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Application of Polypropylene-Based Nanocomposite Films for Sliced Turkish Pastrami under Vacuum/Modified Atmosphere Packaging: A Pilot Study

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Abstract: The purpose of this study was to investigate the effects of polypropylene (PP)-based nanomaterials with improved barrier properties by nanoclay and antimicrobial properties by poly-beta-pinene (PβP) on the quality and shelf life of sliced pastrami as an alternative to the commercial multilayered materials. Sliced pastrami was packaged using nanocomposite films with and *w/o* PβP, and multilayered material under air, modified atmosphere packaging (MAP) and vacuum. Packaged products were screened for microbiological, physicochemical and sensory quality at 4 °C for 6 months. Salmonella spp., *Clostridium perfringens* and coagulase positive *Staphylococus aureus* were not detected in the products during entire storage. No yeast and mold growth occurred for entire storage using antimicrobial nanocomposite and multilayer material under vacuum. The antimicrobial effect of PβP on the pastrami was higher under vacuum compared to MAP applications suggesting that direct contact of the material is required with the food surface. Thiobarbituric acid reactive substances (TBARS) of pastrami under vacuum were lower than those of MAP applications. The initial carbonyl content of the product was determined as 3.38 nmol/mg and a slight increase was observed during storage period for all applications. The shelf life of pastrami is suggested as 150 days using PβP containing nanomaterials under vacuum, which is longer than the shelf life of a commercial product on the market using multilayer materials.

Keywords: nanocomposite; active packaging; shelf life; poly-beta-pinene; meat products; pastrami

1. Introduction

Turkish pastrami is a traditional, highly seasoned and air-dried-cured product made of beef. The final quality of the product is related to the quality of raw material, in particular initial pH and microbial loads. According to the national food codex, the moisture content, pH, salt and cumin paste on the surface of the pastrami should be max 45%, 6, 7 (*w/w*) and 10 (*w/w*), respectively [1]. Whole pastrami is generally sold unpackaged at the retailer, however, the products is sliced for ready to eat purposes and needs high barrier packaging materials to fulfill the expected shelf life.

Food packaging is one of the areas where nanotechnology could improve the quality and safety of food, reduce the use of valuable raw materials and the generation of packaging waste [2–4]. Packaging performances such as gas, moisture, ultraviolet (UV) and volatile barriers, mechanical strength, heat resistance and flame retardancy and weight could be improved by nanotechnology [2,5].

Previous studies have mainly focused on preparation, material properties and characterization of nanocomposites [6–9]. Improvements in the development of polymer nanocomposites increased the potential use of these materials for food-packaging applications. However, there has been limited research on the application of nanomaterials in a real food matrix at pilot scale and interactions between nanomaterials and foods. There are several studies on the application of nanomaterials for fresh fruits and vegetables [3,10–12]. However, there are limited studies in nano-packaging of ready-to-eat meat products.

In a previous work, it was reported that the incorporation of nanoclay and both nanoclay/poly-beta-pinene (PβP) increased mechanical properties and improved the barrier properties of polypropylene (PP) films [4]. The application of these materials on sliced salami (cured and cooked product) was reported indicating that the PβP containing nanomaterial provided 50 days of shelf life under vacuum compared to a commercial product with the shelf life of 3–4 weeks on the market [13]. It was also reported that the color stability of cooked ham under modified atmosphere (MA) using nano-polyamide composite was comparable to high barrier commercial polymer, and it was acceptable for 27 days [14]. Fresh chicken was packaged with polyethylene containing silver, clay, and titanium dioxide nanoparticles, and the results showed that film containing 5% nanosilver and 5% nanotitanium dioxide had the highest antimicrobial effect on Gram-positive and Gram-negative bacteria with the recommendation of 5 days of shelf life at 4 °C [15]. Rainbow trout fillet samples were packaged by nanocomposites including titanium dioxide (TiO_2) and then irradiated at room temperature, and the results indicated that TiO_2 nanocomposite and irradiation at 3 kGy provided better chemical, microbial, and sensory characteristics and extended the shelf life of fish fillets during the cold storage. However, the matrix for nanocomposites is not defined [16].

The aim of this study was to apply previously fabricated PP based film reinforced with nanoclay and poly-beta-pinene to Turkish pastrami and to determine the effects of this nanocomposite blend on quality attributes and shelf life of the sliced dried cured product under a vacuum and modified atmosphere. The commercial packaging polymer was used as the control.

2. Materials and Methods

2.1. Materials

The following materials were used in this work:

- Polypropylene random copolymer, PP, (PP 3221® of Total Petrochemicals);
- Nanoclay (Dellite® 67G, Laviosa Chemistry Mining Inc., Livorno, Italy);
    - Poly-beta-pinene, PβP, (Piccolyte® S115, Hercules Incorporated, Wilmington, DE, USA);
    - Commercial multilayer material with the structure of Polypropylene/Polyamide/Ethylene vinyl alcohol/Polyethylene (PP/PA/EVOH/PE) (Superfilm Co., Gaziantep, Turkey).

Three materials, named M1, M2 and M3, were prepared for the tests on the sliced pastrami as follows: PP film with addition of 1 wt.% of nanoclay (M1) (Dellite® 67G, Laviosa Chemistry Mining Inc., Livorno, Italy), PP film including 1% wt nanoclay plus 5 wt.% PβP (Piccolyte® S115, Hercules Incorporated, Wilmington, DE, USA), (M2) and commercial multilayer material with the structure of PP/PA/EVOH/PE (Superfilm Co., Gaziantep, Turkey), (M3).

Turkish pastrami with 100% beef meat content produced by Maret Co. (Istanbul, Turkey was provided one day before the processing and stored at 4 °C. Pastrami is a cured and dried meat product with the initial pH and moisture content of 5.90 and 44.4%, respectively.

2.2. Fabrication of Nanocomposites

We mixed and processed 1 wt.% of nanoclay, 99 wt.% of PP, and 1 wt.% nanoclay, 5 wt.% PβP and 94 wt.% PP through a 25 mm twin-screw co-rotating extruder (L/D = 24) (Collin Teach-Line Twin screw kneader ZK25T/SCD15, Dr. Collin GMBH, Ebersberg, Germany). The extruded materials were converted into pellets by using pelletizer (Collin Teach-Line Pelletizer171T, Maitenbeth, Germany). The pellets were processed by single screw extruder (Collin Teach-Line Extruder E20T/SCR15, Maitenbeth, Germany) and converted to films by a Collin Teach-Line Chill Roll CR72T (Dr. Collin GMBH, Maitenbeth, Germany). The thickness of the film was about 90 µm. Oxygen transmission rates (OTR) were 1282 and 1060 mL m^{-2} day^{-1} at 23 °C and 0% relative humidity (RH) for PP/nanoclay and PP/nanoclay/PβP, respectively. The OTR was 2 mL m^{-2} day^{-1} for multilayer material. Water vapor transmission rates (WVTR) of PP/nanoclay and PP/nanoclay/PβP were 1.43 and 1.30 g m^{-2} day^{-1} at 38 °C and 90% RH, respectively. The WVTR was 4 g m^{-2} day^{-1} for the multilayer material [4].

2.3. Processing and Packaging of Turkish Pastrami

Produced nanocomposite and multilayer films were cut into 36 × 10.5 cm and sealed with a constant heat sealer (ME-400 CFN, Mercier Corporation, Taiwan) at 120 °C and 145 °C, respectively. The pastrami was sliced into 1.5 mm of thickness with the slicer (Scharfenes 300, Witten, Germany). Sliced pastrami (150 g) was packaged using 3 different pouches (M1: nanocomposite film, M2: active nanocomposite film and M3: commercial multilayer film) under 3 different atmospheres (air as a control, MAP: 50% CO_2 and 50% N_2 and vacuum) using a packaging machine (Reepack rv 300, Seriate, Bergamo, Italy) combined with a gas mixer (KM60-3, Witt, Witten, Germany). Packaged pastrami was stored at 4 °C and 50% RH for 180 days and quality analysis (headspace gas composition, microbial, physical, chemical and sensory evaluation) were performed on 0, 5, 10, 20, 30, 60, 90, 120, 150 and 180 days. Three pouches as replicates were tested for each treatment at each storage time and all quality analysis were performed for total of 270 pouches. Packaging film, packaging method and storage time were the main experimental factors in the study.

2.4. Quality Control During Shelf-Life

2.4.1. Headspace Evolution

Oxygen and carbon dioxide (%) in the headspace of modified atmosphere packages were measured by a gas analyzer (PBI Dansensor, Ringsted, Denmark) on each analysis day. Gas analysis was performed from the headspace using an airtight syringe attached to the analyzer. Three measurements were taken for each application. Gas analysis was not performed in vacuum packages.

2.4.2. Microbiology

The packaged products were scanned for coagulase positive *S. aureus* and sulphite reducing anaerobic bacteria *Clostridium perfiringens* and *Salmonella* spp. required by the Turkish Food Codex [1]. Salmonella spp was tested by the VIDAS (Vitek Immuno Diagnostic Assay System) technique-enzyme based floresan technique [17]. *Clostridium perfiringens* was tested according to the Kuleaşan (2000) [18] and Erol et al. (2008) [19]. *S. aureus* was enumerated according to Baumgart (1997) [20] and Tukel and Doğan (2000) [21]. Total mesophilic aerobic bacteria (TMAB) and yeast and molds were enumerated during 180 days of storage based on the FDA-BAM (Food and Drug Administration-Bacteriological Analytical Manual) methods [22,23].

2.4.3. Color and Texture (Firmness and Toughness)

The color (CIE scale L* a* b*) of sliced pastrami was determined using Minolta Colorimeter (CR-400, Osaka, Japan). a* and b* values were converted into Chroma by using Equation (1). A total of 15 measurements (5 slices from each package) were taken for each application on each analysis day.

$$(C^* = [a^{*2} + b^{*2}]^{1/2}) \quad (1)$$

Textural properties were measured by using TA-XT Plus (Stable Micro System, Godalming, UK). Maximum cutting force (N) and peak area (N s^{-1}) were measured, and the results were presented as firmness and toughness, respectively using a blade set (Warner Blatzer) at a test speed of 5 mm s^{-1}. A load cell of 30 kg was used. A total of 15 measurements (5 slices from each package) were performed for each application on each analysis day.

2.4.4. Moisture Content and pH

The moisture content and pH were analyzed according to AOAC (Association of Official Analytical Chemists) (2000) [24]. The average of three measurements were taken for moisture content on 0 and 180 days of storage and six measurements were taken for pH on each analysis day.

2.4.5. Lipid Oxidation (Thiobarbituric Acid Reactive Substances, TBARS)

Lipid oxidation was determined according to the TBA (thiobarbituric acid)-based method reported by Pikul et al. (1989) [25]. Absorbance at 532 nm was measured against a blank using a UV spectrophotometer (UV-160A-Shimadzu, Kyoto, Japan). A standard curve was obtained using TEP (1,1,3,3-tetraethoxypropane) as malondialdehyde (MDA). Thiobarbituric acid reactive substances (TBARS) values were expressed as mg MDAkg^{-1} sample. Two measurements from each package were performed, and an average of six measurements was taken for each application on each analysis day.

2.4.6. Protein Stability (Carbonyl Content)

Protein stability was analyzed based on the method according to Oliver et al. (1987) [26]. Protein concentration was measured at 280 nm in the control (HCl) using a standard (bovine serum albumin (BSA) in guanidine). The results were presented as nanomoles of DNPH (dinitrophenylhydrazine) fixed per milligram of protein [27]. Two measurements from each package were performed, and an average of six measurements was taken for each application on each analysis day.

2.4.7. Sensory Evaluation

Sensory attributes of sliced pastrami were evaluated by 12 trained panelists during storage. The panelists were chosen among graduate students and faculty members of the food engineering department. The samples were coded with random three digit numbers and served in different orders to each panelist to eliminate the order effect. Each panelist was served with one slice of pastrami from each application and asked to evaluate the product for general appearance, color, odor, texture, taste and overall product acceptability using a 9-point scale at room temperature on each sampling day at room temperature. The sensory attributes were categorized as;

1: sticky, 5: acceptable, 9: fresh for general appearance;
1: pale/dull, 5: acceptable, 9: pinkish/reddish for color;
1: strong/bad, 5: acceptable, 9: characteristic for odor;
1: dry/hard, 5: acceptable, 9: normal/typical for texture;
1: rancid/spoilt, 5: acceptable, 9: normal/typical for taste.

Although statistical analysis was performed for sensory data, scores of 5 and higher were considered as a commercially acceptable limit for each attribute tested [13].

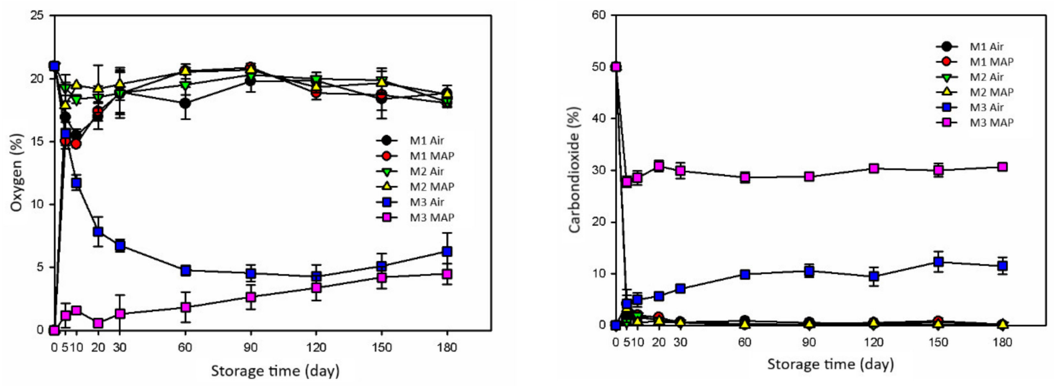
2.4.8. Statistical Analysis

Data were analyzed by using analysis of variance (3-way ANOVA) and the Duncan multiple comparison test at 95% confidence level using the SAS statistical program (Version 8.02, SAS Institute, Cary, NC, USA). The effects of main experimental factors (packaging film, packaging method and storage time) and their interactions for quality attributes were determined.

3. Results and Discussion

3.1. Headspace Gas Evolution

Headspace gas evolution (O_2% and CO_2%) in the pastrami packages during cold storage is presented by Figure 1a,b, respectively. There is no headspace measurement in the vacuum packages. In general, there was decrease in oxygen level during increased storage in all applications. The oxygen levels in PP-based nanocomposite packages started with 21% (air composition) and did not change much during the entire storage possibly due to high OTR. For commercial multilayer material, the oxygen level started with 21% but declined to 6.3% on 180. day. Since the OTR of this material is too low for oxygen transmission through the package, this decrease could be related to the consumption of oxygen in the chemical and microbiological activities of the product. The study by Parra et al. (2010) reported similar results for dried cured ham [28].



(**a**) (**b**)

Figure 1. (**a**) Headspace oxygen and (**b**) carbon dioxide (%) during cold storage of sliced pastrami (M1: polypropylene (PP)/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE (Polypropylene/Polyamide/Ethylene vinyl alcohol/Polyethylene), Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2).

Although both PP-based nanocomposite packages under MAP (50% CO_2 and 50% N_2) started with no oxygen in the headspace, the oxygen level increased gradually and reached 20%–21% after 60 days of storage and did not change much for the rest of the storage time. The oxygen level in the commercial package under MAP reached 4.5% at the end of the storage.

The CO_2 level of PP-based nano package (M1) started with air atmosphere and reached 1.6% on the 10th day and around 1% for the rest of the storage. There was a similar trend observed for the CO_2 evolution of the active nanomaterial. For the air application using commercial material, the CO_2 increased with extended storage and reached 11.5% on the 180. day. This is attributed to the microbial activity of natural microflora of pastrami.

The CO_2 level of PP-based nano packages that started with 50% CO_2 rapidly declined and dropped to less than 5% on the 5th day of storage and remained around 1% for the rest of the storage. This decrease could be attributed to the solubility of CO_2 on the product surface [29] and relatively higher CO_2TR of both nano packages comparing to commercial material. The CO_2 level in the high CO_2 application (50%) using multilayer material decreased to 27.8% on the 5th day and stayed around

26%–30% for the rest of the storage. The rapid decline of CO_2 in the multilayer material is possibly due to the solubility of CO_2 on the product. Nalçabasmaz et al. tested same nanomaterials for sliced salami and reported similar results [13]. It was reported that the decrease in CO_2 could be related to the solubility in the product or absorption by the meat products during storage [13,30]. The oxidative and microbial activity in the meat products could result in a decrease in O_2 and increase in CO_2 content [30].

3.2. Microbial Quality

The food-relevant pathogens were not detected in the products right after the processing and during entire storage of 180 days, which is required by the Turkish Food Codex [1]. It was reported that the growth of Enterobactericia, Salmonella, *S. aureus* and *C. perfiringens* was suppressed by low water activity of the product due to drying process and also relatively high mount of salt and garlic content [31–34].

The initial level of mesophilic aerobic bacteria (7.09 log cfu/g) increased approximately 1–2 log cfu/g for all applications. Pastrami has its own natural microbial flora with the level of 10^6–10^8 cfu/g total aerobic mesophilic bacteria [33,35,36]. The dominant microorganisms of this flora for the pastrami were reported as *Lactobacillus* and *Micrococcus/Staphylococcus* [37,38]. In our study, the level of *Micrococcus/Staphylococcus* was determined as 7.32–9.24 log cfu/g on storage day 180 and there were no significant differences among applications (Table 1).

Table 1. *Staphylococcus* and *micrococcus* count of sliced pastrami packaged with nanomaterials under vacuum and modified atmosphere.

***Staphylococcus–Micrococcus* Count (log cfu/g)**				
Packaging Materials	**Application**	**Day 0**	**Day 90**	**Day 180**
M1	Air	7.09^{Aa}	7.29^{Aa}	7.32^{Aa}
	MAP	7.10^{Aa}	7.56^{Aa}	9.07^{Ab}
	Vacuum	7.03^{Aa}	7.33^{Aa}	9.09^{Ab}
M2	Air	6.15^{Aa}	6.68^{Aa}	7.86^{Ab}
	MAP	6.90^{Aa}	7.12^{Aa}	8.33^{Ab}
	Vacuum	7.03^{Aa}	7.49^{Aa}	9.24^{Ab}
M3	Air	7.10^{Aa}	7.58^{Aa}	8.45^{Aa}
	MAP	7.29^{Aa}	7.74^{Aa}	8.01^{Aa}
	Vacuum	7.32^{Aa}	8.22^{Aa}	8.67^{Aa}

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP (Modified atmosphere packaging): 50% CO_2 50% N_2.

PβP incorporated nanocomposite had 1–1.5 log cfu/g lowest bacterial count under MAP and vacuum compared to air atmosphere. In general, the results showed that packaging materials and atmospheres were not very effective on the total aerobic mesophilic bacteria during 180 days. Anıl (1988) also reported level of 9.2×10^5–4.8×10^7 log/g total aerobic mesophilic bacteria under vacuum packaged pastrami [39]. There is no limit defined for total aerobic mesophilic bacteria by the Turkish Food Codex.

In terms of total yeast and mold count, there was almost no growth observed for 120 days for all applications (Table 2). However, yeast and mold growth increased after 150 days of storage for all atmospheres of plain nanocomposite (M1) and air, and MAP applications of antimicrobial nanocomposite (M2) (5.24–7.15 log cfu/g). However, no growth occurred for the entire storage of antimicrobial nanocomposite under vacuum and all atmospheres of multilayer material. In previous studies, yeast and mold count of pastrami was reported as <2–5.76 log cfu/g [31–33,35,36]. A microbial study indicated that direct contact with the antimicrobial nanocomposite in the case of vacuum might be more effective than modified atmosphere packaging for sliced pastrami for better quality and longer shelf life.

Table 2. Total yeast and mold count during storage of sliced pastrami in different packaging material and atmospheres.

		Total Yeast and Mold Count (log cfu/g)								
Packaging Materials	**Application**	**Day 0**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	2.23 Aa	2.12 Aa	2.26 Aa	2.40 Aa	2.00 Aa	2.43 Aa	2.00 Aa	5.52Ab	5.61 Ab
	MAP	2.23 Aa	2.00 Aa	2.06 Aa	2.06 Aa	2.17 Aa	2.42 Aa	2.12 Aa	6.98Ab	7.15 Bb
	Vacuum	2.23 Aa	2.22 Aa	2.79 Aa	2.06 Aa	2.00 Aa	2.43 Aa	2.00 Aa	3.58Bb	4.45 Ab
M2	Air	2.23 Aa	2.00 Aa	2.34 Aa	2.26 Aa	2.00 Aa	2.00 Aa	2.12 Aa	6.34Ab	6.29 Bb
	MAP	2.23 Aa	2.12 Aa	2.50 Aa	2.00 Aa	2.00 Aa	2.22 Aa	2.00 Aa	4.96Ab	5.24 Ab
	Vacuum	2.23 Aa	2.22 Aa	2.40 Aa	2.00 Aa	2.00 Aa	2.12 Aa	2.00 Aa	2.00Ca	2.00 Ca
M3	Air	2.23 Aa	2.00 Aa	2.48 Aa	2.26 Aa	2.00 Aa	2.12 Aa	2.00 Aa	2.60Ca	2.00 Ca
	MAP	2.23 Aa	2.36 Aa	2.12 Aa	2.95 Aa	2.00 Aa	2.43 Aa	2.00 Aa	2.00Ca	2.00 Ca
	Vacuum	2.23 Aa	2.00 Aa	2.40 Aa	2.17 Aa	2.00 Aa	2.00 Aa	2.00 Aa	2.00Ca	2.52 Ca

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). Total yeast and mold count <2 log cfu/g: no colony formation on the lowest dilution (log cfu/g: log (lowest dilution with no colony × sample volume transferred to petri dishes (0.1 mL)). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50%.

3.3. Physical Quality (Color and Texture)

3.3.1. Color

The color values, L*, a*, b* and C*, of pastrami packaged in nanomaterials and multilayer material under vacuum/modified atmosphere packaging are presented in Table 3. All experimental factors and their interactions had a significant effect on color values of L*, a*, b* and C*. L* value did not differ much during storage for all applications. A significant color indicator a* value representing redness for meat products was better preserved during entire storage by multilayered material with lower OTR compared to nanomaterials. In general, a* value tended to slightly decrease for both nanomaterial applications as the storage time increased. The decrease in redness during storage could be attributed to the headspace oxygen content and in turn oxidation (electron loss) of red color pigments (nitrosomyglobin) turning to brown (metmyoglobin) [40].

All applications of multilayered material were acceptable by sensory panel during 180 days in terms of color perceived. The color of pastrami under MAP of nanomaterial and air atmosphere of active nanomaterial was acceptable for 60 days. This period was determined 120 days for vacuum applications of both nanomaterials and MAP of active nanomaterial.

C* value increased for MAP and vacuum applications of multilayer material during storage. However, there was a decrease in all applications of plain nanomaterial during storage. C* value decreased for air and MAP applications of active nanomaterial, however, it did not change for vacuum during increased storage. The effect of MAP on the color stability of sliced meat products was investigated showing that increased oxygen content in the package and product/headspace ratio were primary factors affecting the color stability [29]. The color (redness and reflectivity) of ham under modified atmosphere was stable for 27 days in polyamide nanocomposite blends, whereas significant color change was observed after 7 days in polyamide pouches [14].

3.3.2. Texture

The effects of packaging materials and atmospheres on the textural properties (hardness and toughness) of sliced pastrami are presented in Table 4. In terms of texture, maximum cutting force (N) was measured and evaluated as the hardness of the product. There was an increase in hardness as the storage time prolonged for most of the applications. The initial hardness was 63.52 N and ranged between 59.23–85.13 N at the end of the storage. Overall, there was no specific trend observed in terms of packaging material used and the atmosphere applied possibly due to the non-homogeneous structure of the pastrami used. Pastrami was acceptable during the whole storage time at all applications of multilayer material by the panelists in terms of hardness. On the other hand, the hardness of the pastrami slices was acceptable for 120 days at all applications of both nanomaterials except air atmosphere of active nanomaterial which is limited to 60 days.

In terms of toughness, there was no obvious general trend observed among applications. For the product packaged in plain nanomaterial, there was slight decrease in toughness during storage under all atmospheres. For active nanomaterial and multilayer material, the product toughness tended to increase under air and MAP applications, however, no significant changes were observed for vacuum applications. A previous study stated that modified atmosphere packaging preserved dried cured ham slices better than vacuum packaging from hardening but all within the normal range for the product [41]. Changes in hardness during dry-cured ham ripening have been related to both water content and state of proteins.

The hardness of sliced pastrami was also evaluated by sensory panel. As a general trend, there was a decline in perceived product attributes as the storage time increased, as expected. The product packaged with multilayer material was sensorially acceptable during the whole storage time under all applications. The other applications except active nanomaterial-air treatment were acceptable for 120 days in terms of texture.

Table 3. Color attributes of Turkish pastrami packaged with nanomaterials under vacuum and modified atmosphere during cold storage.

					L*						
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	33.45 ± 4.01 ^{Abcd1}	35.86 ± 3.50 ^{ABCDab}	32.57 ± 4.98 ^{Bcde}	30.60 ± 3.06 ^{CDe}	33.05 ± 3.10 ^{BCDcde}	31.71 ± 2.14 ^{CDde}	34.28 ± 2.94 ^{BCDbcd}	35.00 ± 3.56 ^{Aabc}	37.21 ± 2.77 ^{ABa}	36.05 ± 2.55 ^{CDab}
	MAP	33.45 ± 4.01 ^{Ac}	38.51 ± 5.60 ^{Aa}	35.12 ± 4.10 ^{ABbc}	36.51 ± 2.50 ^{Aab}	38.05 ± 2.34 ^{Aa}	37.63 ± 1.03 ^{Aab}	36.05 ± 3.10 ^{ABabc}	35.78 ± 3.09 ^{Aabc}	37.50 ± 2.41 ^{ABab}	37.23 ± 2.80 ^{BCab}
	Vac.	33.45 ± 4.01 ^{Abc}	36.92 ± 3.96 ^{ABCa}	36.21 ± 3.92 ^{Aa}	34.89 ± 4.43 ^{ABabc}	32.61 ± 3.17 ^{CDc}	33.00 ± 3.18 ^{Cbc}	35.53 ± 3.00 ^{ABCab}	32.31 ± 2.45 ^{Bc}	36.60 ± 2.79 ^{ABa}	37.55 ± 1.23 ^{BCa}
M2	Air	33.45 ± 4.01 ^{Acd}	37.27 ± 4.94 ^{ABab}	32.45 ± 3.34 ^{Bd}	31.71 ± 3.12 ^{Cd}	35.24 ± 3.64 ^{Bbc}	35.06 ± 3.09 ^{Bbc}	37.94 ± 2.71 ^{Aa}	35.28 ± 2.04 ^{Abc}	37.96 ± 1.77 ^{Aa}	39.33 ± 1.19 ^{Aa}
	MAP	33.45 ± 4.01 ^{Abc}	34.38 ± 4.64 ^{BCDabc}	36.49 ± 3.37 ^{Aa}	32.44 ± 4.03 ^{BCc}	34.95 ± 3.02 ^{BCabc}	32.79 ± 3.13 ^{Cbc}	33.58 ± 3.85 ^{BCDbc}	32.41 ± 3.80 ^{Bc}	35.56 ± 2.77 ^{BCab}	36.56 ± 1.50 ^{BCDa}
	Vac.	33.45 ± 4.01 ^{Abc}	33.04 ± 4.16 ^{Dbcd}	34.86 ± 4.72 ^{ABabc}	29.99 ± 2.53 ^{CDe}	32.48 ± 2.60 ^{CDcde}	30.66 ± 3.03 ^{Dde}	33.07 ± 3.88 ^{CDbcd}	30.54 ± 2.49 ^{Bde}	36.54 ± 2.51 ^{ABa}	35.50 ± 3.14 ^{Dab}
M3	Air	33.45 ± 4.01 ^{Ab}	33.73 ± 4.47 ^{CDb}	33.17 ± 4.30 ^{ABbc}	32.69 ± 4.29 ^{BCbc}	33.91 ± 3.20 ^{BCb}	35.07 ± 1.99 ^{Bab}	33.11 ± 3.28 ^{CDbc}	30.50 ± 2.65 ^{Bc}	33.98 ± 3.16 ^{Cb}	37.33 ± 1.88 ^{BCa}
	MAP	33.45 ± 4.01 ^{Acde}	33.17 ± 3.57 ^{Dde}	34.31 ± 4.29 ^{ABcde}	32.67 ± 4.35 ^{BCe}	32.86 ± 2.64 ^{BCDde}	36.39 ± 1.93 ^{ABab}	35.33 ± 3.72 ^{BCDbcd}	35.02 ± 2.28 ^{Abcde}	35.97 ± 1.43 ^{ABabc}	38.05 ± 1.38 ^{ABa}
	Vac.	33.45 ± 4.01 ^{Acd}	35.08 ± 3.29 ^{ABCDabc}	33.50 ± 4.81 ^{ABbcd}	28.43 ± 2.99 ^{De}	31.20 ± 3.26 ^{Dd}	32.12 ± 2.94 ^{CDd}	32.67 ± 3.03 ^{Dcd}	32.51 ± 3.67 ^{Bcd}	36.22 ± 3.01 ^{ABa}	35.42 ± 2.41 ^{Dab}
					a*						
M1	Air	13.38 ± 2.71 ^{Ab}	16.71 ± 4.53 ^{BCa}	15.10 ± 3.07 ^{BCa}	12.40 ± 1.78 ^{Dbc}	11.49 ± 0.77 ^{Dcd}	11.42 ± 2.08 ^{Dcd}	10.59 ± 0.59 ^{Cde}	9.46 ± 1.30 ^{Eef}	8.41 ± 0.89 ^{Df}	9.46 ± 1.18 ^{DEef}
	MAP	13.38 ± 2.71 ^{Acd}	17.89 ± 3.74 ^{ABCa}	16.39 ± 2.09 ^{Bb}	12.82 ± 0.61 ^{CDd}	14.64 ± 2.37 ^{Bc}	11.20 ± 0.94 ^{De}	10.74 ± 0.83 ^{Ce}	10.74 ± 1.81 ^{DEe}	10.84 ± 0.90 ^{Ce}	11.19 ± 1.97 ^{BCe}
	Vac.	13.38 ± 2.71 ^{Acde}	19.94 ± 5.42 ^{Aa}	15.85 ± 3.10 ^{Bb}	14.32 ± 4.12 ^{BCbcd}	12.83 ± 2.02 ^{CDdef}	15.07 ± 1.71 ^{Bbc}	11.42 ± 1.41 ^{Cfe}	12.19 ± 2.00 ^{Cdef}	11.10 ± 1.57 ^{Cgf}	9.14 ± 0.55 ^{Eg}
M2	Air	13.38 ± 2.71 ^{Abc}	17.76 ± 4.34 ^{ABaC}	12.66 ± 2.07 ^{Cbcd}	11.65 ± 1.84 ^{Dcde}	12.83 ± 1.80 ^{CDbc}	13.46 ± 1.39 ^{Cb}	11.62 ± 0.63 ^{Ccde}	12.32 ± 2.26 ^{Cbcd}	11.04 ± 1.35 ^{Cde}	10.29 ± 0.60 ^{CDe}
	MAP	13.38 ± 2.71 ^{Ab}	15.53 ± 3.27 ^{BCa}	14.83 ± 2.42 ^{BCa}	12.21 ± 1.41 ^{Dbc}	12.24 ± 1.99 ^{Dbc}	12.12 ± 1.63 ^{Dbc}	10.71 ± 1.58 ^{Cc}	11.48 ± 1.32 ^{CDc}	10.72 ± 1.08 ^{Cc}	9.22 ± 0.71 ^{Ed}
	Vac.	13.38 ± 2.71 ^{Abcd}	19.91 ± 3.36 ^{Aa}	19.99 ± 3.82 ^{Aa}	12.37 ± 3.33 ^{Dcd}	14.85 ± 3.77 ^{Bb}	13.30 ± 1.67 ^{Cbcd}	11.31 ± 1.15 ^{Cde}	13.74 ± 2.35 ^{Bbc}	9.99 ± 1.82 ^{Ce}	11.37 ± 1.81 ^{Bde}
M3	Air	13.38 ± 2.71 ^{Abcd}	14.77 ± 3.09 ^{Cabc}	14.46 ± 3.24 ^{BCabc}	12.49 ± 1.82 ^{Dd}	14.06 ± 1.80 ^{BCbcd}	14.93 ± 1.15 ^{Bab}	13.06 ± 2.29 ^{Bcd}	15.87 ± 1.90 ^{Aa}	14.19 ± 1.30 ^{Babcd}	15.10 ± 1.06 ^{Aab}
	MAP	13.38 ± 2.71 ^{Ad}	18.05 ± 2.59 ^{ABb}	19.95 ± 4.05 ^{Aa}	15.47 ± 2.25 ^{ABc}	15.69 ± 1.50 ^{ABc}	15.57 ± 1.30 ^{Bc}	13.44 ± 1.54 ^{Bd}	14.18 ± 1.84 ^{Bcd}	15.15 ± 1.18 ^{ABc}	15.84 ± 1.53 ^{Ac}
	Vac.	13.38 ± 2.71 ^{Ab}	16.46 ± 4.13 ^{BCa}	16.75 ± 3.95 ^{Ba}	16.58 ± 1.87 ^{Aa}	16.85 ± 2.23 ^{Aa}	17.72 ± 1.26 ^{Aa}	15.67 ± 1.36 ^{Aa}	15.62 ± 1.77 ^{Aa}	16.00 ± 2.54 ^{Aa}	15.67 ± 1.74 ^{Aa}
					b*						
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	−6.12 ± 2.53 ^{Aab}	−5.47 ± 0.97 ^{ABa}	−7.56 ± 0.98 ^{Ecd}	−7.45 ± 1.05 ^{Ccd}	−7.48 ± 0.97 ^{Dcd}	−8.10 ± 0.55 ^{Dd}	−6.50 ± 0.79 ^{DEb}	−5.92 ± 1.06^{ABab}	−6.04 ± 0.67 ^{CDab}	−6.89 ± 1.45 ^{CDEbc}
	MAP	−6.12 ± 2.53 ^{Ab}	−4.81 ± 1.34 ^{Aa}	−5.92 ± 1.74B ^{CDab}	−6.04 ± 1.03 ^{ABab}	−5.00 ± 1.50 ^{Aab}	−5.32 ± 0.83 ^{Aab}	−5.21 ± 1.34 ^{ABab}	−5.57 ± 1.31 ^{Aab}	−5.06 ± 1.35 ^{BCab}	−5.94 ± 1.00 ^{Bab}
	Vac.	−6.12 ± 2.53 ^{Abc}	−5.50 ± 1.23 ^{ABab}	−5.38 ± 1.44 ^{ABab}	−5.48 ± 3.32 ^{Aab}	−7.43 ± 1.37 ^{Dc}	−6.10 ± 1.02 ^{ABCbc}	−5.39 ± 1.08 ^{ABCab}	−7.16 ± 1.25 ^{CDc}	−4.70 ± 1.18 ^{ABa}	−7.28 ± 0.32 ^{DEc}
M2	Air	−6.12 ± 2.53 ^{Acd}	−5.65 ± 0.92 ^{ABCbc}	−7.05 ± 1.59 ^{DEde}	−7.26 ± 1.36 ^{BCe}	−6.40 ± 1.29 ^{BCcde}	−5.72 ± 1.43 ^{ABbc}	−4.72 ± 0.89 ^{Aab}	−5.50 ± 1.38^{Abc}	−3.83 ± 0.75 ^{Aa}	−4.93 ± 0.85 ^{Ab}
	MAP	−6.12 ± 2.53 ^{Aab}	−5.92 ± 1.29 ^{BCab}	−5.61 ± 1.09 ^{ABCab}	−6.79 ± 1.04 ^{BCbc}	−5.96 ± 1.27 ^{Bab}	−7.58 ± 0.97 ^{Dc}	−6.72 ± 1.56 ^{DEbc}	−7.44 ± 1.54 ^{Dc}	−5.41 ± 1.56 ^{BCDa}	−7.54 ± 0.96 ^{Ec}
	Vac.	−6.12 ± 2.53 ^{Abcd}	−5.51 ± 1.02 ^{ABab}	−4.43 ± 3.12 ^{Aa}	−7.79 ± 1.33 ^{Ce}	−7.18 ± 1.28 ^{CDde}	−7.82 ± 1.04 ^{De}	−6.99 ± 1.38 ^{Ecde}	−6.52 ± 1.63 ^{ABCDbcde}	−5.59 ± 2.01 ^{BCDabc}	−6.42 ± 1.16 ^{BCbcde}
M3	Air	−6.12 ± 2.53 ^{Aa}	−6.57 ± 1.24 ^{Cab}	−6.90 ± 1.77 ^{CDEab}	−7.35 ± 1.05 ^{Cb}	−6.83 ± 1.47 ^{BCDab}	−6.15 ± 0.63 ^{BCa}	−6.79 ± 1.27 ^{DEab}	−7.13 ± 1.26 ^{CDab}	−6.39 ± 1.30 ^{Dab}	−6.09 ± 0.77 ^{Ba}
	MAP	−6.12 ± 2.53 ^{Abc}	−5.72 ± 1.56 ^{ABCab}	−6.30 ± 1.51 ^{BCDEbc}	−6.92 ± 0.93 ^{BCcd}	−7.70 ± 0.76 ^{Dd}	−5.85 ± 0.89 ^{ABabc}	−5.92 ± 1.36 ^{BCDabc}	−6.16 ± 1.37 ^{ABCbc}	−4.97 ± 0.84 ^{Ba}	−5.87 ± 0.76 ^{Babc}
	Vac.	−6.12 ± 2.53 ^{A}	−6.09 ± 1.31 ^{BCab}	−6.45 ± 1.18 ^{BCDEabc}	−7.96 ± 1.48 ^{Cd}	−7.53 ± 1.34 ^{Dcd}	−6.72 ± 1.30 ^{Cbc}	−6.17 ± 1.05 ^{CDEab}	−6.89 ± 1.71 ^{BCDbcd}	−5.30 ± 1.28 ^{BCa}	−6.65 ± 1.08 ^{BCDbc}
					C*						
M1	Air	14.98 ± 2.29 ^{Ab}	17.68 ± 4.22 ^{ABa}	16.98 ± 2.65 ^{Ba}	14.52 ± 1.63 ^{CDb}	13.75 ± 0.72 ^{Ebc}	14.05 ± 1.76 ^{Eb}	12.45 ± 0.67 ^{CDcd}	11.22 ± 1.15 ^{Ede}	10.38 ± 0.80 ^{De}	11.77 ± 1.39 ^{Dde}
	MAP	14.98 ± 2.29 ^{Ab}	18.57 ± 3.75 ^{ABa}	17.53 ± 1.92 ^{Ba}	14.21 ± 0.49 ^{CDb}	15.55 ± 2.24 ^{CDb}	12.44 ± 0.73 ^{Fc}	11.99 ± 1.01 ^{Dc}	12.18 ± 1.68 ^{Ec}	12.00 ± 1.29 ^{Cc}	12.73 ± 1.75 ^{BCc}
	Vac.	14.98 ± 2.29 ^{Abc}	20.76 ± 5.26 ^{Aa}	16.85 ± 2.74 ^{BCb}	15.78 ± 3.62 ^{BCbc}	14.92 ± 1.70 ^{DEbc}	16.30 ± 1.51 ^{BCb}	12.65 ± 1.60 ^{CDde}	14.21 ± 1.74 ^{CDcd}	12.12 ± 1.49 ^{Ce}	11.69 ± 0.45 ^{De}

Table 3. *Cont.*

		C*									
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M2	Air	14.98 ± 2.29 Ab	18.70 ± 4.13 ABa	14.59 ± 1.99 Cb	13.82 ± 1.57 Dbc	14.40 ± 1.74 DEb	14.70 ± 1.28 DEb	12.57 ± 0.64 CDcd	13.60 ± 1.95 Dbc	11.72 ± 1.22 Cd	11.44 ± 0.67 Dd
	MAP	14.98 ± 2.29 Abc	16.70 ± 3.09 Ba	15.92 ± 2.17 BCab	14.03 ± 1.16 Dcd	13.69 ± 1.76 Ecd	14.34 ± 1.51 Ec	12.71 ± 1.73 CDde	13.78 ± 1.03 Dcd	12.06 ± 1.56 Ce	11.95 ± 0.56 CDe
	Vac.	14.98 ± 2.29 Abc	20.72 ± 3.10 Aa	20.74 ± 3.59 Aa	14.75 ± 2.91 CDbc	16.66 ± 3.15 BCb	15.48 ± 1.47 CDb	13.33 ± 1.53 Ccd	15.32 ± 2.13 BCb	11.61 ± 1.81 Cd	13.15 ± 1.45 Bcd
M3	Air	14.98 ± 2.29 Abc	16.23 ± 3.00 Bab	16.21 ± 2.67 BCab	14.53 ± 1.88 CDc	15.72 ± 1.55 CDbc	16.17 ± 1.03 BCab	14.77 ± 2.32 Bbc	17.46 ± 1.74 Aa	15.61 ± 1.42 Bbc	16.31 ± 0.79 Aab
	MAP	14.98 ± 2.29 Ae	19.01 ± 2.49 ABb	21.01 ± 3.87 Aa	16.97 ± 2.19 Bcd	17.49 ± 1.51 ABc	16.66 ± 1.27 Bcd	14.71 ± 1.88 Be	15.55 ± 1.55 Bde	15.97 ± 1.10 Acde	16.92 ± 1.36 Acd
	Vac.	14.98 ± 2.29 Ac	17.67 ± 3.78 ABab	18.04 ± 3.65 Bab	18.47 ± 1.69 Aab	18.54 ± 1.86 A	19.00 ± 1.02 Aa	16.87 ± 1.41 Ab	17.13 ± 1.93 Aab	16.94 ± 2.29 Ab	17.07 ± 1.60 Ab

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2, Vac: vacuum.

Table 4. Texture (hardness and toughness) of Turkish pastrami packaged with nanomaterials under vacuum and modified atmosphere during cold storage.

		Hardness (Max Cutting Force, N)									
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	63.52 ± 5.91 Ade	68.53 ± 6.15 ABcd	70.19 ± 8.58 ABbc	66.42 ± 8.19 BCcde	62.45 ± 7.79 Ee	63.56 ± 8.31 Ede	76.20 ± 6.60 Ba	75.06 ± 8.42 Bab	76.88 ± 4.57 BCa	67.30 ± 7.77 CDcde
	MAP	63.52 ± 5.91 Acde	67.64 ± 6.66 ABbcd	72.57 ± 6.73 Aab	65.86 ± 9.07 BCcd	74.90 ± 8.75 BCa	68.44 ± 9.68 CDEbc	61.65 ± 6.85 Dde	61.80 ± 7.80 Ede	65.77 ± 6.24 EFcd	59.23 ± 8.63 Ee
	Vac.	63.52 ± 5.91 Ab	62.33 ± 5.73 CDb	70.85 ± 6.25 ABa	64.05 ± 9.52 BCDb	65.44 ± 6.79 DEb	53.61 ± 3.51 Fc	62.97 ± 7.01 Db	64.54 ± 5.79 DEab	65.91 ± 6.23 EFab	61.91 ± 8.79 DEb
M2	Air	63.52 ± 5.91 Ac	60.04 ± 3.52 Dc	70.57 ± 8.34 ABb	69.76 ± 6.42 Bb	83.02 ± 6.18 Aa	84.75 ± 6.52 Aa	85.40 ± 8.42 Aa	86.68 ± 7.31 Aa	85.00 ± 4.19 Aa	85.13 ± 7.48 Aa
	MAP	63.52 ± 5.91 Aef	64.79 ± 5.99 BCDdef	61.15 ± 9.28 CDf	60.82 ± 8.30 CDf	69.90 ± 7.69 CDbcd	73.14 ± 5.25BCbc	68.43 ± 8.35 Ccde	74.37 ± 5.66 Bb	74.17 ± 4.64 CDb	80.26 ± 6.29 ABa
	Vac.	63.52 ± 5.91 Acd	68.03 ± 6.09 ABbc	56.57 ± 2.72 De	58.92 ± 5.54 Dde	71.64 ± 5.07 Cab	65.82 ± 9.81 DEc	73.62 ± 5.8 9BCa	67.18 ± 9.70 CDbc	67.56 ± 5.26 Ebc	66.09 ± 6.79 CDc
M3	Air	63.52 ± 5.91 Ac	66.41 ± 4.17 BCc	66.06 ± 9.85 BCc	79.22 ± 6.87 Aa	72.64 ± 6.07 Cb	71.47 ± 9.13 Cb	62.49 ± 7.36 Dc	60.85 ± 5.28 Ec	62.37 ± 7.30 Fc	77.83 ± 5.93 Ba
	MAP	63.52 ± 5.91 Ad	71.99 ± 9.97 Ac	72.55 ± 8.80 Ac	81.61 ± 7.61 Aab	78.82 ± 8.09 ABb	76.95 ± 2.79 Bbc	72.95 ± 7.85 BCc	85.73 ± 7.39 Aa	79.13 ± 4.45 Bb	82.13 ± 5.84 ABab
	Vac.	63.52 ± 5.91 Ad	66.08 ± 8.30 BCcd	69.31 ± 7.46 ABbc	80.07 ± 5.70 Aa	72.01 ± 7.02 Cb	70.31 ± 5.32 CDbc	68.53 ± 6.91 Cbc	71.93 ± 5.05B Cb	72.17 ± 5.05 Db	70.55 ± 6.20 Cbc
		Toughness (Peak Area, N/s)									
M1	Air	70.99 ± 6.55 Ac	78.58 ± 6.13 Aa	77.90 ± 8.87 ABCa	77.31 ± 9.82 ABab	71.50 ± 6.50 EFbc	77.23 ± 8.51 BCab	76.44 ± 6.33 ABabc	74.71 ± 4.94 BC	77.47 ± 8.28 Aab	60.40 ± 6.35 Dd
	MAP	70.99 ± 6.55 Ab	75.46 ± 7.59 ABab	79.94 ± 9.41 ABa	78.32 ± 7.99 ABa	74.49 ± 9.62 CDEab	69.46 ± 5.93 EFb	69.59 ± 5.48 DEb	70.02 ± 8.23 Cb	55.15 ± 4.68 Dc	55.68 ± 6.94 Dc
	Vac.	70.99 ± 6.55 Ac	70.57 ± 7.02 BCbc	79.53 ± 8.80 ABa	73.51 ± 8.07 BCbc	72.02 ± 4.32 EFbc	68.34 ± 4.71 Fc	74.39 ± 6.38 BCDb	70.63 ± 8.90 BCbc	57.45 ± 3.62 Dd	59.78 ± 5.79 Dd
M2	Air	70.99 ± 6.55 Acd	68.37 ± 5.03 Cd	73.92 ± 6.29 BCDc	73.46 ± 5.32 BCc	83.62 ± 7.17 Aab	80.64 ± 5.92 ABb	80.39 ± 7.47 Ab	85.72 ± 6.52 Aa	75.35 ± 5.07 ABc	83.78 ± 7.55 Aab
	MAP	70.99 ± 6.55 Ab	72.94 ± 5.80 BCab	72.15 ± 5.87 CDab	71.03 ± 3.98 Cb	73.73 ± 5.58 DEab	73.88 ± 2.00 CDEab	71.27 ± 6.36 BCDab	75.97 ± 4.09 Ba	71.27 ± 7.63 Bab	71.04 ± 6.84 Cb
	Vac.	70.99 ± 6.55 Aabc	73.70 ± 3.78 ABa	69.08 ± 8.47 Dabcd	74.29 ± 6.91 BCa	67.91 ± 6.10 Fbcd	70.08 ± 6.07 DEFabc	72.85 ± 6.39 BCDab	69.22 ± 9.77 Cabcd	63.88 ± 3.44 Cd	67.04 ± 8.34 Ccd
M3	Air	70.99 ± 6.55 Acd	74.86 ± 8.48 ABbc	69.91 ± 8.16 Dde	80.45 ± 4.22 Aa	80.89 ± 4.65 ABa	75.49 ± 3.59 Cbc	64.98 ± 8.94 Ef	63.25 ± 5.76 Df	65.32 ± 4.68 Cef	76.72 ± 6.04 Bab
	MAP	70.99 ± 6.55 Ac	75.02 ± 6.84 ABbc	83.08 ± 9.23 Aa	81.92 ± 8.19 Aa	78.98 ± 4.01 ABCab	83.36 ± 6.68 Aa	75.11 ± 4.75 BCbc	83.52 ± 4.69 Aa	72.02 ± 4.65 Bc	78.91 ± 4.31 Bab
	Vac.	70.99 ± 6.55 Acd	71.29 ± 3.85 BCcd	76.53 ± 7.19B Cabc	81.62 ± 5.76Aa	77.17 ± 7.06 BCDab	74.53 ± 8.49 CDbcd	70.94 ± 5.82 CDcd	71.93 ± 9.56 BCbcd	71.00 ± 6.90 Bcd	69.68 ± 5.02 Cd

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2, Vac: vacuum.

3.4. Chemical Quality

3.4.1. Moisture Content and pH

The initial level of moisture, 44.4%, did not change significantly during the entire storage which could be attributed to no moisture loss due to the permeability of the packaging materials used (data not shown). The maximum level of moisture suggested for pastrami is 45% by the national codex. There was 1.75% moisture loss reported by Anıl (1988) for vacuum-packaged pastrami at 20°C for 3 months [39].

The initial pH of the pastrami was 5.90 and was around 5.74–5.89 on the 180th day (Table 5). For good quality pastrami, pH should not be less than 5.5 [36] and should not be higher than 6 according to the national food codex (2018) [1]. Aksu and Kaya (2005) reported that pH of sliced pastrami was 6.11 on the 90th day when MAP was applied. They related this increase with increased nitrogenous products due to proteolysis [36]. In addition, pH decrease was reported when sliced ham was packaged using 50% N_2 + 50% CO_2 at 8 °C for 28 days [42]. Gök et al. (2008) also reported a pH decrease for pastrami after storage of 60 days, and they attributed this decrease to acids produced by microbial activity [43].

3.4.2. Lipid Oxidation Stability

The effect of packaging materials and atmospheres on lipid oxidation is presented by Table 6. Lipid oxidation was determined as TBARS (mg MDA/kg) for pastrami. The initial TBARS was 0.27 mg MDA/kg and increased at different levels at all applications as the storage time was prolonged. TBARS ranged 0.39–0.47 mg MDA/kg on the 180th day. In general, TBARS tended to be lower under vacuum for all materials tested compared to MAP and air applications. The lowest TBARS was measured for vacuum application of multilayer material as 0.39 mg MDA/kg at the end of the storage. MAP and air applications of each material had no significant differences at the end of the storage. This could be related to higher oxygen at MAP and air applications of nanomaterials during cold storage. Although there was no initial headspace oxygen at MAP applications, oxygen increased and carbon dioxide decreased rapidly probably due to relatively higher OTR and CO_2TR of nanomaterials compared to the multilayer material.

The effect of packaging on the sensorial taste of the pastrami was also evaluated since lipid oxidation can result in rancidity which could be perceived in the taste evaluation. All applications of nanomaterial and air atmosphere of active-nanomaterial were limited to 60 days in terms of taste. However, the taste of the pastrami was acceptable for 90 days at MAP application of active nanomaterial. This period was 150 days for vacuum application of active nanomaterial and for all applications of multilayer material. There was no change perceived in taste due to lipid oxidation for products packaged in both nanomaterials with relatively high oxygen content for 60 days. Higher stability in lipid and protein oxidation in the first half of the storage period could be due to the ascorbic acid and nitrite content used in the pastrami. However, the packaging material and method possibly played a significant role for the extended period of storage [13].

Table 5. pH of Turkish pastrami packaged with nanomaterials under vacuum and modified atmosphere during cold storage.

		pH									
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	5.90 ± 0.01 ^{Aa}	5.83 ± 0.01 ^{BCDbc}	5.84 ± 0.05 ^{Bbc}	5.86 ± 0.02 ^{Dab}	5.79 ± 0.03 ^{EFc}	5.87 ± 0.05 ^{BCab}	5.79 ± 0.07 ^{CDc}	5.89 ± 0.03 ^{Aa}	5.73 ± 0.08 ^{Dd}	5.82 ± 0.03 ^{ABCbc}
	MAP	5.90 ± 0.01 ^{Aa}	5.85 ± 0.06 ^{ABCb}	5.77 ± 0.03 ^{Cd}	5.84 ± 0.06 ^{DEbc}	5.78 ± 0.01 ^{Fd}	5.84 ± 0.05 ^{BCbc}	5.78 ± 0.03 ^{Dd}	5.84 ± 0.01 ^{Bbc}	5.80 ± 0.01 ^{BCcd}	5.82 ± 0.01 ^{ABCbc}
	Vac.	5.90 ± 0.01 ^{Ab}	5.79 ± 0.04 ^{Dcd}	5.84 ± 0.04 ^{Bc}	5.80 ± 0.08 ^{EFc}	5.83 ± 0.09 ^{DEFc}	5.98 ± 0.02 ^{Aa}	5.91 ± 0.04 ^{ABb}	5.80 ± 0.03 ^{CDE}	5.74 ± 0.03 ^{Dd}	5.74 ± 0.01 ^{Dd}
M2	Air	5.90 ± 0.01 ^{Aa}	5.88 ± 0.04 ^{Aab}	5.91 ± 0.04 ^{Aa}	5.86 ± 0.04 ^{CDbc}	5.91 ± 0.03 ^{ABCa}	5.92 ± 0.02 ^{ABa}	5.91 ± 0.03 ^{ABa}	5.83 ± 0.01 ^{BCc}	5.88 ± 0.04 ^{Aab}	5.84 ± 0.03 ^{ABc}
	MAP	5.90 ± 0.01 ^{Aab}	5.87 ± 0.04 ^{ABabc}	5.94 ± 0.08 ^{Aa}	5.87 ± 0.05 ^{BCDabc}	5.93 ± 0.06 ^{ABa}	5.80 ± 0.13 ^{Cc}	5.86 ± 0.12 ^{BCabc}	5.82 ± 0.01 ^{BCDbc}	5.90 ± 0.07 ^{Aab}	5.82 ± 0.02 ^{BCbc}
	Vac.	5.90 ± 0.01 ^{Aabc}	5.80 ± 0.02 ^{CDd}	5.94 ± 0.05 ^{Aab}	5.93 ± 0.01 ^{Aab}	5.96 ± 0.03 ^{Aab}	5.91 ± 0.02 ^{ABabc}	5.96 ± 0.03 ^{Aa}	5.92 ± 0.01 ^{Aabc}	5.87 ± 0.02 ^{Ac}	5.89 ± 0.14 ^{Abc}
M3	Air	5.90 ± 0.01 ^{Aa}	5.80 ± 0.00 ^{CDbcd}	5.82 ± 0.01 ^{Bbcd}	5.77 ± 0.03 ^{Fcde}	5.85 ± 0.08 ^{CDEab}	5.82 ± 0.10 ^{Cbcd}	5.82 ± 0.08 ^{CDbcd}	5.84 ± 0.02 ^{Bbc}	5.73 ± 0.05 ^{De}	5.76 ± 0.03 ^{CDde}
	MAP	5.90 ± 0.01 ^{Aab}	5.87 ± 0.03 ^{ABabc}	5.91 ± 0.01 ^{Aab}	5.91 ± 0.01 ^{ABCab}	5.92 ± 0.03 ^{ABa}	5.86 ± 0.06 ^{BCbc}	5.84 ± 0.08 ^{BCDc}	5.78 ± 0.04 ^{Ed}	5.85 ± 0.03 ^{ABc}	5.84 ± 0.06 ^{ABc}
	Vac.	5.90 ± 0.01 ^{Aa}	5.82 ± 0.04 ^{CDb}	5.81 ± 0.07 ^{BCb}	5.92 ± 0.02 ^{ABa}	5.88 ± 0.05 ^{BCDa}	5.81 ± 0.06 ^{Cb}	5.83 ± 0.04 ^{CDb}	5.79 ± 0.01 ^{DEb}	5.79 ± 0.02 ^{CDb}	5.83 ± 0.01 ^{ABb}

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2, Vac: vacuum.

Table 6. Thiobarbituric acid reactive substances (TBARS, mg MDA/kg) of Turkish pastrami packaged with nanomaterials under vacuum and modified atmosphere during cold storage.

		TBARS (mg MDA/kg)									
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	0.27 ± 0.03 ^{Ae}	0.35 ± 0.04 ^{Ad}	0.39 ± 0.03 ^{ABc}	0.42 ± 0.01 ^{Ab}	0.41 ± 0.03 ^{ABb}	0.41 ± 0.03 ^{ABb}	0.42 ± 0.01 ^{Ab}	0.43 ± 0.01 ^{Ab}	0.46 ± 0.04 ^{Aa}	0.47 ± 0.03 ^{Aa}
	MAP	0.27 ± 0.03 ^{Ad}	0.34 ± 0.02 ^{ABc}	0.39 ± 0.05 ^{ABb}	0.40 ± 0.03 ^{ABab}	0.42 ± 0.02 ^{Aa}	0.42 ± 0.01 ^{Aa}	0.42 ± 0.01 ^{Aa}	0.42 ± 0.01 ^{Aa}	0.42 ± 0.03 ^{Ba}	0.43 ± 0.02 ^{BCa}
	Vac.	0.27 ± 0.03 ^{Ae}	0.31 ± 0.04 ^{CDd}	0.37 ± 0.02 ^{ABCc}	0.38 ± 0.04 ^{BCc}	0.39 ± 0.03 ^{BCbc}	0.39 ± 0.03 ^{Dbc}	0.39 ± 0.01 ^{Bbc}	0.39 ± 0.02 ^{Babc}	0.41 ± 0.02 ^{Bab}	0.42 ± 0.01 ^{Ca}
M2	Air	0.27 ± 0.03 ^{Ae}	0.31 ± 0.02 ^{BCDd}	0.36 ± 0.08 ^{ABCc}	0.40 ± 0.03 ^{ABb}	0.40 ± 0.04 ^{ABCb}	0.41 ± 0.03 ^{ABCb}	0.42 ± 0.01 ^{Ab}	0.42 ± 0.01 ^{Aab}	0.43 ± 0.02 ^{Bab}	0.45 ± 0.02 ^{Ba}
	MAP	0.27 ± 0.03 ^{Ae}	0.32 ± 0.02 ^{BCDd}	0.39 ± 0.02 ^{Ac}	0.40 ± 0.01 ^{ABc}	0.42 ± 0.02 ^{Ab}	0.42 ± 0.02 ^{Ab}	0.42 ± 0.01 ^{Ab}	0.41 ± 0.01 ^{Ab}	0.42 ± 0.02 ^{Bb}	0.44 ± 0.02 ^{Ba}
	Vac.	0.27 ± 0.03 ^{Ag}	0.32 ± 0.03 ^{BCf}	0.34 ± 0.03 ^{Ce}	0.36 ± 0.02 ^{CDde}	0.38 ± 0.02 ^{CDcd}	0.39 ± 0.02 ^{CDbc}	0.38 ± 0.02 ^{Ccd}	0.39 ± 0.03 ^{Bbc}	0.41 ± 0.02 ^{Bab}	0.42 ± 0.01 ^{Ca}
M3	Air	0.27 ± 0.03 ^{Ad}	0.30 ± 0.03 ^{CDc}	0.38 ± 0.02 ^{ABb}	0.42 ± 0.04 ^{Aa}	0.42 ± 0.03 ^{Aa}	0.41 ± 0.03 ^{ABCa}	0.42 ± 0.02 ^{Aa}	0.42 ± 0.02 ^{Aa}	0.41 ± 0.02 ^{Ba}	0.43 ± 0.03 ^{BCa}
	MAP	0.27 ± 0.03 ^{Ac}	0.29 ± 0.05 ^{Dc}	0.38 ± 0.04 ^{ABb}	0.39 ± 0.03 ^{BCab}	0.41 ± 0.02 ^{ABa}	0.40 ± 0.02 ^{BCDab}	0.41 ± 0.02 ^{Aa}	0.41 ± 0.02 ^{Aa}	0.41 ± 0.01 ^{Ba}	0.41 ± 0.03 ^{CDa}
	Vac.	0.27 ± 0.03 ^{Ad}	0.29 ± 0.05 ^{Dd}	0.35 ± 0.02 ^{BCc}	0.35 ± 0.04 ^{Dc}	0.36 ± 0.02 ^{Dbc}	0.35 ± 0.01 ^{Ec}	0.36 ± 0.01 ^{Dbc}	0.35 ± 0.01 ^{Cc}	0.38 ± 0.04 ^{Cab}	0.39 ± 0.03 ^{Da}

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2, Vac: vacuum.

3.4.3. Protein Stability (Carbonyl Content)

The effects of packaging material, packaging method and storage time on protein stability are presented in Table 7. The initial carbonyl content of sliced pastrami was 3.38 nmol/mg, and it slightly increased in all applications during cold storage of 180 days. The lowest carbonyl content was determined for the products packaged with multilayer material under vacuum. Carbonyl groups are formed due to the oxidation of amino acids and increase in carbonyl content refers to the increase in protein oxidation or loss of protein stability [44]. The total carbonyl groups are the main indication of protein oxidation which is commonly determined by the DNPH method for raw meat, meat emulsions, and cured meat products [44]. It is reported that an increase in protein oxidation and crosslinking of protein (myosin) under high oxygen application decreased the fresh meat tenderness compared to vacuum application [45]. A previous study showed that carbonyl content of foal steaks increased during storage in the conditions of overwrap and MAP with low (30% O_2 + 70% CO_2) and high oxygen (80% O_2 + 20% CO_2) content compared to vacuum [46]. The higher oxidation was related to high oxygen level and extended storage time as was the case in the present study.

3.5. Sensory Quality

Sensory evaluation of the product packaged with nanomaterials and multilayer material under vacuum and MAP is presented by Table 8. Products packaged with multilayer material under all applications were acceptable in terms of general appearance and color for entire storage. Products packaged with active nanomaterial was acceptable during 120 days in terms of visual attributes under MAP and vacuum. Only vacuum application of plain nanomaterial was acceptable for 120 days in terms of color. In general, the color is better preserved under vacuum applications.

The strong odor of pastrami perceived by panelists decreased during the increased storage period for all applications at different levels. All applications of multilayer material were acceptable during the entire storage for product odor. This period was 150 days for both nanomaterials under vacuum. However, it was limited to ≤120 days for air and MAP applications of both nanomaterials.

The texture scores decreased for all treatments with increased storage indicating hardening of pastrami slices. All applications of multilayer material were acceptable during entire storage for texture. In general, both nanomaterials had 120 days under MAP and vacuum.

The effects of packaging materials and method on the sensorial taste of the pastrami were also evaluated relating with rancidity due to lipid oxidation. All applications of nanomaterial and air atmosphere of the active nanomaterial were limited to 60 days in terms of taste. There was slight change perceived in taste due to rancidity for products packaged in both nanomaterials with relatively high oxygen content for 60 days. However, the taste of the pastrami was acceptable for 90 days in the MAP application of active nanomaterial and 150 days in the vacuum application of active nanomaterial and in all applications of the multilayer material. A product packaged with both nanomaterials under the air, MAP and vacuum except the vacuum application of active nanomaterial was not tasted due to visible fungal growth on the product after 150 days. Anıl (1988) also reported that there was no quality loss in terms of taste, color, firmness and appearance under a vacuum for 3 months storage of pastrami [39].

Table 7. Carbonyl content (nmol DNPH/mg protein) of Turkish pastrami packaged with nanomaterials under vacuum and modified atmosphere during cold storage.

		Carbonyl Content (nmol DNPH/mg Protein)									
Packaging Materials	**Application**	**Day 0**	**Day 5**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	3.38 ± 0.14 ^{Ae}	3.40 ± 0.16 ^{Be}	3.55 ± 0.14 ^{ABe}	3.85 ± 0.20 ^{Ad}	4.20 ± 0.10 ^{Ac}	4.28 ± 0.05 ^{Ac}	4.49 ± 0.19 ^{Ab}	4.58 ± 0.15 ^{Ab}	4.66 ± 0.19 ^{Aab}	4.80 ± 0.21 ^{Aa}
	MAP	3.38 ± 0.14 ^{Ag}	3.45 ± 0.14 ^{ABg}	3.52 ± 0.12 ^{ABg}	3.79 ± 0.16 ^{ABf}	4.05 ± 0.10 ^{Ae}	4.21 ± 0.10 ^{ABde}	4.35 ± 0.12 ^{ABcd}	4.55 ± 0.22 ^{Abc}	4.67 ± 0.26 ^{Aab}	4.77 ± 0.29 ^{Aa}
	Vac.	3.38 ± 0.14 ^{Ag}	3.47 ± 0.13 ^{ABg}	3.53 ± 0.06 ^{ABfg}	3.68 ± 0.14 ^{BCf}	4.09 ± 0.20 ^{Ae}	4.21 ± 0.13 ^{ABde}	4.34 ± 0.08 ^{ABcd}	4.46 ± 0.15 ^{Abc}	4.59 ± 0.20 ^{Aab}	4.67 ± 0.23 ^{Aa}
M2	Air	3.38 ± 0.14 ^{Af}	3.57 ± 0.06 ^{Ae}	3.55 ± 0.10 ^{ABe}	3.68 ± 0.04 ^{BCe}	4.10 ± 0.11 ^{Ad}	4.24 ± 0.14 ^{ABcd}	4.37 ± 0.17 ^{ABbc}	4.53 ± 0.12 ^{Aab}	4.61 ± 0.27 ^{Aa}	4.56 ± 0.16 ^{ABa}
	MAP	3.38 ± 0.14 ^{Ah}	3.44 ± 0.14 ^{ABgh}	3.61 ± 0.14 ^{Afg}	3.66 ± 0.15 ^{BCf}	4.09 ± 0.15 ^{Ae}	4.23 ± 0.13 ^{ABde}	4.29 ± 0.15 ^{Bcd}	4.44 ± 0.08 ^{Abc}	4.62 ± 0.24 ^{Aab}	4.69 ± 0.25 ^{Aa}
	Vac.	3.38 ± 0.14 ^{Af}	3.43 ± 0.10 ^{ABef}	3.60 ± 0.18 ^{Ae}	3.64 ± 0.13 ^{BCe}	4.06 ± 0.11 ^{ABd}	4.13 ± 0.10 ^{Bcd}	4.32 ± 0.13 ^{Bbc}	4.41 ± 0.16 ^{Aab}	4.51 ± 0.27 ^{ABab}	4.56 ± 0.25 ^{ABa}
M3	Air	3.38 ± 0.14 ^{Ae}	3.43 ± 0.06 ^{ABde}	3.55 ± 0.12 ^{ABcd}	3.66 ± 0.10 ^{BCc}	3.87 ± 0.05 ^{BCb}	3.97 ± 0.10 ^{Cb}	4.21 ± 0.10 ^{BCa}	4.23 ± 0.13 ^{Ba}	4.28 ± 0.14 ^{Ba}	4.30 ± 0.19 ^{BCa}
	MAP	3.38 ± 0.14 ^{Ae}	3.40 ± 0.08 ^{Be}	3.50 ± 0.11 ^{ABde}	3.59 ± 0.02 ^{CDcd}	3.76 ± 0.08 ^{CDbc}	3.89 ± 0.05 ^{Cb}	4.11 ± 0.09 ^{Ca}	4.11 ± 0.07 ^{Ba}	4.27 ± 0.20 ^{Ba}	4.21 ± 0.29 ^{Ca}
	Vac.	3.38 ± 0.14 ^{Ad}	3.40 ± 0.03 ^{Bd}	3.43 ± 0.05 ^{Bd}	3.46 ± 0.08 ^{Dcd}	3.63 ± 0.11 ^{Dbc}	3.73 ± 0.05 ^{Cab}	3.77 ± 0.09 ^{Dab}	3.75 ± 0.13 ^{Cab}	3.94 ± 0.29 ^{Ca}	3.93 ± 0.23 ^{Da}

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2, Vac: vacuum.

Table 8. Sensory attributes of Turkish pastrami packaged with nanomaterials under vacuum and modified atmosphere during cold storage.

		General Appearance								
Packaging Materials	**Application**	**Day 0**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	8.5 ± 0.7 ^{Aa}	7.9 ± 1.0 ^{Aab}	7.0 ± 1.2 ^{ABb}	7.2 ± 0.8 ^{ABb}	5.8 ± 1.6 ^{CDc}	5.4 ± 0.8 ^{BCcd}	4.8 ± 0.6 ^{Cd}	3.9 ± 1.4 ^{Be}	3.3 ± 1.3 ^{Be}
	MAP	8.6 ± 0.5 ^{Aa}	7.8 ± 1.1 ^{Aab}	7.5 ± 1.3 ^{ABb}	7.3 ± 1.3 ^{ABb}	5.6 ± 1.4 ^{Dc}	5.4 ± 1.1 ^{BCcd}	5.3 ± 1.2 ^{BCcd}	4.4 ± 1.6 ^{Bd}	3.2 ± 0.7 ^{Be}
	Vac.	8.7 ± 0.5 ^{Aa}	7.3 ± 1.4 ^{ABb}	7.2 ± 1.3 ^{ABb}	7.8 ± 0.6 ^{Aab}	6.0 ± 1.2 ^{CDc}	5.8 ± 1.1 ^{Bc}	5.3 ± 0.8 ^{BCc}	4.3 ± 1.4 ^{Bd}	3.2 ± 1.1 ^{Be}
M2	Air	8.5 ± 0.7 ^{Aa}	7.3 ± 1.4 ^{ABb}	6.9 ± 1.0 ^{ABb}	6.4 ± 1.2 ^{BCb}	5.5 ± 1.2 ^{Dc}	4.8 ± 1.1 ^{Cc}	4.8 ± 1.2 ^{Cc}	3.8 ± 0.9 ^{Bd}	3.2 ± 0.8 ^{Bd}
	MAP	8.6 ± 0.5 ^{Aa}	6.5 ± 1.7 ^{Bb}	6.6 ± 1.6 ^{Bb}	5.8 ± 1.2 ^{Cbc}	6.0 ± 1.1 ^{CDbc}	6.0 ± 1.0 ^{Bbc}	5.0 ± 1.2 ^{Ccd}	4.1 ± 1.1 ^{Bde}	3.3 ± 1.1 ^{Be}
	Vac.	8.7 ± 0.5 ^{Aa}	7.6 ± 1.2 ^{ABb}	7.3 ± 1.1 ^{ABb}	7.5 ± 1.2 ^{Ab}	5.8 ± 1.4 ^{CDc}	5.4 ± 0.9 ^{BCdc}	5.6 ± 0.7 ^{Bc}	4.7 ± 0.9 ^{Bd}	3.5 ± 1.3 ^{Be}
M3	Air	8.5 ± 0.7 ^{Aa}	7.8 ± 1.3 ^{Aab}	8.0 ± 1.1 ^{Aab}	7.5 ± 0.9 ^{Abc}	6.8 ± 1.1 ^{BCcd}	7.3 ± 0.8 ^{Abc}	6.8 ± 1.0 ^{Acd}	6.3 ± 1.0 ^{Ade}	5.8 ± 0.8 ^{Ae}
	MAP	8.6 ± 0.5 ^{Aa}	8.1 ± 1.0 ^{Aab}	7.9 ± 1.0 ^{Aabc}	7.6 ± 1.2 ^{Abc}	7.2 ± 1.1 ^{ABc}	7.5 ± 0.7 ^{Abc}	6.0 ± 0.9 ^{Bd}	6.3 ± 0.7 ^{Ad}	5.8 ± 1.0 ^{Ad}
	Vac.	8.7 ± 0.5 ^{Aa}	8.2 ± 0.8 ^{Aab}	7.7 ± 1.2 ^{ABbcd}	7.9 ± 1.0 ^{Aabc}	7.9 ± 0.3 ^{Aabc}	7.3 ± 0.8 ^{Acd}	7.0 ± 1.0 ^{Ade}	6.4 ± 1.3 ^{Aef}	6.2 ± 1.0 ^{Af}
		Color								
M1	Air	8.4 ± 0.8 ^{Aa}	7.8 ± 1.1 ^{Aab}	6.4 ± 1.8 ^{Dcd}	7.0 ± 1.0 ^{ABbc}	5.7 ± 1.6 ^{Cde}	5.3 ± 0.9 ^{BCDe}	4.8 ± 0.8 ^{CDef}	3.8 ± 1.2 ^{Bfg}	3.0 ± 1.5 ^{Bg}
	MAP	8.6 ± 0.5 ^{Aa}	7.8 ± 1.3 ^{Aa}	6.8 ± 1.5 ^{BCDb}	6.8 ± 1.0 ^{ABb}	5.9 ± 1.5 ^{BCb}	4.9 ± 0.7 ^{CDc}	4.9 ± 1.1 ^{CDc}	3.8 ± 1.3 ^{Bd}	2.9 ± 0.7 ^{Be}
	Vac.	8.4 ± 0.8 ^{Aa}	7.5 ± 1.5 ^{ABab}	7.1 ± 0.8 ^{ABCDb}	7.6 ± 0.5 ^{Aab}	6.0 ± 1.3 ^{BCc}	5.7 ± 1.2 ^{BCc}	5.4 ± 0.8 ^{Cc}	3.9 ± 1.1 ^{Bd}	3.2 ± 1.6 ^{Bd}
M2	Air	8.4 ± 0.8 ^{Aa}	7.4 ± 1.4 ^{ABb}	6.6 ± 1.3 ^{CDbc}	6.2 ± 1.3 ^{Bc}	5.7 ± 1.4 ^{Ccd}	4.8 ± 1.3 ^{Dde}	4.6 ± 0.5 ^{Def}	3.8 ± 1.2 ^{Bfg}	3.1 ± 0.8 ^{Bg}
	MAP	8.6 ± 0.5 ^{Aa}	6.5 ± 1.8 ^{Bb}	6.8 ± 1.3 ^{BCDb}	6.1 ± 1.4 ^{Bbc}	5.9 ± 1.4 ^{BCbc}	5.9 ± 0.9 ^{Bbc}	5.3 ± 0.9 ^{CDc}	3.8 ± 1.4 ^{Bd}	2.7 ± 0.9 ^{Be}
	Vac.	8.4 ± 0.8 ^{Aa}	7.4 ± 1.6 ^{ABb}	7.2 ± 1.1 ^{ABCDb}	6.8 ± 1.1 ^{ABbc}	6.1 ± 1.2 ^{BCcd}	5.3 ± 0.9 ^{BCDde}	5.4 ± 0.9 ^{Cde}	4.8 ± 1.2 ^{Be}	3.1 ± 0.9 ^{Bf}
M3	Air	8.4 ± 0.8 ^{Aa}	7.8 ± 1.4 ^{Aab}	7.7 ± 1.2 ^{ABCabc}	7.2 ± 0.8 ^{Abcd}	6.9 ± 1.3 ^{ABcde}	7.4 ± 0.7 ^{Abcd}	6.8 ± 1.1 ^{ABdef}	6.1 ± 0.8 ^{Aef}	6.0 ± 0.9 ^{Af}
	MAP	8.6 ± 0.5 ^{Aa}	8.0 ± 1.1 ^{Aab}	7.9 ± 1.2 ^{ABab}	7.3 ± 1.3 ^{Ab}	7.3 ± 1.1 ^{Ab}	7.8 ± 0.6 ^{Aab}	6.2 ± 0.8 ^{Bc}	6.4 ± 0.8 ^{Ac}	6.2 ± 1.0 ^{Ac}
	Vac.	8.4 ± 0.8 ^{Aa}	8.0 ± 1.2 ^{Aab}	8.1 ± 1.2 ^{Aab}	7.8 ± 0.8 ^{Aabc}	7.9 ± 0.5 ^{Aabc}	7.3 ± 0.8 ^{Abcd}	7.0 ± 0.9 ^{Acd}	6.6 ± 1.6 ^{Ade}	6.1 ± 1.3 ^{Ae}

Table 8. *Cont.*

Packaging Materials	Application	Day 0	Day 10	Day 20	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Odor										
M1	Air	8.4 ± 0.7 ^{Aa}	7.3 ± 1.3 ^{ABa}	7.2 ± 1.2 ^{Aa}	7.1 ± 1.0 ^{ABCbc}	6.0 ± 1.2 ^{ABCcd}	5.3 ± 1.0 ^{BCde}	4.7 ± 1.1 ^{Ce}	4.8 ± 2.3 ^{Be}	3.4 ± 1.7 ^{Bf}
	MAP	8.4 ± 0.7 ^{Aa}	7.8 ± 1.1 ^{ABab}	6.7 ± 1.2 ^{Ab}	7.3 ± 1.3 ^{ABb}	5.4 ± 1.0 ^{Cc}	5.0 ± 1.3 ^{Cc}	5.0 ± 0.7 ^{BCc}	4.8 ± 2.4 ^{Bc}	3.7 ± 1.6 ^{Bd}
	Vac.	8.3 ± 0.8 ^{Aa}	7.2 ± 1.5 ^{ABb}	6.9 ± 1.2 ^{Ab}	7.3 ± 0.8 ^{ABb}	5.7 ± 1.0 ^{BCc}	5.6 ± 1.1 ^{BcC}	5.4 ± 0.9 ^{BCc}	5.3 ± 1.5 ^{ABc}	3.1 ± 1.1 ^{Bd}
M2	Air	8.4 ± 0.7 ^{Aa}	7.3 ± 1.4 ^{ABb}	7.1 ± 1.3 ^{Abc}	6.3 ± 1.7 ^{BCbc}	6.2 ± 1.3 ^{ABCcd}	5.1 ± 1.3 ^{BCde}	5.2 ± 1.1 ^{BCde}	4.8 ± 1.4 ^{Be}	3.1 ± 1.0 ^{Bf}
	MAP	8.4 ± 0.7 ^{Aa}	6.7 ± 1.5 ^{Bbc}	6.9 ± 1.2 ^{Ab}	6.0 ± 1.2 ^{Cbc}	6.3 ± 1.4 ^{ABCbc}	6.0 ± 1.1 ^{Bbc}	5.7 ± 1.0 ^{Bc}	4.4 ± 1.6 ^{Bd}	3.2 ± 1.3 ^{Be}
	Vac.	8.3 ± 0.8 ^{Aa}	7.3 ± 1.3 ^{ABb}	7.2 ± 1.2 ^{Ab}	6.8 ± 1.1 ^{ABCb}	5.9 ± 0.9 ^{ABCc}	5.3 ± 0.9 ^{BCc}	5.2 ± 0.6 ^{BCc}	5.3 ± 0.8 ^{ABc}	3.6 ± 1.3 ^{Bd}
M3	Air	8.4 ± 0.7 ^{Aa}	7.8 ± 1.4 ^{ABab}	7.7 ± 1.1 ^{Aab}	7.1 ± 1.4 ^{ABCbc}	7.0 ± 1.0 ^{Abc}	7.1 ± 0.7 ^{Abc}	6.5 ± 1.0 ^{Ac}	6.5 ± 0.9 ^{Ac}	5.1 ± 1.0 ^{Ad}
	MAP	8.4 ± 0.7 ^{Aa}	7.9 ± 1.2 ^{Aab}	7.5 ± 1.1 ^{Abc}	7.6 ± 1.0 ^{Abc}	6.7 ± 1.2 ^{ABd}	7.1 ± 0.8 ^{Acd}	5.5 ± 0.8 ^{BCe}	5.6 ± 0.8 ^{ABe}	5.2 ± 0.6 ^{Ae}
	Vac.	8.3 ± 0.8 ^{Aa}	8.0 ± 1.1 ^{Aa}	7.7 ± 1.4 ^{Aab}	7.5 ± 1.2 ^{Aabc}	6.6 ± 1.6 ^{ABc}	6.8 ± 0.9 ^{Abc}	6.5 ± 1.1 ^{Ac}	6.6 ± 1.3 ^{Ac}	5.5 ± 1.0 ^{Ad}
Texture										
M1	Air	8.3 ± 0.9 ^{Aa}	7.7 ± 1.1 ^{ABab}	7.4 ± 1.1 ^{ABab}	7.2 ± 1.1 ^{ABbc}	6.4 ± 1.2 ^{BCc}	5.2 ± 0.9 ^{BCd}	5.3 ± 1.0 ^{Bd}	4.7 ± 1.5 ^{Cd}	3.6 ± 1.3 ^{Be}
	MAP	8.3 ± 0.8 ^{Aa}	7.4 ± 1.3 ^{ABa}	7.3 ± 1.3 ^{ABa}	7.3 ± 1.3 ^{Aa}	5.4 ± 1.3 ^{Cb}	5.3 ± 1.2 ^{BCb}	5.4 ± 1.1 ^{Bb}	4.9 ± 1.5 ^{Cb}	3.7 ± 1.4 ^{Bc}
	Vac.	8.6 ± 0.5 ^{Aa}	7.3 ± 1.6 ^{ABb}	6.8 ± 1.5 ^{ABCbc}	7.5 ± 0.9 ^{Ab}	6.1 ± 1.1 ^{BCcd}	5.7 ± 1.1 ^{Bd}	5.5 ± 0.7 ^{Bd}	4.6 ± 1.0 ^{CDe}	3.3 ± 1.1 ^{Bf}
M2	Air	8.3 ± 0.9 ^{Aa}	7.5 ± 1.5 ^{ABab}	6.7 ± 1.0 ^{BCbc}	6.1 ± 1.5 ^{BCcd}	5.5 ± 0.9 ^{Cde}	4.7 ± 0.7 ^{Cef}	4.5 ± 0.5 ^{Cf}	3.5 ± 1.1 ^{Dg}	3.6 ± 1.3 ^{Bg}
	MAP	8.3 ± 0.8 ^{Aa}	6.6 ± 1.6 ^{Bb}	6.0 ± 1.3 ^{Cbc}	5.9 ± 1.2 ^{Cbc}	6.2 ± 1.3 ^{BCbc}	5.5 ± 0.7 ^{Bc}	5.3 ± 1.0 ^{Bcd}	4.4 ± 1.3 ^{CDd}	3.4 ± 1.2 ^{Be}
	Vac.	8.6 ± 0.5 ^{Aa}	7.3 ± 1.7 ^{ABbc}	7.9 ± 0.8 ^{Aab}	6.7 ± 1.4 ^{ABCcd}	6.2 ± 0.9 ^{BCde}	5.3 ± 0.6 ^{BCef}	5.6 ± 0.5 ^{Bef}	4.7 ± 1.4 ^{Cf}	3.6 ± 1.4 ^{Bg}
M3	Air	8.3 ± 0.9 ^{Aa}	6.9 ± 1.6 ^{ABb}	7.1 ± 1.4 ^{ABCb}	7.1 ± 1.1 ^{ABb}	6.8 ± 0.9 ^{ABb}	7.1 ± 0.8 ^{Ab}	6.8 ± 0.7 ^{Ab}	6.6 ± 0.9 ^{Ab}	5.3 ± 1.1 ^{Ac}
	MAP	8.3 ± 0.8 ^{Aa}	8.0 ± 1.0 ^{Aa}	7.1 ± 1.2 ^{ABCb}	6.8 ± 1.4 ^{ABCb}	6.8 ± 1.5 ^{ABb}	6.8 ± 1.0 ^{Ab}	5.5 ± 0.8 ^{Bc}	5.3 ± 1.3 ^{BCc}	5.0 ± 0.9 ^{Ac}
	Vac.	8.6 ± 0.5 ^{Aa}	7.7 ± 1.3 ^{ABab}	6.9 ± 1.6 ^{ABCbc}	7.5 ± 1.2 ^{Ab}	7.7 ± 1.0 ^{Aab}	6.9 ± 0.9 ^{Abc}	7.0 ± 0.9 ^{Abc}	6.2 ± 1.3 ^{ABcd}	5.4 ± 1.2 ^{Ad}
Taste										
Packaging Materials	**Application**	**Day 0**	**Day 10**	**Day 20**	**Day 30**	**Day 60**	**Day 90**	**Day 120**	**Day 150**	**Day 180**
M1	Air	8.3 ± 0.8 ^{Aa}	7.5 ± 1.2 ^{Aab}	7.1 ± 1.1 ^{Abc}	6.5 ± 1.2 ^{Ac}	6.3 ± 1.4 ^{ABCc}	4.9 ± 0.8 ^{BCd}	4.7 ± 1.2 ^{Dd}	*	
	MAP	8.4 ± 0.7 ^{Aa}	7.6 ± 1.5 ^{Aab}	7.0 ± 1.7 ^{Ab}	6.9 ± 1.3 ^{Ab}	5.8 ± 1.4 ^{Cc}	4.7 ± 1.0 ^{Cd}	4.8 ± 0.6 ^{CDd}		
	Vac.	8.3 ± 0.7 ^{Aa}	7.2 ± 1.4 ^{ABb}	6.8 ± 1.4 ^{Ab}	7.4 ± 0.7 ^{Ab}	5.8 ± 1.7 ^{Cc}	4.9 ± 0.7 ^{BCc}	4.9 ± 0.8 ^{CDc}		
M2	Air	8.3 ± 0.8 ^{Aa}	7.1 ± 1.2 ^{ABb}	6.8 ± 1.3 ^{Ab}	6.5 ± 1.6 ^{Ab}	5.5 ± 1.2 ^{Cc}	4.4 ± 0.8 ^{Cd}	4.6 ± 0.5 ^{Dd}		
	MAP	8.4 ± 0.7 ^{Aa}	6.3 ± 1.2 ^{Bbc}	6.5 ± 1.2 ^{Ab}	5.4 ± 1.3 ^{Bcd}	6.1 ± 0.8 ^{ABCbc}	5.7 ± 0.8 ^{Bbc}	4.8 ± 0.8 ^{CDd}		
	Vac.	8.3 ± 0.7 ^{Aa}	7.3 ± 1.3 ^{ABb}	7.4 ± 1.1 ^{Ab}	6.7 ± 1.3 ^{Abc}	5.9 ± 0.9 ^{BCcd}	5.5 ± 0.9 ^{Bd}	5.5 ± 1.0 ^{BCd}	5.3 ± 1.0 ^{Ad}	3.4 ± 1.4 ^{Be}
M3	Air	8.3 ± 0.8 ^{Aa}	7.5 ± 1.4 ^{Aab}	7.4 ± 1.3 ^{Aabc}	7.4 ± 0.9 ^{Aabc}	6.4 ± 0.9 ^{ABCcd}	7.1 ± 0.7 ^{Abc}	5.8 ± 1.2 ^{Bde}	6.0 ± 1.0 ^{Ad}	5.0 ± 1.8 ^{Ae}
	MAP	8.4 ± 0.7 ^{Aa}	8.0 ± 1.0 ^{Aab}	7.7 ± 1.0 ^{Aabc}	7.3 ± 1.2 ^{Abc}	6.9 ± 0.9 ^{ABc}	6.9 ± 1.1 ^{Ac}	5.3 ± 0.7 ^{BCDd}	5.5 ± 1.0 ^{Ad}	4.8 ± 1.3 ^{Ad}
	Vac.	8.3 ± 0.7 ^{Aa}	7.9 ± 1.0 ^{Aab}	7.2 ± 1.5 ^{Abc}	7.3 ± 1.2 ^{Aabc}	7.2 ± 1.3 ^{Abc}	6.9 ± 1.2 ^{Abc}	6.6 ± 1.1 ^{Acd}	5.8 ± 1.0 ^{Ade}	4.9 ± 1.4 ^{Ae}

[1] Mean values with similar capital letters in the same column for a given storage day are not statistically significant ($p > 0.05$). Mean values with similar small letters in the same row for a given application are not statistically significant ($p > 0.05$). M1: PP/nanoclay, M2: PP/nanoclay/PβP, M3: PP/PA/EVOH/PE, Air: 21% O_2 79% N_2, MAP: 50% CO_2 50% N_2, Vac: vacuum. * Not tasted due to microbial growth.

4. Conclusions

The antimicrobial effect of PβP on the pastrami was determined to be higher under vacuum than the other applications suggesting direct contact of the material with the food surface. PβP is an immobilized antimicrobial agent and not diffusing from the material, and there would be direct contact of the material needed for an antibacterial effect. The shelf life was limited to 90 days at high carbon dioxide application and 60 days in an air atmosphere of the active nanomaterial. The shelf life was also determined as 60 days for all applications of nanomaterial containing only 1% nanoclay. The sliced pastrami was acceptable for 150 days under vacuum using both PβP containing nanomaterial and multilayer material, which is comparable with the existing commercial shelf life of 1–3 months on the market. This is a very promising result since multilayer materials used for the same purpose are very costly, requiring complex production, and are not recyclable. Overall, the developed active nanomaterial could improve the safety and quality of ready-to-eat meat products, and at the same time contributes to reducing raw material use and packaging waste, and to minimizing environmental problems.

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