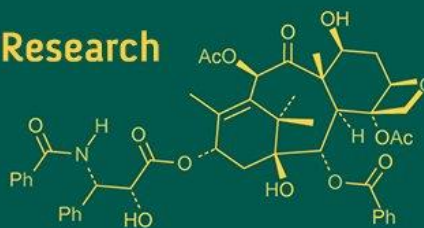


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Vijaya C Gurnalkar

Department of Livestock Products
Technology, College of Veterinary and
Animal Sciences, Parbhani,
Maharashtra, India

Anita M Chappalwar

Professor, Department of Livestock
Products Technology, College of
Veterinary and Animal Sciences,
Parbhani, Maharashtra, India

Sandeep N Rindhe

Department of Livestock Products
Technology, College of Veterinary and
Animal Sciences, Parbhani,
Maharashtra, India

Sanjay V Londhe

Department of Livestock Products
Technology, College of Veterinary and
Animal Sciences, Parbhani,
Maharashtra, India

Mahalsakant G Nikam

Department of Poultry Science,
College of Veterinary and Animal
Sciences, Parbhani, Maharashtra,
India

Prakash M Kekan

Department of Veterinary Physiology,
College of Veterinary and Animal
Sciences, Parbhani, Maharashtra,
India

Laxmikant D Gattewar

Department of Livestock Products
Technology, College of Veterinary and
Animal Sciences, Parbhani,
Maharashtra, India

Sanket S Bhadule

Department of Livestock Products
Technology, College of Veterinary and
Animal Sciences, Parbhani,
Maharashtra, India

Corresponding Author:

Anita M Chappalwar

Professor, Department of Livestock
Products Technology, College of
Veterinary and Animal Sciences,
Parbhani, Maharashtra, India

Application of novel egg albumin-based biodegradable films fortified with antioxidant pomegranate peel extract to enhance the storage stability of chicken cookies

Vijaya C Gurnalkar, Anita M Chappalwar, Sandeep N Rindhe, Sanjay V Londhe, Mahalsakant G Nikam, Prakash M Kekan, Laxmikant D Gattewar and Sanket S Bhadule

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Abstract

The present study investigated the impact of pomegranate peel extract (PPE) incorporating into egg albumin-based biodegradable films and its effectiveness in extending the storage stability of chicken cookies. Biodegradable films were formulated with addition of 0% (C), 0.03% (T₁), 0.06% (T₂), and 0.09% (T₃) pomegranate peel extract and analysed for physicochemical, mechanical, and barrier properties. An increase in PPE concentration significantly ($p < 0.05$) improved film thickness, density, opacity, tensile strength, moisture resistance, and overall barrier properties, while reduced elongation at break, water vapour and oxygen transmission rates. Egg albumin based biodegradable film with 0.09% PPE exhibited excellent overall performance, with enhanced molecular interactions within the film matrix. The quality of chicken cookies packed in LDPE (C), egg albumin film (T₁), and egg albumin film incorporated with 0.09% pomegranate peel extract (T₂) was examined during storage at room temperature. Cookies packaged in T₂ film showed higher sensory acceptance up to 70 days, lower peroxide and thiobarbituric acid values, and delayed microbial growth, demonstrating that pomegranate peel extract in biodegradable films effectively improves food shelf life and safety.

Keywords: Egg albumin film, pomegranate peel extract, chicken cookies, biodegradable packaging film

1. Introduction

Food packaging is an integral part for the product safety, quality preservation and shelf-life extension across the food supply chain (Hillier *et al.* 2017) ^[20]. Conventional plastic packaging dominates the market due to its low cost and favourable mechanical properties however, increasing global plastic production and waste accumulation intensified environmental pollution and greenhouse gas emissions (Dirpan *et al.* 2023) ^[12]. The persistence of plastics and the release of toxic additives pose substantial risks to ecosystems and human health, necessitating the development of sustainable packaging alternatives (Mangaraj *et al.* 2019) ^[34].

Biopolymers loaded with bioactive compound are considered one of the most promising and safest alternatives to other antimicrobial compounds. Biodegradable polymers sourced from renewable materials have attracted significant interest as environmentally friendly alternatives to conventional petroleum-derived plastics. Within this group, protein-based films are valued for their excellent film-forming properties, satisfactory mechanical strength and efficient oxygen barrier characteristics. Egg albumin is considered as a particularly promising biopolymer due to its globular protein nature and the coiled structure of ovalbumin (Lopez Mata *et al.*, 2016) ^[31], which encourages disulfide cross-linking and supports the formation of transparent and flexible films. Although egg albumin films offer several benefits, their high nutrient content renders them vulnerable to oxidative degradation and microbial contamination, which limits their practical use in food packaging. To mitigate these drawbacks, the incorporation of plant-based bioactive compounds has been explored as a promising approach to improve the functional characteristics of biodegradable films.

Pomegranate peel (*Punica granatum* L.), an underutilized by-product of agro-processing industries, is a rich source of phenolic compounds, flavonoids, and ellagitannins that exhibit strong antioxidant and antimicrobial properties (Kumar *et al.*, 2022b) [29]. Ethanolic extracts of pomegranate peel demonstrate notable radical-scavenging activity and have been earlier reported to enhance the mechanical integrity and protective performance of biopolymer films (Malviya *et al.*, 2014) [33].

Recently, consumer demand for ready-to-eat, protein-enriched snack products has increased distinctly, especially for poultry-based items due to their high nutritional value and economic affordability (Berwal *et al.*, 2013) [7]. We are passing through a crucial juncture of global insecurity against the right of everyone to have access to safe and nutritious food (Rindhe *et al.*, 2017) [46]. However, lipid oxidation and microbial proliferation remain major constraints affecting the shelf life and quality of meat-based snacks such as chicken cookies. A number of foods in India have been reported to have high incidence of bacteria, however, there is little/scanty information about the extent of microbial contamination of chicken products sold in Indian supermarkets (Rindhe *et al.*, 2008) [47]. Therefore, the present study was designed to develop an egg albumin-based biodegradable film incorporated with varying levels of pomegranate peel extract and to evaluate its potential in enhancing oxidative stability, microbial safety, and overall storage quality of chicken cookies.

2. Materials and methods

2.1 Peel preparation and extraction

Pomegranate (*Punica granatum* L.) fruits were obtained from the local market of Parbhani city (M.S.). Peels of pomegranate fruit were peeled, washed, oven-dried at 40 ± 5 °C, ground into powder. Ethanolic extracts were obtained by macerating 1 kg of pomegranate peel powder in ethanol:water (3500:1500 mL) for 72 h at room temperature. The extract was filtered by muslin cloth and Whatman's filter paper no.1. which was concentrated by evaporation on hot plate and stored at refrigeration temperature until use.

2.2 Preparation of egg albumin film incorporated with pomegranate peel extract

Films were prepared following Rindhe *et al.* (2020) [44] with modifications. Egg albumin film-forming solution was prepared by dissolving 6 g of egg albumin powder in 100 mL distilled water under continuous stirring at 150 rpm using a magnetic stirrer. Pomegranate peel extract was incorporated at concentrations of 0.03, 0.06, and 0.09%, followed by the addition of 2 mL glycerol as a plasticizer. The pH of the solution was adjusted to 9.0 using 1.0 N sodium hydroxide, after which the mixture was incubated at 60 °C for 40 min. The solution was then cooled, filtered through muslin cloth, poured onto Teflon sheets and dried in hot air oven at (32 ± 2 °C) to obtain the films.

2.3 Preparation of chicken cookies

Chicken cookies were prepared with slight modifications in the method followed by Nemade *et al.* (2021) [39]. Chicken meat powder required for chicken cookies preparation was obtained by grinding of dried clean minced boneless chicken meat in a hot air oven at 60-65 °C for 20-22 hrs. As per table 1. the chicken cookies ingredient mixture was prepared, uniformly mixed, and adjusted to the desired

dough consistency. The dough was rolled, shaped into cookies and baked in a microwave oven at 150-160 °C for 20 minutes then cooled.

Table 1: Basic formulation of chicken cookies

Ingredients%	%
Chicken meat powder	50
Pearl millet flour	24
Wheat flour	12
Vanaspati ghee	25
Sugar	13
Glucose	05
Milk powder	10
Egg albumin	7
Vanilla powder	2
Baking powder	1
Salt	1

*Water was added as per requirements.

2.4 Storage of chicken cookies

Chicken cookies were wrapped in bioactive egg albumin film incorporated with (T_2) or without 0.09% pomegranate peel extract (T_1) along with control (C) packed in a low-density polyethylene (LDPE) pouch and subsequently stored at room temperature. All packaged samples were stored under aerobic conditions at a temperature of 32 ± 2 °C. Sampling of stored cookies was conducted at regular intervals of 10 days to evaluate the storage stability. Throughout the storage period, the shelf life and overall quality of the chicken cookies were assessed to determine the effectiveness of the packaging materials.

2.5 Analytical Procedures for bioactive protein films

Film thickness was measured using a digital electronic vernier caliper with an accuracy 0.0001 mm (Kumari *et al.* 2017) [30]. Film opacity was measured at 660 nm using a UV-VIS spectrophotometer following method of Domene *et al.* (2019) [13] with 3×1 cm film strips placed in water-filled cuvettes and opacity calculated from transmittance values. Film density was determined at 25 °C using the flotation method described by Quarashi *et al.* (1992) [42]. The moisture content of egg albumin films was determined using the gravimetric method demarcated by Rhim *et al.* (1998) [43]. Total soluble mass of egg albumin films was determined according to method outlined by Jiang *et al.* (2007) [22]. Water Vapour Transmission Rate of the coatings was determined according to ISO 2528:2017(E). Film penetrability was measured as per the method followed by Mahajan *et al.* (2017) [30], while tensile strength (MPa) and elongation at break (%) were measured according to ASTM standards (ASTM, 1986; 2001) using texture analyzer (TMS-PRO, Food Technology Corporation, USA). The oxygen transmission rate (OTR) of film coatings was determined using the deoxidizer absorption method (Zhang *et al.* 2019) [57].

2.6 Physicochemical Analysis of Cookies

The pH of chicken cookies was measured according to AOAC (1995). Ten gm of sample was homogenized with 50 mL distilled water, and the pH of the resulting suspension was recorded using a digital pH meter. The peroxide value of chicken cookies was determined based on the method described by Koniecko (1979) [28], with slight modifications.

The Thiobarbituric Acid Reactive Substances value was estimated using the method described by Witte *et al.* (1970) [54].

2.7 Microbial Analysis

Total plate count, psychrophilic count, yeast and mould count, staphylococcal count was determined according to method outline by APHA (1992; 2015) [2, 3].

2.8 Sensory Evaluation

Ready-to-eat chicken cookies were evaluated by a semi-trained panel (n = 21) from COVAS, Parbhani, using an 8-point descriptive scale (Keeton, 1983) [27]. Attributes assessed included appearance and color, texture, flavor,

crispiness, and overall acceptability. Potable water was provided between samples for palate cleansing.

3. Statistical Analysis

The data obtained in the study on various parameters were statistically analysed on “SPSS-16.0” software package for one-way ANOVA as per standard methods of Snedecor and Cochran (1994) [51].

3.1 Result and Discussion

3.1.1 Physicochemical Characteristics of Film

The impact of pomegranate peel extract on the physicochemical, mechanical and permeability properties of biodegradable films is presented in Table 4.1.

Table 2: Effect of different levels of pomegranate peel extract on physico-chemical, mechanical and permeability properties of egg albumin films

Parameter	C	T ₁	T ₂	T ₃
Thickness (mm)	0.18 ^c ±0.00	0.19 ^b ±0.00	0.20 ^{ab} ±0.01	0.20 ^a ±0.00
Opacity (A)	1.35 ^d ±0.02	1.56 ^c ±0.02	1.84 ^b ±0.00	2.04 ^a ±0.03
Density (g/mL)	1.20 ^c ±0.01	1.23 ^{bc} ±0.01	1.25 ^b ±0.00	1.31 ^a ±0.01
Moisture (%)	0.36 ^a ±0.01	0.22 ^b ±0.01	0.16 ^c ±0.01	0.12 ^d ±0.03
Penetrability (N)	4.85 ^d ±0.01	5.70 ^c ±0.02	6.40 ^b ±0.02	7.15 ^a ±0.04
TSM (%)	40 ^a ±0.58	34 ^b ±0.15	30 ^c ±0.58	26 ^d ±0.10
Tensile Strength (MPa)	0.98 ^d ±0.01	1.36 ^c ±0.01	2.98 ^b ±0.01	4.75 ^a ±0.00
Elongation at Break%	35.00 ^a ±0.15	34.20 ^b ±0.15	33.50 ^c ±0.15	32.80 ^d ±0.15
WVTR (g/m ² ·day)	13.52 ^a ±0.03	12.58 ^b ±0.06	12.38 ^c ±0.04	11.92 ^d ±0.05
O ₂ GTR (cm ³ /m ² ·day·atm)	7.81 ^a ±0.03	7.52 ^b ±0.03	7.38 ^c ±0.02	7.09 ^d ±0.03

n = 6, *Mean ± S.E. with different superscripts row-wise (a-d) differ significantly ($p < 0.05$).

C-Control egg albumin film without pomegranate peel extract,

T₁-Egg albumin film added with 0.03% pomegranate peel extract

T₂-Egg albumin film added with 0.06% pomegranate peel extract

T₃-Egg albumin film added with 0.09% pomegranate peel extract

4. Thickness

Film thickness, an indicator of structural integrity, increased significantly ($p < 0.05$) with increasing PPE concentration in chicken cookies, ranging from 0.18±0.00 mm in the control (C) to 0.20±0.00 mm in T₃. This enhancement may be attributed to stronger intermolecular interactions facilitated by polyphenols and other bioactive compounds present in PPE. Comparable increase in film thickness with higher incorporation of PPE has also been reported in chitosan-based films (Min *et al.*, 2021) and gluten-based films (Kumari *et al.*, 2017) [36, 30]. Similarly, Kavas and Kavas (2016) [26] reported that the incorporation of plant extracts increased the thickness of egg albumin films, supporting the present findings that PPE enhances film structure.

5. Opacity

Opacity, a key parameter determining light-barrier efficiency, increased significantly ($p < 0.05$) from 1.35±0.02 (C) to 2.04±0.03 (T₃) with increasing PPE concentrations. The higher opacity indicates reduced light transmission, due to availability of phenolic compounds and natural pigments in PPE which absorb and scatter light. Comparable results have been reported in plant-extract-incorporated protein films by Moghadam *et al.*, (2020) [37]. Increased opacity is beneficial in protecting photosensitive foods from UV induced oxidation (Galus, 2018) [16], demonstrating the effectiveness of PPE in enhancing light-barrier properties.

6. Density

Film density increased significantly ($p < 0.05$) as PPE concentration rose, ranging from 1.20±0.01 g mL⁻¹ in the

control (C) to 1.31±0.01 g mL⁻¹ in T₃. This could be attributed to the development of a denser and more compact film structure, possibly resulting from stronger interactions between the polyphenolic compounds of PPE and the protein matrix (Elsebaie *et al.*, 2023) [15]. Similar consequence of polymer-plasticizer interactions on density have been documented in protein-based films by Atik *et al.*, (2024) [6].

7. Moisture Content

Moisture content decreased significantly ($p < 0.05$) with increasing PPE concentration, from 0.36±0.01 (C) to 0.12±0.03 (T₃). The decrease may be attributed to enhanced intermolecular interactions and reduced water-binding capacity after PPE incorporation, which restricts moisture retention within the matrix (Min *et al.*, 2021; Cao *et al.*, 2021) [36, 9]. Hamarashid *et al.* (2025) [19] also reported a similar reduction in moisture content in protein-based films on addition of plant extract addition have been reported by), indicating improved film stability.

8. Penetrability

Penetrability (puncture resistance) increased significantly ($p < 0.05$) from 4.85±0.01 N (C) to 7.15±0.04 N (T₃) as the level of PPE increased. This improvement reflects enhanced mechanical strength and suitability for food packaging applications. Singh *et al.* (2018) [50] also reported similar effects of film composition and plasticizer content on the puncture resistance of protein-and polysaccharide-based films. In contrast, Kanatt *et al.* (2012) [24] reported no

significant effect of plant extract incorporation on the penetrability of chitosan-PVA composite films.

9. Total Soluble Mass (TSM)

Total soluble mass decreased significantly ($p < 0.05$) from $40.0 \pm 0.58\%$ (C) to $26.0 \pm 0.10\%$ (T_3) with the progressive increase in PPE concentration. Lower TSM suggests improved water resistance and greater structural stability, likely resulting from stronger interactions between PPE constituents and the protein matrix. Cao *et al.* (2021) [9] also observed comparable results in carvacrol-enriched egg albumin films, where decreased solubility was attributed to reduced water-binding capacity. Similar decreases in film solubility with incorporation of plant extracts have been reported by Hu *et al.* (2019) and Moghadam *et al.* (2020) [21, 37].

10. Tensile Strength

Tensile strength increased significantly ($p < 0.05$) from 0.98 ± 0.01 MPa (C) to 4.75 ± 0.00 MPa (T_3) as the concentration of PPE increased. This enhancement reflects improved mechanical resistance and durability, may be attributed to stabilizing interactions between PPE polyphenols and the egg albumin matrix. Similar improvements in tensile properties of polyphenol-enriched biopolymer films were reported by Mushtaq *et al.* (2018) [38].

11. Elongation at Break

Elongation at break decreased significantly ($p < 0.05$) from $35.00 \pm 0.15\%$ (C) to $32.80 \pm 0.15\%$ (T_3) with increasing PPE concentration. The reduced flexibility may result from enhanced hydrogen bonding between phenolic compounds and the protein matrix, producing a more rigid and compact structure. Similar trends were reported in PPE-incorporated biopolymer films by Min *et al.*, (2021) [36].

12. Water Vapour Transmission Rate (WVTR)

Water vapour transmission rate decreased significantly ($p < 0.05$) with increasing PPE concentration, declining from 13.52 ± 0.03 g/m²·day (C) to 11.92 ± 0.05 g/m²·day (T_3). This reduction may be attributed to improved moisture barrier properties, possibly due to hydrophobic phenolic compounds enhancing polymer cross-linking and limiting water diffusion (Deseta *et al.*, 2023) [11]. A similar declining trend was reported by Mushtaq *et al.* (2018) [38] in phenolic-enriched protein films, confirming the role of PPE in enhancing film compactness.

13. Oxygen Gas Transmission Rate (O₂ GTR)

Oxygen gas transmission rate (O₂ GTR) decreased significantly ($p < 0.05$) with increasing pomegranate peel extract (PPE) concentration, from 7.81 ± 0.03 to 7.09 ± 0.03 cm³/m²·day·atm in T_3 . This enhanced oxygen barrier property may be attributed to the formation of a denser microstructure through polyphenolic interactions, thereby restricting oxygen diffusion. Similar reductions in oxygen permeability of plant-extract-enriched egg albumin films were reported by El-Sayed *et al.* (2018), demonstrating the barrier-enhancing potential of PPE.

14. Quality evaluation of chicken cookies stored at room temperature

Chicken cookies were packaged using three different materials: control (C) in LDPE bags, T_1 in egg albumin films, and T_2 in egg albumin films incorporated with 0.09% PPE. The samples were stored at room temperature and periodically analyzed for various quality parameters.

15. Sensory evaluation

The average sensory scores for chicken cookies either wrapped or unwrapped in egg albumin films during room storage are presented in Table 3.

Table 3: Storage related changes in sensory properties of chicken cookies at room temperature ($32 \pm 2^\circ\text{C}$)

Treat/Days	Storage Period (Days)							70 Days
	1 Day	10 Days	20 Days	30 Days	40 Days	50 Days	60 Days	
	Appearance							
C	7.25 ^{ar} ±0.004	6.77 ^{br} ±0.003	6.23 ^{cr} ±0.003	5.74 ^{dr} ±0.002	5.00 ^{er} ±0.002	NP	NP	NP
T ₁	7.42 ^{aq} ±0.002	6.99 ^{bq} ±0.004	6.46 ^{cq} ±0.003	6.08 ^{dq} ±0.002	5.70 ^{eq} ±0.002	5.34 ^{fq} ±0.002	5.08 ^{gq} ±0.002	NP
T ₂	7.65 ^{ap} ±0.002	7.29 ^{bp} ±0.002	6.86 ^{cp} ±0.002	6.55 ^{dp} ±0.001	6.21 ^{ep} ±0.002	5.90 ^{fp} ±0.003	5.59 ^{gp} ±0.002	5.23 ^h ±0.001
Flavour								
C	7.16 ^{ar} ±0.003	7.06 ^{br} ±0.002	6.39 ^{cr} ±0.003	6.02 ^{dr} ±0.002	5.58 ^{er} ±0.003	NP	NP	NP
T ₁	7.21 ^{aq} ±0.002	7.29 ^{bq} ±0.003	6.74 ^{cq} ±0.003	6.38 ^{dq} ±0.002	6.06 ^{eq} ±0.002	5.96 ^{fq} ±0.003	5.62 ^{gq} ±0.003	NP
T ₂	7.46 ^{ap} ±0.003	7.32 ^{bp} ±0.003	7.17 ^{cp} ±0.003	6.84 ^{dp} ±0.003	6.50 ^{ep} ±0.003	6.20 ^{fp} ±0.002	5.92 ^{gp} ±0.003	5.80 ^h ±0.001
Texture								
C	7.38 ^{ar} ±0.002	7.08 ^{br} ±0.002	6.36 ^{cr} ±0.003	6.00 ^{dr} ±0.003	5.78 ^{er} ±0.001	NP	NP	NP
T ₁	7.52 ^{aq} ±0.002	7.13 ^{bq} ±0.002	6.60 ^{cq} ±0.003	6.39 ^{dq} ±0.003	6.15 ^{eq} ±0.002	5.91 ^{fq} ±0.002	5.87 ^{gq} ±0.001	NP
T ₂	7.54 ^{ap} ±0.003	7.15 ^{bp} ±0.002	6.88 ^{cp} ±0.002	6.70 ^{dp} ±0.002	6.49 ^{ep} ±0.002	6.24 ^{fp} ±0.002	6.07 ^{gp} ±0.002	5.97 ^h ±0.001
Crispiness								
C	7.35 ^{ar} ±0.002	6.90 ^{br} ±0.003	6.13 ^{cr} ±0.002	5.75 ^{dr} ±0.003	5.47 ^{er} ±0.003	NP	NP	NP
T ₁	7.43 ^{aq} ±0.002	6.95 ^{bq} ±0.002	6.52 ^{cq} ±0.002	6.25 ^{dq} ±0.003	5.90 ^{ep} ±0.003	5.62 ^{fq} ±0.003	5.33 ^{gq} ±0.002	NP
T ₂	7.54 ^{ap} ±0.002	7.11 ^{bp} ±0.002	6.56 ^{cp} ±0.002	6.46 ^{dp} ±0.001	6.19 ^{ep} ±0.001	5.89 ^{fp} ±0.002	5.57 ^{gp} ±0.002	5.44 ^h ±0.003
Overall Acceptability								
C	7.15 ^{ar} ±0.003	6.73 ^{br} ±0.003	6.39 ^{cr} ±0.003	5.75 ^{dr} ±0.002	5.14 ^{er} ±0.003	NP	NP	NP
T ₁	7.31 ^{aq} ±0.003	6.85 ^{bq} ±0.002	6.47 ^{cq} ±0.003	5.84 ^{dq} ±0.003	5.62 ^{eq} ±0.004	5.49 ^{fq} ±0.003	5.12 ^{gq} ±0.002	NP
T ₂	7.34 ^{ap} ±0.003	6.98 ^{bp} ±0.003	6.63 ^{cp} ±0.002	6.29 ^{dp} ±0.002	6.00 ^{ep} ±0.003	5.92 ^{fp} ±0.003	5.78 ^{gp} ±0.003	5.58 ^h ±0.003

n=21, NP-Not perform,

Mean ± S.E. with different superscripts row-wise (a-h) and column-wise (p-r) differ significantly ($p < 0.05$).

C-Chicken cookies packed in LDPE,

T₁-Chicken cookies wrapped in control egg albumin films,

T₂-Chicken cookies wrapped in 0.09% pomegranate peel extract incorporated in egg albumin films.

Sensory scores declined significantly ($p<0.05$) with increasing storage duration across all treatments. However, T₂ consistently retained higher scores for appearance, flavour, texture, crispiness, and overall acceptability. The deterioration in scores of sensory attributes viz, appearance, flavour, texture, crispiness, and overall acceptability of chicken cookies during storage may be attributed to lipid and protein oxidation, moisture migration, formation of free fatty acids, and microbial growth. Oxidative lipid degradation negatively affects colour, flavour, and texture, as previously reported for meat-based products by Wu *et al.*, (2022) [55]. Comparable reductions in sensory scores associated with lipid oxidation during storage have also been documented by Jung *et al.* (2025) [23] after 270 days in chicken stored at -20 °C. However, T₂ showed better retention of sensory qualities, which may be attributed to the presence of polyphenols and flavonoids in pomegranate peel extract. These bioactive compounds delayed oxidative deterioration, thereby extending shelf life. The improved flavour stability in T₂ may be attributed to antioxidant phenolics that minimize oxidative damage (Giri *et al.*, 2023) [18]. Similar storage-related flavour deterioration in meat-based snacks has been reported previously (Pavan Kumar *et al.* 2016). Throughout storage, T₂ maintained higher texture scores, likely due to improved barrier properties and the stabilizing effect of bioactive compounds in pomegranate peel extract, which limited moisture uptake and structural degradation (Giannakourou *et al.* 2025) [17]. Similar effects of edible packaging on minimizing textural deterioration in snack foods have been reported previously by Karnwal *et al.* (2025) [25]. The reduction in crispiness may be linked to moisture uptake and lipid oxidation, which compromise structural integrity and freshness perception. Similar decline in the crispiness of stored meat-based snack

products previously reported by Sonia (2024), who also reported that the sensory quality of products declines as the storage period increases. Overall acceptability of chicken cookies declined significantly ($p<0.05$) with progression of ambient storage period. However, C was not subjected for sensory evaluation after 40th day and T₁ after 60th day of storage due to existence of signs of incipient spoilage. According to Park *et al.* (2025) [40], the quality of meat products during storage is largely influenced by chemical reactions involving lipids and proteins. The deterioration in sensory attributes may be due to lipid and protein oxidation, release of free fatty acids, and progressive microbial growth during storage (Domínguez *et al.*, 2019) [14]. However, T₂ recorded relatively higher acceptability scores, suggesting the protective role of pomegranate peel extract, as its polyphenolic antioxidants helped to retard oxidative deterioration and spoilage (Giri *et al.* 2023) [18]. Similar shelf-life extension using pomegranate peel extract has been reported previously in meat products (Turgut *et al.* 2016; Mehdizadeh *et al.* 2020) [53, 35].

Chicken cookies packaged in egg albumin film incorporated with 0.09% pomegranate peel extract (T₂) exhibited higher sensory scores than the control. Pomegranate peel extract acts as a natural additive due to its strong antioxidant properties which helped delay spoilage and improve the retention of flavour, texture, and overall acceptability, thereby demonstrating its effectiveness in extending shelf life (Giri *et al.*, 2023) [18].

16. Physico-chemical characteristics

The changes in the physicochemical characteristics of chicken cookies stored at room conditions (32±2 °C) for a period of 70 days, and summarized in Table 4.

Table 4: Storage related changes in physico-chemical characteristics of chicken cookies at room temperature (32±2 °C)

Treat/Days	Storage Period (Days)							
	1 Day	10 Days	20 Days	30 Days	40 Days	50 Days	60 Days	70 Days
pH								
C	6.31 ^{hp} ±0.001	6.36 ^{gp} ±0.026	6.40 ^{fp} ±0.001	6.47 ^{ep} ±0.028	6.58 ^{dp} ±0.003	6.69 ^{cp} ±0.024	6.83 ^{bp} ±0.026	6.98 ^{ap} ±0.026
T ₁	6.12 ^{sq} ±0.001	6.13 ^{gq} ±0.001	6.19 ^{fq} ±0.005	6.32 ^{eq} ±0.001	6.43 ^{dq} ±0.001	6.55 ^{cq} ±0.001	6.71 ^{bq} ±0.001	6.87 ^{aq} ±0.001
T ₂	6.09 ^{hr} ±0.001	6.10 ^{gr} ±0.001	6.12 ^{fr} ±0.001	6.16 ^{er} ±0.001	6.20 ^{dr} ±0.001	6.25 ^{cr} ±0.001	6.34 ^{br} ±0.001	6.52 ^{ar} ±0.001
Peroxide Value (meq/kg)								
C	1.32 ^{hp} ±0.017	2.22 ^{gp} ±0.027	3.26 ^{fp} ±0.036	3.57 ^{ep} ±0.035	3.86 ^{dp} ±0.035	4.05 ^{cp} ±0.031	4.11 ^{bp} ±0.029	4.25 ^{ap} ±0.003
T ₁	1.11 ^{hq} ±0.017	1.63 ^{gq} ±0.018	2.20 ^{fq} ±0.027	2.78 ^{eq} ±0.036	3.12 ^{dq} ±0.004	3.49 ^{cq} ±0.035	3.72 ^{bq} ±0.031	3.82 ^{aq} ±0.029
T ₂	1.03 ^{hr} ±0.013	1.38 ^{gr} ±0.016	1.46 ^{fr} ±0.016	1.52 ^{er} ±0.018	1.63 ^{dr} ±0.018	1.87 ^{cr} ±0.016	1.98 ^{br} ±0.021	2.10 ^{ar} ±0.003
TBA (mgmalonaldehyde/kg)								
C	0.57 ^{hp} ±0.001	0.74 ^{gp} ±0.001	0.96 ^{fp} ±0.001	1.81 ^{ep} ±0.001	1.97 ^{dp} ±0.001	2.16 ^{cp} ±0.001	2.33 ^{bp} ±0.001	2.50 ^{ap} ±0.001
T ₁	0.51 ^{hq} ±0.001	0.72 ^{gq} ±0.001	0.91 ^{fq} ±0.001	1.36 ^{eq} ±0.001	1.58 ^{dq} ±0.001	1.73 ^{cq} ±0.001	1.93 ^{bq} ±0.011	2.01 ^{aq} ±0.001
T ₂	0.48 ^{hr} ±0.001	0.61 ^{gr} ±0.001	0.82 ^{fr} ±0.001	1.14 ^{er} ±0.001	1.37 ^{dr} ±0.001	1.46 ^{cr} ±0.001	1.58 ^{br} ±0.001	1.62 ^{ar} ±0.001

n-21, NP-Not perform,

Mean ± S.E. with different superscripts row-wise (a-h) and column-wise (p-r) differ significantly ($p<0.05$).

C-Chicken cookies packed in LDPE,

T₁-Chicken cookies wrapped in control egg albumin films,

T₂-Chicken cookies wrapped in 0.09% pomegranate peel extract incorporated in egg albumin films.

The pH of chicken cookies increased significantly ($p<0.05$) during ambient storage across all treatments. The control showed the greatest rise (6.31-6.98), followed by T₁ (6.12-6.87), while T₂ recorded the lowest increase (6.09-6.52) over 70 days at room temperature. The comparatively lower pH in T₂ suggests better product stability, likely due to the antimicrobial effect of pomegranate peel extract. Similar pH stabilization effects have been reported by Mehdizadeh *et al.* (2020) and Caglak *et al.* (2024) [35, 8] in pomegranate peel

extract treated products. The gradual increase in pH during storage may be attributed to microbial growth and protein degradation producing alkaline compounds (Rushitha *et al.*, 2024) [48].

Peroxide value (PV) increased significantly in all stored cookies, indicating progressive lipid oxidation. The control packed in LDPE showed the highest increase (1.32-4.25 meq/kg), while T₁ exhibited a moderate rise (up to 3.82 meq/kg). The lowest PV was observed in T₂ (1.03-2.10

meq/kg), packaged in egg albumin film containing 0.09% pomegranate peel extract. The enhanced oxidative stability of T₂ is attributed to phenolic compounds that scavenge free radicals and inhibit lipid peroxidation, as reported by Cava and Ladero (2023) [10]. Similar reductions in peroxide formation for pomegranate peel extract-based film wrapped Kalari cheese during storage have been reported previously by Mushtaq *et al.* (2018) [38].

Similarly, thiobarbituric acid (TBA) values increased significantly ($p < 0.05$) during storage. The control showed the highest rise (0.57-2.50 mg MDA/kg), followed by T₁ (0.51-2.01 mg MDA/kg), whereas T₂ recorded the lowest increase (0.48-1.62 mg MDA/kg), indicating superior

oxidative stability due to the presence of PPE. This reduction in lipid oxidation can be linked to the strong radical-scavenging activity of phenolic compounds in pomegranate peel extract (Xiang *et al.* 2022) [56]. Present findings are consistent with findings obtained by Mehdizadeh *et al.* (2020) [35] during storage of beef wrapped in pomegranate peel extract added film.

17. Microbial quality

The changes in the microbiological quality of chicken cookies stored at room temperature (32±2 °C) for 70-days period enumerated in the table 5.

Table 5: Storage related changes in microbiological quality of chicken cookies at room temperature (32±2 °C)

Treat/Days	Storage Period (Days)							
	1 Day	10 Days	20 Days	30 Days	40 Days	50 Days	60 Days	70 Days
Total plate Count (log₁₀ cfu/g)								
C	3.38 ^{ap} ±0.008	3.42 ^{fp} ±0.008	3.45 ^{ep} ±0.004	3.46 ^{ep} ±0.005	3.53 ^{dp} ±0.004	3.57 ^{cp} ±0.004	3.68 ^{bp} ±0.006	4.10 ^{ap} ±0.003
T ₁	3.37 ^{bp} ±0.006	3.39 ^{gq} ±0.006	3.41 ^{fq} ±0.006	3.44 ^{eq} ±0.006	3.49 ^{dq} ±0.004	3.54 ^{cq} ±0.004	3.62 ^{bq} ±0.005	3.78 ^{aq} ±0.003
T ₂	3.33 ^{hq} ±0.006	3.34 ^{gr} ±0.003	3.36 ^{fq} ±0.004	3.38 ^{er} ±0.003	3.41 ^{dr} ±0.004	3.45 ^{cr} ±0.004	3.49 ^{br} ±0.002	3.55 ^{ar} ±0.003
Psychrophilic Count (log₁₀ cfu/g)								
C	ND	ND	ND	ND	ND	ND	ND	ND
T ₁	ND	ND	ND	ND	ND	ND	ND	ND
T ₂	ND	ND	ND	ND	ND	ND	ND	ND
Yeast and mould count (log₁₀ cfu/g)								
C	ND	ND	ND	ND	ND	ND	3.02 ^b ±0.04	3.50 ^{ap} ±0.003
T ₁	ND	ND	ND	ND	ND	ND	ND	2.98 ^q ±0.008
T ₂	ND	ND	ND	ND	ND	ND	ND	2.60 ^r ±0.015
Staphylococcus count (log₁₀ cfu/g)								
C	ND	ND	ND	ND	ND	ND	2.82 ^b ±0.007	3.15 ^{ap} ±0.012
T ₁	ND	ND	ND	ND	ND	ND	ND	2.72 ^q ±0.008
T ₂	ND	ND	ND	ND	ND	ND	ND	2.60 ^r ±0.015

n=21, NP-Not perform

Mean ± S.E. with different superscripts row-wise (a-h) and column-wise (p-r) differ significantly ($p < 0.05$).

C-Chicken cookies packed in LDPE,

T₁-Chicken cookies wrapped in control egg albumin films,

T₂-Chicken cookies wrapped in 0.09% pomegranate peel extract incorporated in egg albumin films.

Total plate count (TPC) increased significantly ($p < 0.05$) in all cookies during storage. The control packaged in LDPE exhibited the greatest increase (3.38-4.10 log₁₀ cfu/g), followed by T₁ (3.37-3.78 log₁₀ cfu/g), whereas T₂ (egg albumin film incorporated with 0.09% pomegranate peel extract) exhibited the lowest microbial growth (3.33-3.55 log₁₀ cfu/g), indicating the antimicrobial efficacy of pomegranate peel extract, attributed to its bioactive phenolic compounds such as ellagic and gallic acids, as reported by Chen *et al.* (2020). Similar observations regarding the antimicrobial effects of pomegranate peel extract in meat products have also been reported by Shahamirian *et al.* (2019) [49], with emphasizing its potential for extending the shelf life of meat-based snack products.

Psychrophilic bacteria were not detected in any cookie samples during storage at 32±2 °C, as such temperatures are unfavourable for psychrophilic microorganisms, that thrive at lower temperatures (around 13 °C). The absence of psychrophilic bacteria in this study might be linked to unfavourable thermal conditions and the protective effect of packaging, which limited the activity of cold-adapted microbes (Son *et al.*, 2023) [52].

Yeast and mould counts remained undetectable in treated cookies up to day 60 and in the control up to day 50. By day 70, the control exhibited the highest fungal count (3.50 log₁₀ cfu/g), followed by T₁ (2.98 log₁₀ cfu/g), while T₂ recorded

the lowest count (2.60 log₁₀ cfu/g). The suppressed fungal growth in T₂ can be ascribed to the antifungal properties of phenolic compounds present in pomegranate peel extract. As per Turgut *et al.* (2016) [53] pomegranate peel extract inhibits yeast and mould growth by disrupting microbial cell membranes. Similar findings on the antifungal efficacy of pomegranate peel-based active packaging have been reported by Deseta *et al.* (2023) [11], with confirming its role in improving the microbial stability of meat-based bakery products during storage.

From the study it is concluded that the inclusion of 0.09% pomegranate peel extract was found to be optimal for enhancing the physicochemical, mechanical, and barrier properties of the egg albumin film and storage stability of chicken cookies for up to 70 days at ambient temperature without significant deterioration in quality attributes.

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