



Short Paper

Feasibility of biodegradable bags for vacuum-packaging of beef: a small-scale study

Machbarkeit des Einsatzes biologisch abbaubarer Beutel zur Vakuumverpackung von Rindfleisch: eine Studie im Kleinmaßstab

Fattibilità dell'impiego di sacchetti biodegradabili per il confezionamento sottovuoto della carne di manzo: uno studio su piccola scala

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ABSTRACT

The growing demand for environmentally sustainable food packaging has stimulated interest in biodegradable alternatives to conventional materials, not only at an industrial level but also for small-scale craft productions. This pilot study evaluated the feasibility of using biodegradable and compostable poly-butylene adipate-coterephthalate (PBAT)-based vacuum bags as an alternative to standard polyamide/polyethylene (PA/PE) bags for fresh beef packaging under artisanal conditions. Beef steaks were vacuum-packed, stored at 4 °C for 11 days, and packaging performance was evaluated over time through measurements of pH, water activity, drip loss, microbiological quality, and color of meat. Overall, biodegradable bags showed similar performances to those of PA/PE throughout storage. No relevant differences were observed concerning all parameters under investigation, indicating that the biodegradable packaging adequately preserved the quality of meat under the experimental conditions tested. Results support the feasibility of PBAT-based bags for vacuum-packaging of beef steaks in small-scale production systems.

KEYWORDS

Biodegradable packaging, PBAT, fresh meat, shelf life, sustainability, artisanal meat production

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INTRODUCTION

Food packaging plays a fundamental role in preserving product quality and safety by protecting foods against physical damage, chemical deterioration, moisture loss, and microbial contamination throughout storage and distribution [1] [2]. In fresh meat, packaging is particularly important because meat provides an ideal environment for microbial growth and is highly susceptible to quality deterioration, including color changes, lipid oxidation, off-flavour development, and spoilage processes that ultimately limit shelf life [3] [4] [5]. Consequently, vacuum packaging and modified-atmosphere packaging (MAP) have become widely adopted technologies for preserving fresh meat quality and extending storage stability [3] [6].

Conventional fossil-fuel-based plastic polymers are widely used for food packaging, due to their high performance in terms of mechanical properties, barrier protection, flexibility, and low production costs [7]. Nevertheless, despite the advantages, their persistence in the environment raises concern. The food packaging industry accounts for the largest volume of plastic packaging materials used globally [8], contributing significantly to environmental plastic pollution [9]. There is a growing awareness of these issues within the broader context of the bioeconomy, which aims to reduce waste, seek more sustainable consumption patterns and reduce CO₂ emissions [10]. This has likely promoted the development of bio-based and biodegradable alternatives in the food packaging sector.

Demand for sustainable food systems has increased significantly, and consumers associate eco-friendly packaging with reusability, recyclability, and biodegradability [11], generally perceiving it as a mark of higher food quality, especially in foods regarded as healthy [12]. Studies have reported that consumers are willing to pay a premium for sustainable packaging solutions, probably because of the association between sustain-

ability and quality [12] [13]. However, there are still some significant limitations: production costs are generally higher than those of conventional plastics, while the environmental benefits depend on the existence of adequate waste management infrastructure and on ensuring that the product's preservation is comparable to that achieved with standard packaging. Indeed, sustainability assessments have highlighted that the environmental benefits associated with biodegradable materials may be offset if packaging performance leads to increased food losses through reduced shelf life [14]. Therefore, the functionality of biodegradable packaging materials must be assessed alongside their environmental advantages.

Even in the sector of small-scale artisan food production, there is a growing focus on sustainability, particularly given that packaging labelled as sustainable is associated by consumers with quality and naturalness [12] [15]. Differently from industrial packaging settings, local farmers and small meat processors frequently rely on manual operations and domestic or semi-professional packaging equipment; furthermore, the environmental conditions may differ from industrial ones. Studies conducted in real-world processing environments have shown that microbial contamination and spoilage dynamics are strongly influenced by handling practices and surrounding environmental conditions, with spoilage-associated microbiota being closely linked to processing environments [5]. This highlights the importance of evaluating packaging systems under practical production conditions.

The selection of biodegradable packaging requires consideration of its suitability for the intended application, its availability, and its environmental impact. As comprehensively reviewed by Siddiqui et al. [8], the main biodegradable alternatives to conventional plastics investigated for the packaging of fresh and processed meat products include polysaccharide-based materials, such as cellulose, starch, and chi-

tosan; as well as protein-based materials, including collagen, gelatin, wheat gluten, and soy proteins; and biodegradable polyesters, such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), polycaprolactone (PCL), polybutylene succinate (PBS), polybutylene succinate adipate (PBSA), and polybutylene adipate-coterephthalate (PBAT). However, some of these materials may present limited mechanical and barrier properties, which may require improvement through blending, crosslinking, or the incorporation of reinforcing fillers. Among these PBAT-based bags were chosen because, despite being PBAT a fossil fuel-based copolyester, it is of particular interest for meat packaging due to its high flexibility, excellent mechanical performance, and compostability [16] [17].

In this context, the objective of the study was to evaluate the feasibility of using biodegradable PBAT-based vacuum bags as an alternative to conventional PA/PE ones under condition designed to simulate those found in a small-scale production setting. To simulate the operating conditions typically encountered by small farms and artisanal meat processors, beef steaks were manually prepared and vacuum-packaged using a professional manual vacuum-sealing machine. The performance of biodegradable and conventional packaging systems was compared over 11 days of refrigerated storage at 4 °C through the assessment of physicochemical parameters (pH, water activity, and drip loss), microbiological counts, and instrumental color characteristics. The study aimed to provide preliminary evidence regarding the suitability of biodegradable vacuum packaging for small-scale meat production systems and to identify potential limitations affecting its practical adoption.

MATERIALS AND METHODS

PACKAGING MATERIALS

The packaging materials used in this study consisted of two vacuum packaging systems: a conven-

tional multilayer polyamide/polyethylene system (VP) and a biodegradable PBAT-based system (BioVP). The conventional packaging consisted of transparent PA/PE side-seal vacuum pouches manufactured by allfo GmbH & Co. KG (Waltenhofen, Germany), with a nominal film thickness of 90 µm and a tolerance of ±10%. The biodegradable packaging consisted of PBAT-based vacuum pouches supplied by VAMA Maschinenbau GmbH (Wildpoldsried, Germany), with a nominal film thickness of 75 µm. Both packaging systems were purchased through a local retailer. The main barrier properties relevant to meat preservation, including oxygen transmission rate (OTR), water vapor transmission rate (WVTR), and temperature range for use, are summarized in table 1. Values were obtained from the manufacturers' technical documentation.

SAMPLE PREPARATION AND MEASUREMENT

The sirloin tip beef cut was purchased from a local butcher shop (Macelleria Matha, Bolzano, Italy) and cut with a meat slicer (GL 30, Van Berkel International S.r.l., Italy) into 15 slices approximately 1 cm thick. Slices were taken from the whole cut and allocated among the experimental groups so that each group included portions from different anatomical positions, thereby reducing variability related to heterogeneity within muscles. Three slices were analyzed immediately after cutting, considered as time-point 0 (T0). The remaining 12 slices were assigned to two packaging treatments (six to VP, and six to

BioVP).

Vacuum packaging was performed using a professional chamber vacuum-sealing machine (Komet Modell Plus Vac 23) under identical operating conditions for both packaging systems. All packaged samples were stored at 4 °C. Three samples from each packaging condition were analyzed after 4 days (T1) and after 11 days (T2).

At each time-point, pH, water activity (aw), drip loss, instrumental color, photos collection and microbiological quality were assessed.

PH, AW, AND DRIP LOSS

The pH of the meat was measured on each steak at each sampling time using a penetration pH meter (PHT 810, Ebro, Ingolstadt, Germany), after calibration with a buffer solution at pH of 4.01 and 7.00.

Aw was measured at each sampling time using an AQUALAB water activity meter (Addium Inc., Pullman, WA, USA). Several portions were collected from different areas of each steak and finely minced with a knife to obtain a representative composite sample. The minced meat was then transferred into an AQUALAB sample cup and analysed, after instrument calibration.

Drip loss was determined gravimetrically for samples stored until T1 and T2. Each steak was weighed immediately before vacuum packaging and again after storage. Drip loss was expressed as the percentage weight loss relative to the initial sample weight and calculated as follows:

Drip loss (%) = [(initial weight – final weight) / initial weight] x 100.

COLOR ASSESSMENT AND IMAGE ACQUISITION

Images were acquired using a digital camera (EOS 850D, Canon Inc., Japan) equipped with an EF-S 18-135 mm lens and operated in manual exposure mode. Acquisition settings were: exposure time 1/100 s, aperture f/6.3, ISO 125, focal length 18 mm, and automatic white balance. The flash was disabled. Samples were photographed inside a photo box equipped with integrated LED lighting to provide diffuse and uniform illumination. The distance between the camera lens and the sample surface was fixed at 44 cm.

Instrumental color was measured directly on the surface of each steak using a portable colorimeter (Chroma Meter CR-400, Konica Minolta, Tokyo, Japan). Color was expressed according to the CIE L*a*b* system, where L* represents lightness, a* the red-green coordinate, and b* the yellow-blue coordinate.

At each sampling time, a minimum of 15 measurements were taken evenly across the exposed meat surface to account for color heterogeneity. Mean L*, a*, and b* values were calculated for each steak.

The mean color coordinates of the three T0 steaks were used as a common color starting point. The total color difference was calculated comparing T0 with T1 and T2 according to the following equation:

$$\Delta E_{ab}^* = \left[(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2 \right]^{1/2}$$

Tab. 1: Main barrier properties of the vacuum packaging materials.

Packaging type	Material	Thickness [µm]	OTR [cm ³ /(m ² ·24 h·bar)]	WVTR [g/(m ² ·24 h)]	Temperature range for use [°C]
VP	PA/PE	90	≤56 at 50% RH; ≤80 at 75% RH	≤3 at 85% RH	-25 to +70
BioVP	PBAT-based	75	1.46	19.65	-25 to +90

For VP, OTR values were calculated based on tests according to ISO 15105-2/DIN 53380-3. For VP, WVTR values were calculated based on tests according to ISO 15106-2/DIN 5312. Test methods for BioVP were not reported in the available technical documentation.

Tab. 2: pH, aw, drip loss % and microbial counts of sample during refrigerated storage (4 °C).

Packaging	Timepoints	Microbial counts (log10 CFU/g $\pm$ SD), pH and aw during storage							
		pH	aw	Mesophilic	Psychrotrophic	LAB	<i>Staphylococcus</i> and <i>Micrococcus</i> spp.	Enterobacteriaceae	Yeast/molds
VP/BioVP	0	5.65 $\pm$ 0.02 a	1.000 $\pm$ 0.005 a	5.49 $\pm$ 0.33 a	5.97 $\pm$ 0.29 a	3.45 $\pm$ 0.21 a	3.18 $\pm$ 0.02 a	2.52 $\pm$ 0.01 a	1.42 $\pm$ 0.39 a
VP	1	5.57 $\pm$ 0.01 a	0.991 $\pm$ 0.003 b	6.63 $\pm$ 0.21 b	7.66 $\pm$ 0.21 b	4.71 $\pm$ 0.05 b	3.38 $\pm$ 0.70 a	3.24 $\pm$ 0.67 ab	1.49 $\pm$ 0.60 a
BioVP	1	5.57 $\pm$ 0.02 a	0.991 $\pm$ 0.003 b	6.57 $\pm$ 0.40 b	7.39 $\pm$ 0.43 b	4.63 $\pm$ 0.29 b	3.02 $\pm$ 0.35 a	3.44 $\pm$ 0.74 ab	0.93 $\pm$ 0.89 a
VP	2	5.28 $\pm$ 0.06 b	0.988 $\pm$ 0.002 b	7.92 $\pm$ 0.37 c	7.91 $\pm$ 0.27 b	7.35 $\pm$ 0.09 c	3.04 $\pm$ 0.49 a	4.65 $\pm$ 0.34 b	1.36 $\pm$ 0.39 a
BioVP	2	5.31 $\pm$ 0.06 b	0.991 $\pm$ 0.003 b	8.06 $\pm$ 0.01 c	7.99 $\pm$ 0.09 b	7.47 $\pm$ 0.07 c	3.58 $\pm$ 0.37 a	4.48 $\pm$ 0.30 b	1.59 $\pm$ 0.11 a

*Different letters (a-c) within the same column indicate statistically significant differences between time points ($p < 0.05$).

a $\neq$ b - statistically significant difference (sd = $p < 0.05$)

ab - no significant difference (ns)

MICROBIOLOGICAL ANALYSES

Meat samples were aseptically collected and analyzed according to ISO 4833-1:2013. Results were expressed as log₁₀ CFU/g. All analyses were performed in triplicate (one sampling for each steak). Ten grams of sample were collected from different points of the beef steak and transferred into sterile bags containing 90 mL of sterile saline solution (0.85% NaCl, 0.1% peptone). Samples were homogenized for 2 min using a stomacher (BagMixer® 400, P, Inter-science, Saint Nom la Breteche, France). The homogenate was serially diluted in the same saline solution, and appropriate dilutions were plated.

Total mesophilic and psychrotrophic aerobic bacteria were enumerated on Plate Count Agar (PCA) after incubation at 30 °C for 72 h and 7 °C for 10 days, respectively. Lactic acid bacteria (LAB) were enumerated on de Man, Rogosa and Sharpe (MRS) agar, after incubation under anaerobic conditions at 30 °C for 72 h. Enterobacteriaceae were enumerated on Violet Red Bile Glucose Agar (VRBGA) after incubation at 30 °C

for 48 h. *Staphylococcus* spp. and *Micrococcus* spp. were enumerated on Mannitol Salt Agar (MSA) after incubation at 30 °C for 72 h. Yeasts and molds were enumerated on Rose Bengal agar at 20 °C for 5 days.

STATISTICAL ANALYSIS

All experimental data, including plate counts, aw, pH, drip loss, and colorimetric measurements, were analysed using IBM SPSS Statistics for Windows, Version 29.0.1.0 (IBM Corp., Armonk, NY, USA). A one-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) post hoc test for multiple comparisons was applied for the comparison of the three time-points. Student's t-test for independent samples was applied for the comparison of the two packaging conditions. Differences were considered statistically significant at $p < 0.05$.

RESULTS

PHYSICO-CHEMICAL AND MICROBIOLOGICAL ANALYSES

Values of pH, aw, drip loss, and microbial counts for samples stored under VP and BioVP are reported in table 2.

The initial pH of the samples was on average 5.65 and remained stable after 4 days of storage in both packaging systems. A significant decrease in pH was observed at T2, reaching 5.28 ± 0.06 for VP and 5.31 ± 0.06 for BioVP.

Water activity slightly decreased during storage from an initial average value of 1.000 to values between 0.988 and 0.991 after 4 and 11 days. However, no significant differences were observed between T1 and T2 for both packaging systems. No significant differences between packaging systems were detected for either pH or aw at any time point. Drip loss did not exceed 2% over storage, with no significant differences between packaging systems or storage times ($p > 0.05$).

Microbial counts tended to increase over storage in both packaging systems. Total mesophilic bacteria

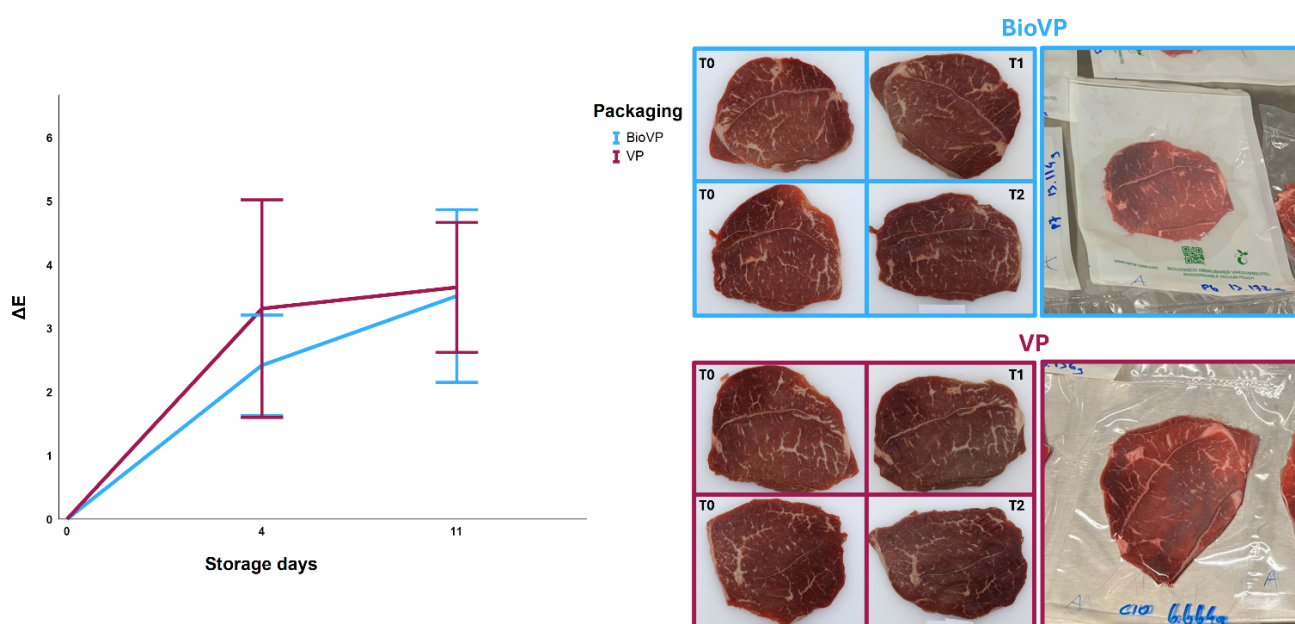


Fig. 1: Total color difference (ΔE) of beef steaks stored at 4 °C under two packaging conditions: bio-based vacuum packaging (BioVP) and conventional vacuum packaging (VP). Representative photographs show the samples before storage (T0) and after 4 (T1) and 11 days (T2) of storage, together with examples of steaks packaged in the two types of bags.

showed a significant increase from $5.49 \pm 0.33 \log_{10}$ CFU/g at T0 to approximately $6.6 \log_{10}$ CFU/g at T1, reaching $8.0 \log_{10}$ CFU/g at T2. Similarly, psychrotrophic bacteria increased significantly between T0 and T1, followed by no further significant changes between T1 and T2.

LAB exhibited a pronounced growth throughout storage, increasing from $3.45 \pm 0.21 \log_{10}$ CFU/g at T0 to values above $7.3 \log_{10}$ CFU/g at T2. Significant differences were observed between all-time points.

Enterobacteriaceae counts tended to increase during storage and was statistically significant only between T0 and T2. *Staphylococcus* spp. and *Micrococcus* spp. counts remained relatively stable during storage, with no significant differences between time points.

Yeasts and molds showed no significant changes over time in VP or BioVP samples, and no significative differences were observed between the two packaging systems at either storage time.

Overall, comparable trends in microbial dynamics were observed in both VP and BioVP systems throughout storage, indicating similar performance under the tested conditions.

COLORIMETRIC ANALYSIS AND VISUAL APPEARANCE OF SAMPLES

Figure 1 shows the changes in ΔE , representative images comparing the samples over storage for the two packaging systems, and pictures of samples packaged in the two types of bags. BioVP samples showed a trend to have lower ΔE

values than VP samples at both T1 (2.42 ± 0.79 vs. 3.31 ± 1.71) and T2 (3.51 ± 1.36 vs. 3.64 ± 1.02); however, these differences were not statistically significant ($p > 0.05$).

Table 3 reports the mean L^* , a^* , and b^* values for each experimental group.

Among the three color coordinates, a^* showed the greatest variation, decreasing during shelf life and indicating a progressive loss of redness.

Figure 1 also shows the clear visual difference between the two types of packaging.

DISCUSSION

INFLUENCE OF PACKAGING SYSTEM ON MICROBIAL ECOLOGY, PH, AW, DRIP LOSS, AND COLOR

In the present study, VP and BioVP showed similar microbial growth patterns, indicating that the packaging material had a slight influence on microbial development. The comparable microbial behaviour observed in both systems can be explained by the selective conditions created by vacuum packaging. It is well known that reduced oxygen availability, as occurs under VP and MAP conditions, inhibits aerobic spoilage organisms while allowing the growth of facultative anaerobes [18]. In most cases, this, combined with a low storage temperature, promotes a microbiome characterized by psychrotrophic bacteria, particularly LAB, which commonly become dominant during refrigerated storage [18] [19]. Consequently, the decrease in pH during storage is consistent with LAB

growth and organic acid production [19] [20].

Water activity remained high and did not differ significantly between treatments, suggesting that both packaging materials provided comparable barrier properties and storage conditions.

The mean ΔE values ranged from 2.42 to 3.64 and were therefore within a range that may be perceptible to the human eye [21]. However, a barely perceptible color difference does not necessarily imply lower consumer acceptability [22]. The representative photographs also showed broadly similar color changes in the two packaging systems, in agreement with the absence of significant differences in the instrumental measurements. These changes are characteristic of vacuum-packaged meat and are associated with the formation of deoxymyoglobin under low-oxygen conditions [3] [23] [24]. The absence of noticeable color differences further supports the comparable performance of both packaging systems. Nevertheless, the two materials used for packaging are clearly different in terms of their visual appearance (Fig. 1). This is due to the low transparency of PBAT which, together with its high production costs, represents a significant disadvantage for this material [25] [26].

Overall, the present findings are consistent with previous studies reporting similar preservation performance of biodegradable and conventional meat packaging systems [27] [28].

Tab. 3: Effect of packaging material and storage time on CIELAB color parameters and total color difference of beef slices.

Packaging	Time (days)	L^*	a^*	b^*
VP/BioVP	0	40.62 ± 2.52	19.58 ± 0.40	9.60 ± 0.79
VP	4	40.66 ± 2.01	17.12 ± 2.24	8.95 ± 0.76
BioVP	4	40.05 ± 2.10	18.48 ± 0.71	8.45 ± 0.45
VP	11	39.60 ± 1.64	17.08 ± 0.32	7.58 ± 1.05
BioVP	11	38.88 ± 1.84	18.20 ± 0.33	7.14 ± 0.52

CONCLUSION

The present study demonstrates that BioVP performs comparably to conventional VP during refrigerated storage of fresh beef. No significant differences were observed in microbial development, pH, drip loss, water activity, or color stability, indicating similar preservation performance between packaging sys-

tems.

Importantly, BioVP was successfully applied under conditions representative of small-scale meat production systems without negatively affecting product stability. In addition, biodegradable packaging may help address increasing consumer demand for more sustainable food systems. Although economic and waste-management challenges re-

main, the present findings indicate that BioVP represents a promising packaging option for small-scale and regional meat producers seeking to improve packaging sustainability while maintaining product quality and shelf life. Further studies involving larger sample size and economic analyses are needed to support their broader use in meat supply chain.

ZUSAMMENFASSUNG

Die steigende Nachfrage nach ökologisch nachhaltigen Lebensmittelverpackungen hat das Interesse an biologisch abbaubaren Alternativen zu herkömmlichen Materialien verstärkt, und zwar nicht nur auf industrieller Ebene, sondern auch für handwerkliche Kleinproduktionen. In dieser Pilotstudie wurde die Eignung biologisch abbaubarer und kompostierbarer Vakuumbbeutel auf Basis von Polybutylenadipat-co-terephthalat (PBAT) als Alternative zu herkömmlichen Polyamid/Polyethylen-Beuteln (PA/PE) für die Verpackung von frischem Rindfleisch unter handwerklichen Bedingungen untersucht. Die Rindersteaks wurden vakuumverpackt und 11 Tage lang bei 4 °C gelagert. Die Leistung der Verpackungen wurde im Verlauf der Lagerung anhand des pH-Werts, der Wasseraktivität, des Tropfsaftverlusts, der mikrobiologischen Qualität und der Farbe des Fleisches beurteilt. Insgesamt zeigten die biologisch abbaubaren Beutel während der gesamten Lagerungsdauer eine mit den PA/PE-Beuteln vergleichbare Leistung. Bei keinem der untersuchten Parameter wurden relevante Unterschiede festgestellt. Dies deutet darauf hin, dass die biologisch abbaubare Verpackung die Qualität des Fleisches unter den getesteten Versuchsbedingungen angemessen bewahrte. Die Ergebnisse zeigen, dass PBAT-basierte Beutel für die Vakuumverpackung von Rindersteaks in kleinbetrieblichen Produktionssystemen eingesetzt werden können.

RIASSUNTO

La crescente domanda di imballaggi alimentari ecosostenibili ha stimolato l'interesse verso alternative biodegradabili ai materiali convenzionali, non soltanto a livello industriale, ma anche nelle produzioni artigianali su piccola scala. Questo studio pilota ha valutato la fattibilità dell'impiego di sacchetti biodegradabili e compostabili a base di polibutilene adipato-co-tereftalato (PBAT), come alternativa ai comuni sacchetti in poliammide/polietilene (PA/PE), per il confezionamento sottovuoto di carne bovina fresca in condizioni artigianali. Le bistecche di manzo sono state confezionate sottovuoto e conservate a 4 °C per 11 giorni. Le prestazioni degli imballaggi sono state valutate nel corso della conservazione attraverso la misurazione del pH, dell'attività dell'acqua, della perdita di liquidi (drip loss), della qualità microbiologica e del colore della carne. Nel complesso, i sacchetti biodegradabili hanno mostrato prestazioni comparabili a quelle dei sacchetti in PA/PE durante l'intero periodo di conservazione. Non sono state osservate differenze rilevanti per nessuno dei parametri analizzati, indicando che, nelle condizioni sperimentali adottate, l'imballaggio biodegradabile ha preservato adeguatamente la qualità della carne. I risultati supportano la fattibilità dell'impiego di sacchetti a base di PBAT per il confezionamento sottovuoto di carne bovina in sistemi produttivi su piccola scala.

REFERENCES

- [1] Cutter C.N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science* 74 (1), 131-142, DOI:10.1016/j.meatsci.2006.04.023.
- [2] Ruban S.W. (2009). Biobased Packaging - Application in Meat Industry. *Veterinary World* 2 (2), 79-82, DOI:10.5455/vetworld.2009.79-82.
- [3] McMillin K.W. (2017). Advancements in meat packaging. *Meat Science* 132, 153-162, DOI:10.1016/j.meatsci.2017.04.015.
- [4] Schumann B., Schmid M. (2018). Packaging concepts for fresh and processed meat - Recent progresses. *Innovative Food Science & Emerging Technologies* 47, 88-100, DOI:10.1016/j.ifset.2018.02.005.
- [5] Stellato G., La Stora A., De Filippis F. et al. (2016). Overlap of Spoilage-Associated Microbiota between Meat and the Meat Processing Environment in Small-Scale and Large-Scale Retail Distributions. *Applied and Environmental Microbiology* 82 (13), 4045-4054, DOI:10.1128/AEM.00793-16.
- [6] Gil M., Rudy M. (2023). Innovations in the Packaging of Meat and Meat Products. A Review. *Coatings* 13 (2), 333, DOI:10.3390/coatings13020333.
- [7] Sid S., Mor R.S., Kishore A. et al. (2021). Bio-sourced polymers as alternatives to conventional food packaging materials. A review. *Trends in Food Science & Technology* 115, 87-104, DOI:10.1016/j.tifs.2021.06.026.
- [8] Siddiqui S.A., Sundarsingh A., Bahmid N.A. et al. (2023). A critical review on biodegradable food packaging for meat: Materials, sustainability, regulations, and perspectives in the EU. *Comprehensive Reviews in Food Science and Food Safety* 22 (5), 4147-4185, DOI:10.1111/1541-4337.13202.
- [9] D'Almeida A.P., De Albuquerque T.L. (2024). Innovations in Food Packaging: From Bio-Based Materials to Smart Packaging Systems. *Processes* 12 (10), 2085, DOI:10.3390/pr12102085.
- [10] Bell J., Paula L., Dodd T. et al. (2018). EU ambition to build the world's leading bioeconomy. Uncertain times demand innovative and sustainable solutions. *New Biotechnology*, 40, 25-30, DOI:10.1016/j.nbt.2017.06.010.
- [11] Herbes C., Beuthner C., Ramme I. (2018). Consumer attitudes towards biobased packaging - A cross-cultural comparative study. *Journal of Cleaner Production* 194, 203-218, DOI:10.1016/j.jclepro.2018.05.106.
- [12] Magnier L., Schoormans J., Mugge R. (2016). Judging a product by its cover: Packaging sustainability and perceptions of quality in food products. *Food Quality and Preference* 53, 132-142, DOI:10.1016/j.foodqual.2016.06.006.
- [13] Singh G., Pandey N. (2018). The Determinants of Green Packaging that Influence Buyers' Willingness to Pay a Price Premium. *Australasian Marketing Journal* 26 (3), 221-230, DOI:10.1016/j.ausmj.2018.06.001.
- [14] Hutchings N., Smyth B., Cunningham E. et al. (2021). Comparative life cycle analysis of a biodegradable multilayer film and a conventional multilayer film for fresh meat modified atmosphere packaging - and effectively accounting for shelf-life. *Journal of Cleaner Production* 327:129423, DOI:10.1016/j.jclepro.2021.129423.
- [15] Binnering A.-S. (2017). Perception of Naturalness of Food Packaging and Its Role in Consumer Product Evaluation. *Journal of Food Products Marketing* 23 (3), 251-266, DOI:10.1080/10454446.2014.885868.
- [16] Pietrosanto A., Scarfato P., Di Maio L. et al. (2020). Evaluation of the Suitability of Poly(Lactide)/Poly(Butylene-Adipate-co-Terephthalate) Blown Films for Chilled and Frozen Food Packaging Applications. *Polymers* 12 (4), 804, DOI:10.3390/polym12040804.
- [17] Wongphan P., Promhuad K., Srisa A. et al. (2024). Unveiling the Future of Meat Packaging: Functional Biodegradable Packaging Preserving Meat Quality and Safety. *Polymers* 16 (9), 1232, DOI:10.3390/polym16091232.
- [18] Dougeraki A.I., Ercolini D., Villani F. et al. (2012). Spoilage microbiota associated to the storage of raw meat in different conditions. *International Journal of Food Microbiology* 157 (2), 130-141, DOI:10.1016/j.ijfoodmicro.2012.05.020.
- [19] Odeyemi O.A., Alegbeleye O.O., Strateva M. et al. (2020). Understanding spoilage microbial community and spoilage mechanisms in foods of animal origin. *Comprehensive Reviews in Food Science and Food Safety* 19 (2), 311-331, DOI:10.1111/1541-4337.12526.
- [20] Calderón-Oliver M., Escalona-Buendía H.B., Ponce-Alquicira E. (2020). Effect of the addition of microcapsules with avocado peel extract and nisin on the quality of ground beef. *Food Science & Nutrition* 8 (3), 1325-1334, DOI:10.1002/fsn3.1359.
- [21] Konica Minolta Sensing Europe (2026). Understanding Colour Difference: What is Delta E. Retrieved August 27, 2026, from <https://sensing.konicaminolta.eu/min-en/colourblogtop/colour-blog/whatisdeltae>.
- [22] Altmann B.A., Gertheiss J., Tomašević I. et al. (2022). Human perception of color differences using computer vision system measurements of raw pork loin. *Meat Science* 188:108766, DOI:10.1016/j.meatsci.2022.108766.
- [23] Mancini R.A., Hunt M.C. (2005). Current research in meat color. *Meat Science* 71 (1), 100-121, DOI:10.1016/j.meatsci.2005.03.003.
- [24] King D.A., Hunt M.C., Barbut S. et al. (2023). American Meat Science Association Guidelines for Meat Color Measurement. *Meat and Muscle Biology* 6 (4), 1-81, DOI:10.22175/mmb.12473.
- [25] Jariyasakoolroj P., Leelaphiwat P., Harnkarnsujarit N. (2020). Advances in research and develop-

ment of bioplastic for food packaging. *Journal of the Science of Food and Agriculture* 100 (14), 5032-5045, [DOI:10.1002/jsfa.9497](https://doi.org/10.1002/jsfa.9497).

- [26] Jiao J., Huang X., Zeng X. (2020). An overview on synthesis, properties and applications of poly(butylene-adipate-co-terephthalate)-PBAT. *Advanced Industrial and Engineering Polymer Research* 3 (1), 19-26, [DOI:10.1016/j.aiepr.2020.01.001](https://doi.org/10.1016/j.aiepr.2020.01.001).
- [27] Hawthorne L.M., Beganović A., Schwarz M. et al. (2020). Suitability of Biodegradable Materials in Comparison with Conventional Packaging Materials for the Storage of Fresh Pork Products over Extended Shelf-Life Periods. *Foods* 9 (12), 1802, [DOI:10.3390/foods9121802](https://doi.org/10.3390/foods9121802).
- [28] Panzeri S., Martino P.A., Cagnardi P. et al. (2018). Feasibility of biodegradable based packaging used for red meat storage during shelf-life. A pilot study. *Food Chemistry*. 249, 22-29, [DOI:10.1016/j.foodchem.2017.12.067](https://doi.org/10.1016/j.foodchem.2017.12.067).