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Original article

Quality characteristics of minimally processed leek packaged using different films and stored in lighting conditions

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Summary Since minimal processing of vegetables does not impede their capacity to react to external stimuli, this work sought to study the effect of lighting on minimally processed leek during storage. White and green cuts were processed separately and packaged using films with different permeability: a totally permeable PVC film and two P-Plus films: P-Plus 120 and P-Plus 90, with O_2 permeability of 8000 and 5000 $cm^3\ m^{-2}\ 24\ h^{-1}\ atm^{-1}$ at 25 °C, respectively. All the packaged leek was stored at 4 °C for more than 26 days in two different conditions: in complete darkness and in light. Lighting caused an increase in stomatal aperture and respiratory rate. Thus, the white cut achieved atmospheres with higher CO_2 (10%) and lower O_2 (12%) content than samples packed in the same film kept in the dark. The green cut saw respiratory activity compensated by photosynthesis, and the atmosphere composition remained similar to atmospheric conditions until day 18. Lighting also affected the colour, accelerating the changes in appearance. Exposure to light had a negative effect on the quality parameters.

Keywords Colour, leek, light, minimally processed products, packaging film, shelf-life, texture.

Introduction

Minimally processed vegetables (MPV), or fresh-cut vegetables, are ready-to-eat foodstuffs which have only been washed, peeled, cut and packaged in plastic film. This type of processing appeared in the 1980s as a response to the demand for easily prepared products which are as similar as possible to the fresh product. Thus, unlike other forms of preservation, in MPV the plant tissue is still living, respiring, so that the atmosphere inside the packaging modifies its composition in a way which depends on the vegetable and the film used. If the composition of this atmosphere is not appropriate, it can accentuate the deterioration of the vegetable and make it unmarketable, whether for safety or sensory reasons. In addition, this deterioration can be further accentuated by the inevitable exposure of these foodstuffs to light in the points of sale.

It has been proved necessary to establish an approach which will allow us to evaluate the various parameters which determine the shelf life of each MPV in the various conditions of processing and storage: packaging films, storage temperature, exposure to light, etc. This approach must be suitable for the different characteristics of the vegetable under examination and, clearly, this will be different depending on whether it is a leafy vegetable (lettuce, spinach), an inflorescence (cauliflower, broccoli), a root (carrot) or a stalk like the leek. Aspects such as the rate of respiration, pigmentation or morphology will affect the evolution of the various attributes to be assessed during storage and display for sale.

Colour is one of the most important sensory attributes that determine food quality (Hutchings, 1999) and it is highly affected by light and atmosphere composition. Changes in colour during the processing and storage of food products need to be measured and controlled. The most evident symptom of senescence in harvested vegetables is the loss of the green colour due to breakdown of chlorophyll in green vegetables, while in non-pigmented vegetables, browning is the process which mostly affects colour (Nilsson, 2000).

Another important attribute which determines the quality of vegetable foodstuffs is texture. Texture analysis using a universal texturometer has become a useful means of analysing a series of textural parameters in fresh fruits and vegetables. Storage conditions can cause the texture properties of a vegetable to vary,

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leading to rejection by the consumer. The morphology of the vegetable studied requires the adaptation of the approach to be used so as to obtain values which allow us to study the evolution of this parameter for each specific vegetable.

The speed with which changes occur in the attributes of colour and texture in MPV products is clearly affected by the conditions of storage and display. Many studies have concentrated on the influence of storage temperature on the shelf life of these products (Watada *et al.*, 1996; Roura *et al.*, 2000; Jacxsens *et al.*, 2002; Tsouvaltzis *et al.*, 2006). However, few studies have analysed the influence that the unavoidable exposure to light during the time they are on sale has on the evolution of the quality parameters of these products (Nilsson, 2000).

Leek (*Allium porrum* L.) is a highly popular vegetable with an annual worldwide production of about 1860 million tons (FAOSTAT. FAO.ORG, 2005). The edible part is a semi-buried stalk made up of the radicle bud and layers of fleshy leaves. The underground part has no pigmentation and it gains photosynthetic pigments as it grows to the surface.

The aim of this study is to evaluate quality parameters of the minimally processed leek packaged with films of different permeability during the storage period, establishing a comparison between the behaviour of its white and green cuts. In addition, the influence of the exposure to light on quality parameters will be determined for each of the edible parts of the leek.

Materials and methods

Preparation of samples

Leeks (*Allium porrum* L.) of the Selecta variety (distributed by Clause Tezier, Portes-lès-Valence, France) were grown in the Entrena area (La Rioja, Spain). The leeks were harvested in February 2007 and transported directly from the fields to the laboratory. All the plants were of high quality and free from defects. For the experiment, around 30 kg of leek were processed.

After manual removal of the outer leaves, each plant was cut into three pieces each about 10 cm long: green, white, and transition zone. The latter cut was rejected so as to carry out the study separately on the green and white samples. For each colour, four to six 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^{-1}). Washing conditions were established according to the results obtained in previous experiments (Nguyen-The & Carlin, 1994; Sanz *et al.*, 2002). Samples were then rinsed until the free chlorine levels were below 0.3 ppm and the excess water was removed by centrifugation.

The leek was packaged using three types of films. One was a perforated PVC (polyvinylchloride) film (13 μm thickness) supplied by FEISA (Madrid, Spain) in 60 cm × 1500 m reels, totally permeable to O_2, CO_2 and vapour (control batch). The other two films were 35 μm P-Plus films (made of polypropylene) supplied by Danisco (Bristol, UK) in 20 × 25 cm bags: 35PA 120 film (P-Plus 120), and 35PA 90 (P-Plus 90), with O_2 permeability of 8000 and 5000 cm^3 m^{-2} 24 h^{-1} atm^{-1} at 25 °C, respectively. According to the manufacturer's specifications, the number 35 in each case 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, with a higher number representing a more permeable film.

From the optical point of view, the films used in this study performed identically when exposed to light, as we observed when we compared the respective absorption spectra in the 300–1200 nm range (Spectroradiometer PR-714, Photo Research Div. of Kolmorgen Instruments Corp., Chatsworth, CA, USA).

Four batches were packaged: White in Darkness (WD), White under Light (WL), Green in Darkness (GD) and Green under Light (GL), with a total of forty-five samples per batch (three films used per 5 days of sampling by three repetitions). When PVC film was used, the leeks were placed by hand on polystyrene trays 140 mm wide by 230 mm long which were covered and sealed using a Hand Wrapper hot plate, model WS500E (Barcelona, Spain). In the case of P-Plus films, the leeks were placed by hand into 20 × 25 cm bags sealed using a Vaessen-Schoemaker machine (Barcelona, Spain). All the pieces of leek for each sample were packed in a single layer.

All the packaged leek was stored in the same cold store at the same temperature (4 ± 1 °C) for more than 26 days in two different conditions: WD and GD batches in complete darkness and WL and GL batches in light. The packs were placed just below the lamps, 30 cm away and in a single layer, 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 was used for batches L (Cool white fluorescence lamps FSL, 36 w, 2600 Lux, radiance 1.855 w sr^{-1} m^{-2} with maximum peaks at 432, 548 and 480 nm, YZ36RR26 Foshan Electrical and Light Co. Ltd, Foshan City, China). This type of light is similar to that used in retail outlets. In each package, each piece received a comparable level of light exposure.

Three samples of each condition tested (type of vegetable, lighting conditions and packaging film) were taken on day 0 and after 4, 11, 18 and 26 days of storage.

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

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

Colour determination

For each sample, the reflectance spectra were measured at six different points on the leek surface, after which the mean reflectance spectrum was obtained separately for each surface. These measurements were taken with a Minolta CM 2600 days spectrophotometer with d/8º geometry and a xenon lamp with 8 mm aperture size, manufactured by Minolta Co. Ltd (Osaka, Japan). The mean spectrum allowed the colour 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, UK) using the software application provided with the apparatus (Texture Expert for Windows, version 1.0, Stable Micro Systems Ltd). The probe used was a reversible blade with a knife edge (reference code: HDP/BS). The following experimental conditions were selected for all tests: pre-test speed 5 mm s^{-1}, test speed 1 mm s^{-1} and post-test speed 10 mm s^{-1}; penetration 100%; trigger force 7 gp; and data acquisition rate 200 pulses per second. To obtain a good estimation, measurements were made on four leeks from each tray. Final results were expressed as maximum force in kilopond (kp).

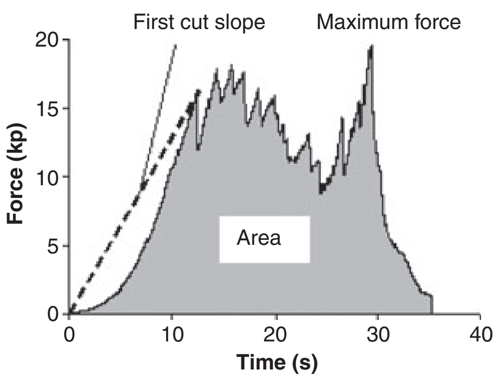

Figure 1 Parameters considered in the instrumental analysis of the texture.

The following parameters were analysed for the comparison of the packaging and storage conditions tested in the evolution of the texture (Fig. 1):

- *Firmness* slope of the graph until the first peak, which corresponds to the cut of the first leaf.
- *Maximum force* corresponding to the highest peak on the graph.
- *Total work necessary* corresponding to the area of the graph.

Sensory evaluation

Sensory evaluation was used to discriminate between the visual appearance, texture, and odour of the samples of the green cut and of the white cut of the leek packaged with different films. The judges were selected from an original group that included twenty-five volunteers, between 23 and 55 years old, connected in some way with the Department of Agriculture and Food at the University 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 & Durán (1981). Finally a panel of seven judges were selected and trained on the sensory characteristics of the packaged vegetables.

During the training, panellists were presented with an array of vegetable products to help the development of terms, which included: colour, browning, firmness, consistency and odour (Costell & Durán, 1981). Then the judges were specifically trained in the discriminative evaluation of leeks, 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. Vegetables just cut and washed were 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 days. The products were presented on coded plastic dishes. The training sessions were conducted under normal lighting conditions (ISO/DIS 8589, 1988).

Two simple scorecards (one for the green cut of the leek and another for the white cut) were devised to quantify each sensory attribute: colour, texture, odour, and general acceptability. The intensity of the attributes evaluated was quantified on a scale from 1 to 5 (Shewfelt, 1993) in the following way:

For the white cut of the leek, colour was rated using 5 = white, uniform colour, without defects, 3 = yellowish colour, cut browning, and 1 = severe browning. Texture was rated using 5 = very firm and turgid, 3 = slightly soft but acceptable, and 1 = very soft.

Odour was rated using 5 = no off-odours, 3 = slight but obvious off-odour, and 1 = strong off-odour. 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 yellowish, less compact, few slight defects), and 1 = unmarketable (that is, showing yellowing, very soft, and major defects).

For the green cut of the leek: Colour was rated using 5 = dark green, uniform colour, without defects; 3 = lighter green and 1 = showing yellowish hues or browning. Texture was rated using 5 = fresh, firm; 3 = slightly soft but acceptable and 1 = very soft. Odour was rated using 5 = no off-odours, 3 = slight but obvious off-odour and 1 = strong off-odour. General acceptability was rated using 5 = excellent or having a fresh appearance (i.e. dark green, firm and no defects), 3 = average (i.e. lighter green, slightly soft and few defects) and 1 = unmarketable (i.e. yellowing or browning, very soft and major defects).

In both cases, sensorial evaluation was used to determine the shelf life of these products. 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 randomised. The samples were evaluated under normal lighting conditions (ISO/DIS 8589, 1988).

Other determinations

Free chlorine was determined by colourimetric reaction with DPD (*N*,*N*-diethyl-1,4-phenylenediamine) (Merck, Darmstadt, Germany).

Weight of samples was measured by a Sorvall balance model B410 (Sartorius, Barcelona, Spain). Weight loss was calculated by the difference between initial weight (at day 0) and weight at day of sampling. Weight loss was expressed as a percentage of initial weight.

Carbon dioxide and oxygen inside the packages were measured using an O_2 and CO_2 head space gas analyser (Checkmate model 9900; PBI-Dansensor, Ringsted, Denmark). For each measurement, the analyser automatically extracted a small amount of gas with a needle inserted into the package, which was immediately analysed.

For the microbial analysis of both the green and the white cuts of the leek the following procedure was adopted: the sample to be analysed was chopped under sterile conditions, and 25 g were aseptically weighed and homogenised for 2 min with 225 mL of soy peptone water (0.1% soy peptone plus 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, MI, USA) following the pour plate method and incubated at 31 ± 1 °C for 72 h (ICMSF, 1978).

Statistical analysis

Three samples were analysed 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 three samples. Each item in the table is the average and standard deviation of the scores given by seven judges of the tasting panel to three samples.

Variance analysis was performed using the SPSS program for Windows; Statistics version 14.0. 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

Colour

The colour coordinates which showed significant variation during storage time are L^* and h_{ab} (Fig. 2).

The behaviour of the L^* coordinate, which represents lightness, was different in the white cut to in the green cut. It is observed that in samples stored in darkness, the white cut barely suffered change for the L^* coordinate in any of the films used, while those stored under lighting showed a decrease, (that is they got darker), which was more marked in the samples packed in PVC, with those packed in P-Plus 90 being the ones with the lowest variation in the L^* coordinate. The tendency of non-pigmented MPV to darken when exposed to light has been described in cauliflower (Sanz *et al.*, 2007) and chard (Sanz *et al.*, 2008).

Moreover, the green cuts stored in the dark did experience, for all types of film used, an increase in the L^* values. This increase in the L^* values was much more marked in conditions of lighting.

In the green cuts, the h_{ab} coordinate which represents the hue, increased over the first days in samples stored in the dark, but then showed a slight decrease until the end of the storage period. However, in the samples stored under lighting, this coordinate saw a progressive decrease during storage until by day 26 they had reached a much lower value than those obtained with samples stored in darkness, with the samples packed in PVC again being the ones which showed the greatest variation on the h_{ab} coordinate and those packed in P-Plus 90 those that had the smallest variation. This all results in yellowing of the green cuts, much more marked in the cases of samples exposed to light. These results contradict those offered by Heaton *et al.* (1996),

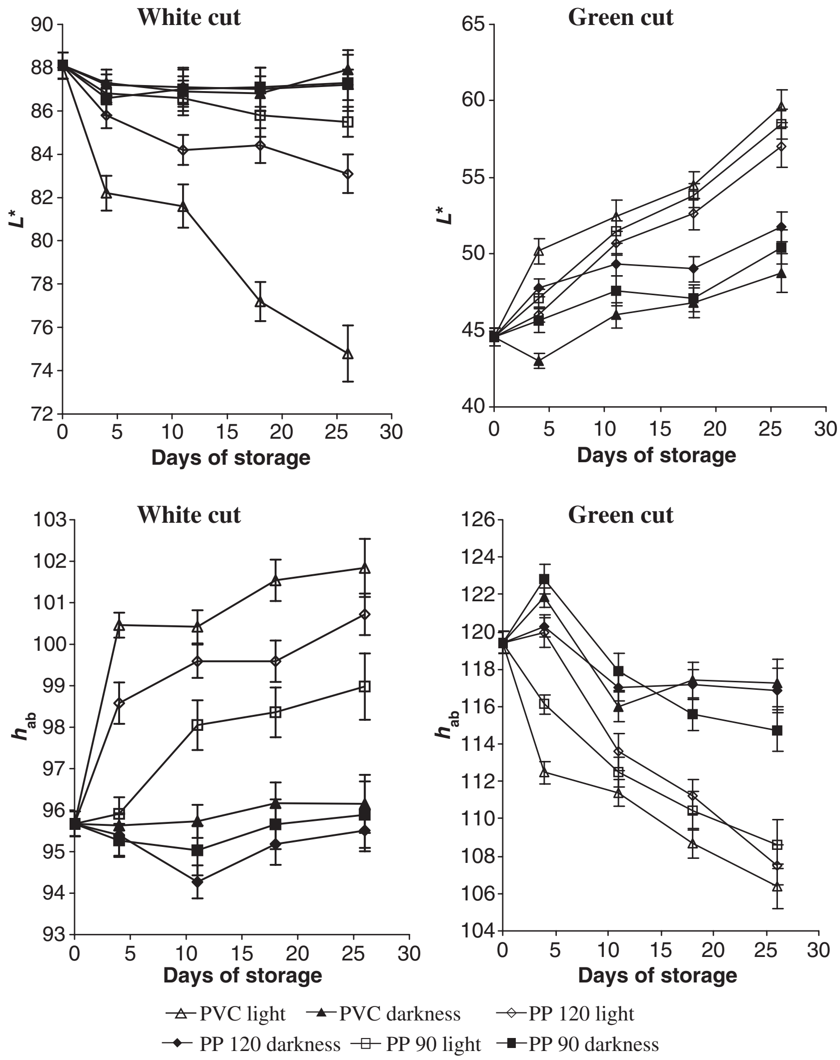

Figure 2 Colour of white and green cuts of leek stored under different conditions Data are means of the six measurements taken in each of three analysed samples.

which suggest that slight exposure to light could contribute to preserving the green colour of vegetables, although their work was performed with cabbage which had not been processed and was not packed. Other authors (Kasim & Kasim, 2007) reported that, while exposure to light reduced yellowing in Brussels sprouts, in the case of broccoli yellowing was accentuated by the opening of the florets.

For its part, in the white cut an increase was noted in the h_{ab} coordinate when the samples are stored in lighting, which shows a shift towards green hues, which can be due to the synthesis of photosynthetic pigments stimulated by exposure to light. Thus, while in the samples stored in the dark the value of the h_{ab} coordinate remained practically constant, in the lit samples a notable increase was observed. This increase was proportional to the permeability of the film. While the availability of O_2 has not been directly linked to the synthesis of photosynthetic pigments, it does seem to be the indirect cause by favouring the metabolic reactions which give the plant the energy necessary for the synthesis of complex molecules (Rolle & Chism, 1987). The relationship between metabolic activity and pigment synthesis has been proved by Tsouvaltzis *et al.* (2006) in studying the evolution of the colour of leeks stored at different temperatures. In their study these authors conclude that storage at high temperatures (20 °C) induces a greater colour change than at low temperatures in which the leeks' metabolic activity is much less.

Texture

Figure 3 shows examples of the graphs obtained for the measurement of texture performed on the raw material on day 0 and day 26 of storage of the white and green cut of the leek.

In the measurements made on the raw material (day 0) it can be seen that there are significant differences in

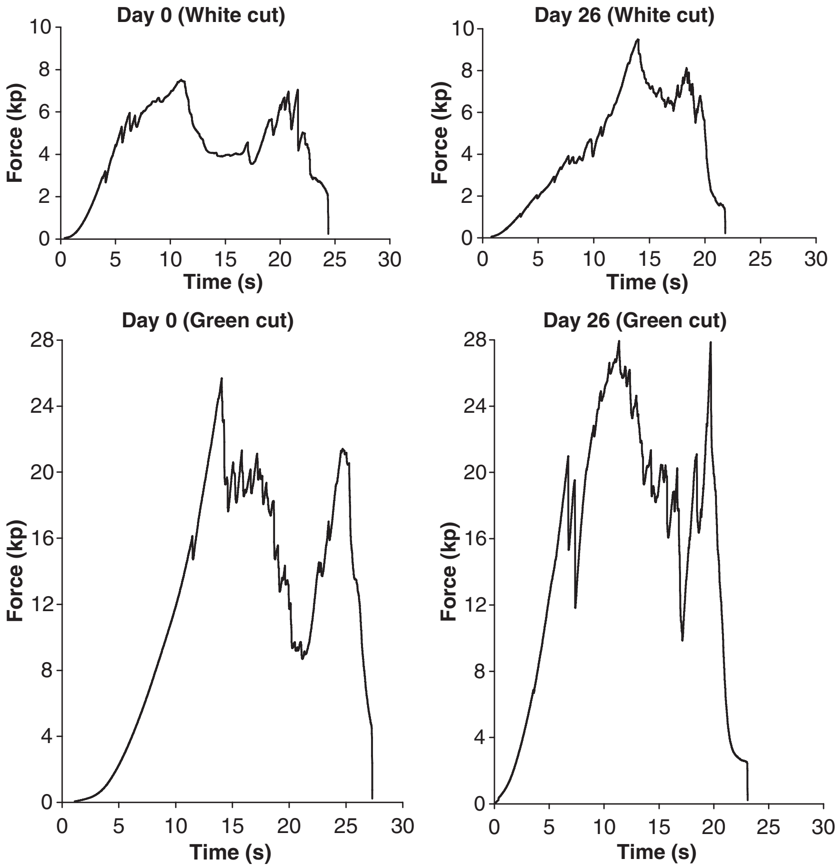

Figure 3 Typical graphs obtained for texture of white and green cuts made on the raw leeks (day 0) and on the last day of storage (day 26).

texture between the green and white cuts due mainly to the morphological differences existing between them. Thus, in the green cut the greater consistency of the already differentiated leaves is reflected in the saw-tooth profile which corresponds to the cut of each leaf as the probe advances. In the white cut, these peaks are less clear since the leaves are fleshier and more compact. In addition, the work necessary to cut them (measured from the area of the graph) of the white cut was notably less than in the green cut.

During storage, the dehydration and the lignification of the leaves caused, in both the white and green cut, a greater resistance of each leaf in cutting and an increase of the space between layers. The latter aspect means that as the probe enters, the samples become more compact giving rise to the variations which can be clearly seen in the graph obtained (Fig. 3, day 26).

The effect of the different packaging and storage conditions studied on texture parameters (firmness, maximum force and total work) is presented in Fig. 4.

In the white cut no significant differences were noted between the two types of P-Plus film used, whether stored in light or darkness. However, in the samples packed in PVC, especially when stored under lighting, the maximum force necessary to make the cut and the total work necessary were greater than in the other samples.

In the white cut a reduction in the time to penetrate the first layer was observed, which was reflected in a progressive increase in firmness during the first 11 days, especially in samples packed in PVC and stored under light. With the exception of the PVC film, during these first few days the evolution of the maximum force applied and total work necessary barely changed. However, from this moment on an increase occurred in the time necessary to make the first cut, so that the firmness value decreased to similar levels to those at the beginning. This evolution may be due to the progressive dehydration of the samples which has led to an increase in the space between the layers of the leek so that the diameter becomes smaller. In addition, while the 'maximum force' parameter remained constant, the total work necessary (area of the graph) underwent a progressive increase.

Due to the structural and morphological differences that exist with regard to the white cut, the green cut of the leek showed much higher values for maximum force and total work necessary compared to those obtained for the white cut. In the green cut, from day 11, a very marked reduction in firmness was recorded as well as an

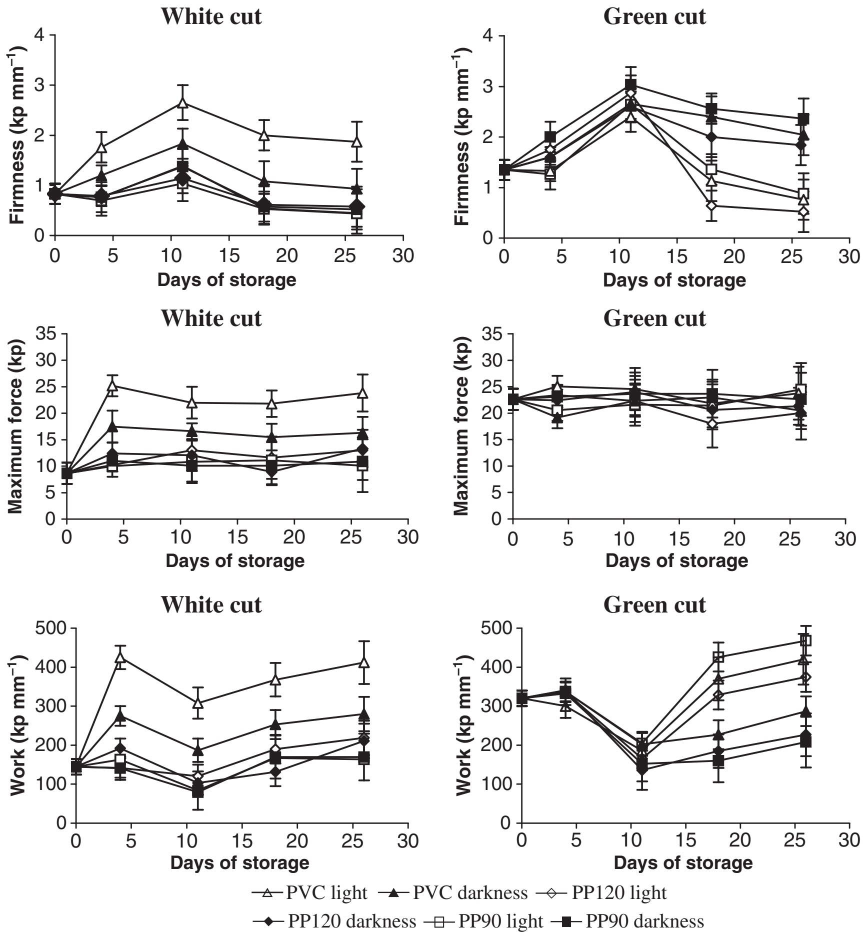

Figure 4 Texture values of white and green cut of leek stored under different conditions.

increase in the total work necessary. It is in this period and for these parameters that significant differences are noted between samples stored in darkness and those stored under lighting. As in the case of the white cut, the dehydration that the green cut of the leek suffers during the final phase of storage, especially in the case of storage under lighting, leads to a decrease in the thickness of the layers and an increase in the space between them. As the probe advances, it compacts the layers of the leek increasing the total work necessary and requiring a longer time to cut through the first layer, which is reflected in a reduction in the firmness values. Both the increase in the work necessary and the decrease in firmness were more marked the greater the dehydration that the sample had experienced, which in our case occurred with exposure to light. This evolution was similar in all the films used.

The influence of packing conditions on the texture of MPV has been mentioned by several authors. Thus, Bolin & Huxsoll (1991), Barry-Ryan *et al.* (2000) and Viña & Chaves (2003) observed increases in firmness in lettuces, sliced carrots and celery, respectively. These authors coincide in attributing the changes in texture during the storage of these vegetables to a loss of moisture ('drying out') together with an increase in the degree of lignification. The results shown by these authors and the causes to which they are attributed agree with those obtained in this study. However, although factors such as storage temperature of MPV or the permeability of the packaging films used have been analysed, we have found no other work on the effect of the exposure to light in the texture.

Sensory evaluation

The data corresponding to sensory evaluation of the leek samples submitted to different packaging and storage conditions are reflected in Table 1.

In samples stored in darkness (batches WD and GD), the longest shelf life was achieved for the white cuts of leeks packed in P-Plus films (26 days); these cuts packed in PVC film have a shelf life of 18 days. In this case texture was the attribute that underwent the greatest deterioration and which therefore determined end of shelf life. The different evolution of the texture in the samples of the white cut stored in PVC compared to

Table 1 Sensory evolution of minimally processed leek (white and green cut) stored under darkness and light condition

	Darkness			Light		
Sensory attribute	**PVC**	**P-Plus 120**	**P-Plus 90**	**PVC**	**P-Plus 120**	**P-Plus 90**
White cut						
Colour						
4 days	4.7 ± 0.2	4.9 ± 0.1	4.8 ± 0.1	3.3^{c} ± 0.4	4.1^{b} ± 0.2	4.5^{a} ± 0.1
11 days	4.4 ± 0.2	4.6 ± 0.3	4.3 ± 0.1	3.0^{c} ± 0.2	3.5^{b} ± 0.3	4.2^{a} ± 0.1
18 days	4.1^{ab} ± 0.1	4.3^{a} ± 0.1	3.9^{b} ± 0.2	2.6^{b} ± 0.2	3.2^{a} ± 0.3	3.5^{a} ± 0.1
26 days	3.1^{b} ± 0.4	4.0^{a} ± 0.1	3.4^{b} ± 0.2	2.1 ± 0.1	2.4 ± 0.1	2.5 ± 0.3
Texture						
4 days	4.3^{b} ± 0.2	4.7^{a} ± 0.1	4.6^{ab} ± 0.1	4.3 ± 0.1	4.5 ± 0.3	4.4 ± 0.2
11 days	3.9^{b} ± 0.3	4.5^{a} ± 0.2	4.4^{a} ± 0.1	3.6^{b} ± 0.2	4.2^{a} ± 0.1	4.0^{a} ± 0.1
18 days	3.3^{b} ± 0.3	4.0^{a} ± 0.2	3.9^{a} ± 0.1	2.5^{b} ± 0.3	3.7^{a} ± 0.1	3.6^{a} ± 0.2
26 days	2.5^{b} ± 0.2	3.2^{a} ± 0.3	3.0^{a} ± 0.2	2.0^{b} ± 0.1	2.5^{a} ± 0.2	2.4^{ab} ± 0.4
Odour						
4 days	5	5	5	5	5	5
11 days	5	5	5	5	5	5
18 days	5	5	5	5	5	5
26 days	5	5	5	5	5	5
G. accept.						
4 days	4.7 ± 0.2	4.9 ± 0.1	4.9 ± 0.1	4.2 ± 0.3	4.5 ± 0.2	4.7 ± 0.2
11 days	4.4 ± 0.1	4.6 ± 0.2	4.5 ± 0.3	3.7^{b} ± 0.1	4.1^{a} ± 0.2	4.3^{a} ± 0.2
18 days	3.6^{b} ± 0.1	4.1^{a} ± 0.1	3.9^{ab} ± 0.2	2.5^{b} ± 0.2	3.6^{a} ± 0.1	3.8^{a} ± 0.4
26 days	2.4^{b} ± 0.3	3.6^{a} ± 0,2	3.4^{a} ± 0.2	2.1 ± 0.1	2.4 ± 0.3	2.5 ± 0.3
Green cut						
Colour						
4 days	4.6 ± 0.2	5	4.9 ± 0.1	4.3 ± 0.1	4.8 ± 0.3	4.6 ± 0.2
11 days	4.0^{b} ± 0.2	4.6^{a} ± 0.1	4.5^{a} ± 0.1	3.8 ± 0.3	4.2 ± 0.1	4.0 ± 0.3
18 days	3.7^{b} ± 0.3	4.2^{a} ± 0.1	4.0^{ab} ± 0.2	3.2^{b} ± 0.1	3.7^{a} ± 0.2	3.5^{ab} ± 0.2
26 days	3.1^{b} ± 0.1	3.6^{a} ± 0,2	3.5^{a} ± 0.2	2.4 ± 0.4	2.8 ± 0.1	2.7 ± 0.2
Texture						
4 days	4.6 ± 0.1	4.9 ± 0.2	4.7 ± 0.3	4.4 ± 0.3	4.7 ± 0.2	4.6 ± 0.1
11 days	4.2 ± 0.4	4.6 ± 0.2	4.4 ± 0.1	3.6 ± 0.1	4.1 ± 0.3	3.9 ± 0.4
18 days	3.3^{b} ± 0.2	3.7^{a} ± 0.1	3.8^{a} ± 0.2	3.0^{b} ± 0.2	3.6^{a} ± 0.3	3.4^{a} ± 0.1
26 days	2.4 ± 0.2	2.8 ± 0.3	2.5 ± 0.4	1.9^{b} ± 0.3	2.5^{a} ± 0.2	2.2^{ab} ± 0.1
Odour						
4 days	5	5	5	5	5	5
11 days	5	5	5	5	5	5
18 days	5	5	5	5	5	5
26 days	5	5	5	5	5	5
G. accept.						
4 days	4.7 ± 0.2	4.9 ± 0.1	4.8 ± 0.2	4.2 ± 0.3	4.6 ± 0.2	4.4 ± 0.3
11 days	4.4 ± 0.3	4.7 ± 0.1	4.6 ± 0.1	3.8 ± 0.1	4.1 ± 0.3	4.0 ± 0.1
18 days	3.7 ± 0.1	3.9 ± 0.2	3.9 ± 0.2	3.1^{a} ± 0.2	$3,7^{a}$ ± 0.2	3.6^{ab} ± 0.3
26 days	2.3^{b} ± 0.1	2.6^{a} ± 0.2	2.5^{ab} ± 0.2	2.0 ± 0.3	2.2 ± 0.1	2.2 ± 0.2

The data are the average ± SD values. For each storage condition, means in the same file bearing different superscripts differ significantly. Values in bold indicate that the product has been rejected by the judges.

those packed in P-Plus film had been reflected in the instrumental values of this parameter (Fig. 4).

For the green cuts stored in darkness, shelf life was the same in all films used (18 days), and texture was again the decisive attribute. For these samples too, the sensory evaluation of the texture coincides with the instrumental measurements taken. The testers pointed out that the low scores given for texture in certain samples was due to their dehydrated, stiff appearance.

Exposure of minimally processed leeks to light produced a different response depending on the cut of the vegetable studied (Table 1). Thus in the white cut, storage under lighting led to a reduction in shelf life, which was limited to 11 days for samples packaged in PVC and 18 days for those packed in P-Plus films. Colour and texture were the attributes most affected by the light, especially in samples packed in PVC, as the instrumental readings had already shown.

However, in the green cut, exposure to light did not mean a reduction of shelf life, which continued to be 18 days for all the films used. The colour of all the samples stored under lighting were affected in such a way that the jury gave scores of below three for this parameter on day 26, at which point those samples stored in the dark still maintained an acceptable colour.

The texture of the green cut was not affected by light, since this parameter received the same scores regardless of the storage conditions. This result coincides with the lack of differences between samples in the instrumental measurement of 'maximum force necessary to make the cut' (Fig. 4). Nevertheless, the differences in 'firmness' and 'total work necessary for the cut' (significant from day 11 between the samples stored under lighting compared to those stored in darkness) were not detected by the judges in the sensory evaluation.

Atmosphere inside packages and weight loss

The evolution of O_2 and CO_2 concentrations inside packages are shown in Fig. 5.

The white cut of leek 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 values of 0% for CO_2 and ~20% for O_2 in the PVC packs, while in the least permeable film used, P-Plus 90, the composition of the atmosphere in balance was 7% CO_2 and 15% O_2. Exposure to light significantly increased respiratory activity with results for P-Plus 90 film reaching 10% CO_2 and 12% O_2. This result is explained by the increase in the stomata aperture produced by exposure of the vegetables to light, which encouraged and improved the efficiency of gaseous exchange, causing the greatest change in the composition of the atmosphere inside the packs (Noichinda *et al.*, 2007).

Regarding the green cut of the leek, respiration in darkness modified the atmosphere inside the packs even less than in the white cut and, in fact, in the P-Plus 90 film only reached levels of 5% CO_2 and 16.5% O_2. These results can be accounted for by the greater metabolic activity of the white cut, the area of the leek which corresponds to a radicle bud in permanent multiplication, whereas the green cut is made up of a leafy area of already differentiated adult tissue.

Lighting of the green cut did not alter the atmosphere inside the packs, unlike what happened with the white cut of the leek. It was from day 18 onwards that an increase occurred in the concentration of CO_2 accompanied by a reduction in levels of O_2 inside the packs, reaching values on day 26 of 11% CO_2 and 8% O_2 in the P-Plus 90 packs. The difference between the white and green cuts can probably be explained by the fact that light allowed both photosynthesis and respiration in the green cuts. Only once the photosynthetic activity ceases due to the breakdown of photosynthetic pigments from day 18, does respiration determine the composition of

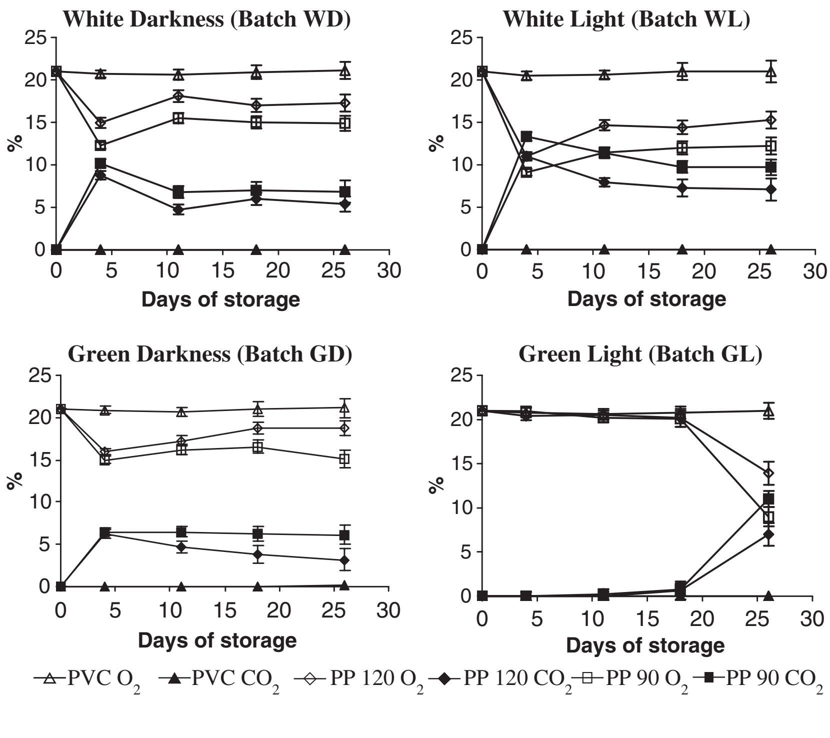

Figure 5 Gas levels inside packages of white and green cut of leek stored under different conditions.

the atmosphere. This behaviour has been described by our team in other vegetables (Sanz *et al.*, 2007, 2008; Olarte *et al.*, 2009).

The fact that lighting stimulates stomata aperture and therefore the exchange of gases between the plant tissue and the atmosphere that surrounds it, also explains the different degrees of weight loss found in the samples packed in PVC, a film permeable to water vapour, kept in darkness or under lighting. Thus, at the end of the storage period, the weight losses recorded were: for the white cut 2.98 ± 0.51% and 11.02 ± 0.76% respectively for WD and WL batches; and for the green cut 3.03 ± 0.32% and 7.72 ± 0.69%, respectively for GD and GL batches. These results are to be expected since in darkness the stem stoma remain practically closed, whether in the green or the white cut. In contrast, under lighting, these stoma open causing a greater loss of moisture which will be more intense in the area with a greater water content. In leeks, the greater moisture content of the white cut (which acts as the plant's reserve tissue), explains the greater weight loss when the stoma remain open. This white area also shows higher metabolic activity (radicle bud with actively dividing cells) as was reflected in the greater respiratory activity compared to the green area, the leafy part made up of differentiated adult tissues.

Weight losses were not significant in the batches packed in P-Plus films (less than one percentage in all cases) although substantial water condensation was observed in the inner surface of the films in packages of WL and GL batches. This is due to the low permeability to water vapour of this type of film.

In fact, the differences in the intensity and speed of dehydration coincide with those found in the evaluation of texture, both in the sensorial evaluation made by the panel and in the instrumental measurements.

Microbial counts

The microbial counts of the raw material were respectively 5.77 and 6.53 cfu g^{-1} for the white and green cut of the leek. Peeling and washing managed to reduce the microbial load to 5.22 and 5.99 cfu g^{-1}, respectively, a reduction in line with that referred to by other teams for vegetables with similar characteristics using the same disinfectant agent (Nguyen-The & Carlin, 1994).

During storage, the microbial counts increased slightly, reaching a level on day 26 of around 1.5 logarithmic units higher than at the start. No significant differences were found between the white and green cut, types of packaging films or storage conditions.

The differences in the composition of the atmosphere established in the different packages did not prove sufficiently great to affect the speed of microbial growth (Daniels *et al.*, 1985; Francis *et al.*, 1999).

Conclusion

Texture was the parameter which determined end of shelf life for minimally processed leek, although the different packaging films tested and the storage conditions had different effects of importance depending on which cut of the leek was being studied.

Hence, the shelf life of the green cut of the leek was reduced to 18 days irrespective of the type of packaging film used and whether or not it was exposed to light during storage. In addition, lighting affected the evolution of the colour of the green cut but this was not a determining factor in its end of shelf life.

On the other hand, the packaging film did have a determining effect on the shelf life of the white cut of the leek stored in darkness. With P-Plus films, this was more than 26 days whereas in PVC packaging it was only able to maintain acceptable levels for texture until day 18. Exposure to light of this cut accelerated the deterioration of texture and colour. Also, under lighting the packaging film was a determining factor, with a shelf life of only 11 days established for samples packaged in PVC compared to 18 days for those packaged in P-Plus.

In conclusion, exposure to light had a negative effect on the quality parameters of the leek, for both texture and colour parameters. However, it was only in the white cut that this caused a significant reduction of shelf life. It is necessary to look more deeply into the influence of light on maintaining quality during the processing and retailing of MPV, taking into account the different physiological responses of the different vegetables. Understanding and evaluating the effect of light on MPV must therefore be a factor to consider when selecting the most suitable film for packaging them.

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