



## Effect of peeling and segmentation on quality of heat-treated white asparagus during storage

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### Abstract

The present work investigated the possibility of utilization of white asparagus spear segments as a minimally processed product. Freshly harvested spears (cv. Dariana) were subjected to hot water treatment (by immersion in water at 55°C for 3 min), followed by peeling (or left unpeeled-control), cutting in 7 cm segments (tip, upper, mid, lower and base) and tray-packaging (with a 16 µm stretch film) before storage at 3°C for 6 days. Peeled segments accumulated less CO<sub>2</sub> and ethylene during storage and had decreased lightness and chroma as well as higher hue angle values than the unpeeled segments. Tip segments accumulated more CO<sub>2</sub> and ethylene during storage and had higher soluble solids content, titratable acidity, antioxidant capacity and color attributes of less lightness or higher chroma and hue angle values than the mid and base segments. Spear segments showed lower pH and titratable acidity, higher antioxidant capacity and lower chroma and hue angle values after storage. The sensory evaluation showed that the peeled segments tended to retain better color, flavor, texture and overall acceptability than the unpeeled ones. The tip segments had higher bitterness but lower color and overall acceptability scores than the bottom segments. The mean overall acceptability scores of all segments, however, were above the borderline indicating that they can be utilized as an unpeeled or peeled minimally processed product.

**Key words:** Asparagus, peeling, minimally processed, fresh cut, heat treatment, quality, sensory, color, ethylene, carbon dioxide, storage, postharvest physiology.

### Introduction

Traditionally, white asparagus is commercialized as whole unpeeled spears though it is peeled before processed or cooked. Quality standards of white asparagus spears include color, shape and size among other attributes; rejected spears (that do not meet these standards) often times present a significant percentage of yield.

White asparagus spears undergo many compositional and physiological changes after harvest, resulting in severe quality deterioration. Such changes include development of purple coloration in tip, toughening as well as losses of water, ascorbic acid, soluble solids, carbohydrates and protein <sup>1,2</sup>. The application of hot water treatment at 55°C for 2-3 min before peeling storage controlled the development of purple color during storage<sup>3</sup>. Hot water treatment has also been reported to reduce respiration and ethylene production of spears while compositional changes during storage are minimal <sup>4</sup>. Water loss is prevented by packaging of asparagus spears in modified atmosphere packaging (MAP) using semi-permeable films. Such packaging allows a moderate modification of package atmosphere and thus avoiding of the risk of potential low O<sub>2</sub> or high CO<sub>2</sub> injury <sup>5</sup>.

Lately, white asparagus spears have been developed as a minimally processed product following peeling and tray-packaging. By peeling of harvested white asparagus toughness and skin defects are avoided, however, water loss is enhanced and respiration increased <sup>6</sup> while spear composition changes are induced <sup>7</sup>. Furthermore, the undesirable purple color also develops

during storage similarly to unpeeled spears since peeling is applied in all spear surfaces except of a 2-3 cm part below the tip.

Although asparagus is considered one of the most valuable crops because of its nutritive value <sup>8</sup>, there is virtually no reports on utilization of spears with shape or size defects which are normally rejected and perished. Such spears could be utilized as spear segments (following removal of defected spear part), unpeeled or peeled (following peeling to remove color defects) followed by packaging, storage or marketing in MAP, similarly to intact spears. However, peeling and cutting of asparagus spears to segments introduces extensive wounding which enhances the respiratory, compositional and color changes during storage <sup>9,10</sup> in addition to purple color development in tip segments. These changes might be controlled to different extent by hot water treatment at 55°C for 2-3 min before peeling <sup>3</sup>.

This study aims in providing data on utilization of white asparagus segments by investigating the visual, nutritive and sensory quality responses of hot water-treated spears to peeling, segmentation and storage at 3°C for 6 days in MAP packaging.

### Materials and Methods

**Plant material:** White asparagus (*Asparagus officinalis* L.) spears of the cultivar Dariana were morning-harvested from ridged plants of a commercial plantation near Gianitsa, region of Macedonia-Greece and placed into a styrofoam container to reduce exposure to light. After 2 h transportation in darkness at ambient temperature

(~25°C), the spears were immersed in cool water (1-2°C) for 10 min, trimmed to 21 cm in length and washed thoroughly. Straight and undamaged spears, 16-24 mm in diameter with closed bracts were selected. The maximum exposure of the spears to ambient light during the harvest and handling was about 3 hours.

**Treatments:** Spears were immersed in a hot water bath held at temperature of 55°C for 3 min<sup>3</sup>, cooled in water containing 150 ppm chlorine at ambient temperature for 10 min and then placed on absorbent paper to remove the excess surface moisture.

Spears were then divided in two groups; spears of the first group were left unpeeled and those of the second were manually peeled to 3 cm below the tip. Spears of both groups were cut in segments (sizes) starting from the tip as follows: tip (0-7 cm) or non-tip {upper (3.5-10.5 cm), mid (7-14 cm), lower (10.5-17.5 cm) and base (14-21 or cm)} segments. The weight of the unpeeled and peeled segments was monitored.

For each treatment three replications were used; each replication consisting of 12 spear segments. Three replications were also used for the day zero analysis.

**Packaging and storage:** Spear segments of each replication were weighed, their color was measured and they were placed in polystyrene trays of 16 cm x 11 cm x 3.2 cm. The trays were hand wrapped with a 16 µm stretch film (Fabbri Arti Grafiche S.R.L-Vignola, Modena, Italy). The film surface area of each package was 468 cm<sup>2</sup>. The film had O<sub>2</sub> and CO<sub>2</sub> transmission rates of 583 and 1750 ml.m<sup>-2</sup>.h<sup>-1</sup> atm<sup>-1</sup>, respectively, and a moisture vapor transmission rate of 14.6 g.m<sup>-2</sup>.h<sup>-1</sup>.atm<sup>-1</sup> at 39°C and 90% RH (film permeability measured by manufacturer). The trays were kept at 3°C for 6 days.

**Package atmosphere analysis:** The atmosphere within the packages was sampled after wrapping at times as shown in Figs 1, 2 and 3. At each sampling time, three 1 ml samples from each package were taken using an insulin-type syringe through a rubber septum glued on the surface of the package for carbon dioxide, oxygen and ethylene determination.

Carbon dioxide and oxygen were measured according to Saltveit and Strike<sup>11</sup> by injecting the gas sample into a stream of N<sub>2</sub> carrier gas flowing through a CO<sub>2</sub> and O<sub>2</sub> analyzer (model Compo 280, David Bishop Instruments, UK).

Ethylene was measured by injecting the gas sample into a Varian 3300 gas chromatograph (Varian Instruments, Walnut Creek, CA) equipped with a 60/80 porapak N column and a flame ionization detector. Operating conditions were: detector at 120°C, injector at 80°C and column at 50°C. The flow rate of the Argon carrier gas was 30 ml min<sup>-1</sup>.

**Determination of physicochemical quality characteristics:** Before and after storage, the fresh weight, color and DPPH radical scavenging activity as well as soluble solids, pH and titratable acidity were determined in unpeeled and peeled spear segments of each replication. Color readings of the spears were performed with a chromameter (Minolta CR-200, Minolta, Osaka, Japan), equipped with an 8 mm measuring head and a C illuminant (6774 K). The meter was calibrated using the manufacturer's standard white plate. Color changes were quantified in the L\*, a\*, b\* color space. Hue angle [(H° = 180 + tan<sup>-1</sup>(b\*/a\*))] and chroma values [C\* = (a\*<sup>2</sup>+b\*<sup>2</sup>)<sup>1/2</sup>] were calculated from a\* and b\* values<sup>12</sup>. L\*

refers to the lightness, ranging from 0 = black to 100 = white; C\* represents color saturation, which varies from dull (low value) to vivid (high value); and H\* value is defined as a color wheel, with red-purple at an angle of 0°, yellow at 90°, bluish-green at 180° and blue at 270°. On the middle of each spear segment, two readings were taken at two opposite sites.

After the determination of weight and color the unpeeled and peeled spear segments of each replication were macerated in a blender to perform compositional analysis. Soluble solids content (SSC) was measured in the juice of the blended material using a portable Atago PR-1 refractometer (Atago Co. Ltd., Tokyo, Japan). DPPH radical scavenging activity was determined using a modified method of Brand-Williams *et al.*<sup>13</sup>. Sample homogenate, 5 g, was extracted with 25 ml methanol in ice, centrifuged at 5000g for 10 min and filtered through Whatman No 1. The supernatant was filled with methanol to 25 ml and 50 µl of that extract, was added to 2950 µl of 100 µM methanolic DPPH, vortexed and kept in dark at room temperature. The decrease in absorbance of the resulting solution was monitored at 517 nm for 30 min. Ascorbic acid was used as a standard. DPPH radical scavenging activity has been expressed in mg of ascorbic acid equivalents antioxidant capacity (AAEAC) per 100 g fresh weight. The pH and titratable acidity (TA) were determined in a 50-ml filtrate obtained from a mixture of 10 g blended material with 100 ml deionized water. The filtrate was titrate to pH 8.2 with 0.01 NaOH and the titration data were expressed as milliequivalents of anhydrous citric and malic acid per 100 g f.w., since asparagus contains equal amounts of these acids<sup>8</sup>.

**Sensory quality evaluation:** The consumer acceptability and preference of peeled and unpeeled segments in addition to fresh asparagus spears were evaluated by a 6 trained member panel after storage. Spear segments were boiled for 10 min and each group of segments was served to each panelist in a random order, identified by code numbers<sup>5</sup>.

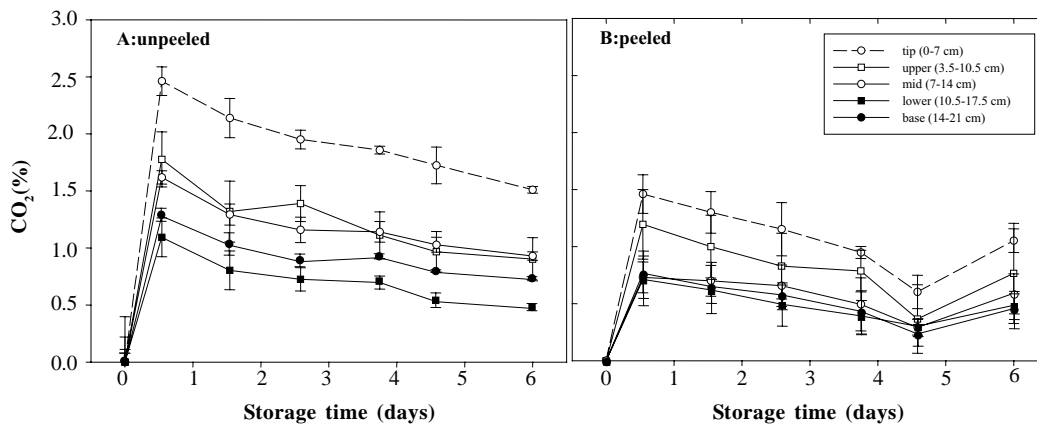
To determine consumer acceptability the panelists were asked to observe, smell, taste and rank the samples using a six-point intensity scale for color (1 = brown, 5 = white), texture (1 = very tought, 5 = very soft), bitterness (1 = no bitter, 5 = extremely bitter) and flavor (1 = not detectable, 5 = very strong).

The panelists also evaluated each sample for overall acceptability and indicated the extent of their preference for each sample in a nine-point hedonic scale ranging from like extremely (1) to dislike extremely (9). Using the above numeric scaling system, the mean scores for these samples were obtained. Products were considered acceptable if their mean scores for overall acceptability were above 5 (neither like nor dislike).

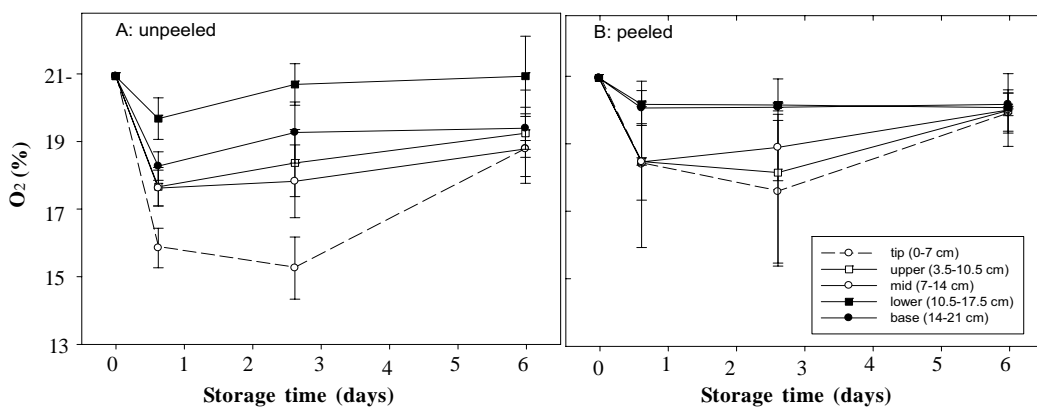
**Statistical analysis:** The quality data were statistically evaluated by ANOVA, with mean differentiation by the Duncan's multiple range test ( $\alpha = 0.05$ ) and the statistical software used was MSTAT, Version 4.00/EM (Michigan State University) while the package atmosphere composition data are means  $\pm$  S.E.

## Results and Discussion

**Package atmosphere composition:** Package atmospheric modification occurred soon after storage at 3°C; maximum CO<sub>2</sub> accumulation (Fig. 1) or maximum O<sub>2</sub> depletion (Fig. 2) occurred within the first 12 h of storage as a result of the high respiration rate and had a similar pattern in all unpeeled or peeled spear



**Figure 1.** Carbon dioxide concentration of packages containing unpeeled (A) and peeled (B) asparagus spear segments (tip, upper, mid, lower and base) during storage at 3°C for 6 days. Each data point is the mean of three replications. Vertical bars in each point represent  $\pm$  SE.



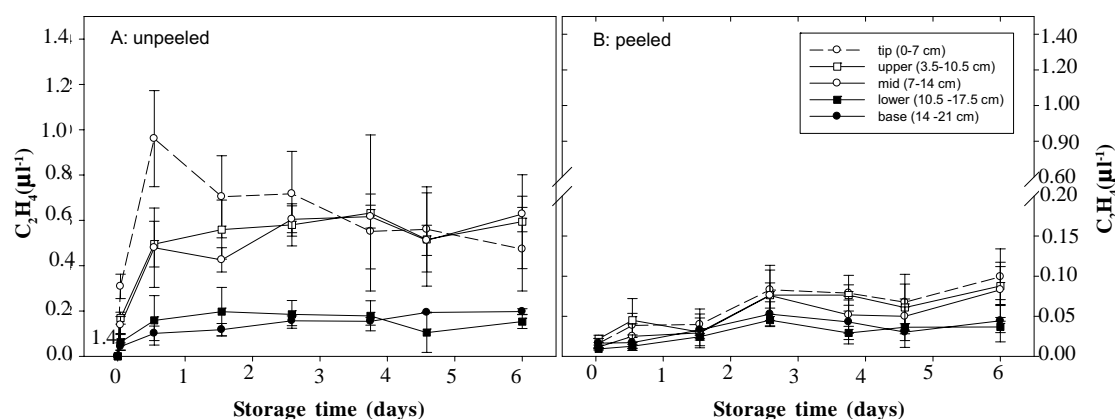
**Figure 2.** Oxygen concentration of packages containing unpeeled (A) and peeled (B) asparagus spear segments (tip, upper, mid, lower and base) during storage at 3°C for 6 days. Each data point is the mean of three replications. Vertical bars in each point represent  $\pm$  SE.

segments. However, packages with peeled segments had lower levels of  $\text{CO}_2$  (Fig. 1) and higher levels of  $\text{O}_2$  (Fig. 2) than the unpeeled ones. Peeling has been reported to increase  $\text{CO}_2$  production rates in unheated asparagus spears<sup>7</sup>. On the other hand, hot water treatment significantly lowers the respiration of commodities during storage and shelf life<sup>4</sup>. A reduction of respiration rates of heat-treated pre-climacteric plums was caused by mechanical damage<sup>14</sup>. The data indicated that hot water treatment was very effective in reducing respiration in the cortex and the significant respiratory activity retained by the unpeeled segments was due to the peel. Siomos *et al.*<sup>7</sup> and Agar *et al.*<sup>15</sup> previously reported that the peel itself significantly contributes to total  $\text{CO}_2$  production of asparagus and kiwifruit, respectively. The apparent higher modification of  $\text{CO}_2$  in spear segment packages compared to that of  $\text{O}_2$  might be due to the lower permeability of the film used for packaging to  $\text{CO}_2$  compared to  $\text{O}_2$ .

The degree of atmospheric modification was also greatly influenced by the type of spear segment (Figs 1-3). Packages with tip segments had the highest  $\text{CO}_2$  accumulation of all packages followed by those containing the upper and mid segments while the lower and base segments had the lowest one. This indicated that the increase in package  $\text{CO}_2$  was mainly due to respiratory activity of spear tip which is reported to produce  $\text{CO}_2$  at four times

the rate than that of spear base<sup>9,10</sup>. However, increased respiratory activity has been reported to be the main responsible factor for spear quality deterioration during storage<sup>1,9</sup>. Generally, package  $\text{CO}_2$  and  $\text{O}_2$  levels during storage were below those suggested to be injurious to green and white asparagus spears at optimal temperature<sup>2,16,17</sup>.

Unlike packages with peeled spear segments which accumulated very low ethylene (below  $0.10 \mu\text{l l}^{-1}$ , Fig. 3B), those with unpeeled spear segments accumulated as high as  $0.96 \mu\text{l l}^{-1}$  for tip, about  $0.20 \mu\text{l l}^{-1}$  for lower and base and intermediate levels for upper, mid, spear segments. All packages exhibited low ethylene concentrations due to hot water treatment<sup>18</sup>. Accumulated ethylene in packages with spear segments indicated "wound-inducible" ethylene production which is reported to be a general response of plant tissues to injuries through an activation of ACC synthase and ACC oxidase<sup>19</sup>. Wound ethylene is induced by cutting in green and white asparagus<sup>20,21</sup>. Similarly to  $\text{CO}_2/\text{O}_2$ , since both unpeeled and peeled segments were subjected to hot water treatment, the difference in their package ethylene concentration observed could also be attributed to the metabolic activity of the peel.



**Figure 3.** Ethylene concentration of packages containing unpeeled (A) and peeled (B) asparagus spear segments (tip, upper, mid, lower and base) during storage at 3°C for 6 days. Each data point is the mean of three replications. Vertical bars in each point represent  $\pm$  SE.

**Physicochemical quality characteristics:** Peeling, spear segment and storage as well as their interactions had a significant effect on fresh weight loss, but most of the total variance (99%) was accounted for by differences before and after storage (Table 1). Tip segments exhibited the highest weight loss (1.53%) among unpeeled segments (1.20-1.38%), while no significant effect of spear segment was observed after peeling (1.40-1.54%). The observed weight loss was intermediate to reported values<sup>5,22</sup>.

Most of the total variance of SSC was accounted for by differences between spear segment followed by peeling (58 and 14%, respectively). Tip segments had higher SSC than the non-tip ones (Table 1).

Most of the total variance for DPPH radical scavenging activity was accounted for by differences before and after storage (92%), although significant effect of peeling and spear segment was also observed (Table 1). At the end of storage, with the exception of unpeeled tip segments, both unpeeled and peeled spear segments showed an increase of their DPPH radical scavenging activity. Minimal processing and storage has been reported to increase the antioxidant capacity compared to the non-wounded controls of ready-to-eat carrot and lettuce<sup>23,24</sup>. Our results for DPPH radical scavenging activity were lower than the reported one<sup>25</sup>.

Titrate acidity was mainly affected by storage and spear segment (54 and 40% of total variance, respectively). Both the unpeeled and peeled spear segments showed a decrease in their titrate acidity at end of storage. The tip spear segments exhibited the highest titrate acidity before and after storage among all treatments (Table 1).

Most of the total variance for pH was accounted for by differences before and after storage (88%), although significant effects of spear segment as well as of that of interaction of peeling x spear segment were also observed. At the end of storage, both unpeeled and peeled spear segments showed an increase of their pH (Table 1).

Most of the total variance (60%) of lightness was accounted for by differences between peeling x storage interaction though only the effect of peeling was significant (Table 1). Chroma was affected by peeling and spear segment (53 and 37% of the total variance, respectively). Peeling resulted in a decrease of chroma

in all spear segments before or after storage. Tip segments had higher chroma than the non-tip ones.

Most of the total variance of hue angle was accounted for by differences before and after storage as well as peeling (67 and 22%, respectively). Storage resulted in a decrease of hue angle of mid to lower unpeeled or peeled spear segments (Table 1).

**Sensory quality:** Spear tip segments retained good bract compactness, while both tip and non-tip spear segments retained their freshness following storage. Spear segment color was mainly affected by peeling and segmentation (25 and 40% of total variation, respectively), texture by segmentation and storage (53 and 32% of total variation, respectively), bitterness only by segmentation and overall acceptability by segmentation, storage and peeling (35, 18 and 26% of total variation, respectively). None of the factors had any significant effect on flavor (Table 2).

Peeled segments had higher color (more white) and overall acceptability score than the unpeeled. Spear segmentation affected all sensory parameters except of flavor. Tip and upper-middle segments had the lowest color scores, although they did not develop any purple coloration, while the middle to lower segments had the highest one, since they retained their initial color (Table 2). These effects were attributed to the effects of heat treatment<sup>3</sup>. Tip-mid segments had higher texture scores than mid to base ones<sup>26</sup> probably due to lignin accumulation mainly in the middle and basal sections of fresh white asparagus upon refrigerated storage<sup>27</sup>. Increased bitterness scores were recorded in tip to middle spear segments compared to segments obtained from the middle and the base of the spears (Table 2).

All samples were considered as acceptable after storage. No significant differences among the peeling or storage treatments were detected. The mean score for overall acceptability was above the borderline of acceptability (Table 2). The results suggest that all segments, particularly peeled ones, are sharing similar acceptance with those of fresh samples.

**Table 1.** Mean squares (MS) and mean comparison for fresh weight loss (FWL), soluble solids content (SSC), pH, titratable acidity (TA), DPPH radical scavenging activity (AAEAC) and color parameters (L, chroma and hue angle) of unpeeled or peeled asparagus spear segments (tip, upper, mid, lower and base) stored at 3°C for 0 and 6 days.

	DF	FWL (%)	SSC (%)	pH	TA meq 100 g <sup>-1</sup>	AAEAC mg 100 g <sup>-1</sup>	L	chroma	hue angle
MS									
Peeling (A)	1	0.07 **	0.56 ***	0.01	0.00	11.40 *	7.70 *	46.46 ***	59.28 ***
Spear segment (B)	4	0.02 *	2.28 ***	0.04 ***	0.36 ***	6.75 *	1.64	32.60 ***	9.96 **
(A x B)	4	0.01 *	0.34 ***	0.06 ***	0.02 *	0.76	5.74	0.52	5.21
Storage (C)	1	28.95 ***	0.01	1.11 ***	0.50 ***	348.15 ***	1.14	5.00 ***	177.92 ***
(A x C)	1	0.07 *	0.29 **	0.01	0.01	0.81	32.44	0.61	4.73
(B x C)	4	0.02 *	0.16 **	0.01	0.02 *	2.35	2.71	0.65 *	5.96 *
(A x B x C)	4	0.01	0.26 **	0.01	0.01	5.37	1.48	0.63 *	0.58
Error	40	0.01	0.03	0.01	0.01	2.08	1.31	0.23	2.13
Effects of peeling									
unpeeled		1.32 a	5.42 a	6.49 a	1.12 a	12.26 a	80.05 a	8.41 a	103.24 b
peeled		1.41 a	5.61 a	6.51 a	1.14 a	11.34 a	79.10 b	6.52 b	104.90 a
Effects of segment									
tip		1.53 a	6.28 a	6.60 a	1.45 a	12.69 a	78.85 b	10.23 a	105.40 a
upper		1.24 a	5.30 b	6.46 a	1.23 b	12.03 a	79.43 ab	7.44 b	104.50 a
mid		1.32 a	5.23 b	6.47 a	1.06 c	12.07 a	80.01 a	6.46 c	103.80 bc
lower		1.40 a	5.42 b	6.49 a	1.06 c	10.61 a	79.97 a	6.28 cd	103.20 c
bottom		1.34 a	5.34 b	6.48 a	1.02 c	11.60 a	79.57 ab	6.65 d	103.60 bc
Effects of storage									
before storage		0.00 b	5.50 a	6.37 b	1.22 a	9.42 b	79.32 a	7.73 a	105.10 a
after storage		1.37 a	5.53 a	6.63 a	1.04 b	14.18 a	79.79 a	7.14 b	102.27 b

\*Significant effect at the 0.05 level, \*\* Significant effect at the 0.01 level, \*\*\* Significant effect at the 0.001 level. Each value is the mean of three replications. Means within each parameter followed by different letters are significantly different according to Duncan's multiple range test at the 0.05 level.

**Table 2.** Mean squares (MS) and mean comparison for sensory evaluation parameters (color, texture, bitterness, flavor and overall acceptability) of unpeeled or peeled asparagus spear segments (tip, upper, mid, lower and base) stored at 3°C for 0 and 6 days.

	DF	Color	Texture	Bitterness	Flavor	Overall acceptability
MS						
Peeling (A)	1	10.8 **	2.1	0.1	3.7	3.7 *
Spear segment (B)	4	17.3 ***	31.2 ***	9.7 ***	0.5	7.0 ***
(A x B)	4	0.1	0.2	0.0	0.7	0.0
Storage (C)	1	0.0	19.2 ***	0.7	5.2	5.2 **
(A x C)	1	10.8 **	2.1	0.1	3.7	3.7 *
(B x C)	4	3.2 *	4.1 **	2.4	0.2	0.6
(A x B x C)	4	0.1	0.2	0.0	0.7	0.0
Error	100					
Effects of peeling						
unpeeled		4.1 b	3.2 a	3.7 a	3.3 a	4.60 a
peeled		4.7 a	3.5 a	3.7 a	3.6 a	5.00 a
Effects of segment						
tip		3.2 c	4.4 a	4.5 a	3.6 a	4.10 d
upper		3.9 b	4.3 a	4.1 ba	3.5 a	4.50 dc
mid		5.2 a	3.8 a	3.5 bc	3.5 a	5.50 a
lower		5 a	2.5 b	3.2 c	3.3 a	5.10 ba
bottom		4.9 a	1.8 c	3.0 c	3.3 a	5.00 bc
Effects of storage						
before storage		4.5 a	3.0 b	3.6 a	3.2 a	5.03 a
after storage		4.5 a	3.8 a	3.8 a	3.7 a	4.62 a

\*Significant effect at the 0.05 level, \*\* significant effect at the 0.01 level, \*\*\* significant effect at the 0.001 level. Each value is the mean of 6 replications. Means within each parameter followed by different letters are significantly different according to Duncan's multiple range test at the 0.05 level.

## Conclusions

The present work explored the possibility of utilizing white asparagus as a minimally processed product; spears were initially hot water-treated, following peeling, cutting in segments and tray-packaging with a semi-permeable film. The collected data showed that peeling and spear segment significantly affected modification of package atmosphere during storage as well as asparagus composition and color. However, visual quality evaluation showed that all spear segments of both unpeeled and peeled asparagus had a good to excellent overall appearance. Asparagus segments can be utilized as an unpeeled or peeled minimally processed product.

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