Application of MAP and ethylene–vinyl alcohol copolymer (EVOH) to extend the shelf-life of green and white asparagus (*Asparagus officinalis* L.) spears

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Abstract

In this study, ethylene vinyl alcohol copolymer (EVOH) and polypropylene/polyethylene (PP/PE) films combined with MAP packaging were developed to enhance the shelf-life of green and white asparagus spears. The scope of the research included measurements of weight loss, pH, acidity, color, texture, and sensory analysis as indicators of green and white asparagus spear quality for up to 17 days of storage at 2 and 10 °C. The application of modified atmosphere packaging combined with EVOH-based packaging material and refrigeration at 2 °C promoted a reduction in asparagus weight loss, preventing changes in color and texture as well as sensory quality, thereby extending the shelf-life of the asparagus. According to the obtained results, it was possible to maintain good quality of green and white asparagus for up to 17 and 10 days, respectively, when packed in MAP using EVOH-based packaging stored at 2 °C. Asparagus stored in packaging with PP/PE film showed lower quality during storage at 2 and 10 °C. These results suggest that EVOH films are potential candidates for advanced packaging materials for the asparagus packaging application.

Keywords Asparagus · Shelf-life · PP/EVOH/PE · PP/PE · Modified atmosphere packaging

Introduction

Asparagus (*Asparagus officinalis* L.) has been increasingly consumed due to its high nutritional and low-calorie value. Compared to white asparagus, green asparagus has a higher nutritional value and contains almost 20 times more vitamin A, 2 times more vitamin B and 2 times more vitamin C, while white asparagus contains 1.5 times more protein [1]. In general, asparagus spears are rich sources of carbohydrates (sucrose, fructose, and glucose insoluble sugars), which affect the lignification process [2]. Reports have shown that, consumption of this vegetable or food products

supplemented with asparagus spear extracts may help treat digestive disorders, cardiovascular diseases and diabetes [3].

Asparagus has a short shelf-life (3–5 days) due to its high respiration rate, which continues after harvesting. The high respiration rate leads to high sensitivity of asparagus during storage, and rapid quality deterioration. The loss of quality after harvesting is also connected with chlorophyll degradation in green spears and anthocyanin synthesis in white spears, which occurs due to light exposure and temperature changes [4]. Furthermore, water loss and changes in ascorbic acid content, which influence total antioxidant activity decreases, occur in asparagus after harvesting [5, 6]. All of these quality changes and decay of asparagus can be reduced by cold storage and modified atmosphere packaging, MAP [7–9]. The recommended gas composition for plants with high transpiration rate (including asparagus) is 5–14% CO₂ and 3–21% O₂ [10].

Maintaining the quality of asparagus is possible via active packaging with ethylene–vinyl alcohol copolymer (EVOH) layers. This packaging material provides high oxygen barrier properties. Ethylene has hydrophobic and olefinic properties, and the hydroxyl substituent has hydrophilic properties [11]. However, EVOH is highly sensitive to humidity, which alters

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its resistance to O_2 permeability [12]. Therefore, EVOH material is often combined by coextrusion with other polymeric materials, such as PP and PE, to increase barrier properties, as well as water-resistant polymers [13]. Packaging materials containing EVOH have high mechanical resistance to stretching and punching, and are less permeable to fumigants compared to other packaging films, such as HDPE and LDPE [14, 15]. Furthermore, high barrier films strongly affect the gas composition, mainly low O_2 and high CO_2 concentrations, which can slow the transpiration rate and weight loss of products during storage [16]. The influence of MAP technique on the quality and shelf-life of asparagus has been widely described. EVOH-packaging film has been applied to extend the shelf-life of mushrooms [6], milk [17], high transpiring fruits [18], and white cheese [19]. However, there is a lack of studies concerning MAP with material based on PP/EVOH/PE. Therefore, the aim of the present research is to evaluate the combined effect of MAP PP/EVOH/PE-based packaging material and storage temperature on the shelf-life of green and white asparagus spears.

Materials and methods

Sample preparation

White and green asparagus spears of the cultivar *Gijnlim* were freshly purchased from a local market (52° 13' N 20° 50' E, Ozarów Mazowiecki, Poland) in central Poland. In the laboratory the asparagus spears were washed with cold water, air-dried, sorted according to EC quality standard class 1 (UN/ECE FFV-04), cut into 18 cm pieces (mean spear diameter of 1.9 ± 0.4 cm) and white and green spears were randomly separated into 6–8 spears (approx. 200 g) for each sample. Asparagus pieces were packed on PP/EVOH/PE trays (approximately 580 μ m thick) with a 10 μ m thick EVOH layer with two films: PP/PE with an oxygen transmission rate of 3000 $cm^3/m^2/24$ h and PP/EVOH/PE with an oxygen transmission rate of 2 $cm^3/m^2/24$ h at standard temperature and pressure, and packed with a Sealpac Tray-sealer M3 (Sealpac, Germany) machine. Tray dimensions were $187 \times 137 \times 50$ mm for both white and green asparagus samples. Asparagus spears were packed under the following modified atmosphere packaging (MAP) conditions: $5\% \pm 2\%$ CO_2 , $15\% \pm 2\%$ O_2 and $80\% \pm 2\%$ N_2 . The trays were stored for 17 days at a relative humidity (RH) of approx. 90%, under identical conditions, in the absence of light (Fig. 1). Three replicates were conducted for each of the packaging conditions and storage time. All parameters, such as gas composition, weight loss, color, shear force, and sensory analysis, were determined at the beginning and on the 6th, 10th, 14th and 17th day of storage.

Fig. 1 Combination of samples and film type used for packaging green and white asparagus spears

Gas analysis

Gas composition analysis (O_2 and CO_2) under all conditions was measured using a WITT Gasetechnik Analyzer (Witt-Gasetechnik, Model PA-S/P, Witten, Germany). The sensor needle pierced through the film with a specially fitted air-impermeable septum to measure the gas concentration in the headspace before opening the package. Oxygen and carbon dioxide concentrations were determined in triplicate for each tested container.

Weight loss

Weight loss (WL) was determined in triplicate by weighing asparagus spears at the beginning and on the last day of sampling. WL was expressed as a percentage of WL concerning the initial weight as follows: $WL\% = (w_0 - w_1 / w_0) \times 100$; where w_0 is the weight at the beginning; and w_1 is the weight on the last storage day.

Acidity and pH

Green and white asparagus spears were separately minced and homogenized with 20 mL of distilled water for 180 s, and 5 g was used for the measurement. The pH value was measured using the potentiometric method with a handheld pH meter (Model 205, Testo AG, Germany). The samples of each asparagus were titrated by adding 50 mL of 0.1 N NaOH with phenolphthalein as an indicator until the pH reached a value of 8.2 according to PN-EN 12147:2000 [20]. Acidity was measured in triplicate during storage for each day of sampling (and trays) and expressed as a citric acid percentage.

Texture

The textural properties of green and white asparagus were determined as the shear force, which was measured using a Warner–Bratzler texturometer with load cell 500N and V-shaped blade (Model 5965, Instron, Canton, USA) with Bluehill®2 software. Texture parameters were determined by measuring the maximum shear force necessary to cut pieces the asparagus samples at the mid-section (9.0 cm from the base) with a displacement speed of 200 mm/min. The tests were conducted in triplicate for each container, in which one speed test (10 mm/min) was applied.

Color

The instrumental measurement of the color of asparagus was performed using the $L^*a^*b^*$ color system as follows: L^* , lightness; a^* , color axis ranging from greenness ($-a^*$) to redness ($+a^*$); and b^* , color axis ranging from blueness ($-b^*$) to yellowness ($+b^*$). The color was measured using a Minolta chromameter (CR-400, Konica Minolta, Inc., Tokyo, Japan), which was calibrated using a white standard plate ($L^* = 98.45$, $a^* = -0.10$ and $b^* = -0.13$). A measuring head was 8 mm in diameter and D65 (6500K color temperature) illuminant. Color measurements were performed directly after opening the package. The determination of color parameters was performed by measuring 10 different randomly selected places on 10 asparagus surfaces. ΔE was calculated using the following equation: $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$; where ΔE represents the degree of overall color change in comparison to color values of the control group.

Sensory evaluation of asparagus

The sensory characteristics of the asparagus samples were assessed using the quantitative response scale, following the procedure described in ISO standard 4131:2003 [21]. The sensory assessment was performed by trained panelists (ten members). The panelists fulfilled the requirements of ISO standard 8586:2012 [22]. Individual samples were placed in plastic containers and covered with lids. The samples were evaluated for firmness, color, odor and hardness (by hand) [23], on the following verbally anchored 5-point squared scale with interval spacing. These attributes were used for sensory analyses, which are shown in Table 1. A score of 2 was considered borderline acceptability. Samples were given to the panelists in random order (30 g each, row), and were encoded with 3-digit codes.

Table 1 Quality scores and descriptors for sensory evaluation

Scale	Description
1	Very bad quality, unfresh spears
2	Bad quality, untypical odor, no turgor
3	Medium quality, typical odor and color
4	Good quality, fresh, small color and texture changes
5	Excellent quality, fresh, no color and texture changes

Statistical analysis

All experiments were performed in triplicate (except for color measurement, which was performed in 10 replicates), and average values with standard deviation were calculated. The significant differences were compared using one-way ANOVA and Tukey's post hoc test ($\alpha = 0.05$). To determine the overall impact of all factors on the chosen indexes, multi-factorial analysis of variance was performed. Analyses were conducted using Statistica Software (version 12.0; Tulsa, USA).

Results

Gas analysis

Three factors, including storage time, temperature and asparagus type, had a significant impact on changes in the atmosphere composition in the packages (Figs. 2, 3). These changes in atmospheric composition were observed both in PP/PE and PP/EVOH/PE packaging. The increase in CO_2 in green asparagus packaged in PPPE10 was faster than in EVOH10. The lowest CO_2 increase was observed in EVOH2 followed by PPPE2. As expected, the highest O_2 decrease was found in PPPE10 and the lowest decrease in PPPE2. The total O_2 consumption occurred after 17 days of storage, where the CO_2 content increased to 42% (EVOH2) and 57.2% (PPPE10). In white asparagus, the fastest increase of CO_2 occurred in EVOH10 (up to 60%), indicating that white asparagus had higher transpiration than green asparagus. Moreover, cold storage possessed the lowest CO_2 increase in PPPE2 (up to 45%). In PPPE2, total O_2 consumption occurred after 17 days of storage, while EVOH allowed for a partial slowdown of the breathing process.

Weight loss

As shown in Table 2, the highest WL for green and white asparagus was observed in C10 and C2. In contrast, the lowest WL was observed in EVOH2 (weight loss of 0.2% and 1.7% for green and white asparagus, respectively). WL was more dramatic using PPPE2 packaging with 1.3% and 9.5%

Fig. 2 Oxygen and carbon dioxide concentrations of green asparagus packed in two different layers and stored at two different temperatures 2 °C and 10 °C for up to 17 days. Values followed by different small letters (a, b, c) are significantly different ($p \leq 0.05$). Values are means of three replicates $\pm$ standard deviation

Fig. 3 Oxygen and carbon dioxide concentrations of white asparagus packed in two different layers and stored at two different temperatures 2 °C and 10 °C for up to 17 days. Values followed by different small letters (a, b, c) are significantly different ($p \leq 0.05$). Values are means of three replicates $\pm$ standard deviation

for green and white asparagus, respectively. Therefore, WL was greater for white asparagus and higher barrier EVOH films were more suitable for vegetables with high respiration rate.

Acidity and pH

Table 2 shows the acidity and pH analysis results of white and green asparagus during postharvest storage. The temperature, time and package type had a significant influence on the acidity (Table 3). Fresh white and green asparagus had an initial acidity of 0.039% and 0.042%, respectively. During storage, the largest increase in acidity was observed for C2 and C10. The use of MAP led to a less intense acidity increase in the spears. The applied type of packaging had an impact on acidity, where the asparagus packaged in EVOH had lower acidity than those in PPPE. The pH decreased significantly during the storage time for each sample. The initial pH values of fresh green and white asparagus were 6.10 and 5.65, respectively. The smallest pH change was obtained with EVOH packaging. For green and white asparagus stored in EVOH2, the pH values decreased to 5.79 and 5.72, respectively, during 17 days of storage, while

stored in PPPE2, the pH values decreased to 5.59 and 5.61, respectively.

Texture

The results of the cutting force in the present study are shown in Table 4. Statistical analysis showed a significant impact of temperature, asparagus type, storage time and packaging on the hardness of asparagus (Table 3). The initial hardness values of green and white asparagus were approx. 41.23 and 48.25 N, respectively. The lowest and highest increase of hardness for green asparagus during storage was observed in EVOH2 and C10, respectively. This trend was also observed for white asparagus stored in EVOH packaging, and the increase of hardness in EVOH packaging was less than in PP/PE packaging.

Lightness and change of color

Time, asparagus type, and packing method altered L^* value of white and green asparagus during storage (Table 4). A rapid darkening of white asparagus in C2 and C10 was observed after 10 days of storage (79.12 and 77.54, respectively), while the color of C2 and C10 green spears remained

Table 2 Evolution of physicochemical properties (pH, acidity and weight loss) of white and green asparagus stored at 2 °C and 10 °C along different storage periods (0, 6, 10, 14, 17 days)

Green asparagus		White asparagus									
Day of storage		0	6	10	14	17	0	6	10	14	17
pH											
C2		6.10 ± 0.04 ^{aA}	5.93 ± 0.02 ^{aB}	5.90 ± 0.12 ^{aA}	5.87 ± 0.02 ^{aA}	5.55 ± 0.00 ^{bA}	5.65 ± 0.01 ^{abA}	5.87 ± 0.02 ^{aA}	5.69 ± 0.05 ^{bbB}	5.24 ± 0.02 ^{bC}	5.39 ± 0.03 ^{bbB}
C10		6.10 ± 0.04 ^{aA}	5.90 ± 0.05 ^{bbB}	5.67 ± 0.04 ^{bcbB}	5.45 ± 0.06 ^{cB}	5.32 ± 0.02 ^{cB}	5.65 ± 0.01 ^{abA}	5.80 ± 0.05 ^{aA}	5.65 ± 0.03 ^{abB}	5.30 ± 0.01 ^{bbC}	5.15 ± 0.17 ^{bC}
EVOH2			5.98 ± 0.00 ^{aB}	5.95 ± 0.07 ^{aA}	5.80 ± 0.11 ^{bA}	5.79 ± 0.04 ^{ca}		6.02 ± 0.13 ^{aA}	5.89 ± 0.07 ^{abA}	5.81 ± 0.05 ^{bA}	5.72 ± 0.03 ^{bA}
EVOH10			6.09 ± 0.09 ^{aB}	5.87 ± 0.05 ^{bA}	5.82 ± 0.02 ^{bA}	5.73 ± 0.07 ^{ca}		5.96 ± 0.12 ^{aA}	5.85 ± 0.09 ^{abA}	5.71 ± 0.04 ^{bA}	5.73 ± 0.12 ^{bA}
PPPE2			6.10 ± 0.02 ^{aA}	6.00 ± 0.04 ^{aA}	5.73 ± 0.08 ^{bA}	5.59 ± 0.09 ^{ca}		5.89 ± 0.09 ^{aA}	5.76 ± 0.10 ^{abAB}	5.69 ± 0.02 ^{bbB}	5.61 ± 0.02 ^{bA}
PPPE10			5.80 ± 0.03 ^{aC}	5.56 ± 0.01 ^{bcbB}	5.61 ± 0.04 ^{bA}	5.52 ± 0.10 ^{ca}		5.74 ± 0.02 ^{aB}	5.65 ± 0.03 ^{abB}	5.59 ± 0.02 ^{bbB}	5.41 ± 0.10 ^{bbB}
Acidity (% citric acid)											
C2		0.042 ± 0.03 ^{ca}	0.049 ± 0.02 ^{cB}	0.083 ± 0.01 ^{bAB}	0.092 ± 0.02 ^{bA}	0.101 ± 0.09 ^{aA}	0.039 ± 0.01 ^{ca}	0.049 ± 0.01 ^{ca}	0.072 ± 0.07 ^{bA}	0.104 ± 0.013 ^{aA}	0.108 ± 0.11 ^{aA}
C10		0.042 ± 0.03 ^{bA}	0.092 ± 0.01 ^{aA}	0.101 ± 0.00 ^{aA}	0.103 ± 0.01 ^{aA}	0.109 ± 0.08 ^{aA}	0.039 ± 0.01 ^{dA}	0.064 ± 0.04 ^{ca}	0.085 ± 0.014 ^{bcaA}	0.121 ± 0.019 ^{aA}	0.110 ± 0.01 ^{aA}
EVOH2			0.042 ± 0.04 ^{Ab}	0.062 ± 0.02 ^{aB}	0.069 ± 0.02 ^{aC}	0.075 ± 0.06 ^{aB}		0.041 ± 0.02 ^{cB}	0.050 ± 0.04 ^{bbB}	0.055 ± 0.05 ^{bbB}	0.071 ± 0.02 ^{aB}
EVOH10			0.049 ± 0.02 ^{bbB}	0.071 ± 0.05 ^{bbB}	0.081 ± 0.05 ^{Ab}	0.092 ± 0.04 ^{aA}		0.049 ± 0.03 ^c	0.054 ± 0.05 ^c	0.063 ± 0.014 ^b	0.088 ± 0.09 ^a
PPPE2			0.042 ± 0.02 ^{cB}	0.062 ± 0.03 ^{bbB}	0.069 ± 0.02 ^{aC}	0.075 ± 0.03 ^{aB}		0.041 ± 0.09 ^{cB}	0.066 ± 0.06 ^{bbB}	0.067 ± 0.03 ^{bbB}	0.083 ± 0.012 ^{aB}
PPPE10			0.049 ± 0.03 ^{cB}	0.071 ± 0.01 ^{bbB}	0.101 ± 0.01 ^{aA}	0.108 ± 0.06 ^{aA}		0.051 ± 0.06 ^{cB}	0.078 ± 0.011 ^{bbB}	0.081 ± 0.04 ^{bbB}	0.099 ± 0.09 ^{abB}
Weight loss (%)											
C2			9.92 ± 0.12 ^{bC}	14.60 ± 0.67 ^{bbB}	21.80 ± 0.02 ^{bA}	24.80 ± 1.04 ^{bA}		13.40 ± 0.98 ^{bC}	23.70 ± 2.03 ^{bbB}	19.00 ± 1.04 ^{bbB}	33.10 ± 2.01 ^{bA}
C10			20.30 ± 2.01 ^{aC}	33.80 ± 1.03 ^{aB}	45.50 ± 4.09 ^{aB}	60.40 ± 4.09 ^{aA}		26.30 ± 1.02 ^{aD}	41.30 ± 1.17 ^{aC}	56.10 ± 2.83 ^{aB}	68.70 ± 5.03 ^{aA}
EVOH2			0.20 ± 0.02 ^{cB}	0.10 ± 0.01 ^{cB}	0.50 ± 0.03 ^{ca}	0.10 ± 0.00 ^{dB}		0.20 ± 0.02 ^{cB}	0.90 ± 0.04 ^{ca}	1.00 ± 0.10 ^{ca}	1.70 ± 0.61 ^{dA}
EVOH10			0.30 ± 0.00 ^{cB}	1.20 ± 0.12 ^{ca}	1.10 ± 0.05 ^{ca}	1.80 ± 0.31 ^{ca}		0.60 ± 0.11 ^{cC}	2.00 ± 0.00 ^{ca}	1.20 ± 0.04 ^{cB}	1.50 ± 0.21 ^{dA}
PPPE2			1.30 ± 0.21 ^{ca}	0.70 ± 0.06 ^{cB}	0.30 ± 0.03 ^{cB}	0.30 ± 0.05 ^{dB}		0.80 ± 0.05 ^{cC}	0.60 ± 0.06 ^{cC}	1.30 ± 0.03 ^{cB}	9.50 ± 1.02 ^{ca}
PPPE10			0.50 ± 0.03 ^{cC}	1.00 ± 0.00 ^{cB}	1.70 ± 0.09 ^{cB}	2.60 ± 0.12 ^{ca}		0.30 ± 0.01 ^{cC}	1.00 ± 0.07 ^{cB}	1.20 ± 0.21 ^{cB}	1.70 ± 0.05 ^{dA}

Data are expressed as mean standard deviation. Values followed by different small letters (a, b, c, d) in the same row are significantly different ($p \leq 0.05$). Values followed by different capital letters (A, B, C, D) in the same column are significantly different ($p \leq 0.05$)

Table 3 Results of the variance analysis

Δ					
Factor	L*	ΔE	Texture	Acidity	Loss weight
ST	*	*	***	***	***
T	ns	ns	*	**	ns
A	***	ns	**	ns	**
P	**	***	*	***	***
T $\times$ A	ns	ns	ns	ns	***
ST $\times$ P	ns	***	ns	***	***
ST $\times$ P $\times$ A	*	**	ns	ns	ns

Effect of time storage (ST), temperature (T), type of asparagus (A), and package (P) on color (L*), color change (ΔE), hardness, acidity and loss weight

ns not significant

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

constant on each measurement day. The color changes of asparagus were stronger in spears stored at 10 °C than those at 2 °C. An increase of ΔE value indicated greater differences in the color ratio to the reference sample. White asparagus showed higher value changes in EVOH packaging (1.7 to 7.1), indicating significant change. Smaller changes of L* and ΔE were observed at 2 °C. The L* value of green asparagus showed a substantial change according to storage time and type of packaging. However, in the present study, greening of green asparagus was noted, except for spears packaged in PPPE2, whose color suddenly changed after 17 days.

Sensory analysis

Scores for firmness, color, hardness, and odor for fresh green and white asparagus stored in PP/EVOH/PE and PP/PE packages are shown in Supplementary Data 1. The degree of tip coloration (purple color) in white asparagus was investigated. The value of sensory features showed a negative decrease toward storage time and type of package. The type of package and MAP dramatically impacted the appearance during storage. Regardless of package type, asparagus stored at 2 °C was characterized by higher scores than asparagus stored at 10 °C. In the case of green asparagus stored in EVOH2 decreased slower than asparagus stored in PPPE2. Moreover, the odor score of green asparagus after 6 days of storage in EVOH was less than that in PPPE, 4.21 and 4.00, respectively. The results obtained for white asparagus showed a similar trend for firmness and color. Asparagus stored in EVOH2 had the lowest decrease of firmness (from 5.0 to 3.78) and color (from 4.8 to 3.50) during storage compared to PPPE2 samples, which varied from 5.0 to 1.0 for firmness and 4.8 to 2.0 for color. Based on the acceptable score of 2.0, only asparagus in EVOH2 could be stored for

17 days. Without any packaging, the sensory analysis scores decreased more intensely, limiting the stored time to only 6 days according to the acceptable score. Additionally, the purple tip coloration in white asparagus was investigated. In EVOH packaging, the increase of coloration was less than that in PPPE sample.

Discussion

Minimally processed products are one of the most important segments in food retail. However, fresh-cut produce is more perishable to spoilage than whole produce. The processing operations involved in the preparation of vegetables induce synthesis of secondary metabolites and membrane disruption and increases respiration rates. Hence, the food chain of minimally processed products is restricted due to short shelf-life, rapid deterioration of components and microbial growth [24, 25]. Changes in gas composition of packaging atmosphere can influence physical attributes, which are related to maintaining freshness of raw produce. For instance, when O₂ concentration declines below the critical limit required for sustaining anaerobic respiration, fermentation would occur, resulting in the development of off-flavor compounds. Furthermore, high CO₂ concentration can also have a negative effect on product quality by accelerating changes in color, firmness and increasing the solubilization of pectic compounds [26, 27]. In contrast, CO₂ also has a minor suppression effect on the respiration of some fresh fruits and vegetables, which can help extend their shelf life. Also, CO₂ reduces the sensitivity of plant tissues to the ripening hormone ethylene by CO₂ concentration [28].

The presence of water in the raw material promotes the mold growth. The low concentration of O₂ has no impact on mycotoxin formation in raw materials, while high levels of CO₂ do not guarantee elimination of spoilage. According to other studies, the use of EVOH film possesses protective properties against water vapor and gas permeability [29–31]. The asparaguses respiration changes during the first 2 days of storage, which were determined as a crucial factor affecting raw material shelf-life. The use of PP/PE packaging foil together with MAP preserves with a constant ratio of gases (15% O₂, 5% CO₂) during the first two days of storage. However, the results obtained in the current study show changes in gases ratio (increase of CO₂ and decrease of O₂) on the second day of storage. Previous reports have shown that PP/PE foil is the most airtight for processed green asparagus packed in MAP without O₂ (CO₂ 30% and N₂ 70%) over 30 days of storage at 4 °C [7]. Studies concerning shelf-life of green asparagus have found a comparable relationship between the atmosphere composition and temperature, which is in agreement with this current research. A higher temperature causes a greater drop in O₂ content

Table 4 Evolution of physical parameters lightness (L^*), total color change (ΔE) and hardness of white and green asparagus stored at 2 °C and 10 °C along different storage periods (0, 6, 10, 14, 17 days)

Δ	Green asparagus						White asparagus					
	Day of storage	0	6	10	14	17	0	6	10	14	17	
L*												
C2		52.57 ± 0.62 ^{aA}	53.31 ± 1.23 ^{aA}	55.29 ± 0.43 ^{aA}	51.83 ± 1.39 ^{aA}	50.85 ± 1.23 ^{bA}	84.45 ± 0.55 ^{aA}	83.09 ± 0.89 ^{aA}	79.12 ± 0.45 ^{aC}	75.61 ± 0.84 ^{bC}	72.33 ± 0.76 ^{cC}	
C10		52.57 ± 0.62 ^{aA}	52.42 ± 1.87 ^{aA}	52.30 ± 0.78 ^{aA}	50.91 ± 1.24 ^{aA}	50.36 ± 1.01 ^{bA}	84.45 ± 0.55 ^{aA}	81.49 ± 1.34 ^{aB}	77.54 ± 2.01 ^{bC}	73.02 ± 1.84 ^{cD}	69.45 ± 0.98 ^{dD}	
EVOH2			56.35 ± 0.44 ^{aA}	48.09 ± 0.87 ^{bB}	44.67 ± 0.09 ^{bB}	45.57 ± 0.26 ^{bB}		83.14 ± 0.34 ^{aA}	82.16 ± 1.01 ^{aA}	81.23 ± 2.22 ^{aA}	79.23 ± 1.34 ^{bA}	
EVOH10			54.30 ± 1.02 ^{aA}	50.93 ± 2.13 ^{aA}	48.27 ± 1.84 ^{bB}	46.59 ± 2.31 ^{bB}		81.34 ± 0.98 ^{aB}	80.87 ± 0.62 ^{aB}	80.71 ± 1.75 ^{aA}	78.03 ± 1.32 ^{bA}	
PPPE2			52.22 ± 2.21 ^{bA}	54.57 ± 1.43 ^{bA}	39.95 ± 0.43 ^{cC}	76.77 ± 0.68 ^{aC}		82.11 ± 0.42 ^{aA}	81.30 ± 0.57 ^{aA}	79.76 ± 0.75 ^{aB}	69.75 ± 0.67 ^{bA}	
PPPE10			54.49 ± 1.56 ^{aA}	49.61 ± 0.99 ^{aB}	43.86 ± 1.03 ^{bB}	38.97 ± 1.15 ^{cD}		80.61 ± 1.14 ^{aC}	79.9 ± 1.31 ^{aB}	78.2 ± 0.12 ^{aB}	75.21 ± 0.86 ^{bB}	
ΔE												
EVOH2/C2			1.80 ^{cC}	3.2 ^{bA}	3.5 ^{bB}	4.15 ^{cC}		1.7 ^{cC}	5.8 ^{bA}	6.2 ^{aA}	6.5 ^{aB}	
EVOH10/C10			2.25 ^{cB}	3.5 ^{bA}	3.9 ^{bB}	4.3 ^{aC}		2.4 ^{bB}	6.15 ^{aA}	6.7 ^{aA}	7.1 ^{aA}	
PPPE2/C2			3.9 ^{bA}	2.8 ^{bB}	4.6 ^{bA}	4.9 ^{aB}		3.0 ^{bA}	3.8 ^{bB}	5.1 ^{aB}	5.6 ^{aB}	
PPPE10/C10			2.7 ^{cB}	3.8 ^{bA}	4.5 ^{bA}	5.3 ^{aA}		3.4 ^{ca}	4.2 ^{bB}	5.5 ^{aB}	6.8 ^{aA}	
Hardness (N)												
C2		41.23 ± 4.65 ^{dA}	44.67 ± 5.11 ^{ca}	49.85 ± 5.18 ^{ca}	54.42 ± 5.70 ^{bC}	67.18 ± 1.98 ^{aA}	48.25 ± 4.94 ^{dA}	52.64 ± 4.94 ^{ca}	59.31 ± 4.83 ^{aA}	57.30 ± 1.50 ^{bB}	64.45 ± 3.51 ^{aBC}	
C10		41.23 ± 4.65 ^{ca}	46.92 ± 4.68 ^{ca}	55.95 ± 5.11 ^{bA}	61.23 ± 3.21 ^{bA}	72.56 ± 3.12 ^{aA}	48.25 ± 4.94 ^{dA}	53.51 ± 4.50 ^{ca}	61.59 ± 2.71 ^{bA}	58.21 ± 2.41 ^{bAB}	77.44 ± 1.11 ^{aA}	
EVOH2			42.35 ± 1.93 ^{ca}	43.71 ± 2.54 ^{bB}	56.23 ± 3.34 ^{aBC}	57.49 ± 2.93 ^{aB}		49.09 ± 4.90 ^{bA}	51.89 ± 1.90 ^{bC}	59.84 ± 3.48 ^{aAB}	61.81 ± 5.2 ^{aC}	
EVOH10			44.64 ± 1.60 ^{ca}	47.41 ± 2.92 ^{bA}	59.34 ± 0.45 ^{aB}	58.46 ± 1.01 ^{aB}		51.08 ± 3.22 ^{ca}	58.18 ± 1.45 ^{bA}	62.50 ± 2.82 ^{abA}	68.57 ± 1.7 ^{bAB}	
PPPE2			45.89 ± 5.93 ^{ca}	50.96 ± 4.29 ^{abA}	55.68 ± 5.15 ^{aC}	59.0 ± 5.52 ^{aB}		53.54 ± 1.57 ^{bA}	55.56 ± 2.83 ^{bB}	68.53 ± 5.63 ^{aA}	65.01 ± 0.72 ^{aBC}	
PPPE10			46.34 ± 5.14 ^{dA}	52.75 ± 2.71 ^{ca}	60.35 ± 1.31 ^{bA}	67.74 ± 2.21 ^{aA}		52.93 ± 2.96 ^{ca}	55.32 ± 3.42 ^{cB}	63.97 ± 5.64 ^{bA}	71.21 ± 4.53 ^{aA}	

Data are expressed as mean standard deviation. Values followed by different small letters (a, b, c, d) in the same row are significantly different ($p \leq 0.05$). Values followed by different capital letters (A, B, C, D) in the same column are significantly different ($p \leq 0.05$).

compared with cooler temperature [32]. A study on strawberry fruit displayed an intense drop in O_2 and increase in CO_2 during storage in EVOH-based packaging [33]. Bodbodak and Moshfeghifar [28] reported that residual amount of $0.5 \pm 0.2\%$ of O_2 after storage is necessary to avoid an anaerobic environment, thus preventing the growth of anaerobic bacteria, which is consistent with our results. A similar study on white asparagus shows that higher content of CO_2 (10% CO_2 and 17% O_2) has no negative effect when stored at 20 °C [34].

The decrease in pH and higher acidity in PP/PE packaging are related to higher CO_2 content in the package, leading to increase in carbonic acid concentration. Reports have confirmed the positive influence of MAP on stored asparagus by limiting the increase of acidity and decreasing pH, which is in agreement with our results [32, 33]. WL is an important indicator during postharvest storage, and quality indicator of the packing method. More than 8% of weight loss leads to reduced customer acceptability. The results obtained in this study indicate that WL is greater in white asparagus and higher barrier EVOH films are more suitable for vegetables with high respiration rate [5]. Asparagus WL is lower (1–3%) during cold storage and in MAP packaging [35, 36]. These results are consistent with those reported for other products with high respiration rate and packed in EVOH, including raspberry with WL of 0.5% and strawberry with WL of 0.9% [16]. Wang [37] stated that the primarily concentration of 60% CO_2 during storage of asparagus prevents WL. Both white and green asparagus stored at ambient temperature without packaging lost 4.85% of initial weight, while those packed in MAP lost 0.8% after 14 days of storage [7].

The effect of MAP on maintaining texture is usually related to the control of WL, previous studies have demonstrated that products with high WL have greater reduction in texture [38]. However, asparagus spears during storage become increasingly tough and fibrous, which is related to the degree of lignification of pericyclic fibers and subsequent increase in cell polymers [37]. The increase in hardness over time is more intense for white asparagus than green asparagus. However, due to EVOH strong barrier properties, the shelf-life of asparagus can be extended, and the lignification process minimized. Furthermore, the present study confirmed that fresh white asparagus has higher hardness values and that the lignification process occurs more rapidly than in green asparagus [5, 34, 39]. Albanese et al. [35] reported good hardness (acceptable by consumers) for untreated asparagus stored in the refrigerator for 5 days. Huyskens-Keil and Herppich [8] stated that high CO_2 concentration reduces texture by inhibiting the synthesis of cell wall components, which can cause asparagus spear toughness, which in turn suppresses firming of asparagus spears. This is in agreement with studies that

show high CO_2 and low O_2 concentrations inhibit the phenylalanine ammonia-lyase (PAL) activity, a key enzyme used in lignin synthesis [2]. Simón and Gonzalez-Fandos [40] showed no significant effect of any factors (time, temperature and film) on the texture of spears during storage in MAP. However, according to other studies, factors such as type of harvesting season, climate and temperature 24 h before collection are important for maintaining the texture of asparagus [32].

The color parameter of vegetables is the first visible quality point assessed by consumers, and indicates putrefying time [41]. Asparagus has a patchy color with browning during storage time. Lower asparagus parts are lighter than higher parts, which are typical properties of green spears. Color change along the edible portion indicates the effect triggered by the cellular respiration process and is commonly associated with breakdown of cellular chloroplasts, chromoplasts, natural pigments and is a major factor in determining the quality of asparagus spears [42]. Darkening of white asparagus is associated with the biosynthesis of anthocyanins, which are generated in the apical part [43], while the color change in green asparagus is more intense due to degradation of chlorophyll [35]. Color change is also related to enzymatic browning, which is associated with the activity of the enzyme polyphenol oxidase, ascorbic acid oxidase, and glycolic acid oxidase [27]. Numerous reports have shown the advantage of low or high O_2/CO_2 concentrations for maintaining the color attributes of asparagus [5, 27, 32, 40]. Tzoumaki et al. has shown that high CO_2 content and low O_2 content have a positive effect on the inhibition of anthocyanin synthesis [44]. The color changes of green asparagus after 6 days of storage have been reported by Sergio et al. [7]. According to Cruz-Romero et al. [45], the ΔE value of green asparagus varies from 1.8 to 5.3, indicating significant change during storage. In contrast, Nindo et al. [46] reported that the L^* of raw green asparagus is 40.2, which is much lower than our results. These differences between color coordinates may be due to the method of raw material measurement, as well as asparagus cultivar, and growing conditions [4].

Obtained results of sensory analysis in the current study are in agreement with results reported by Villanueva et al. [32] and Tzoumaki et al. [44]. The change of odor in the investigated samples is related to high barrier film and anaerobic conditions inside, thus formation of off-odor compounds was examined [23]. According to Yoon et al. [47] the quality of asparagus packed in different oxygen transmission rate EVOH film (from 10 to 100 $cm^3/m^2/24$ h) based on sensory analysis showed that the least off-odor was detected in the highest transmission rate film, while the highest firmness of spear was observed in the lowest transmission rate film, which is not consistent with current research.

Conclusion

Packaging in MAP with an appropriate ratio of gases and EVOH layer may extend the shelf-life of asparagus. The results showed that the use of EVOH with $5\% \pm 2\%$ CO₂, $15\% \pm 2\%$ O₂ and $80\% \pm 2\%$ N₂ had a positive effect on WL, acidity, pH value, color and texture quality for up to 17 days of storage for green asparagus and 10 days of storage for white asparagus as compared to unpackaged spears. Decreasing the O₂ level and increasing the CO₂ level may reduce respiration and decelerate various compositional changes associated with storage. Each asparagus type showed the best quality when stored at 2 °C. According to the obtained results, prolonged freshness can be provided by combining low cooling temperature and packaging material containing an EVOH layer.

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