Modified atmosphere packaging of white asparagus spears: composition, color and textural quality responses to temperature and light

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Abstract

Freshly harvested white asparagus (Asparagus officinalis L.) spears (about 500 g per package) were over-wrapped with a 16 µm stretch film. Packages were kept at 2.5°C, 5°C, 10°C, 15°C, 20°C and 25°C under continuous darkness or light (15 ± 1.9 W m⁻²) for 6 days. At all temperatures, an atmosphere of 4.5–6.9% CO₂ and 3–6.7% O₂ developed during the first hour; after 8 h, CO₂ increased to a maximum of 5.8–9.8%, whereas O₂ decreased to a minimum of 0.7–1%. At equilibrium, the atmosphere had 4.6–7% CO₂ and about 1% O₂. Bract opening (‘feathering’), toughening, anthocyanin synthesis and ascorbic acid breakdown were suppressed in the packages during 6 days. However, at temperatures above 15°C visual deterioration and development of severe off-odors occurred. The presence of light in the storage environment had no significant effect on spear quality.

Key words: Asparagus officinalis L.; Low O₂; High CO₂; Fermentation volatiles; Fiber; Toughness; Anthocyanin

1. Introduction

Fresh asparagus (Asparagus officinalis L.) deteriorates rapidly after harvest. Physiological and compositional changes during storage that reduce spear quality

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include toughening and loss of water, and changes in ascorbic acid, carbohydrates, protein and amino acids (Chang, 1987). These undesirable changes can be reduced by a combination of rapid cooling after harvest, storage at low temperatures and use of controlled or modified atmosphere storage (Lipton, 1990).

Toughness of harvested asparagus is a major factor in determining spear quality. Toughening of asparagus is mainly related to the degree of lignification of the spears in both the fiber ring and the vascular bundles. The lignification is controlled by enzymes, such as phenylalanine ammonia-lyase (PAL), peroxidase and isoperoxidases. Temperature and light stimulate the activity of the above enzymes and thus enhance lignification (Chang, 1987). Although the importance of reducing temperature to maintain asparagus textural quality is well documented, clear data on the influence of temperature on the rate of change of spear toughness are limited (Lipton, 1990).

Spears can undergo undesirable chlorophyll degradation in green asparagus and anthocyanin synthesis in white asparagus (Chang, 1987). Anthocyanin accumulation in plant tissues is influenced by many environmental factors, of which the most important is light (Grisebach, 1982). A combined treatment of low temperature (2–4°C), darkness and water immersion has been reported to slow down anthocyanin synthesis in stored white asparagus spears (Chen et al., 1980; Lin and Tsai, 1980), but independent effects of temperature and light are not known.

Controlled atmospheres have been used to retard deterioration of asparagus during cool storage, but they provided little added benefit (Lipton, 1990). However, with the development of new semi-permeable plastic films, further investigations into modified atmosphere packaging (MAP) show some promise for extending shelf-life of spears using this technology (Tomkins and Cumming, 1988; Baxter and Waters, 1991; Everson et al., 1992). Most of the MAP research has been on green asparagus, and there are only inconclusive results on the effect of MAP on the quality of white asparagus (Lipton, 1990).

The purpose of the present study was to determine whether atmospheres obtained by MAP had a detrimental or beneficial effect on the quality of stored white asparagus in relation to storage temperature and light conditions.

2. Materials and methods

2.1. Plant material and handling

White asparagus spears of the double hybrid ‘Larac’ were harvested from a 9 year-old commercial plantation near Gianitsa, Macedonia, Greece and placed immediately into a styrofoam container to prevent exposure to light. After 2 h at
ambient temperature (~22°C) they were immersed in water at 1–2°C for 12 min. Straight, undamaged spears, 16–24 mm in diameter with closed bracts were then washed thoroughly and trimmed to 22 cm in length. The total time that spears were exposed to ambient light was about 3 h. This experiment was carried out twice with spears harvested at the 35th and 60th day of the harvesting period (from 20 March to 20 May). The data presented are from the second experiment but similar results were obtained for the other one.

2.2. Packaging

10–12 spears (about 500 g) were bunched and either were left unwrapped (control) or 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 about 550 cm². The film had O₂ and CO₂ transmission rates of 583 and 1750 ml m⁻² h⁻¹ atm⁻¹, respectively and a moisture vapor transmission rate of 14.6 g m⁻² h⁻¹ atm⁻¹ at 39°C and 90% RH (film permeability measured by manufacturer).

2.3. Storage conditions

The bunches (wrapped and unwrapped) were placed vertically in 5 l glass jars in an air-flow system kept at 2.5°C, 5°C, 10°C, 15°C, 20°C and 25°C for 6 days. Humidified air, free of ethylene (removed by an Ethysorb ethylene scrubber) was passed through the jars at a rate of 100 ml min⁻¹. At each temperature, for each packaging treatment (wrapped and unwrapped bunches), three jars were covered with aluminum foil, while three others were placed under continuous light from cool-white fluorescent lamps (Tungram daylight). The irradiance at the level of the spear tips was 15 ± 1.9 W m⁻². Daylight fluorescent lamps are an effective source of irradiation for the promotion of anthocyanin synthesis in apples (Proctor and Creasy, 1971). Three bunches of spears were used for the day zero analysis.

2.4. Package atmosphere analysis

The atmosphere within the illuminated packages at 2.5°C, 10°C and 20°C was sampled at 20, 40 and 60 min and 2, 4, 8, 21, 47, 116 and 144 h after wrapping. A 1 ml sample from each package was taken using an insulin-type syringe through a rubber septum glued on the surface of the package. The air sampled was replaced with room air to prevent the formation of a vacuum. The gas samples were analyzed for CO₂ and O₂ using a Varian 3300 gas chromatograph (Varian Instruments, Walnut Creek, CA) equipped with 60/80 porapak N and 45/60 molecular sieve 13× columns and a thermal conductivity detector. Column
temperature was 50°C for 4 min, then programmed to increase 30°C min⁻¹ up to 160°C, where it was kept for 6 min. Operating conditions were: detector at 120°C, injector at 80°C and TCD filament temperature 150°C. The flow rate of the Ar carrier gas was 30 ml min⁻¹.

2.5. Volatile analysis

Acetaldehyde and ethanol accumulation within the illuminated packages at 2.5°C, 10°C and 20°C was monitored after 6, 10, 18, 53, 68, 80 and 104 h of wrapping, in a 1 ml sample withdrawn from the package atmosphere using a glass syringe as described above. Gas analysis was performed on a Varian 3700 gas chromatograph (Varian Instruments, Walnut Creek, CA) equipped with a glass column containing 5% carbowax 20M on 60/80 carbopak B support (Supelco, Bellefonte, PA) and a flame ionization detector. Nitrogen was used as a carrier gas at a flow rate of 20 ml min⁻¹. After 6 days of storage, the acetaldehyde and ethanol accumulated in the spear tissues were determined in the extractable juice obtained by macerating the spears as described by Davis and Chace (1969).

2.6. Compositional analysis

Dry matter, total soluble solids and ascorbic acid content were measured on the day of harvest and after 6 days of storage. Spears were macerated in a blender and their dry matter content determined after drying at 70°C for 72 h. Soluble solids content (SSC) was measured in the juice of the pulp using a refractometer (Atago, Tokyo, model PR-1). Ascorbic acid content was determined by the 2,6-dichlorophenol-indophenol method (Ranganna, 1977).

The fiber content of the spears was determined on the day of harvest and after 6 days of storage according to Sosa-Coronel et al. (1976). Toughness of the spears was measured on the day of harvest and after 6 days of storage using a Chatillon penetrometer (John Chatillon and Sons, New Gardens, NY) equipped with a plunger of 3.2 mm in diameter and 9.5 mm in length (MacGillivray, 1933). In each spear, three measurements were taken 7, 14 and 21 cm from the tip (apical, middle and basal segment, respectively).

Anthocyanin content was determined on the day of harvest and after 6 days of storage as described by Cheour et al. (1990). The 7 cm apical segments of the spears were macerated in a blender and the anthocyanins were extracted from a 5 g sample with acidified ethanol. The absorbance of the extract was measured at the most anthocyanin-sensitive wavelength of 532 nm, which was determined after scanning. The results were expressed as absorbance per gram of fresh weight. Color readings of the spears were performed on the day of harvest and after 6 days of storage with a Minolta CR-200 chromameter (Minolta, Osaka, Japan), equipped with an 8 mm measuring head and a C illuminant (6774 K).
Color changes were quantified in the $L^*$, $a^*$, $b^*$ color space. A negative value of $a^*$ indicates a white color, while a positive number indicates an intense purple color. On each spear, three readings were taken at 1, 2 and 3 cm from the tip.

2.7. Statistical analysis

The experimental design was a completely randomized one with three replications, each replication consisting of one bunch (wrapped or unwrapped) of 10–12 spears. Data analysis was done by an analysis of variance, with mean separation by LSD at the 0.05 level.

3. Results

3.1. Package atmospheric composition

In illuminated packages at 2.5°C, 10°C and 20°C, CO$_2$ concentrations increased to 4.5–6.9% within 1 h, reached a maximum of 5.8–9.8% during the first 8 h and equilibrated at 4.6–7% (Fig. 1). Oxygen concentrations decreased to 3–6.7% during the first hour, 1% or less within the first 8 h and thereafter showed little change. There was hardly any effect of temperature on development of these modified atmospheres.

3.2. Fermentation volatiles

Traces of acetaldehyde and ethanol were present in the packages after 48 h of storage. They rose to maximum concentrations (1.5–2 µl acetaldehyde/l and 2–120 µl ethanol/l) after 96 h, and declined slightly thereafter. The greatest concentration was at the highest temperature (data not shown). After 6 days of storage, the amount of ethanol accumulated in spear tissues was linearly related to the storage temperature ($r = 0.999$, $P < 0.0001$) (Fig. 2). The acetaldehyde concentrations ranged from 10 to 20 µl l$^{-1}$ after 6 days, with the greatest concentration at the highest temperature.

3.3. Fresh weight loss

Weight loss of the spears stored in MAP increased exponentially with temperature ($r = 0.891$, $P < 0.0001$) (Fig. 3A). After 6 days of storage the spears stored at 2.5–15°C had lost <1% of their initial fresh weight and those at 20°C and 25°C had lost 1.9 and 2.9%, respectively. However, the weight loss of the packaged spears was significantly lower at all temperatures compared to the weight loss of spears stored in air.
3.4. Composition

In spears stored in MAP, a significant loss in dry matter had occurred after 6 days of storage at all temperatures (Fig. 3B). The loss of dry matter was linear with increasing storage temperature ($r = -0.923, P < 0.00002$). No significant effect of packaging on the reduction of dry matter was observed.

A significant decrease of SSC of the packaged spears was observed after 6 days of storage only at temperatures $\geq 15^\circ$C (Fig. 3C). The decrease of SSC of the packaged spears was significantly lower than the decrease of SSC of spears stored in air, at temperatures $\geq 10^\circ$C.

The ascorbic acid (AA) content remained unchanged at all temperatures over the 6 day-storage period in spears stored in MAP (Fig. 3D). On the contrary, in spears stored in air, the AA content decreased significantly at all temperatures and that decrease was linear with increasing storage temperature ($r = -0.935, P < 0.00001$).

Fig. 1. Concentration of $O_2$ (- - O - -) and $CO_2$ (---) in film-wrapped packages containing about 500 g of white asparagus spears stored at 2.5°C, 10°C and 20°C under continuous light (15 ± 1.9 W m$^{-2}$). The inserts show changes in the concentrations of $O_2$ (- - O - -) and $CO_2$ (---) during the first 8 h after wrapping.
No significant differences in toughness of apical, middle and basal segment of the spears stored in MAP were found between the harvest values and those after 6 days of storage (Fig. 4A–C). On the contrary, in spears stored in air, toughness of the apical and middle segment increased significantly at temperatures ≥5°C and ≥15°C, respectively.

A significant increase of the fiber content of the spears stored in MAP was found after 6 days of storage at 10°C and 15°C (Fig. 4D). Spears stored in air had a higher fiber content in comparison to spears stored in MAP at 20°C and 25°C.

Very little anthocyanin accumulation was observed at the tips of the spears stored in MAP during 6 days of storage (Fig. 5B). But, more important, this quantity of anthocyanin did not affect the spear visual appearance; the tips were still white at the end of storage. This was confirmed by the color a* values, which showed no significant changes over harvest values (Fig. 5A). On the contrary, in spears stored in air, the anthocyanin content increased significantly at all temperatures, resulting in an intense purple color of the tips. The presence of light in the storage environment had little or no effect on any of these measurements.

3.5. Visual appearance

Spear quality was best after 6 days of storage in packages at 2.5°C and 5°C. Spears stored at 10°C and 15°C were rated acceptable, but spears stored at 20°C and 25°C developed a browning, mainly at their base (data not shown). A soft rot
Fig. 3. Fresh weight loss (A), dry matter (B), soluble solids (C) and ascorbic acid (D) content of white asparagus spears after 6 days of storage in modified atmosphere packages (---) or in air (—) at 2.5°C, 5°C, 10°C, 15°C, 20°C and 25°C under continuous light (15 ± 1.9 W m⁻²) (□) or in the dark (■). Each data point is the mean of three replicates. The vertical bars represent the 5% LSD value. The horizontal lines represent the corresponding values on the day of harvest.
Fig. 4. Toughness of apical (A), middle (B) and basal (C) segment, as well as fiber content (D) of white asparagus spears after 6 days of storage in modified atmosphere packages (- - - -) or in air (—) at 2.5°C, 5°C, 10°C, 15°C, 20°C and 25°C under continuous light (15 ± 1.9 W m⁻²) (□) or in the dark (■). Toughness was measured at 7, 14 and 21 cm from the tip of the spears (toughness of apical, middle and basal segment, respectively). Each data point is the mean of three replicates. The vertical bars represent the 5% LSD value. The horizontal lines represent the corresponding values on the day of harvest.
was also evident in the high temperature treatments; the incidence of infection was relatively low at 20°C, but very high at 25°C. When the packages containing infected spears were opened, a putrid off-odor was detected. There were no visual symptoms in the spears, similar to those described by Lipton (1965), to indicate injuries due to high CO₂ levels.

4. Discussion

Atmospheric modification occurred rapidly during the first hour after wrapping as a result of the high respiration rate of the packaged spears, but the degree of atmosphere modification was not greatly influenced by storage temperature (Fig. 1). At the time of packaging, the spears had a temperature of 21°C and after 1 h of storage at 2.5°C their temperature was 13°C (data not shown). Thus, initial temperature was responsible for the uniform attainment of MA in the packages.
Levels of O₂ below 5–10% and CO₂ levels above 10–15% have been suggested to be injurious to green asparagus spears at optimal temperature (Lipton, 1965; Herner, 1987; Kader et al., 1989; Gorris and Peppelenbos, 1992). At higher than optimal storage temperatures the harmful level of CO₂ has been reported to be >7% (Herner, 1987). At low O₂ levels ethanol accumulation can cause alcoholic off-flavors. An ethanol content >200 µl l⁻¹ caused a slight off-flavor in pears, but it took >1000 and 2000 µl ethanol/l to cause a slight off-flavor in apples and plums, respectively (Ke et al., 1991). According to Gariepy et al. (1991), the O₂ concentration under which respiration process became anaerobic in green asparagus was around 3%, although a brief (6 h) anaerobic exposure (O₂ level below 0.1%) of green asparagus spears did not significantly affect subsequent quality (Torres-Penaranda and Saltveit, 1994). Thus, the O₂ levels in those packages was apparently too low (Fig. 1), but at 2.5–10°C, the depletion of O₂ had no effect on the visual appearance or odor of the spears, although concentrations of 9–13 and 84–403 µl l⁻¹ of acetaldehyde and ethanol, respectively in the tissues were determined (Fig. 2). This suggests that white asparagus is more tolerant to low O₂ than green asparagus.

The prevention of weight loss due to the maintenance of high relative humidity is a major advantage of packaging; the beneficial effect of this practice in asparagus was evident in this study (Fig. 3A), agreeing with earlier studies (Tomkins and Cumming, 1988).

MAP was effective in AA retention of white asparagus spears during storage (Fig. 3D). On the contrary, the spears stored in air lost 36–83% of their initial AA after 6 days, depending on the storage temperature. In many vegetables, MAP or CA storage resulted in greater AA retention than storage in air (Kader, 1986). This beneficial effect is the result of the MA inside the package. The lower the O₂ concentration of the storage atmosphere was, the smaller were the losses of AA, due to the inhibition of AA breakdown (Weichmann, 1987).

In spears stored in air, the anthocyanin content increased significantly, resulting in an intense purple color of the tips (Fig. 5A and B). These results suggest that post-harvest anthocyanin synthesis in white asparagus spears progressed, after an initial stimulation by light (during the 3 h exposure to light), irrespectively of temperature and light conditions during storage in air. On the contrary, the wrapped spears had the best overall color, since the original white color was retained for the storage period of 6 days. Although anthocyanin synthesis has been found to slow down in several fruits and vegetables kept in CA and MAP (Kader, 1986), we found no report for the effect of MAP on anthocyanin synthesis of white asparagus spears.

The atmospheres in these packages were remarkably effective in suppressing compositional changes in these spears regardless of temperature (Fig. 3). However, some adverse effects occurred above 15°C, presumably due to microbial growth.
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References


