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Evolution of Quality Characteristics of Minimally Processed Asparagus During Storage in Different Lighting Conditions

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ABSTRACT: The effect of different types of lighting (white, green, red, and blue light) on minimally processed asparagus during storage at 4 °C was studied. The gas concentrations in the packages, pH, mesophilic counts, and weight loss were also determined. Lighting caused an increase in physiological activity. Asparagus stored under lighting achieved atmospheres with higher CO_2 and lower O_2 content than samples kept in the dark. This activity increase explains the greater deterioration experienced by samples stored under lighting, which clearly affected texture and especially color, accelerating the appearance of greenish hues in the tips and reddish-brown hues in the spears. Exposure to light had a negative effect on the quality parameters of the asparagus and it caused a significant reduction in shelf life. Hence, the 11 d shelf life of samples kept in the dark was reduced to only 3 d in samples kept under red and green light, and to 7 d in those kept under white and blue light. However, quality indicators such as the color of the tips and texture showed significantly better behavior under blue light than with white light, which allows us to state that it is better to use this type of light or blue-tinted packaging film for the display of minimally processed asparagus to consumers.

Keywords: asparagus, color, light, minimally processed products, texture

S: Sensory & Food Quality

Introduction

White asparagus (*Asparagus officinalis* L.) is one of the most highly appreciated vegetables due to its special culinary characteristics. Spain, with production of 60500 tons, is 4th in the ranking of producer countries with 1.1% of the world's production (FAO 2005). However, fresh white asparagus deteriorates rapidly after harvest. Physiological and compositional changes during storage that reduce spear quality include bract opening ("feathering"), toughening, and color and texture changes (Siomos and others 2000). This rapid deterioration and the crop's seasonal nature, has meant that this product is mainly consumed as a canned vegetable.

Minimal processing appears in the 1980s as a response to the demand for quick to prepare products that are as similar as possible to the fresh product. This type of processed vegetables has only received minimal processing: washing, peeling, cutting, and packaging in plastic film. Thus, unlike other forms of preservation, in minimally processed vegetables (MPV), the plant tissue is still living and physiological changes continue to take place. The suitability of this type of processing for both white and green asparagus has been widely studied and the causes of the end of shelf life are well known (Siomos and others 2000, 2001; Scheer and others 2003; Albanese and others 2006).

In minimally processed white asparagus, color changes are caused by enzymatic browning and anthocyanin synthesis. Darkening due to enzymatic browning occurs when the polyphenol oxidases come into contact with phenolic substrates in the presence of oxygen. The inevitable breaking of tissue, which occurs during peeling, means that this contact will result. For their part, the presence of anthocyanins in white asparagus is evident from the development of the purple color. According to quality standards (European Commission 1992), spears with a purple color are judged to be of an inferior quality. Biosynthesis of anthocyanins in plant tissue either requires, or is enhanced by light (Mancinelli 1985).

It is also necessary to consider that the acceptance or rejection of asparagus by consumers largely depends on texture. The increase in the toughness of asparagus after harvesting has traditionally been associated with lignification (Sharma and Wolfe 1975), but recent studies have shown that other modifications of the cell wall composition could also be related to these mechanisms. These consist of the following: increase in phenolic compounds and deposition of polysaccharides (Rodríguez and others 2004; Jaramillo and others 2007).

The speed with which changes occur in the attributes of color and texture in minimally processed asparagus is clearly affected by the conditions of storage and display. Several studies have concentrated on the influence of storage temperature on the shelf life of this product or packaging film permeability (Everson and others 1992; Siomos and others 2000). However, few studies have analyzed the influence that the unavoidable exposure to light during the time they are on sale has on the evolution of the quality parameters of this product (Nilsson 2000; Siomos and others 2000).

In fact, it is precisely the influence of light on the quality of MPV that has been demonstrated in various vegetables, either for the effect on synthesis or changes in pigments, or on the metabolic activity of the packaged product (Sanz and others 2007, 2008a, 2008b; Ayala and others 2009 (in press); Olarte and others 2009), which makes exposure to light a determining factor in the shelf life of MPV products.

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The aim of this study was to estimate the influence of the exposure to different types of light on the evolution of the parameters, which determine the shelf life of the minimally processed white asparagus.

Materials and Methods

Preparation of samples

White asparagus of the Blanca de Navarra variety (distributed by Semillas Fitó, Barcelona, Spain) was grown in the Ebro river area (Navarra, Spain). The asparagus was harvested in April 2008 and transported directly from the fields to the laboratory. All the plants were of high quality and free from defects, 14 to 19 mm of diameter and over 22 cm of length. For the experiment, around 50 kg of asparagus were processed.

After peeling and trimmed to 22 cm in length, 4 to 6 pieces were taken at random to make up a final weight per sample of 300 g. The samples were washed separately by brief immersion for 5 min in water (containing 50 ppm free chlorine) at 4 ± 2 °C (10 L/kg). Washing conditions were established according to the results obtained in previous experiments (Nguyen-The and Carlin 1994; Sanz and others 2002). Samples were then rinsed until the free-chlorine levels were below 0.3 ppm and the excess water was removed by centrifugation.

The asparagus was packaged using a P-Plus film (made of polypropylene) supplied by Danisco (Bristol, U.K.) in 20 × 25 cm bags: 35PA 160 film (P-Plus 160), with O_2 permeability of 15000 $cm^3/m^2/24$ h/atm at 25 °C. According to the manufacturer's specifications, the number 35 represents the thickness of the film in microns. The set of letters corresponds to the type of film and the last figure is the permeability code.

Five batches were packaged: Darkness (D), White Light (W), Green Light (G), Blue Light (B) and Red Light (R), with a total of 24 samples per batch (8 d of sampling by 3 repetitions). The asparagus was placed by hand into bags sealed using a Vaessen–Schoemaker machine (Vaessen-Schoemaker Industrial S.A., Barcelona, Spain). All the pieces of asparagus for each sample were packed in a single layer.

All the packaged asparagus was stored in the same cold store at the same temperature (4 ± 1 °C) for more than 25 d in 5 different conditions: batch D in complete darkness, W, G, B, and R batches in white, green, blue, and red light, respectively. The packs were placed just below the lamps, 30 cm away, with the light shining down on them perpendicularly. The storage conditions under light were controlled in such a way that the angle and the intensity of the light received was identical for all the packs.

Fluorescent light tubes were used for illuminating the batches. For batch W (Cool white fluorescence lamps FSL, 36 W, YZ36RR26, Foshan Electrical and Light Co. Ltd, Foshan, China), similar to that used in retail outlets. For batches G, B, and R, respectively, the tubes L36 W/66 green (main emission spectrum 485 to 495 and 540 to 555 nm), L36 W/67 blue (main emission spectrum 400 to 550 nm), and L36 W/60 red (main emission spectrum 580 to 630 nm) manufactured by Osram (Munich, Germany) were used. In each package, each piece received a comparable level of light exposure.

A total of 3 samples of each lighting condition were taken on day 0 and after 3, 7, 11, 15, 19, 21, and 25 d of storage, although the level of deterioration of some samples meant that they were eliminated from the sample before the end of the total storage period.

The following determinations were made for each sample: atmosphere composition within the packages, microorganism counts, color, texture, and sensory evaluation of the product.

All of the analyses were performed in duplicate, taking the mean of the 2 measurements obtained as the reading.

Color determination

For each sample, the reflectance spectra were measured at 6 different points on the asparagus spears surface and at other 4 points on the asparagus tip, after which the mean reflectance spectrum was obtained separately for each surface. These measurements were taken with a Minolta CM 2600d spectrophotometer with d/8° geometry and a xenon lamp with 8-mm aperture size, manufactured by Minolta Co. Ltd. (Osaka, Japan). The mean spectrum allowed the color coordinates L^*, a^*, b^*, C^*, and h_{ab} within the CIELAB space to be calculated for each sample, using illuminant D65 (CIE 1991a) and standard observer CIE64 (CIE 1991b), in accordance with CIE specifications (CIE 1986).

Texture tests

Texture tests were performed with a Texture Analyzer TA-XTplus (Stable Micro Systems Ltd., Godalming, Surrey, U.K.) using the software application provided with the apparatus (Texture Expert for Windows, version 1.0, Stable Micro Systems Ltd.). The probe used was a blade with a knife edge. The following experimental conditions were selected for all tests: pretest speed 5 mm/s, test speed 1 mm/s, and posttest speed 10 mm/s; cut 100%; trigger force 7 gp; and data acquisition rate 200 pulses/s. To obtain a good estimation, measurements were made on the asparagus pieces from each tray. The cut was made in the midpoint of each spear, so that the blade sliced through the whole diameter of the asparagus.

To minimize the differences in texture attributable to the different thicknesses of the asparagus, the various parameters measured (maximum force, total area of the graph, maximum slope, and so on) were divided by the total displacement of the probe (spear diameter).

Sensory evaluation

Sensory evaluation was used to discriminate between the visual appearance, texture, and odor of the samples of the packaged white asparagus. The judges were selected from an original group that included 25 volunteers, between 23 and 55 y old, connected in some way with the Dept. of Agriculture and Food at the Univ. of La Rioja, on the basis of their interest, time available, liking for vegetables, aptitude for describing the sensory characteristics of food products, and sensory evaluation experience according to the criteria established by Costell and Durán (1981). Finally, a panel of 7 judges were selected and trained on the sensory characteristics of the packaged vegetables.

During the training, panelists were presented with an array of vegetable products to help the development of terms, which included: color, browning, firmness, consistency, and odor (Costell and Durán 1981). Then the judges were specifically trained in the discriminative evaluation of white asparagus, with the same variety and source as those used to prepare experimental samples. The vegetables used in the training sessions had been subjected to various storage times and treatments. Asparagus just peeled and washed was used as a control and received the maximum score for each of the sensory qualities assessed. The training panel observed the effects of storage in different conditions over 25 d. The products were presented on coded plastic dishes. The training sessions were conducted under normal lighting conditions (ISO/DIS 8589 1988).

A simple scorecard was devised to quantify each sensory attribute: tips color, spear color, texture, odor, and general acceptability. The intensity of the attributes evaluated was quantified on a scale from 1 to 5 (Shewfelt 1993) in the following way: tips color was rated using 5 = white, uniform color, without defects; 3 = greenish color; and 1 = intense green. Spears color was rated using 5 = white, uniform color, without defects; 3 = yellowish color, reddish-brown hues; and 1 = intense reddish-brown color. Texture was rated using 5 = very firm and turgid; 3 = slightly soft but acceptable; and 1 = very soft. Odor was rated using 5 = no off-odors; 3 = slight but obvious off-odor; and 1 = strong off-odor. Acceptability was rated using 5 = excellent or having a freshly harvested appearance (that is, bright white, compact and firm, no defects); 3 = average (that is, light color alteration, less compact, few slight defects); and 1 = unmarketable (that is, showing severe color alteration, very soft, and major defects).

Sensorial evaluation was used to determine the shelf life of the product. A score below 3 for any of the attributes evaluated was deemed to indicate the end of shelf life.

During the test sessions, the pieces of each sample were removed from their packs and presented together on a plastic dish to the panel of judges. The order of presentation of the samples was randomized. The samples were evaluated under normal lighting conditions (ISO/DIS 8589 1988).

Other determinations

Free chlorine was determined by colorimetric reaction with DPD (*N*,*N*-diethyl-1,4-phenylenediamine) (Merck, Darmstadt, Germany) (ISO 7393-2 1985). Carbon dioxide and oxygen inside the packages were measured using an O_2 and CO_2 headspace gas analyzer (Checkmate model 9900, PBI-Dansensor, Ringsted, Denmark).

For the microbial analysis of the asparagus the following procedure was adopted: the sample to be analyzed was chopped under sterile conditions, and 25 g was aseptically weighed and homogenized for 2 min with 225 mL of soy peptone water (0.1% soy peptone and 0.5% sodium chloride) using a Stomacher TM (IUL, Barcelona, Spain). Further decimal dilutions were made with the same diluent. Mesophilic microorganisms were enumerated on Plate Count Agar (Difco, Detroit, Mich., U.S.A.) following the pour plate method and incubated at 31 ± 1 °C for 72 h (ICMSF 1978).

Statistical analysis

A total of 3 samples were analyzed for each day and each condition tested, and all the analyses were performed in duplicate. Thus, each of the points in the figures corresponds to the average data resulting from the measurements taken in 3 samples. Each item in the Tables is the average and standard deviation of the scores given by 7 judges of the tasting panel to 3 samples.

Analysis of variance (ANOVA) was performed using the SPSS program for Windows; Statistics version 15.0 (SPSS Inc., Chicago, Ill., U.S.A.). A significance level of $P < 0.05$ was used. Tukey's test for comparison of means was performed using the same program.

Results and Discussion

Atmosphere inside packages

The evolution of O_2 and CO_2 concentrations inside packages are shown in Figure 1.

The asparagus stored in conditions of darkness did not show great respiratory activity and the atmosphere inside the packs depended on the permeability of the film, reaching, on day 3, an equilibrium atmosphere of 5% for CO_2 and approximately 17% for O_2. Exposure to light significantly increased respiratory activity. White light and blue light obtained very similar results, reaching, on day 7, an equilibrium atmosphere of around 10% for O_2 and 15% for CO_2. By contrast, samples illuminated under green and red light did not reach an equilibrium atmosphere and respiratory activity was very high throughout the period studied. Thus, on day 19, concentrations of 4% O_2 and around 25% CO_2 were achieved for green lighting and 0% O_2 and around 40% CO_2 for red lighting. From this point, the intense deterioration suffered by the samples in these batches made it pointless to continue their analysis.

This result is explained by the increase in the physiological activity produced by exposure of the vegetables to green and red light, which encouraged the gaseous exchange that caused the greatest change in the composition of the atmosphere inside the packs (Noichinda and others 2007).

The low permeability to water vapor of P-Plus film explains the presence of water condensation in the inner surface of the films in the packages. The fact that lighting stimulates physiological activity and, therefore, the exchange of gases between the plant tissue and the atmosphere that surrounds it, also explains the substantial differences among degree of water condensation present into packages. Thus, while condensation inside packages stored in darkness was moderate even at the end of the storage period, in the illuminated packages the condensation was appreciable under white and blue light and became very high in the samples stored under green and red light. In the samples of these batches corresponding to the end of shelf life, the amount of water collected when the packs were opened was up to 30 mL. Undoubtedly, the presence of such a high quantity of water inside the bags contributed in a decisive way to the deterioration of these samples. In fact, the differences in the intensity and speed of dehydration coincide with those found in the evaluation of quality parameters, both in the sensorial evaluation made by the panel and in the instrumental measurements.

Microbial counts

The microbial counts of the raw material were 7.8 CFU/g. Peeling and washing managed to reduce the microbial load to 5.2 CFU/g, a

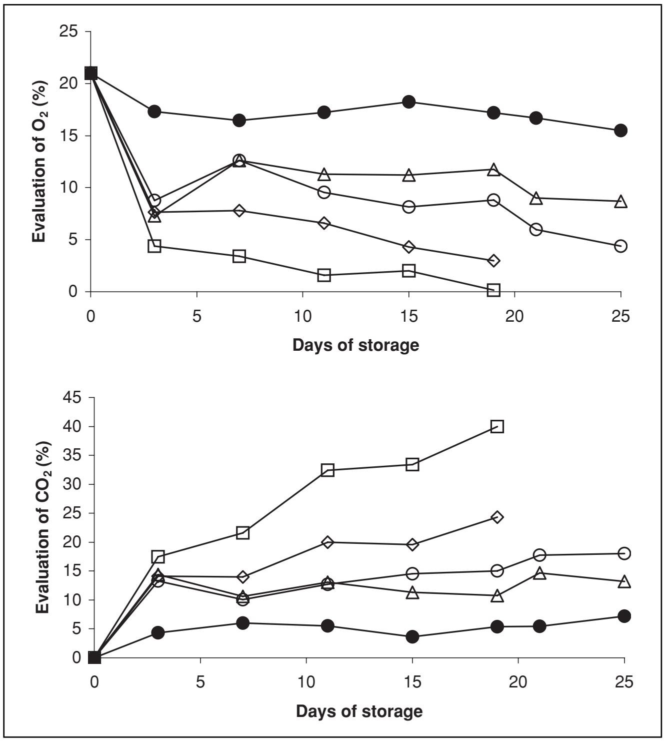

Figure 1 — Gas evolution inside the packages of minimally processed asparagus stored in different light conditions. (•) Batch D, (◦) batch W, (Δ) batch B, (□) batch R, and (◊) batch G.

reduction in line with that referred to by other teams for vegetables with similar characteristics using the same disinfectant agent (Nguyen-The and Carlin 1994).

During storage (Figure 2), the microbial counts increased, reaching a level at the day 19 of storage of around 3 to 4 logarithmic units higher than at the start for illuminated batches. No significant differences were found between the different kinds of lighting conditions used. However, from day 9 of storage, there were differences in the microbial counts of the samples stored in darkness compared to those stored under lighting. In fact, on day 19 of storage, microbial counts of the samples of batch D did not reach 7 logarithmic units, that is, they remained within the tolerance limits established by law (BOE 2001).

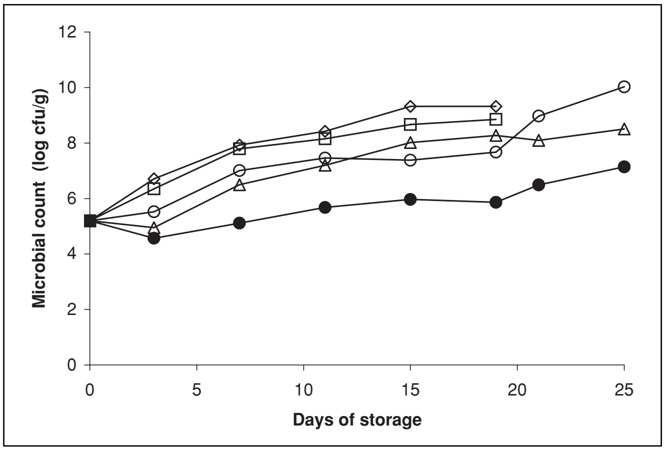

Figure 2—Microbial counts of minimally processed asparagus stored in dark and different light conditions. (•) Batch D, (○) batch W, (Δ) batch B, (□) batch R, and (◊) batch G.

The greater physiological activity undergone in samples subjected to light meant an acceleration in the mechanisms of cell and tissue degradation, as well as a greater quantity of free water, which would account for the higher microbial growth observed in these samples (Brackett 1987). However, the differences in the composition of the atmosphere established in the different packages did not prove a deciding factor in the speed of microbial growth (Daniels and others 1985; Francis and others 1999).

Color

The color coordinates which show significant variation during storage time are L^* and h_{ab} (Figure 3).

Exposure to light had a negative effect on color evolution. Samples stored under darkness conditions had the best behavior, with their L^* coordinate remaining almost constant during the entire storage period, in both the spear and the tip. However, the samples subjected to lighting under with the different types of light underwent a progressive decline in the value of coordinate L^* during the period under study. In the spear, the L^* values of batches W and B did not reveal significant differences in comparison with batch D values. However, from day 11, the values of L^* in batches

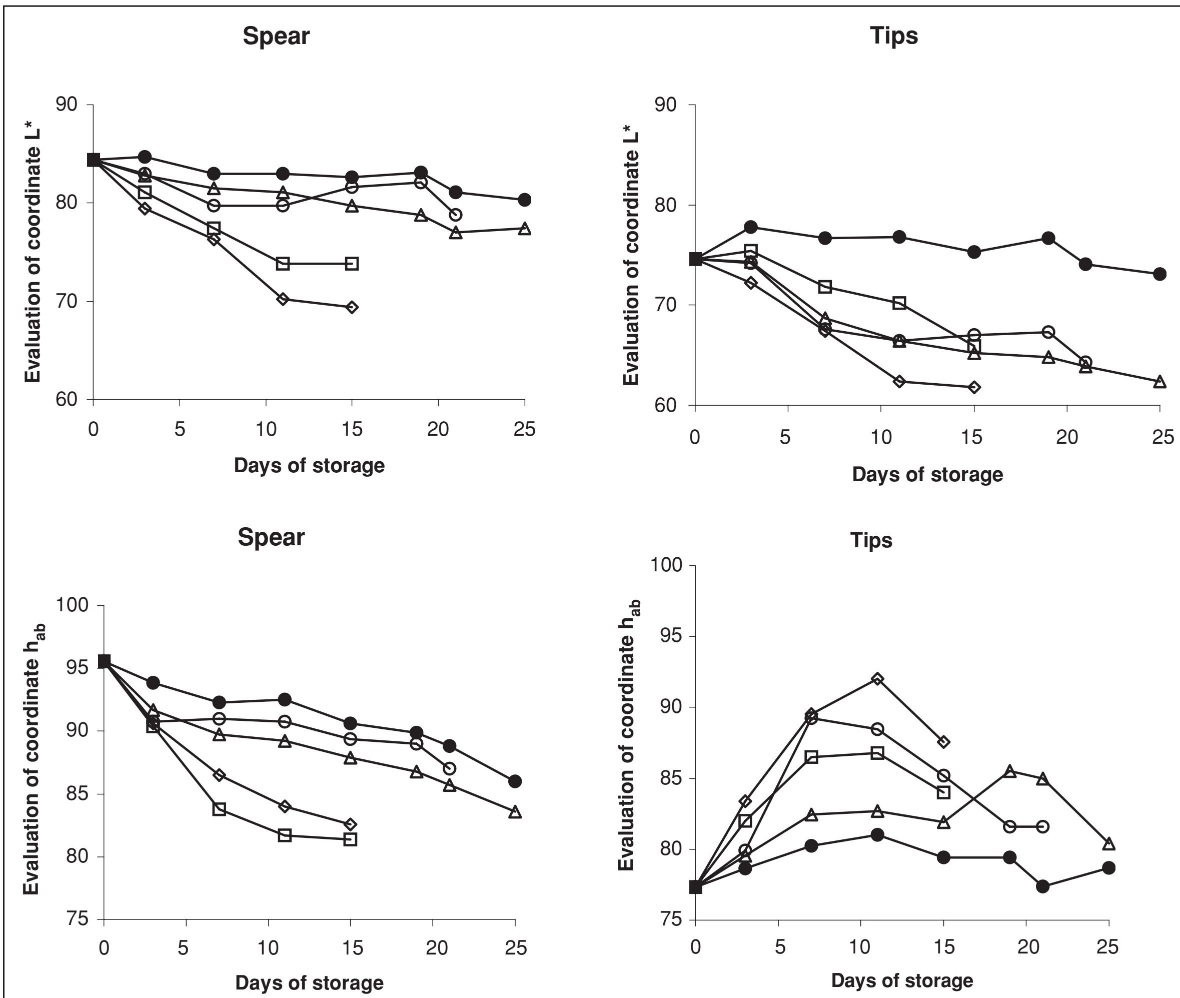

Figure 3—Color evolution of minimally processed asparagus stored under different light conditions. (•) Batch D, (○) batch W, (Δ) batch B, (□) batch R, and (◊) batch G.

R and G did show significant differences. In the case of the tips, the effect of illumination on the L^* values was similar for all the illuminated batches, which revealed significant differences in comparison to batch D from day 11.

In the spear, a progressive decrease was observed in the coordinate for h_{ab} during the storage period, particularly in the illuminated samples. This decrease may be attributable to both the enzymatic browning and the appearance of a reddish-brown coloring, which was very intense in certain areas. The appearance of this coloring is due to the anthocyanin synthesis, which is enhanced by light (Grisebach 1982; Mancinelli 1985; Chang 1987).

The evolution of this h_{ab} coordinate was similar between the samples stored in darkness and those stored under white or blue light. However, red and green illumination saw a faster and more intense appearance of reddish-brown colors, as is shown by the sharp fall in the h_{ab} values. The values of this coordinate for the samples from the R and G batches were significantly different from day 11 of storage

A different situation was noted in the tips, where exposure to light caused an increase in the h_{ab} coordinate due to their evolution towards green colors. The increase in the h_{ab} values was especially intense in batch G in which the highest values were reached on day 11 of storage. From this point on, however, the degradation suffered by the tips affected their color and led to a decline in the h_{ab} values. Similar behavior, although less intense, was observed in samples illuminated with white and red light. For their part, those samples stored under blue light only displayed a small increase in the h_{ab} values, which only intensified after day 19. Samples stored in the dark maintained virtually constant values throughout the entire storage period. The exposure to light of vegetables enhanced the synthesis of photosynthetic pigments (Mohr and Schopfer 1995). This phenomenon is well known in the growing practices of this crop and lowers the quality of the product, which is why asparagus are picked at the point just before they emerge from below the soil and are exposed to light. It is necessary to underline that the change in color due to the appearance of reddish-brown patches, as reflected in the section on sensory analysis, was better tolerated by the judges than the appearance of greenish hues.

Texture

During storage, a morphological change occurs in the asparagus, which is reflected in the graphs for texture (Figure 4). The parameters considered for assessing the evolution of texture in asparagus varies from study to study. Some researchers (Sharma and Wolfe 1975; Lipton 1990) discuss some of the procedures used for assessing texture and more recently we can cite the study of Rodríguez and others (2004), which uses indicators such as Strength (force at the 1st maximum peak divided by the diameter of the spear) and toughness (average force multiplied by diameter of spear and dividing by the area of cut surface), or other researchers such as Villanueva and others (2005) who directly compare shear force. In our case, the parameters that proved most useful for evaluating the evolution of the texture of the minimally processed asparagus was the measurement of the area of the graph between the maximum peak of force and the end of the cut, A_2 (Figure 4). The quotient between this parameter and the total displacement, d, quantifies the average force necessary to finish cutting the asparagus from the moment when the maximum force is applied (A_2/d).

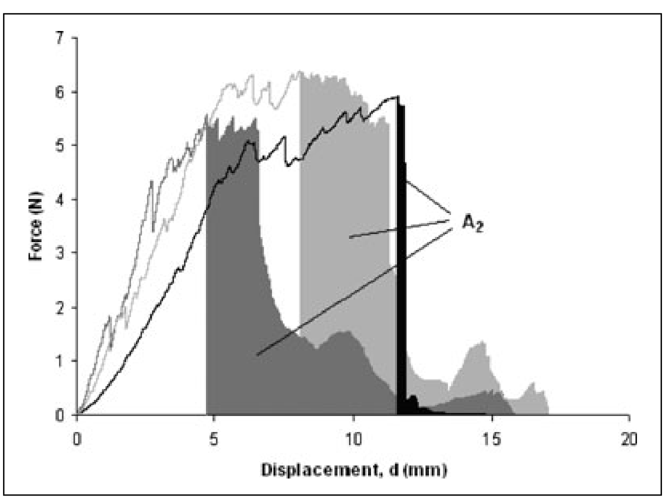

Figure 4 — Examples of the graphs obtained in the measurement of texture of minimally processed asparagus. (▬) Fresh asparagus, (▬) asparagus day 7, and (▬) asparagus at the end of shelf life.

The change in texture of asparagus has been related to fibrousness and can be attributed to lignification, but different studies have shown that other modifications of the cell wall composition could also be related to this alteration (Everson and others 1992; Rodríguez and others 2004; Albanese and others 2007). In our case, minimally processed asparagus underwent gradual softening during storage which made cutting more difficult and meant an increase in the effort necessary to complete it (A_2 in Figure 4).

Figure 5 shows the evolution of this average force during the storage period for the different types of lighting tested. It can be seen that a steady increase occurs, which was more pronounced in the samples subjected to green and red light. In samples illuminated by blue light, this increase was slight until day 11, from which point it became more pronounced. Very similar behavior was observed in samples stored in darkness. Samples subjected to illumination under white lighting showed a behavior midway between the two. As can be seen in the sensory evaluation, values for this parameter of over 0.25 were considered as being of an unacceptable texture.

The results shown indicate that exposure to light accelerates the change of texture in a very clear way if we compare this with storage in the dark. Of the different types of light used, only blue light has an effect similar to storage in darkness. Therefore, a light of this color would be the most suitable for preserving the texture of the asparagus if it is not possible to keep it in the dark.

Sensory evaluation

The data corresponding to the sensory evaluation of the asparagus samples subjected to different storage conditions are reflected in Table 1.

In samples stored in darkness (batches D), the shelf life achieved was 11 d. In this case, tip color was the attribute that underwent the greatest deterioration and which, therefore, determined end of shelf life. The color of the spears of asparagus stored in the dark remained acceptable until day 19. For their part, odor and texture received scores of 3 or more until the end of the period evaluated.

Exposure to light of minimally processed asparagus produced a different response depending on the type of light studied (Table 1).

As with the measurements taken with instruments, exposure to red and green light led to a greater and more rapid deterioration in the sensory qualities of the asparagus. In both cases, shelf life was reduced to only 3 d with the color, of both spears and tips, being the most affected parameter. Coinciding with the instrumental measurement of texture, the sensory evaluation of this parameter remained acceptable until day 7 and from this point the scores given were the lowest. From day 19 of storage, the deterioration of the samples was so great that it was no longer possible to carry out sensory evaluation of them.

Batches B and W had similar behavior, in both cases, the shelf life was 7 d due again in these batches to the change of the color of the tips. The scores given in all the parameters considered were very similar, although finally, on day 25, the samples subjected to white light (batch W) were so spoiled that they could not be evaluated.

The appearance of green hues in the asparagus tips was the factor that most governed the scores given by panel members during the sensory evaluation, with this aspect being more penalized than the presence of reddish-brown coloring that developed in the spears of the samples subjected to light.

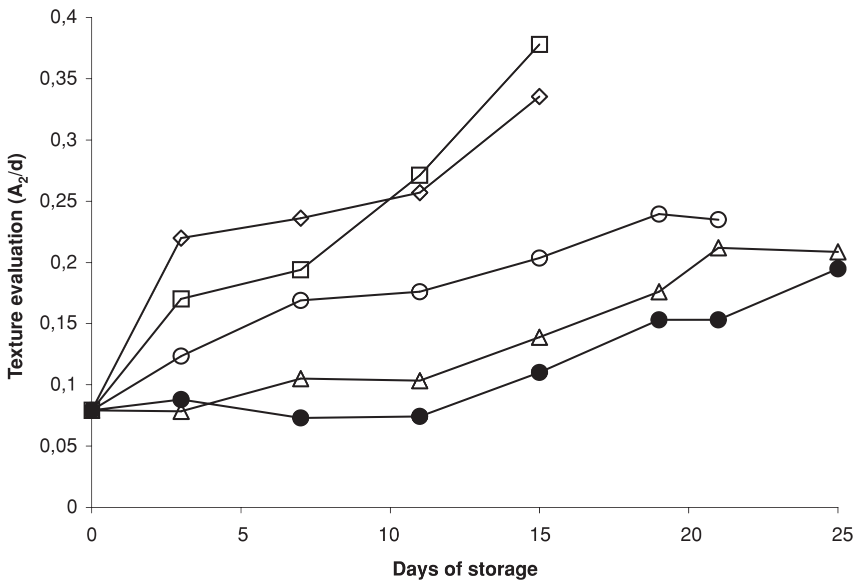

Figure 5—Texture evolution of minimally processed asparagus stored under different light conditions. (•) Batch D, (○) batch W, (△) batch B, (□) batch R, and (◊) batch G.

Table 1—Sensory evolution of minimally processed asparagus.

Sensorial attribute		Batch D	Batch W	Batch B	Batch R	Batch G
Spears color	3 d	$4.9^{a} \pm 0.1$	$4.1^{b} \pm 0.2$	$4.7^{a} \pm 0.1$	$3.5^{c} \pm 0.3$	$3.6^{c} \pm 0.3$
	7 d	$4.2^{a} \pm 0.2$	$3.1^{b} \pm 0.1$	$3.9^{a} \pm 0.1$	**$2.3^{c} \pm 0.3$**	**$2.7^{bc} \pm 0.2$**
	11 d	$3.7^{a} \pm 0.3$	**$2.4^{b} \pm 0.1$**	$3.4^{a} \pm 0.4$	**1.0^{c}**	**1.0^{c}**
	15 d	$3.4^{a} \pm 0.4$	**$2.0^{b} \pm 0.2$**	**$2.7^{a} \pm 0.3$**	**1.0^{c}**	**1.0^{c}**
	19 d	$3.1^{a} \pm 0.2$	**$1.6^{c} \pm 0.3$**	**$2.5^{b} \pm 0.2$**	**1.0^{d}**	**1.0^{d}**
	21 d	**$2.5^{a} \pm 0.2$**	**$1.1^{c} \pm 0.1$**	**$2.0^{b} \pm 0.1$**	–	–
	25 d	**$1.9^{a} \pm 0.1$**	–	**$1.5^{b} \pm 0.1$**	–	–
Tip color	3 d	$4.8^{a} \pm 0.2$	$4.1^{b} \pm 0.2$	$4.6^{a} \pm 0.2$	$3.7^{b} \pm 0.2$	$3.9^{b} \pm 0.1$
	7 d	$3.9^{a} \pm 0.3$	$3.1^{b} \pm 0.1$	$3.8^{a} \pm 0.3$	**$2.1^{c} \pm 0.4$**	**$2.4^{c} \pm 0.3$**
	11 d	$3.2^{a} \pm 0.1$	**$2.3^{b} \pm 0.2$**	**$2.9^{a} \pm 0.3$**	**1.0^{c}**	**1.0^{c}**
	15 d	**$2.5^{a} \pm 0.2$**	**$2.1^{b} \pm 0.1$**	**$2.5^{a} \pm 0.2$**	**1.0^{c}**	**1.0^{c}**
	19 d	**$2.1^{a} \pm 0.2$**	**$1.5^{b} \pm 0.2$**	**$2.0^{a} \pm 0.2$**	**1.0^{c}**	**1.0^{c}**
	21 d	**$1.7^{a} \pm 0.1$**	**1.0^{b}**	**$1.7^{a} \pm 0.1$**	–	–
	25 d	**1.3 ± 0.1**	–	**1.2 ± 0.1**	–	–
Odor	3 d	5.0	5.0	5.0	5.0	5.0
	7 d	5.0^{a}	5.0^{a}	5.0^{a}	$3.5^{b} \pm 0.3$	$3.5^{b} \pm 0.4$
	11 d	$4.6^{a} \pm 0.1$	$4.1^{b} \pm 0.2$	$4.5^{a} \pm 0.1$	**1.0^{c}**	**1.0^{c}**
	15 d	$4.1^{a} \pm 0.2$	$3.6^{b} \pm 0.1$	$3.9^{a} \pm 0.2$	**1.0^{c}**	**1.0^{c}**
	19 d	$3.8^{a} \pm 0.3$	$3.3^{b} \pm 0.2$	$3.7^{a} \pm 0.1$	**1.0^{c}**	**1.0^{c}**
	21 d	$3.4^{a} \pm 0.2$	$3.0^{b} \pm 0.1$	$3.3^{a} \pm 0.1$	–	–
	25 d	$3.1^{a} \pm 0.2$	–	**$2.3^{b} \pm 0.3$**	–	–
Texture	3 d	5.0^{a}	5.0^{a}	5.0^{a}	$4.1^{b} \pm 0.3$	$4.4^{b} \pm 0.1$
	7 d	5.0^{a}	5.0^{a}	5.0^{a}	$3.5^{b} \pm 0.3$	$3.5^{b} \pm 0.3$
	11 d	$4.5^{a} \pm 0.2$	$4.0^{b} \pm 0.2$	$4.4^{a} \pm 0.1$	**1.0^{c}**	**1.0^{c}**
	15 d	$3.9^{a} \pm 0.1$	$3.5^{b} \pm 0.2$	$3.9^{a} \pm 0.1$	**1.0^{c}**	**1.0^{c}**
	19 d	$3.6^{a} \pm 0.2$	$3.2^{b} \pm 0.1$	$3.5^{a} \pm 0.1$	**1.0^{c}**	**1.0^{c}**
	21 d	$3.3^{a} \pm 0.1$	$3.0^{ab} \pm 0.1$	$3.2^{a} \pm 0.1$	–	–
	25 d	3.1 ± 0.1	–	**2.8 ± 0.2**	–	–
General acceptability	3 d	$4.8^{a} \pm 0.1$	$4.4^{b} \pm 0.1$	$4.7^{a} \pm 0.1$	$3.7^{c} \pm 0.3$	$3.9^{c} \pm 0.2$
	7 d	$4.4^{a} \pm 0.2$	$3.3^{b} \pm 0.3$	$4.1^{a} \pm 0.2$	**$2.5^{c} \pm 0.4$**	**$2.8^{bc} \pm 0.2$**
	11 d	$3.9^{a} \pm 0.2$	**$2.5^{c} \pm 0.2$**	**$2.9^{b} \pm 0.1$**	**1.0^{d}**	**1.0^{d}**
	15 d	**$2.9^{a} \pm 0.1$**	**$2.1^{b} \pm 0.2$**	**$2.6^{a} \pm 0.2$**	**1.0^{c}**	**1.0^{c}**
	19 d	**$2.4^{a} \pm 0.2$**	**$1.6^{b} \pm 0.1$**	**$2.2^{a} \pm 0.3$**	**1.0^{c}**	**1.0^{c}**
	21 d	**$1.9^{a} \pm 0.4$**	**1.0^{b}**	**$1.9^{a} \pm 0.3$**	–	–
	25 d	**$1.5^{a} \pm 0.3$**	–	**$1.1^{b} \pm 0.1$**	–	–

The data are the average ± standard deviation values. For each condition, means in the same row bearing different superscripts differ significantly.

Conclusions

Exposure to light had a negative effect on the quality parameters of the minimally processed asparagus. These results do not concur with those reported by Siomos and others (2000) who stated that exposure to light did not affect the visual appearance of minimally processed white asparagus, however, the storage period considered by these researchers was only 6 d and they only used cool-white lamps.

Lighting accelerates metabolical and physiological changes, which lead to the deterioration of asparagus, with the parameters worst affected by illumination being the color of the tips and spears and, second, texture.

Of all the shades of light evaluated, red and green lighting caused a greater deterioration and significantly shortened shelf life of samples subjected to lighting of this tone.

Blue light appears to work better than white lighting, as it preserves the sensory qualities of minimally processed asparagus, particularly color and texture, for a longer period. It seems appropriate to recommend illumination with this type of lighting for this product or else the use of packaging films with the right permeability and with a blue-tinted color.

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