Capacity (WHC) (Panel b), TVBN (Panel c), and TBAR (Panel d) of dried meat (Landhi) showing changes across treatments (T0-T4) and storage durations (Day 0, Day 14, and Day 21)

Effect of storage on color of prepared dried meat (Figure *0.4*)

Effect of PSP Treatment on the Color Characteristics of Dried Meat

Color is a critical quality attribute that strongly influences consumer perception, selection, and acceptance of meat products, with brightness, redness, and yellowness serving as indicators of freshness and processing quality. Lightness decreased across treatments, with T^0 having the highest (32.06 to 28.45) and T^4 the lowest (29.72 to 28.45). Redness (a* value) also declined significantly, from 15.76 (T^0) to 14.16 (T^4), with values dropping further to 4.77 (T^0) and 3.56 (T^4) during extended

storage, reflecting fading of the red tone. Similarly, yellowness (b* value) reduced from 7.28 (T^0) to 6.53 (T^4), reaching 4.10 (T^0) and 3.08 (T^4) by day 21, indicating loss of yellow tones. Overall, PSP addition influenced the initial color characteristics by reducing brightness, redness, and yellowness, while prolonged storage intensified darkening and color fading. These findings align with the results of Lim et al. (2012), confirming that both natural antioxidants and storage time markedly alter the visual quality of dried meat.

Microbiological Stability and Total Plate Count (TPC) in Dried Meat with PSP Treatment

Microbiological assessment of meat is vital for ensuring food safety, as microbial load directly affects consumer health and product shelf life. Total Plate Count (TPC), which reflects the growth of aerobic mesophilic organisms, was significantly influenced by both treatment and storage days. The results showed that T^0 had the highest mean TPC (2.50) at 0 days, followed by T^1 (2.35), T^2 (2.18), T^3 (2.01), and T^4 (1.86), with T^4 consistently showing the lowest microbial load. This demonstrates that increasing levels of pomegranate seed powder (PSP) effectively reduced TPC, thereby delaying spoilage and enhancing the microbiological stability of dried meat during storage.

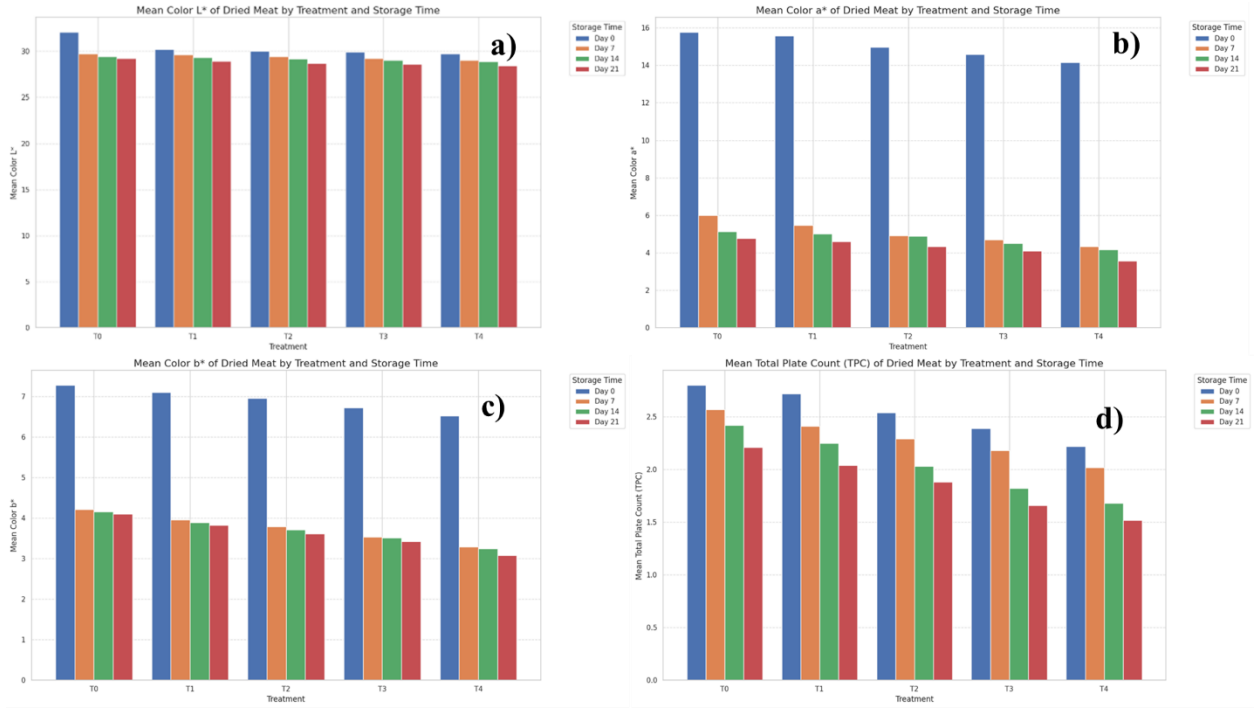

Figure 0.4: Mean color (L*, a*, b*) and total plate count (TPC) of dried meat showing changes in lightness (Panel a), redness (Panel b), yellowness (Panel c), and TPC (Panel d) across treatments (T0-T4) and storage durations

Sensory Evaluation of Dried Meat (Figure *0.5*)

Effect of PSP Treatment on Tenderness in Dried Meat

Tenderness is one of the most critical attributes influencing consumer preference for meat products. The results show that tenderness scores increased consistently across treatments with higher levels of pomegranate seed powder (PSP). At day 0, T^0 exhibited the lowest tenderness score (5.1), while T^4 showed the highest (6.0). Over 21 days of storage, all treatments showed slight increases in tenderness, with T^4 reaching its maximum (6.3). The improved tenderness with PSP addition may be attributed to its antioxidative effects that slow down protein

oxidation, thereby maintaining muscle fiber integrity and improving perceived texture.

Impact of PSP Treatment on Juiciness in Dried Meat During Storage

Juiciness scores declined progressively with storage across all treatments. T0 initially recorded the highest juiciness (5.2), while T4 had the lowest (4.7). By day 21, juiciness decreased in all treatments, with T0 at 4.7 and T4 at 4.0. The decline in juiciness during storage can be explained by moisture loss and reduced water-holding capacity (WHC), as previously discussed. Treatments with higher PSP levels showed slightly lower juiciness, likely due to the polyphenolic interactions that bind water molecules and reduce free moisture.

Overall Acceptability of Dried Meat with PSP Treatment and Storage Duration

Overall acceptability decreased with prolonged storage, with T^0 consistently maintaining the highest acceptability and T4 the lowest. On day 0, T^0 scored above 5.5, while T^4 was slightly lower (4.8). By day 21, these values declined to 4.9 and 4.1, respectively. The reduction in acceptability reflects combined changes in juiciness, color, and flavor stability during storage. While PSP-treated samples demonstrated better oxidative stability and microbial quality, their lower scores in juiciness and lighter sensory traits may have influenced panelist preferences.

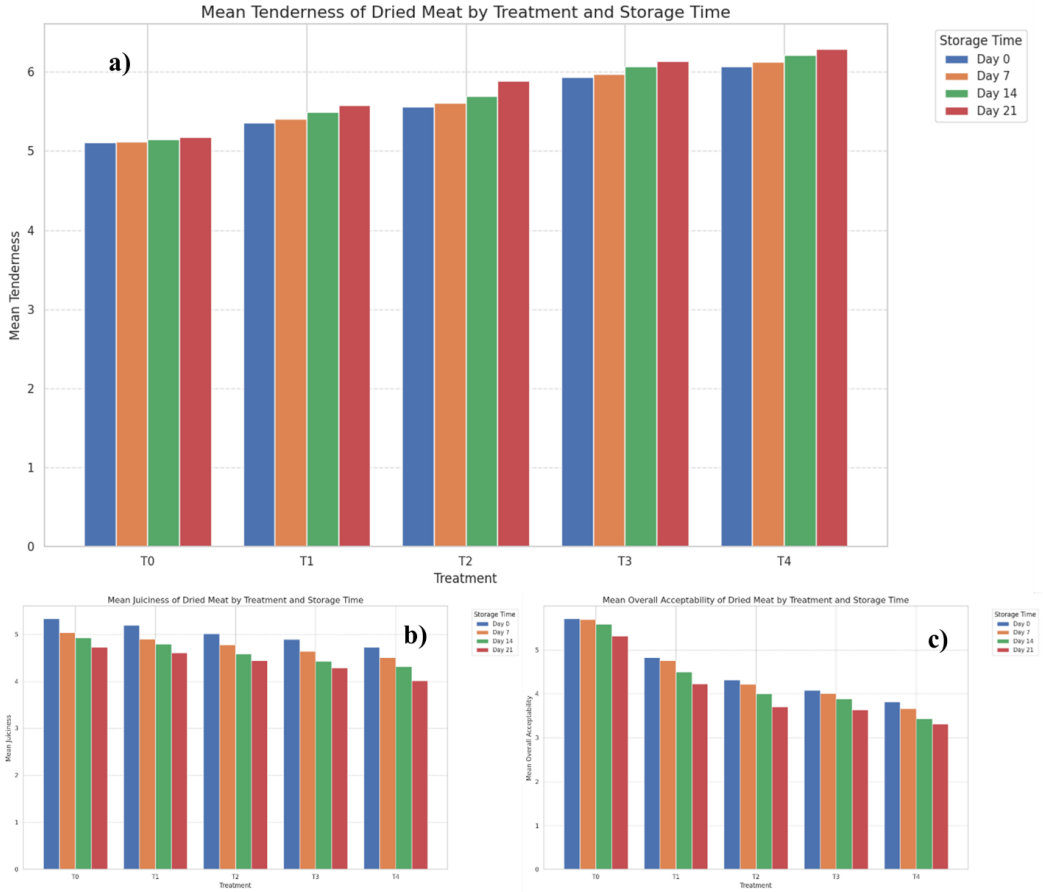

Figure 0.5: Mean tenderness (Panel a), juiciness (Panel b), and overall acceptability (Panel c) of dried meat (Landhi) showing changes across treatments (T0-T4) and storage durations (Day 0, Day 7, Day 14, and Day 21)

Conclusion

The incorporation of pomegranate seed powder (PSP) in the preparation of traditional Balochi dried meat (Landhi) proved to be a promising natural preservation strategy. PSP treatments effectively lowered moisture content, inhibited oxidative deterioration, and preserved crude protein, thereby enhancing the nutritional profile and storage stability of the product. Sensory evaluations confirmed that PSP-treated samples exhibited superior flavor, texture, and overall acceptability compared to the control. These outcomes highlight the potential of PSP as a cost-effective and eco-friendly alternative to synthetic preservatives, aligning with consumer demand for healthier and natural food products. While the study was limited by its short storage duration and regional focus, the results provide a strong foundation for further research on the long-term preservation effects of PSP and its broader applicability in the meat industry.

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