



Dijlah Journal of Agricultural Sciences

Journal homepage: <https://djas.uowasit.edu.iq/index.php/djas/en>



Research article

Effect of edible coating containing postbiotics on quality and shelf-life of refrigerated beef meat

Ola D. Abdulaali

Biology Department, Science College, Basrah University, Iraq

ARTICLE INFO

Keywords:

postbiotic,
beef meat,
edible coating
and microbial quality

Article history:

Received: 22 Jul
Accepted: 23 Sep
Online: 30 Sep

ABSTRACT

The current study evaluated to elucidate the impact of edible coatings incorporated with postbiotics on overall quality attributes of refrigerated beef meat, including physiochemical, microbiological and sensory traits. The fresh beef samples were categorized among four experimental groups: T1: control(uncoated), T2: edible coating alone, T3: edible coating supplement with 1% postbiotics and T4: edible coating supplement with 2% postbiotics. All samples were refrigerated condition ($4 \pm 1^\circ\text{C}$) for three weeks during which physiochemical, microbial and sensory acceptability were assessed at regular intervals. Beef samples treated with edible coating postbiotics prove effective in significantly reducing quality deterioration in beef quality retention over the entire storage period. Compared with control group and treated sample showed inhibited microbial development, minimized level of lipid oxidation, greater color stability and superior sensory score. The results further indicated that among the tested treatments coating supplemented with 2% postbiotics showed the highest level of microbial inhibition and better retention of quality attributes than those other treatments. At 21 days, this treatment had lower total viable counts the TBARS, values (0.70 versus 2.34 mg MDA/kg), the TVB-N values (17.8 versus 35.3 mg N/100 g), and, (5.34 versus 9.04 $\log_{10}$ CFU/g) than the control, and was more acceptable sensorially (6.4 versus 1.7 on a nine-point scale). A notable increase in shelf-life extension approximately 1to 2 weeks compared with control group. Based on the present results, postbiotic-fortified edible coating can effectively improve the storage stability of refrigerated beef meat and represent a promising potion for replacing synthetic preservative in meat industry.

1. Introduction

Beef holds a significant place among sources of animal protein, as it is contain abundant nutrients including vitamins, essential minerals and amino acids, , and vital that support human health and well-being. It also plays a clear role in achieving food security and fostering economic growth in many countries. Despite these benefits, a major drawback is its rapid spoilage; this deterioration is attributed to high water and moisture content, as well as an abundance of nutrients that create an ideal environment for microbial growth. This leads to rapid chemical changes that reduce the meat's quality and shelf life (Saucier, 2016). Immediately after the slaughter of cattle, meat quality begins to deteriorate because microbial activity, physical, and chemical alterations. During refrigerated storage,

✉ *Corresponding author:
ola.dhahir@uobasrah.edu.iq (Ola D. Abdulaali)

the environment can become ideal for the growth of microorganisms that alter the properties, safety, and quality of meat manifesting as unpleasant odors and a color shift from red to brown because of oxidative rancidity along with rapid proteolysis. This leads to product spoilage, resulting in massive economic losses as consumers refrain from purchasing the affected products (Luong *et al.*, 2020). While various factors influence the organoleptic characteristics of meat products, aldehydes and ketones compounds responsible for the undesirable olfactory properties associated with oxidative rancidity are among the most significant (Geng *et al.*, 2023). A key challenge facing fresh, refrigerated beef is microbial spoilage, which becomes active and accumulates when a suitable growth environment is available. Microbial activity leads to the formation of a slimy layer on the meat surface and the release of unpleasant, undesirable olfactory properties that compromise product quality. As a result, edible coatings fortified with postbiotics have emerged as a promising technology for preserving meat product quality (Zhu *et al.*, 2024; Oh and Lee, 2024). Freezing, refrigeration, and vaporization are among the methods employed to extend the shelf life of meat products (Zhu *et al.*, 2024; Zhang *et al.*, 2022). Recently, consumer interest has shifted toward natural preservatives that pose no health risks and serve as effective alternatives to synthetic preservatives (Wen *et al.*, 2024). Edible coatings preserve product quality by acting as a protective barrier on the meat surface; this barrier inhibits vapor transmission, thereby retaining product moisture. Chitosan, along with sugars and lipids, is a key material used in the production of these coatings (Rastogi *et al.*, 2023). Chitosan inhibits biodegradation, while starch prevents moisture accumulation, collectively maintaining the product's quality and safety (Yuan *et al.*, 2016; Pateiro *et al.*, 2021). Therefore, this work aimed to address preservation challenges within the meat technology sector. To this end, a postbiotic-fortified edible coating was applied to refrigerated fresh beef to evaluate its effectiveness in prolonging preservation period and preserving product quality and safety against microbial spoilage.

2. Methodological Approach

2.1. Design of study

Fresh beef samples were obtained a few hours after slaughter from a local modern abattoir and stored at 4°C. Using the method described by Pateiro *et al.* (2021), Each sample was cut into 5-gram portions. They were randomly allocated to four treatments, with three replicates per treatment: T1 (control), T2 (treated with an edible coating only), and two groups treated with an edible coating fortified with postbiotics at two different concentrations 1%, 2% for T3, T4 respectively. The specimens were kept at 4°C for 21 days and analyzed on days 0, 4, 9, 14, and 21.

2.2. Postbiotic preparation

. A *Lactobacillus plantarum* isolate was obtained from local dairy products and identified; the isolate was maintained in the laboratory for the purpose of preparing a postbiotic. Following genetic analysis to ensure the selection of an active isolate, the culture was exposed to (MRS) growth medium and supplemented with at 37°C for 24 h. Subsequently, the culture was spun at $10,000 \times g$ at 4 ± 1 °C for 15 min, and the supernatant underwent filtration. Finally, the filtrate was freeze-dried to obtain the postbiotic powder (Aguilar-Toalá *et al.*, 2018).

2.3 Polymeric coating solution Preparation

Chitosan 2%, was dissolved in 1% ethanoic acid and stirred continuously for 4 hours; subsequently, 5% glycerol was added to the solution, yielding the polymeric coating solution (Hoa *et al.*, 2022). The solution was then divided into three parts: the first T2 consisted solely of chitosan, while the remaining parts T3 and T4 were fortified with postbiotic powder at concentrations of 1% and 2%, respectively. Finally, a mechanical homogenizer was used at 10,000 rpm for 5 minutes to homogenize the active coating ingredients.

2.4. Application of edible coating

Beef samples were treated by immersion over a 2 min period, then allowed the drain for 2 min to remove excess coating, and subsequently exposed to sterile air for half an hour to dry prior to packaging (Vital *et al.*, 2016).

2.5. Storage conditions and sampling interval

After coating, the beef samples were individually packaged in sterile trays covered with oxygen-permeable film and held in refrigerated chamber for preservation period. Physical, chemical, microbiological, sensory characteristics were assessed at scheduled intervals: days 0, 4, 9, 14 and 21.

2.6. Physiochemical quality assessment

2.6.1. Acidity (pH) measrement

Acidity pH measurement underwent performed utilizing a calibrated electronic pH measuring instrument, reported by the standard methodology recommended by the AOAC (2019).

2.6.2. Water Holding Capacity Measurement

Water-holding capacity was assessed via the press method using filter paper described by szmańko, *et al.* (2021).

2.6.3. Color Assessment

Samples color was measured with a Minolta Colorimeter, and chromatic values were recorded according to the CIE Lab color system, where Lightness value (indicating brightness), the a* describing the red- to- green color coordinate spectrum and the yellowness- blueness(b*). (Mancini, & Hunt, 2005)

2.6.4. Assessment of lipid peroxidation

Oxidation of the lipid in specimens was analyzed using the TBA assay reagent-, and TBARS values were exposed as mg MDA/ kg beef. (Botsoglou *etal*,1994)

2.6.5. Assessment of total violate basic nitrogen

Protein degradation was assessed by measured (TVB-N) levels were expressed as mg N per100 g beef. (Ruiz & Moral, 2001).

2.7. Microbiological evaluation

The samples underwent a series of microbiological analyses, including the determination of Total Viable Count, along with counts of cold tolerant microbial population, lactic acid bacteria, and yeasts and molds. Data were reported as $\log_{10}$ CFU/gm (Sallam, 2007).

2.8. Analysis of sensory properties

Sensory properties of samples was evaluated by qualified of 10 panelists, covering a nine point Hedonic scale was used to assess texture, aroma , color and overall acceptability(Stone, etal,2020).

2.9. Data Analysis

IBM SPSS statistics (version 24.0) served as to analyze the data. One-way and two-way ANOVA were employed to analyze variance and examine the effects of various factors and treatments. Variation between experimental groups estimated mean were measured with Duncan's post hoc test at the 5% significance level. (Montgomery,2020).

3. Results

Table (1) shows that the untreated group (T1) observed the most evaluated increase in pH over the storage period; conversely, treatment (T4) which involved a 2% postbiotic concentration recorded the lowest pH values at the final storage interval. The results in table (2) indicate that the control treatment (T1) experienced the greatest decline in meat water-holding capacity, whereas treatment (T4) (using 2% postbiotic) recorded the highest level of water-holding capacity. Regarding oxidation levels, the control treatment (T1) exhibited the highest oxidation values (based on TBARS); in contrast, treatments utilizing edible coatings demonstrated a reduction in this increase. In table 3, treatment T4, supplemented with a 2% concentration of postbiotics, exhibited the lowest TBARS values, indicating greater effectiveness in inhibiting oxidative rancidity compared to the control treatment. The finding indicted in table (4) demonstrate TVB-N values which reflect the extent of protein degradation and meat freshness showing that the untreated group (T1) observed the most evaluated across all storage interval, reaching 35.3 mg N/100 g on day 21. In contrast, the T4 treatment (2% postbiotic concentration) recorded the lowest TVB-N values, representing the best result compared to the control treatment (T1). The control treatment showed a marked increase in bacterial counts, whereas the T4 treatment (2% postbiotic) recorded the lowest bacterial count (Tables 5 and 6). Table 7 shows that the control treatment yielded the highest value for yeasts and molds, while the T4 treatment (2% postbiotic) yielded the lowest. Table 8 indicates that the untreated group (T1) showed the greatest decrease in redness (a^*) values. On the other hand, treatment T4, supplemented with a 2% concentration of postbiotics, exhibited the maximum value for red color stability in the meat compared to the control group.. The results in Table 9 showed the most rapid decline in the sensory evaluation of odor, with a score of 2.0 recorded on day 21 for the control treatment (T1); conversely, the T4 treatment (2% postbiotic) recorded the highest score (6.4) at the final point of the beef chilled conditions. In Table 10, the untreated group (T1) showed a decline in overall sensory acceptability from 7.6 on day 0 to 1.7 on day 21, whereas T4 (coating + 2% postbiotic) achieved the highest sensory acceptability throughout the storage period, recording 6.4 on day 21.

Table 1: Influence of postbiotic incorporated acidity of the coating formulation of beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	5.51±0.02	5.67±0.03 ^a	5.91±0.03 ^a	6.24±0.04 ^a	6.71±0.05 ^a
T2(coating)	5.50±0.01	5.59±0.02 ^b	5.77±0.02 ^b	5.99±0.04 ^b	6.31±0.05 ^b
T3(coating+1% postbiotic)	5.49±0.01	5.54±0.02 ^c	5.65±0.02 ^c	5.81±0.03 ^c	5.94±0.04 ^c
T4(coating+2% postbiotic)	5.50±0.00	5.51±0.01 ^d	5.59±0.02 ^d	5.69±0.03 ^d	5.79±0.03 ^d

The lowercase letters above the numbers indicate the presence of significant differences.

Table 2: Impact of postbiotic incorporated edible coating on Water Holding Capacity % of beef d within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	71.2±1.0 ^a	68.6±1.1 ^c	65.3±1.3 ^d	60.1±1.6 ^d	55.0±0.0 ^d
T2(coating)	71.4±0.09 ^a	70.0±0.09 ^b	68.5±1.1 ^c	66.2±1.3 ^c	63.0±1.4 ^c
T3(coating+1% postbiotic)	71.6±0.09 ^a	71.0±0.08 ^{ab}	70.0±0.09 ^b	68.6±1.1 ^b	67.2±1.2 ^b
T4(coating+2% postbiotic)	71.5±0.09 ^a	71.2±0.07 ^a	71.0±0.08 ^a	70.2±1.0 ^a	69.4±1.1 ^a

The lowercase letters above the numbers indicate the presence of significant differences.

Table 3: Influence of postbiotic incorporated food grade coating on TBARS level, presented as mg MDA per kg beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	0.19±0.02 ^a	0.40±0.01 ^a	0.77±0.02 ^a	1.41±0.03 ^a	2.34±0.07 ^a
T2(coating)	0.19±0.02 ^a	0.31±0.01 ^b	0.58±0.03 ^b	0.94±0.02 ^b	1.61±0.05 ^b
T3(coating+1% postbiotic)	0.19±0.03 ^a	0.23±0.02 ^c	0.40±0.02 ^c	0.67±0.02 ^c	1.04±0.04 ^c
T4(coating+2% postbiotic)	0.19±0.02 ^a	0.17±0.00 ^d	0.28±0.00 ^d	0.48±0.01 ^d	0.70±0.02 ^d

The lowercase letters above the numbers indicate the presence of significant differences.

Table 4: Influence of postbiotic incorporated edible coating on TVB-N result, reported as mg N per 100 g beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	7.3±0.2 ^a	10.4±0.3 ^a	16.1±0.4 ^a	24.7±0.7 ^a	35.3±1.0 ^a
T2(coating)	7.3±0.1 ^a	9.5±0.2 ^b	13.6±0.2 ^b	19.3±0.6 ^b	27.5±0.8 ^b
T3(coating+1% postbiotic)	7.3±0.1 ^a	8.7±0.2 ^c	11.5±0.3 ^c	15.7±0.4 ^c	21.4±0.6 ^c
T4(coating+2% postbiotic)	7.3±0.2 ^a	8.0±0.2 ^d	10.2±0.2 ^d	13.1±0.3 ^d	17.8±0.5 ^d

The lowercase letters above the numbers indicate the presence of significant differences.

Table 5: Influence of postbiotic incorporated edible coating total viable bacterial count ($\log_{10}$ CFU g^{-1}) of beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	3.14±0.07 a	4.69±0.09 a	6.04±0.11 a	7.81±0.14 a	9.04±0.17 a
T2(coating)	3.11±0.05 b	4.24±0.08 b	5.19±0.09 b	6.44±0.11 b	7.31±0.13 b
T3(coating+1% postbiotic)	3.10±0.05 c	3.84±0.07 c	4.64±0.08 c	5.51±0.09 c	6.07±0.11 c
T4(coating+2% postbiotic)	3.09±0.04 d	3.54±0.06 d	4.14±0.07 d	4.87±0.08 d	5.34±0.09 d

The lowercase letters above the numbers indicate the presence of significant differences.

Table 6: Influence of postbiotic incorporated edible coating on Psychotropic bacterial count ($\log_{10}$ CFU/g) of beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	2.84 ^a	4.11 ^a	5.69 ^a	7.14 ^a	8.43 ^a
T2(coating)	2.83 ^a	3.80 ^b	4.91 ^b	5.81 ^b	6.77 ^b
T3(coating+1% postbiotic)	2.82 ^a	3.47 ^c	4.21 ^c	4.84 ^c	5.51 ^c
T4(coating+2% postbiotic)	2.81 ^a	3.17 ^d	3.78 ^d	4.17 ^d	4.64 ^d

The lowercase letters above the numbers indicate the presence of significant differences.

Table 7: Influence of postbiotic incorporated edible coating on Fungal counts ($\log_{10}$ CFU/gm) of beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	1.71 ^a	2.54 ^a	3.71 ^a	4.81 ^a	6.04 ^a
T2(coating)	1.70 ^a	2.19 ^b	3.04 ^b	3.91 ^b	4.84 ^b
T3(coating+1% postbiotic)	1.70 ^a	1.99 ^c	2.59 ^c	3.14 ^c	3.77 ^c
T4(coating+2% postbiotic)	1.69 ^a	1.84 ^d	2.19 ^d	2.64 ^d	3.01 ^d

The lowercase letters above the numbers indicate the presence of significant differences.

Table 8: Influence of postbiotic incorporated edible coating on Redness (a*) values of beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	17.3	16.0	14.3	12.1	9.7
T2(coating)	17.4	16.7	15.8	14.4	12.7
T3(coating+1% postbiotic)	17.5	17.0	16.4	15.7	14.8

T4(coating+2% postbiotic	17.4	17.1	16.8	16.3	15.7
-----------------------------	------	------	------	------	------

Table 9: Influence of postbiotic incorporated edible coating on Odor sensory scores of beef within refrigerated preservation

Group/preservation Day	0	4	9	14	21
T1(control)	7.7	7.1	6.0	4.1	2.0
T2(coating)	7.7	7.3	6.7	5.8	4.7
T3(coating+1% postbiotic	7.7	7.5	7.1	6.7	6.0
T4(coating+2% postbiotic	7.7	7.6	7.3	7.0	6.4

(1 = Extremely poor ,9 = Excellent)

Table 10: Overall Sensory Acceptability

Group/preservation Day	0	4	9	14	21
T1(control)	7.6	7.0	5.7	3.8	1.7
T2(coating)	7.6	7.2	6.6	5.7	4.3
T3(coating+1% postbiotic	7.7	7.4	7.0	6.5	5.7
T4(coating+2% postbiotic	7.7	7.5	7.2	6.8	6.4

4. Discussion

Table (1) illustrates the effect of applying postbiotic-fortified edible coatings to refrigerated beef over time across various experimental treatments. The data reveal a significant effect ($P \leq 0.05$) of the postbiotic addition on pH levels; specifically, treatment T4 (containing 2% postbiotic) recorded the lowest pH values, whereas the control group (T1) recorded the highest. The elevated pH values in the control group (T1) may be attributed to microbial proteolysis, which results in the release of ammonia (Nychas *et al.*, 2007). Conversely, the lower pH values observed in refrigerated meat treated with postbiotics may be attributed to the presence of bacteriocins within the postbiotics; these act as inhibitors of microbial growth, thereby slowing the spoilage process of the stored meat. This result aligns with the findings of Żółkiewicz *et al.* (2020), who indicated that the incorporation of postbiotics into edible coatings significantly affects pH levels by influencing microbial activity and inhibiting growth on refrigerated meat. Table (2) indicates a significant effect of applying edible coatings enriched with postbiotics on the water-holding capacity of meat stored under refrigeration for various durations. Treatment T4 (containing 2% postbiotics) exhibited the highest water-holding capacity values, whereas the control group showed the lowest. This increase in water-holding

capacity for treatment T4 is attributed to the formation of a protective barrier by the edible coating on the meat surface, which prevents the loss of water vapor. Conversely, the lower water-holding capacity in the control group is attributed to the denaturation of myofibrillar proteins, which impairs the meat's ability to retain water (Leygonie *et al.*, 2012). Table (3) demonstrates a significant effect ($P \leq 0.05$) of applying edible coatings on lipid oxidation values in refrigerated meat stored for varying durations. Treatment T4, supplemented with 2% postbiotic, recorded the lowest TBARS values, whereas the control treatment exhibited the highest. This reduction in the postbiotic-supplemented treatments is attributed to the formation of a protective barrier on the meat surface that restricts oxygen penetration, thereby preventing or minimizing oxidation; additionally, the presence of sugars and peptides within the postbiotic acts as an antioxidant (Houshmand *et al.*, 2024). Table (4) demonstrates a significant effect ($P \leq 0.05$) of using edible coatings on Total Volatile Basic Nitrogen (TVB-N) levels in chilled meat stored for varying periods. Treatment (T4), supplemented with 2% postbiotics, recorded the lowest TVB-N values, whereas the control treatment recorded the highest. This elevation in TVB-N values in the control treatment is attributed to ongoing microbial activity and proteolysis. This effect can be attributed to postbiotic metabolites that delay the microbial growth responsible for the spoilage of refrigerated meat (Kaynakci, 2025). Tables (5, 6, and 7) indicate a reduction in the counts of psychrophilic bacteria, total aerobic bacteria, yeasts, and molds—particularly in treatment T4—compared to the control group, which showed the opposite trend. This suggests the potential of using the edible coating to extend the shelf life of meat. The higher counts of total bacteria, psychrotrophs, yeasts, and molds in the control treatment can be attributed to the bacteriocins and hydrogen peroxide produced by lactic acid bacteria; these substances alter the microbial community and create an environment conducive to the growth of spoilage microorganisms, thereby reducing the meat's shelf life. (Trymers *et al.*, 2025). Regarding the effect of adding postbiotic-fortified edible coatings on the redness and color stability of refrigerated meat stored for various durations, the results in Table (8) indicate a significant effect ($P \leq 0.05$) of the postbiotic addition on this parameter. The highest values for redness and color stability were recorded in treatment T4 (supplemented with 2% postbiotic), whereas the lowest values were observed in the control treatment. The enhanced redness and color stability in treatment T4 (2% postbiotic) may be attributed to the antioxidant properties of the postbiotic, which inhibit meat oxidation and help maintain the red color. Regarding the effect of adding postbiotics to edible coatings on sensory evaluation scores, the results presented in Tables 9 and 10 showed a marked increase associated with the addition of postbiotics in the treatments containing edible coatings. The highest sensory evaluation score was recorded for treatment T4 (containing 2% postbiotics), whereas the lowest score for this attribute was observed in the control treatment. This may be attributed to the effective role of the postbiotic and the edible coating in inhibiting microbial growth and retarding oxidation, thereby helping to preserve desirable sensory attributes throughout the storage period. These findings are consistent with those reported in (Kaynakci, 2025). The findings of this research paper indicate that the notable improvement in meat preservation stems from the synergistic effect and complementary roles of postbiotics and edible coatings in mitigating spoilage and maintaining quality. Postbiotics provide antioxidant properties that inhibit meat deterioration, while the edible coating acts as a protective barrier preventing oxygen from reaching the meat surface and reducing moisture loss; consequently, meat quality is preserved, and spoilage rates during storage are minimized. Overall, the results of this research paper indicate that postbiotic-

fortified edible coatings effectively contributed to mitigating physical, chemical, and microbiological changes while preserving the product's sensory characteristics throughout the storage period.

5. Conclusion

Edible coatings incorporated with postbiotic enhanced quality retention of the beef during the refrigerated storage at $4 \pm 1^\circ\text{C}$ for 3 weeks. In the presence of the coatings, and the postbiotic were found to be more effective in retarding microbial growth, TVB-N production and lipid peroxidation while more effectively preserving water holding capacity, sensory scores and redness compared to the uncoated control and coating alone. The best performance of all the treatments was observed with the coating containing 2% postbiotics. Thus, these results indicate that postbiotic enriched edible coatings can be considered as a natural preservation approach for chilled beef. Additional studies are required to demonstrate shelf-life extension through defined sensory and microbiological acceptance criteria, and to assess effectiveness.

References

- Saucier (2016).** Microbial spoilage, quality and safety within the context of meat sustainability. *Meat Sci*, 120,78-84. <https://doi.org/10.1016/j.meatsci.2016.04.027>
- Luong, N. D. M., Coroller, L., Zagorec, M., Membré, J.-M., and Guillou, S. (2020).** Spoilage of chilled fresh meat products during storage: A quantitative analysis of literature data. *microorganisms*, 8(8), 1198. <https://doi.org/10.3390/microorganisms8081198>
- Geng, L., Liu, K., and ,Zhang,H,(2023).**lipid oxidation in foods and implications on proteins,*Frontiers in Nutrition*,10,1192199. <https://doi.org/10.3389/fnut.2023.1192199>
- Zhu,Y., Gu, M.,Su, Y., U,Z.,Xiao, Z.,Lu,F.,and Han,C(2024).** Recent advances in spoilage mechanisms and preservation technologies in beef quality:a review. *Meat Sci*,213,109481. <https://doi.org/10.1016/j.meatsci.2024.109481>
- Oh,H. and Lee,J.(2024).**Sychrotrophic bacteria threatening the safty from animals derived foods characteristics, contamination and control strategies.*Food Sci, of Anim.,Res.* 44(5),1011-1027. <https://doi.org/10.5851/kosfa.2024.e70>
- Wen, L., He, H., Liu, Y., Wang, W., Du, P., Hu, P., Cao, J., & Ma, Y. (2024).** research progress on natural preservatives of meat and meat products: Classifications, mechanisms and applications. *Journal of the Science of Food and Agriculture*, 104(14), 7085–7095. <https://doi.org/10.1002/jsfa.13495>
- Rastogi, M.,(2023).**recent advance in edible coating and their application in food packaging. *Food Res. Int.*,173=113366 <https://doi.org/10.3390/foods10040748>
- Pateiro, M., Gómez, B., Munekata, P.E.S. and Lorenzo, J.M. (2021).** Preservation of fresh meat using edible coatings and films. *Foods*, 10, 748. <https://doi.org/10.3390/foods10040748>
- Aguilar-Toalá, J. E., Garcia-Varela, R., Garcia, H. S., Mata-Haro, V., González-Córdova, A. F., Vallejo-Cordoba, B., & Hernández-Mendoza, A. (2018).** Postbiotics: An evolving term within

the functional foods field. *Trends in Food Science & Technology*, 75, 105–114.
<https://doi.org/10.1016/j.tifs.2018.03.009>

Hoa, V.-B., Song, D.-H., Seol, K.-H., Kang, S.-M., Kim, H.-W., Kim, J.-H., Moon, S.-S., & Cho, S.-H. (2022). Application of a Newly Developed Chitosan/Oleic Acid Edible Coating for Extending Shelf-Life of Fresh Pork. *Foods*, 11(13), 1978. <https://doi.org/10.3390/foods11131978>

Vital, A. C. P., Guerrero, A., Monteschio, J. O., Valero, M. V., Carvalho, C. B., Abreu Filho, B. A., Madrona, G. S., & Prado, I. N. (2016). Effect of Edible and Active Coating (with Rosemary and Oregano Essential Oils) on Beef Characteristics and Consumer Acceptability. *PLOS ONE*, 11(8), e0160535.

<https://doi.org/10.1371/journal.pone.016053>

AOAC International. (2019). official methods of analysis of AOAC International (21st ed.). Gaithersburg, MD, USA: AOAC International.

Szmańko, T., Lesiów, T., & Górecka, J. (2021). The water-holding capacity of meat: A reference analytical method. *Food Chemistry*, 357, 129727.
<https://doi.org/10.1016/j.foodchem.2021.129727>

Mancini, R. A., & Hunt, M. C. (2005). Current research in meat color. *Meat Science*, 71(1), 100–121. DOI: <https://doi.org/10.1016/j.meatsci.2005.03.003>

Botsoglou, N. A., Fletouris, D. J., Papageorgiou, G. E., Vassilopoulos, V. N., Mantis, A. J., & Trakatellis, A. G. (1994). Rapid, sensitive, and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissues, food, and feedstuff samples. *Journal of Agricultural and Food Chemistry*, 42(9), 1931–1937. <https://doi.org/10.1021/jf00045a019>

Ruiz-Capillas, C., & Moral, A. (2001). Correlation between biochemical and sensory quality indices in hake stored in ice. *Food Research International*, 34(5), 441–447.
[https://doi.org/10.1016/S0963-9969\(00\)00189-7](https://doi.org/10.1016/S0963-9969(00)00189-7)

Sallam, K. I. (2007). Antimicrobial and antioxidant effects of sodium acetate, sodium lactate, and sodium citrate in refrigerated sliced salmon. *Food Control*, 18(5), 566–575. DOI: <https://doi.org/10.1016/j.foodcont.2006.02.002>

Stone, Herbert, Sidel, Joel L., Bleibaum, Renée N., & Thomas, Heather A. (2020). Sensory Evaluation Practices (5th ed.). Academic Press. DOI: <https://doi.org/10.1016/C2015-0-01266-8>

Montgomery, Douglas C. (2020). Design and Analysis of Experiments (10th ed.). Wiley.
<https://doi.org/10.1002/9781119722106>

Koutsoumanis, K. P. (2008). Meat spoilage during distribution. *Meat Science*, 78(1–2), 77–89.
<https://doi.org/10.1016/j.meatsci.2007.06.020>

Żółkiewicz, J., Marzec, A., Ruszczyński, M., & Feleszko, W. (2020). Postbiotics—A step beyond pre- and probiotics. *Nutrients*, 12(8), 2189. <https://doi.org/10.3390/nu12082189>

Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Science*, 91(2), 93–98. DOI: <https://doi.org/10.1016/j.meatsci.2012.01.013>

- Houshmand Sharafi, H., Divsalar, E., Rezaei, Z., Liu, S.-Q., & Moradi, M. (2024).** The potential of postbiotics as a novel approach in food packaging and biopreservation: A systematic review of the latest developments. *Critical Reviews in Food Science and Nutrition*, 64(33), 12524–12554. <https://doi.org/10.1080/10408398.2023.2253909>
- Kaynakci, E. C. (2025).** Evaluation of alginate-based coatings enriched with postbiotics from *Bifidobacterium* spp. on the quality and safety of Turkey meat. *Scientific Reports*, 15, 23634. <https://doi.org/10.1038/s41598-025-09913-z>
- Trymers, M., Wiśniewski, P., Tkacz, K., & Zakrzewski, A. (2025).** From Production to Application: Postbiotics in Meat, Meat Products, Other Food Matrices, and Bioactive Packaging. *Foods*, 14(21), 3598. <https://doi.org/10.3390/foods14213598>
- Su, L., Zhao, Z., Xia, J., Xia, J., Nian, Y., Shan, K., Zhao, D., He, H., & Li, C. (2024).** Protecting meat color: The interplay of betanin red and myoglobin through antioxidation and coloration. *Food Chemistry*, 442, <https://doi.org/10.1016/j.foodchem.2024.138410>
- Kaynakci, E. C. (2025).** Evaluation of alginate-based coatings enriched with postbiotics from *Bifidobacterium* spp. on the quality and safety of turkey meat. *Scientific Reports*, 15, 23634. <https://doi.org/10.1038/s41598-025-09913-z>