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Influence of ultra-high barrier packaging on the shelf-life of microwave-assisted thermally sterilized chicken pasta

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ABSTRACT

This accelerated shelf life study of a ready-to-eat meal processed with a microwave-assisted thermal sterilization (MATS) system aimed to evaluate the performance of double metal oxide coated polyethylene terephthalate (PET) layers-based ultra-high barrier packaging along with ethylene vinyl alcohol (EVOH)-based pouches, and aluminum (AL) foil-based pouches (served as control). First, we evaluated barrier changes in the two types of pouches (double-layered PET and EVOH) caused by MATS processing. Next, we determined the influence of barrier properties on the physical, chemical and sensory quality of MATS-processed chicken pasta meals at accelerated storage conditions at 49 °C. Sensory evaluation was also done at lower storage temperature of 38 °C. Results demonstrated that MATS processing did not affect the barrier properties of double metal oxide coated PET pouches, however, it significantly influenced the barrier properties of EVOH-based pouches. After storage at 49 °C for 60 days, there was a small total color change ($\Delta E = 3.5$) in chicken pasta meals in the double coated film pouches. This result was similar to that obtained for aluminum foil pouches ($p > 0.05$), but significantly lower than that for the EVOH pouches ($\Delta E = 5.5$). The double metal oxide coated PET packaging provided an excellent barrier against lipid oxidation similar to that of aluminum (AL) foil-based pouches. A trained sensory panel scored the recipe between 6.0 and 6.45 immediately after MATS processing on a labelled effective magnitude (LAM) scale from 1 to 9 (worst to best quality). Results indicate that the newly developed double-layered PET pouches offer an excellent alternative to higher density metal foil-based packaging.

1. Introduction

Shelf stable, ready-to-eat meals are sterilized to inactivate the spores of *C. botulinum* (type A) in order to extend the shelf life of food products to 1–8 years (depending upon product composition) at ambient storage conditions (Catauro & Perchonok, 2012). These products are often processed using conventional retorts, which can significantly degrade the quality of some food products due to longer processing times. However, microwave-assisted thermal sterilization (MATS) has shown promise in producing products with improved quality attributes due to its volumetric heating and shorter processing time (Tang, 2015; Zhang, Bhunia, Tang, & Sablani, 2018; Zhang et al., 2019).

Packaging plays an important role in maintaining the storage stability and shelf life of in-package processed food products. Commonly, aluminum-foil based multilayer pouches are used for shelf stable retorted food products, which are impermeable to gases and water vapor. But these aluminum foil laminated (AL) pouches cannot be used in MATS processing, as they interfere with electromagnetic waves. Hence, polymeric packaging is a preferred alternative (Tang, 2015). However, the oxygen and water vapor barrier properties of polymeric packaging degrade during thermal processing (Dhawan et al., 2014; Zhang et al., 2017). These changes in barrier properties often affect the food quality during storage and the shelf life of the food (Patel et al., 2019, 2020; Sonar, Al-Ghamdi, Marti, Tang, & Sablani, 2020; Zhang et al., 2019).

Polymer packaging with very high oxygen and water vapor barriers, similar to AL pouches, are needed for a longer shelf life of sterilized products. Multilayer packages with high-barrier properties, such as EVOH, metal oxide-coated PET, and oxygen scavenger embedded structures have been developed to improve barrier properties. However,

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EVOH is hydrophilic and tends to absorb moisture even when it is protected by a hydrophobic layer (Mokwena & Tang, 2012). Metal oxide-coated layers are prone to develop cracks and pinholes during thermal sterilization processes (Ayvaz et al., 2012; Parhi, Bhunia, Rasco, Tang, & Sablani, 2019). Similarly, the water barrier properties of pouches with oxygen scavenger layer decreases significantly after thermal processing (Patel et al., 2019).

To address these issues, multilayer structures with two layers of Al_2O_3 coated polyethylene terephthalate (PET) protected by other layers have recently been developed. According to Parhi, Tang & Sablani (2020), two layers of metal oxide can provide a better barrier against oxygen ingress in case one layer develops cracks or pinholes during thermal processing or during storage. Such packaging is suitable for microwave processes and can be used to achieve a required shelf life of 3–5 years for extended duration space missions and army field operations. However, research is needed on the shelf life performance of foods with different chemical compositions packaged in these pouches to understand how they perform as compared with control AL foil pouches.

The objectives of this study were to evaluate the barrier performance of the newly fabricated pouches with two layers of Al_2O_3 coated PET after MATS processing. Specifically, we compared the performance of metal oxide coated pouches with control AL and EVOH-based pouches using the physical, chemical, and sensory quality parameters of a multicomponent recipe based on chicken pasta at accelerated storage condition of 49 °C for 60 days.

2. Materials and methods

2.1. Chicken pasta preparation

The chicken pasta formulation was inspired from ready-to-eat meals for U.S. Army rations, with some modifications. Table 1 lists the ingredients of the formulation. To make the recipe, 500 g fettucine pasta was cooked for 4 min in 4 L boiling water prior to MATS processing (Barnett, Sablani, Tang, & Ross, 2019). An 8 L cooking pot was used to make the sauce for each batch. First, butter was melted, and then a slurry of water and starch were added, followed by whipped cream. When the temperature reached 82 °C, the spices, chipotle seasoning, and salt were added and mixed thoroughly. Once the sauce reached room temperature, the noodles, onion, sundried tomatoes, and precut chicken pieces (2 × 1.2 × 2 cm approx.) were added into individual pouches, followed by adding the sauce. The pouches were then stored in refrigerated conditions (20–30 min) until they were sealed.

2.2. Packaging

Two types of pouches were compared in this study: PET-based ultra-high barrier pouches fabricated using two layers of Al_2O_3 (called Double-Layer pouches) (Fig. 1) and EVOH-based pouches. The initial weight of the meals was 230 g for each pouch. The pouches were vacuum sealed (99%) using Easy-Pack (UltraSource. LLC. Kansas, MO) at 180-200 °C for 3–5 s. One set of Double-Layer pouches were vacuum sealed into aluminum foil-based pouches (AL) (KSM Enterprises, Gig Harbor, WA) after MATS processing to protect the food matrix from permeation of gases and water vapor. These pouches served as a control. The reason for this over-sealing of polymer pouches with AL pouches is that the AL pouches cannot be MATS-processed. EVOH-based pouches have lower oxygen and water vapor barriers than the metal oxide-coated film-based pouches (Mokwena, Tang, Dunne, Yang, & Chow, 2009). EVOH-based pouches were selected to demonstrate the effects of the oxygen transmission rate (OTR) and the water vapor transmission rate (WVTR) of the packaging on the chicken pasta.

The OTR and WVTR of the pouch films were measured before and after MATS processing using the Mocon Ox-Tran 2/21 MH permeability instrument and Permatran 3/33 MG model (Modern Control, Minneapolis, MN). Conditions for the OTR test were 55% relative humidity (RH) at 23 °C and 1 atm, following D3985 and ASTM F372-99 standards. Conditions for the WVTR test were 100% RH at 38 °C and 1 atm, following ASTM F1927 standards. Two replicate films of 50 cm^2 surface area were used for the barrier property tests. Pouch film thickness was measured using an electronic disc micrometer (Model 15769, Flexbar Machine Co., Islandia, NY) at three locations.

Table 1
Ingredients and their percentage for chicken pasta formulation.

Bulk Ingredients	% of total weight of pouch at 230 g
Fettucine Pasta (DeCecco Fettucine no 6, Italy)	20
Chicken breasts (Safeway brand)	25.5
Sun-dried tomatoes (California Sun dry, WI)	1.83
Onion (Great value, Walmart)	0.75
Sauce Ingredients	
Southwest chipotle seasoning (Mrs Dash, NJ)	0.79
Water	25.66
UHT Whipped cream (Darigold, WA)	23.43
Salt (Morton, IL)	0.21
Dried basil (McCormick, MD)	0.08
Black pepper (McCormick, MD)	0.08
Garlic powder (McCormick, MD)	0.13
Unsalted Butter (Darigold, WA)	0.81
ThermoFlo Starch (Ingredion, IL)	0.58
Total Sauce	52

2.3. Microwave-assisted thermal sterilization (MATS)

The single-mode pilot-scale microwave-assisted thermal sterilization system (MATS) (25 kW, 915 MHz) at Washington State University was used in this study. A detailed description of this system can be found in Tang (2015). Pre-calibrated Ellab sensors (Ellab, Centennial, CO) were used to record the temperature profile at the cold spot during processing (Fig. 2). The belt speed was set to achieve the targeted lethality. Processing conditions were: microwave power of 4.7, 5.2, 2.9, and 2.2 kW for each of the four heating cavities, operating pressure of 34 psig/336 kPa, 25 min preheating in water at 61 °C, 3.9 min microwave heating in circulating water at 121 °C, 4.0 min holding in circulation water at 121 °C, and 5 min cooling in tap water at 20 °C cooling. The obtained lethality at the cold spot in pouches was $F_o = 12.7$ min. Equation (1) was used to calculate the lethality value, F_o:

$$F_0 = \int_0^t 10\frac{T - T_{ref}}{z} dt \tag{1}$$

where T (°C) is the cold spot temperature during processing at time t, T_{ref} is the reference temperature (121.1 °C), and z is the temperature sensitivity of decimal reduction time in the target pathogen, taken as 10 °C.

2.4. Storage

According to the accelerated shelf-life testing (ASLT) hypothesis, storing at 49 °C for 4 weeks and at 38 °C for 6 months is equivalent to 3 years of storage at 23 °C (Robertson, 2012). Since we were interested in determining whether polymer packaging could provide beyond 3 years of shelf life, the chicken pasta samples were stored for 60 days (~8 weeks) at 49 °C. Half of the MATS-processed pouches were sent to US Army Natick Soldier Center (Natick, MA. USA) for sensory analysis, and the rest were stored at 49 ± 0.1 °C/120 °F in an incubator for 60 days at Washington State University (Pullman, WA, USA). For sensory analysis, the packages were stored at two temperatures, 38 °C and 49 °C, for 6 months and 4 weeks, respectively, and compared with samples immediately after processing.

The following quality attributes of chicken pasta were investigated during storage:

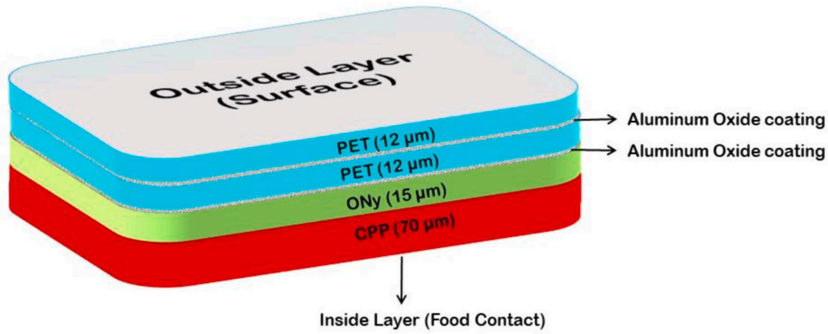

Fig. 1. Schematic of a double metal oxide coated barrier film.

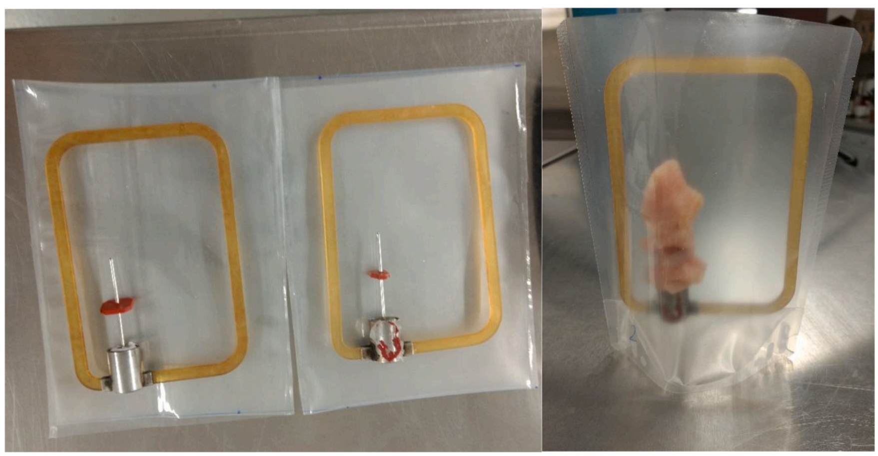

Fig. 2. Ellab sensors with chicken pieces placed in pouches for time-temperature measurement at the cold spot (n = 3).

2.4.1. Product weight/moisture loss

Product weight/moisture loss is an important measure of any packaged shelf-stable food since it influences the physical and chemical qualities of the food. After MATS processing, the initial weight of three packages of each type was recorded, and weight loss during storage at 49 °C was monitored using a GK703-model balance scale (Sartorius, Goettingen, Germany) for 60 days ($n = 3$).

2.4.2. Color analysis

Color parameters (L^*, a^*, b^*) were measured using a CM-5 spectrophotometer from Konica Minolta (Ramsey, NJ). Since it was difficult to measure the color of the multicomponent recipe, a 100-g of chicken pasta sample was blended with 200 mL water, and color parameters were recorded while the blended sample was in a 5 cm diameter Petri dish. The total color difference was calculated as $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$. At least nine samples were taken for color measurements at each time point (n = 9).

2.4.3. pH

pH is a good indicator of apparent chemical and microbial changes during storage time. Therefore, pH of the blended sample was measured using a pH meter (SevenGo SG2, Mettler Toledo, Schwerzenbach, Switzerland). Three replicate samples from each pouch were taken for pH measurements (n = 3).

2.4.4. Instrumental texture

Chicken pieces were taken out of the pouches, excess sauce was wiped off the surface of the pieces before mechanical measurement. The size of chicken pieces was approximately 1.5 × 0.7 × 1.5 cm. The chicken pieces were subjected to Warner-Bratzler blade with rectangular slot blade (3 mm) at speed of 1 mm/s, and peak force was recorded (N) using an instrumental texture analyzer TA-XT2 from Stable Micro Systems Ltd. (Surrey GU7 1 YL, United Kingdom).

2.4.5. Lipid oxidation

Lipid oxidation was measured spectrophotometrically using a modified 2-thiobarbituric acid reactive substance (TBARS) method (Bhunia, Ovissipour, Rasco, Tang, & Sablani, 2017). Absorbance was measured at 532 nm, and lipid oxidation value was expressed as TBARS in mg of malonaldehyde (MDA) kg^{-1} of the sample (n = 6).

2.4.6. Sensory attributes

Twelve trained panelists at the US Army Natick Center administered the sensory assessment for the chicken pasta and were asked to evaluate the meals based on appearance, odor, flavor, texture, and overall acceptance on a qualitative scale ranging from 1 to 9. The sensory evaluation of chicken pasta was administered immediately after MATS processing, after 3 and 6 months at 38 °C, and after 4 weeks at 49 °C during storage. The meals were warmed before serving, and each serving size was 15–25 g. Sample evaluations occurred in random order at the time of each storage pull. Samples were presented randomly to panelists in individual booths with controlled lighting and climate conditions. Each booth was equipped with a computer system for collecting data and comments to explain ratings. Panelists were trained in conjugation with Tufts University Sensory Science Centre, Boston, MA. Sensory evaluation data was collected and analyzed using SIMS2000 software (Sensory Information Management Systems, Berkeley Heights, NJ).

2.5. Data analysis

The data was analyzed using pairwise Tukey's honestly significant difference (HSD) via JMP 14 (SAS Institute Inc., Cary, NC). A significance value of α = 0.05 was used for the analysis. All experiments before and after processing were conducted in triplicate sampling from different packages unless otherwise noted.

3. Results and discussion

3.1. Oxygen and water vapor transmission rates

Table 2 shows the changes in OTR and WVTR after processing and after 60 days' storage at 49 °C. The OTR of the Double-Layer pouch was below the detection limit of the instrument before MATS processing, and it remained very low (below detection limit) after MATS processing. This indicates the superior oxygen barrier performance of this pouch. Similarly, the WVTR of this pouch did not change ($p > 0.05$) after MATS processing. Previous studies on pouches with one layer of metal oxide-coated PET found significant changes in the OTR and WVTR after MATS processing (Patel et al., 2020, 2019; Zhang et al., 2019). According to Zhang et al. (2019), the OTR of three polymeric pouches with single layer of metal oxide increased significantly after MATS processing, from 0.016 to 0.039 cc/m^2.day to 0.052–0.3 cc/m^2.day, and the WVTR increased from 0.12 to 1.35 g/m^2.day to 0.66–3.36 g/m^2.day. In another study, the OTR of pouch based on a single layer of the metal oxide increased by 3–8.5 times and the WVTR increased by 2.4–23 times after MATS processing (Patel et al., 2019). The barrier deterioration in metal oxide coated films was due to cracks and pinholes during thermal processing and storage (Parhi et al., 2019). However, for the double layer metal oxide-coated film, the barrier changes were negligible, with minimal cracking in the metal oxide coating due to the extra metal oxide layer. At the end of the storage, the OTR of Double-layer pouches changed to 0.02 cc/m^2.day. This could be due to higher temperature storage (49 °C), which may have added to minor cracks and pinholes in metal oxide layers. Despite a small increase in the OTR of Double-Layer pouches, the value was still very low (0.02 cc/m^2.day) compared with other single layer coated films (0.068–0.65 cc/m^2.day) reported in other storage studies (Patel et al., 2019; Zhang et al., 2016, 2017, 2018, 2019). No significant change ($p > 0.05$) in the WVTR of Double-Layer caused by MATS processing (from 0.11 g/m^2.day before processing and to 0.13 g/m^2.day right after processing) was observed. Zhang et al. (2017) found a 1.5-fold increase in the WVTR of the MATS-processed pouches with a single metal oxide layer.

Under similar MATS processing conditions, the EVOH film demonstrated significant increase ($p < 0.05$) in OTR value. The OTR of EVOH film was about 0.25 cc/m^2.day before processing, it was increased to 0.59 cc/m^2.day right after MATS processing. This increase in the OTR of EVOH-based film caused by thermal processing was also observed in other studies (Al-Ghamdi, S., Sonar, C. R., Patel, J., Albahr, Z., & Sablani, S. S.,2020; Dhawan et al., 2014; Mokwena & Tang, 2012). However, after storage at 49 °C for 60 days, the OTR of EVOH pouches decreased to 0.44 cc/m^2.day. This could be due to possible recrystallization of EVOH polymer during storage. It is also possible that high storage temperatures such as 49 °C led to faster recovery of OTR due to drying of the film (Zhang et al., 2017). On the other hand, the WVTR of the EVOH film was not changed significantly ($p > 0.05$) by MATS processing (from 1.67 g/m^2.day before processing to 1.57 g/m^2.day right after processing), but it increased to 6.05 g/m^2.day at the end of the 60 days' storage at 49 °C. This 3.8-fold increase in moisture barrier properties could be due to higher crystallinity at high temperature storage. A similar trend (a 49% decrease in OTR) was observed by (Zhang et al., 2017) in MATS-processed EVOH based polymer pouches during 5 weeks' storage at 45 °C. The author reported a higher EVOH crystallinity in pouches at 45 °C compared with that in pouches stored at room temperature. He also reported a 30% increase in WVTR value of EVOH pouch during storage at 45 °C for 5 weeks.

3.2. Product weight/moisture loss

Fig. 3 depicts the weight loss in all the three types pouches (Double-Layer PET, EVOH, and AL) during the storage at 49 °C for 60 days. The product weight/moisture loss of the Double-Layer pouch at end of the storage was approximately 0.4%, while that of the EVOH-based pouch was about 14%. The double-layered metal oxide-coated PET pouches retained most moisture in the product during storage as compared with the EVOH pouches. In fact, the double-layered pouches showed similar performance ($p > 0.05$) to AL pouches in term of product weight loss. Patel et al. (2020) reported a 2.5% weight loss in garlic mashed potatoes packaged in polymeric pouches with a single layer of aluminum oxide PET film; the pouch were processed with the MATS and stored at a high temperature of 45 °C for 2 months. The results in our current study demonstrate the advantage of double coated film over single-layer metal oxide coated and EVOH-based films for in-package sterilized ready-to-eat meals. Weight loss in product also affects other quality parameters such as color, texture and sensory quality of food (Patel et al., 2019; Zhang et al., 2019).

3.3. Color

The lightness L^* of the blended mixture of chicken, pasta, and sauce decreased significantly ($p < 0.05$) for all three types of pouches during storage at 49 °C for 60 days (Table 3). In AL and Double-Layer pouches, the L^* value decreased by 4.8%, while in EVOH pouches, it decreased by 7.6%. At the end of the storage, the L^* values of the Double-Layer and the aluminum pouches were similar ($p > 0.05$) but significantly different ($p < 0.05$) from that of the EVOH pouches. Fig. 4 represents images of the product that shows that the lightness of the chicken pasta changed most markedly in EVOH pouches. Lightness changes during storage may be due to the Maillard reaction and water loss. Pasta in the EVOH pouches became much drier than that in the pouches of other two films.

Table 2
Oxygen Transmission Rate (OTR) and Water Vapor Transmission Rate (WVTR) of polymer pouches before and after MATS processing and after storage at 49 °C.

Pouch Type	Thickness (μm, n = 3)	Film Structure	OTR (cc/m^2.day)				WVTR (g/m^2.day)			
			Before Processing	After Processing	After Storage @49 °C/28 Days	After Storage @49 °C/60 Days	Before Processing	After Processing	After Storage @49 °C/28 Days	After Storage @49 °C/60 Days
Double-Layer	112 ± 1	AlOx-coated PET (12 μm)//AlOx-coated PET (12 μm)//ONy (15 μm)//CPP(70 μm)	N.D.	N.D.	0.01 ± 0.00^a	0.02 ± 0.01^b	0.11 ± 0.02^a	0.13 ± 0.02^a	0.19 ± 0.00^b	0.22 ± 0.05^b
EVOH	100 ± 1	HDPE//PA//PE tie/ EVOH/PE tie//HDPE	0.25 ± 0.12^a	0.59 ± 0.03^b	0.46 ± 0.10^{bc}	0.44 ± 0.09^c	1.67 ± 0.02^a	1.57 ± 0.17^{ab}	3.65 ± 0.24^c	6.05 ± 1.25^d

Values with the same small subscription letter are not significantly different ($p > 0.05$) at comparing process influence among columns. N.D. = Not Detectable, because the value is lower than the detection limit of the instrument. ONy = Biaxially oriented nylon 6, CPP = Cast polypropylene, PA = Polyamide.

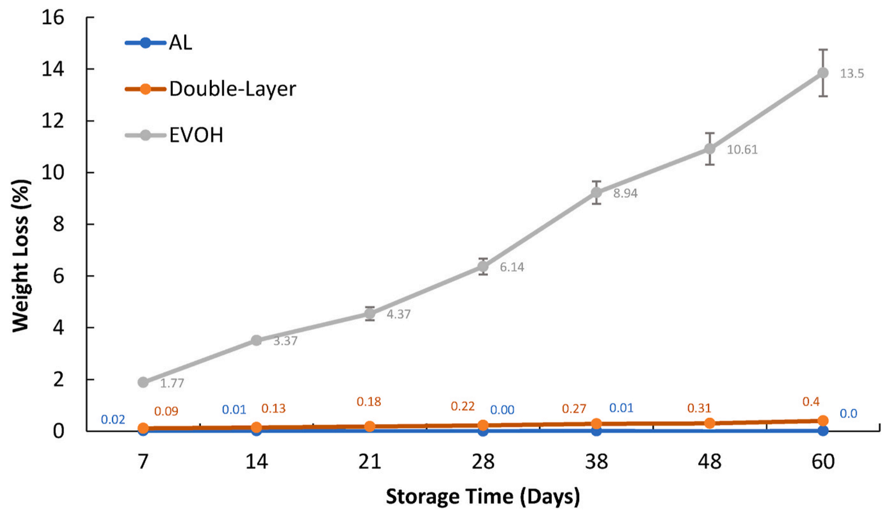

Fig. 3. Weight loss in pouches during the storage at 49 °C for 60 days ($n = 3$).

Table 3
Lightness (L*) values of the blended mixture of chicken, pasta, and sauce sampled from different types of pouches during storage at 49 °C for 60 days (n = 9).

Storage Time (Days)	Lightness (L*)		
	AL	Double-Layer	EVOH
0	61.89 ± 1.12^{aA}	61.89 ± 1.12^{aA}	61.33 ± 1.02^{aA}
7	59.86 ± 0.46^{aBC}	61.73 ± 0.49^{bA}	58.92 ± 0.28^{cCD}
14	59.61 ± 0.60^{aBC}	59.26 ± 0.45^{aC}	59.37 ± 0.60^{aBCD}
21	60.59 ± 0.61^{abB}	60.96 ± 0.30^{aAB}	60.06 ± 0.64^{bB}
28	58.39 ± 0.82^{aD}	61.66 ± 1.20^{bA}	58.66 ± 0.91^{aD}
38	60.32 ± 0.75^{aB}	59.96 ± 0.85^{aBC}	60.00 ± 0.31^{aBC}
48	58.29 ± 0.77^{aD}	59.99 ± 0.85^{bBC}	57.15 ± 0.73^{cE}
60	58.91 ± 0.41^{aCD}	58.87 ± 0.62^{aC}	56.68 ± 0.28^{bE}

Values with the same capital letter subscription letter is not significantly different from each other at ($p > 0.05$) comparing storage time influence between rows, small letters are comparing between packages in each column at ($p > 0.05$), and ± sign indicates standard deviation.

This was due to moisture loss, which favored the Maillard reaction in EVOH pouches (Acquistucci, 2000).

The overall total color difference (ΔE) values of the blended mixture of chicken, pasta, and sauce sampled from for all the three types of pouches during the storage at 49 °C for 60 days were presented in Fig. 5. All the ΔE values were below 6. The ΔE value reached 3.4, 3.6 and 5.5 for AL, Double-Layer and EVOH pouches, respectively, at end of the storage. The sauce of chicken pasta included cream and butter, making it rich in fat. Statistically, the ΔE values of the samples from both the AL and Double-Layer pouches were similar ($p > 0.05$), but significantly different from those of the samples from the EVOH pouches ($p < 0.05$). Therefore, it can be inferred that the oxygen barrier properties of the pouches played a major role in preserving the color of the chicken pasta meal. Two layers of metal oxide-coated PET in the Double-Layer pouches reduced color degradation in the chicken pasta. Hence, the Double-Layer pouches and AL pouches can achieve a similar shelf life for ready to eat chicken pasta meals.

3.4. pH

Findings indicated that the pH of chicken pasta in Double-Layer pouches did not change significantly ($p > 0.05$), from 5.47 to 5.37 over 60 days' storage at 49 °C. However, the pH changed in the EVOH and AL pouches ($p < 0.05$), from 5.58 to 5.30 and 5.47 to 5.31, respectively (Fig. 6). This may be due to oxidation of lipids, as the sauce

Fig. 4. Images of chicken pasta in three different types of pouches before and after storage at 49 °C for 60 days.

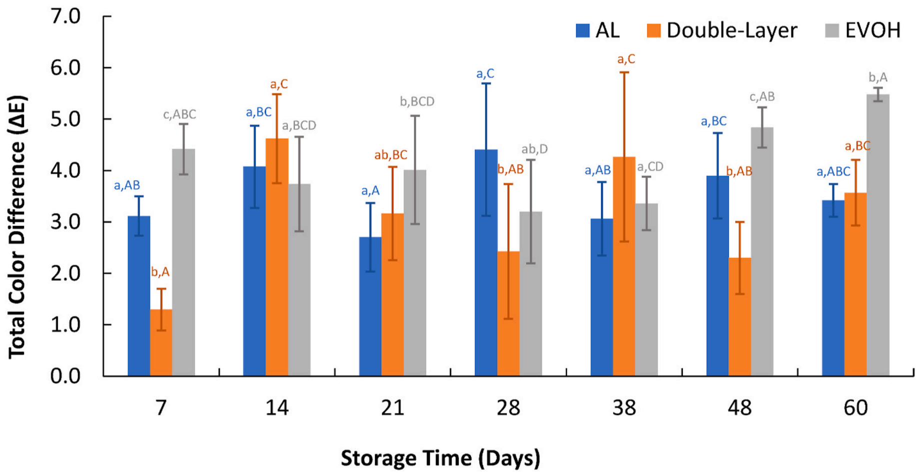

Fig. 5. Total color difference of the blended mixture of chicken, pasta, and sauce sampled from different types of pouches during storage at 49 °C for 60 days (n = 9). Value points with the same small letter is not significantly different from each other at *(p > 0.05)* comparing within packages at each storage time points and value points with same capital letter is not significantly different from each other at *(p > 0.05)* comparing storage time influence for each packaging. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

is rich in fat (Liu, Tsau, Lin, Jan, & Tan, 2009).

3.5. Instrumental texture

The cutting force of chicken pieces after processing increased significantly ($p < 0.05$) during the first 2 weeks' storage at 49 °C (Fig. 7). There was an increase in the cutting force of chicken (p > 0.05) in the EVOH pouches than in the other two types of pouches on 14th day. The cutting force for chicken pieces increased from 30 N ± 8.4, 27 ± 8.2 N and 23 ± 7.6 N on 7th day of storage, to 41 ± 10 N, 32 ± 10 N and 34 ± 9.7 N on 14th day of the storage in the EVOH, Double-Layer and AL pouches, respectively. This variation could be attributed to weight/moisture loss, which is strongly associated with the WVTR of the packages. Storage time had more impact on the texture of chicken pieces than package barrier properties. At the end of the storage at 49 °C for 60 days, the cutting force required for chicken in EVOH, Double-Layer and AL pouches was 43 ± 9.1 N, 44 ± 8.0 N and 40 ± 7.0 N, respectively. There was no significant difference in the cutting forces ($p > 0.05$) for chicken at each storage point within all the three types of pouches but after 60 days storage, there was significant difference ($p < 0.05$) in cutting force from day 0 to day 60 for all three pouches. This indicates that the chicken texture was not dependent on the barrier properties of the packages. Similar results were reported for a multicomponent recipe of tuna noodle casserole (Catauro & Perchonok, 2012).

3.6. Lipid oxidation

Lipid oxidation (TBARS, mg of MDA kg^{-1} of the sample) in the recipe was investigated on the blended mixture of chicken, pasta and sauce. There was a variable trend depending on the packaging type during storage at 49 °C for 60 days. (Fig. 8). The initial TBARS value right after MATS processing was 1.23 ± 0.43, 0.99 ± 0.24, and 0.99 ± 0.24 mg MDA/kg for the product packed in EVOH, Double-Layer and AL pouches, respectively. This changed to 2.04 ± 0.36, 0.78 ± 0.34, and 0.88 ± 0.21 mg MDA/kg at the end of storage. For the product packed in EVOH pouches, the TBARS value decreased in the first 4 weeks' storage and increased significantly ($p < 0.05$) in the last 32 days' storage, while it remained relatively stable ($p > 0.05$) for product in AL and Double-Layer pouches. The TBARS values of the samples in EVOH pouches significantly ($p < 0.05$) differed from those in the other two types of pouches. On the other hand, there was no significant ($p > 0.05$) difference between the TBARS values of the samples in AL and Double-Layer pouches.

The presence of oxygen in package accelerates the rate of lipid oxidation. An increase in lipid oxidation for the samples in EVOH-based pouches during storage is likely due to the higher OTR of this type of pouch compared with the other two types of pouches. Sonar, Al-Ghamdi, Marti, Tang, & Sablani, 2020 reported a similar trend for lipid oxidation in pasteurized salmon in sauce packed in different OTR pouches

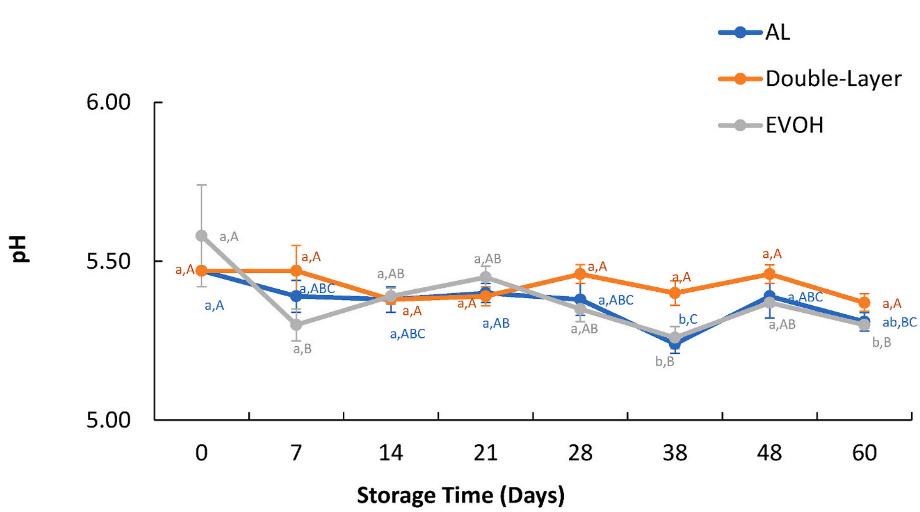

Fig. 6. pH change in chicken pasta blended mixture in different types of pouches during storage at 49 °C for 60 days (n = 3). Value points with the same small letter is not significantly different from each other at *(p > 0.05)* comparing within packages at each storage time point and value points with same capital letter is not significantly different from each other at *(p > 0.05)* comparing storage time influence for each packaging.

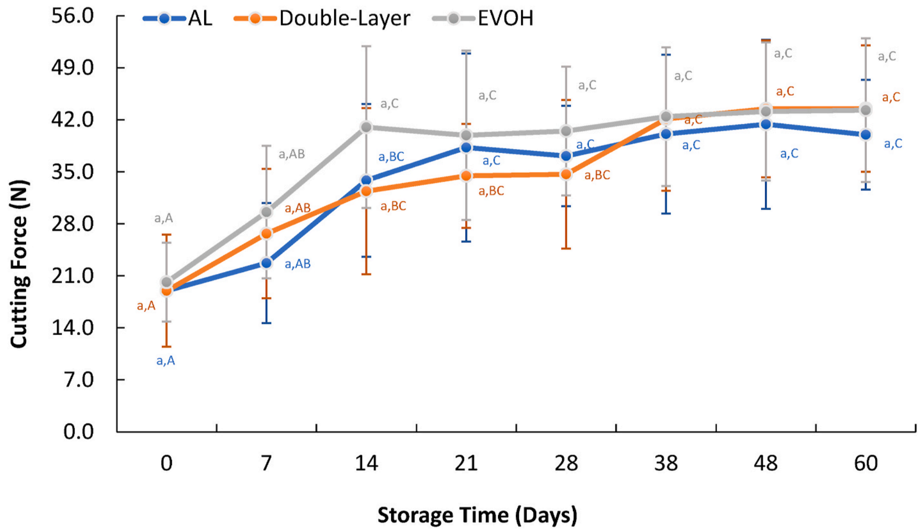

Fig. 7. Force (N) required to cut the pieces of chicken from different types of pouches during storage at 49 °C for 60 days (n = 9). Value points with the same small letter is not significantly different from each other at *($p > 0.05$)* comparing within packages at each storage time point and value points with same capital letter is not significantly different from each other at *($p > 0.05$)* comparing storage time influence for each packaging.

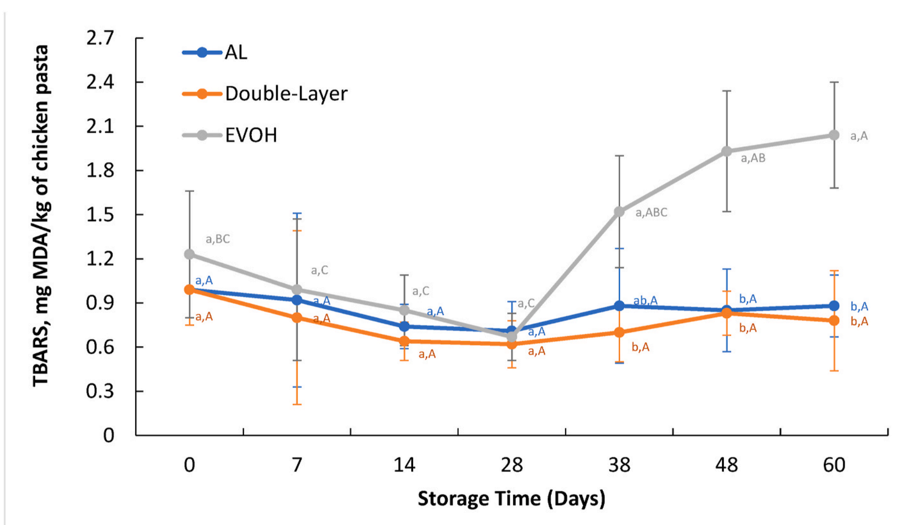

Fig. 8. Lipid oxidation of chicken pasta meals in different types of pouches during storage at 49 °C for 60 days (n = 6). Value points with the same small letter is not significantly different from each other at *($p > 0.05$)* comparing within packages at each storage time points and value points with same capital letter is not significantly different from each other at *($p > 0.05$)* comparing storage time influence for each packaging.

(81–619 cc/m^2.day) and stored at 4 °C for 10 days. They also observed a positive correlation between the headspace oxygen concentration and the TBARS value. Jang and Lee (2012) also reported similar results in ready-to-eat ginseng chicken porridge in trays with lid film and an OTR of 1 cc/m^2.day. They reported an increasing trend in TBA value from 0.45 to 0.95 mg MDA/kg when stored at 25 °C for 28 weeks.

3.7. Sensory attributes

Table 4 shows the sensory attribute scores of chicken pasta in three types of pouches under different storage conditions. Immediately after MATS processing, the chicken pasta in all three types of pouches was scored between 5.9 and 6.45 for all attributes, and there was no significant difference ($p > 0.05$) in sensory scores among the pouches. After storage at 49 °C for 4 weeks, at 38 °C for 3 months and at 38 °C for 6 months, chicken pasta in EVOH pouches was scored significantly lower ($p < 0.05$) than that in Double-Layer and AL pouches. This could be due to higher lipid oxidation, color loss, and oxidative degradation of spices related to the low barrier properties of the EVOH pouches. On the other hand, the Double-Layer pouches proven similar performance and received similar sensory attribute scores ($p > 0.05$) to the AL pouches during the storage. According to the quality scale, 5 and above is considered as acceptable. The chicken pasta in both AL and Double-Layer pouches was scored above 5 after 6 months of storage at 38 °C, which is equivalent to 3 years' storage at 23 °C (Robertson, 2012). For AL and Double-Layer pouches, panelists noted that, even after 6 months of storage at 38 °C, chicken pasta illustrated good color, but the chicken pieces were dry. For the EVOH pouches, panelists noted off-flavors and aromas. Thus, based on the sensory scores, it can be predicted that both Double-Layer and AL pouches can provide a similar shelf life of 3–5 years at room temperature for chicken pasta meals.

Table 4
Sensory attribute scores of chicken pasta in three types of pouches stored at different conditions ($n = 12$).

Sensory Attribute	Pouch Type	After MATS processing	4 Weeks @ 49 °C	3 Months @ 38 °C	6 Months @ 38 °C
Appearance	AL	6.25 ± 0.72^a	6.25 ± 0.66^a	6.13 ± 0.53^a	6.17 ± 0.65^a
	Double-Layer	6.40 ± 0.70^a	6.19 ± 0.53^a	6.13 ± 0.43^a	6.21 ± 0.62^a
	EVOH	6.25 ± 0.59^a	4.19 ± 0.96^b	4.92 ± 1.04^b	3.58 ± 1.41^b
	P-value	0.2898	0.0001	0.0001	0.0001
Odor	AL	6.30 ± 0.54^a	6.13 ± 0.35^a	6.13 ± 0.48^a	6.13 ± 0.68^a
	Double-Layer	6.45 ± 0.44^a	6.19 ± 0.46^a	6.04 ± 0.50^a	6.04 ± 0.69^a
	EVOH	6.35 ± 0.47^a	4.81 ± 0.88^b	5.46 ± 0.81^b	4.42 ± 1.15^b
	P-value	0.3274	0.0001	0.0024	0.0001
Flavour	AL	6.10 ± 0.66^a	6.06 ± 0.42^a	6.00 ± 0.56^a	6.04 ± 0.69^a
	Double-Layer	6.10 ± 0.74^a	5.94 ± 0.56^a	5.83 ± 0.62^a	5.79 ± 0.54^a
	EVOH	6.10 ± 0.66^a	4.56 ± 1.27^b	5.13 ± 0.96^b	3.67 ± 01.35^b
	P-value	1.0000	0.0004	0.0028	0.0001
Texture	AL	5.90 ± 0.91^a	5.94 ± 0.78^a	5.88 ± 0.68^a	5.88 ± 0.68^a
	Double-Layer	6.15 ± 0.75^a	5.75 ± 0.80^a	5.96 ± 0.40^a	5.42 ± 1.08^a
	EVOH	6.00 ± 0.78^a	4.69 ± 1.36^b	5.00 ± 1.05^b	3.88 ± 1.60^b
	P-value	0.1815	0.0009	0.0030	0.0001
Overall acceptance	AL	5.95 ± 0.90^a	6.00 ± 0.71^a	5.92 ± 0.60^a	6.00 ± 0.64^a
	Double-Layer	6.10 ± 0.74^a	5.81 ± 0.75^a	5.83 ± 0.62^a	5.54 ± 0.99^a
	EVOH	6.05 ± 0.64^a	4.25 ± 1.07^b	4.83 ± 0.91^b	3.54 ± 1.32^b
	P-value	0.3274	0.0001	0.0003	0.0001

Values with the same small subscription letter are not significantly different ($p > 0.05$) at comparing pouch influence between rows.

4. Conclusions

In conclusion, multilayer structures with two layers of aluminum oxide coated PET can provide similar barrier as aluminum foil based retort grade pouch for chicken pasta recipe. Double-Layer pouches sustained MATS processing conditions and maintained barrier properties after MATS processing, as observed with minimal weight loss and lipid oxidation similar to the control metal-foiled pouch. It was found that package permeability to oxygen and water vapor greatly affected the color, lipid oxidation and sensory quality of the chicken pasta meal during the storage. Overall, the Double-Layer pouches showed similar performance to the AL pouches in terms of retention of physical, chemical, and sensory quality of chicken pasta during the storage. Results suggested that the MATS-processed chicken pasta recipe packaged in high barrier, Double-Layer pouches could be stored up to 3–5 years at room temperature. Therefore, this recipe and packaging material selection may be suitable for U.S. Army rations and NASA extended duration space missions.

CRediT authorship contribution statement

Juhi Patel: Formal analysis, Data curation, Writing - original draft, performed the experiments, participated in analyzing the data, interpretation of results and drafted first draft of the manuscript. participated in designing the research. **Chandrashekhar R. Sonar:** Formal analysis, Data curation, Writing - original draft, performed the experiments, participated in analyzing the data, interpretation of results and drafted first draft of the manuscript. participated in designing the research. **Saleh Al-Ghamdi:** Formal analysis, Data curation, Writing - original draft, performed the experiments, participated in analyzing the data, interpretation of results and drafted first draft of the manuscript. participated in designing the research. **Zhongwei Tang:** assisted with MATS process development and processing of pouches. participated in designing the research. **Tom Yang:** coordinate sensory study. participated in designing the research. **Juming Tang:** assisted with MATS process development and processing of pouches. participated in designing the research. **Shyam S. Sablani:** Writing - review & editing, direct the study, participated in interpretation of results and editing of the manuscript. All authors approved the final manuscript. participated in designing the research.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2020.110287.

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