Evaluation of different varieties of cauliflower for minimal processing

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Abstract: The impact of minimal processing technology on the sensory quality and the growth of micro-organisms in eight varieties of cauliflower packaged in four different films (one PVC and three P-Plus) was measured and quantified during more than 25 days of storage at 4 °C. Other important parameters such as weight loss and gas concentration in the packages were also determined. The composition of the atmosphere in the packages of minimally processed cauliflower depended on both the permeability of the film used for the packaging and the variety of cauliflower. When establishing shelf-life, loss of sensory quality was the deciding factor rather than loss of microbiological quality. The initial microbial load proved more important than the composition of the atmosphere inside the packages. In sensory evaluation the most important aspect was colour. In instrumental evaluation, coordinate *b was the main means of estimating shelf-life. The combination of P-Plus 120 film and varieties of cauliflower of large size and great vigour allowed the atmosphere inside the packages to have an O_2 level below 10% and a CO_2 level above 10%. That atmosphere composition proved essential for maintaining the sensory quality of minimally processed cauliflower. In these conditions, samples attained a shelf-life of more than 25 days. However, the different behaviours of the cauliflower varieties make it necessary to establish particular packaging conditions. The use of less permeable films than those used in this study, or the use of actively modified atmospheres, could be an alternative for those varieties that require special packaging conditions when processed using this technology.**

Keywords: minimally processed; colour variation

INTRODUCTION

Cauliflower (*Brassica oleracea* L. var. *botrytis* L.) is a highly appreciated vegetable with an annual world production of about 14×10^6 t. At present, more than 100 varieties with different agronomic characteristics are grown throughout the world. There are varieties with different speeds of development (cycles which run for between 80 and 240 days), different cultivation periods (from October to May in the case of Spain) and different sizes of inflorescence (from 600 g to more than 2000 g). A large proportion of this production is commercialised fresh (65% in Spain). For this market, growers prefer to use varieties of cauliflower and agricultural techniques (such as high-density planting of up to 11 plants per m^2) that produce very small plants (200 g, called 'minicauliflowers'). This preference is probably due to the fall in the size of the family unit. The remaining production is destined for processing – freezing or fermentation – although in recent years there has been interest in an 'intermediate' form of commercialised cauliflower as a minimally processed product (MPP).

The extension of the shelf-life of MPPs is achieved by means of a combination of correct refrigerated storage throughout the entire cold chain, modified atmosphere packaging (MAP) and good manufacturing and handling practices. For minimally processed vegetables (MPVs) the gas composition in the package is modified by the respiration of the plant tissue (passive modification). After a certain time an equilibrium modified atmosphere is created depending on the respiration activity of the product, the storage temperature and the permeability characteristics of the packaging material.[1]

Most MAP approaches to respiring products are based on a reduction in O_2 concentration and an increase in CO_2 concentration. A losw O_2 level and a high CO_2 level may delay browning and loss of fresh appearance but can also cause off-flavours and flavour losses.[2]

Many reports have been published on the use of permeable polymeric films to extend the shelf-life of MPVs by modifying the package's atmospheric conditions.[3–11] The main spoilage mechanisms affecting MPVs are microbial growth, oxidation (enzymatic browning) and moisture loss. MAP is effective at inhibiting these spoilage mechanisms as well as at reducing the respiration rate of vegetables.[12]

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Contract/grant sponsor: Consejería de Educación, Cultura y Deportes, Government of La Rioja, Spain; contract/grant number: ANGI2003/16
(*Received 15 July 2005; revised version received 18 October 2005; accepted 4 September 2006*)
Published online 14 December 2006; DOI: 10.1002/jsfa.2715

Among the sensory parameters that determine the quality of food, colour is one of the most important.[13] Changes in this parameter during processing and storage of food products need to be calculated and controlled.

In the case of cauliflower the agronomic differences among the many varieties cultivated make it necessary to study means of adaptation of the vegetable to this preservation technology. The specific physiological behaviour (speed of growth or vigour, respiration rate, etc.) of each variety and the morphological differences between them (size, pigment content, compactness of inflorescence, etc.) will all affect the plant's reaction to packaging as an MPP.

The aim of this study was to assess the suitability of different varieties of cauliflower to this preservation technology and to evaluate the impact on visual quality and the growth of micro-organisms in minimally processed cauliflower packaged in different films.

EXPERIMENTAL

Preparation of samples

Eight different varieties of cauliflower were assayed: Abruzzi (commercialised by Royal Luis), Dulis (Vilmorin), Casper (Rijk Zwaan), Serrano (Syngenta Seeds), Caprio (Bejo Zaden), Nautilus and Beluga (Clause Tezier) and Arbon (Seminis). All of these were grown in the Calahorra area of Spain in 2004 and 2005 (see Table 1) and directly transported from the field to the laboratory. All plants were of high quality and free from defects. In all cases, planting density was four plants per m^2.

After manual removal of outer leaves and cutting, the cauliflower inflorescences were quickly washed by immersion for 5 min in 50 $mg\,kg^{-1}$ free chlorine water at $4 \pm 2\,°C$ (10 $L\ kg^{-1}$). Washing conditions were established according to results obtained in previous experiments. The inflorescences were then rinsed until the free chlorine level was below 0.3 $mg\,kg^{-1}$, and excess water was eliminated by centrifugation.

The cauliflower was packaged using four types of film. One was a PVC (polyvinylchloride) microperforated film (13 µm) supplied by FEISA (Madrid, Spain) in 60 cm × 1500 m reels (control batch). The other three films were 35 µm P-Plus films (made of polypropylene) supplied by Danisco (Bristol, UK) as 20 cm × 25 cm bags: 35PA 120 (P-Plus 120), 35PA 160 (P-Plus 160) and 35PA 240 (P-Plus 240), with O_2 permeabilities of 8000, 15 000 and 36 000 $cm^3\,m^{-2}\,day^{-1}\,atm^{-1}$ at 25 °C respectively. According to the specifications of the manufacturer, the first number stands for the thickness of the film in microns, the set of letters corresponds to the type of film and the last number is the permeability code (the higher this number, the more permeable the film).

Eight samples (and their respective duplicates) of each cauliflower variety were packaged with each film. When PVC film was used, 300 g of cauliflower was placed on 140 mm × 230 mm polystyrene trays. The trays were covered and sealed using a hot plate Hand Wrapper (model WS500E, Lovero, Barcelona, Spain). For P-Plus films, 300 g of cauliflower was placed in the bags, which were sealed using a Vaessen-Schoemake machine (Barcelona, Spain). The packaged cauliflower was stored at 4 °C for more than 25 days. Samples were taken on day 0 and after 1, 3, 7, 11, 15, 21 and 25 days of storage.

The entire experiment was repeated twice. The following determinations were made on each occasion: gas, colour, weight loss, microbiological analysis and sensory evaluation. All these analytical determinations were performed in duplicate.

Gas determination

Carbon dioxide and oxygen were determined using an O_2 and CO_2 headspace gas analyser (Checkmate model 9900, PBI-Dansensor, Ringsted, Denmark).

Colour determination

For each sample, measurements of reflectance were taken at six different points on the cauliflower surface and at six different points of cut zones, after which the mean reflectance spectrum was obtained for each zone separately. These measurements were made with a Minolta CM 2600d spectrophotometer with d/8 geometry and a xenon lamp (Minolta Co. Ltd, Osaka Japan). From the mean spectrum the colour coordinates L^*, a^*, b^* within the CIELAB space were calculated for each sample, using illuminant D65[14] and standard observer CIE64[15], following CIE specifications.[16]

Other determinations

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

The weight of the samples was measured with a Sorvall balance (model B410, Sartorius, Barcelona, Spain).

Microbiological analysis

Cauliflower samples (25g) were aseptically weighed and homogenised for 2 min in a stomacher (IUL, Barcelona, Spain) with 225 mL of sterile peptone water (1 $g\,L^{-1}$ peptone + 5 $g\,L^{-1}$ sodium chloride). Further decimal dilutions were made with the same diluent.

The total number of aerobic mesophilic micro-organisms was determined on plate count agar (PCA; Merck) following the pour plate method by incubation at 30 °C for 72 h.[17]

Sensory evaluation

Sensory evaluation was used to discriminate between the visual appearance, texture and odour of cauliflower samples packaged with different films. A simple scorecard was devised to quantify each sensory attribute. The intensity of the attributes evaluated was quantified on a scale from 1 to 5, where 1 = very poor, 2 = poor, 3 = fair, 4 = good and 5 = excellent. The judges relied on their training experience to score products. The sensory evaluation was used to determine the shelf-life of these products. A score below 3 for any of the attributes assessed was considered to indicate end of shelf-life.

During the test sessions the order of presentation of the samples was randomised. Evaluation of the samples was carried out under normal lighting conditions (ISO/DIS 8589).

Statistical analysis

The entire experiment was carried out twice for each condition tested and, for each one, all analyses were performed in duplicate.

Analysis of variance was done using the program Statistics v10.0 for Windows (SPSS, Ibérica, Madrid, Spain). A level of $P < 0.05$ was considered significant. Tukey's test for comparison of means and correlation coefficients between different parameters was performed using the same program.

Plate count data were converted to logarithms prior to their statistical treatment.

RESULTS AND DISCUSSION

Atmosphere inside packages

The composition of the atmosphere inside the packages changed during the storage period according to the film permeability and the variety of cauliflower. The atmosphere in the P-Plus packages changed during the first 24–48 h, after which an equilibrium modified atmosphere was reached. In the case of PVC the atmosphere within the packages had the same composition as the ambient air during the whole storage period.

Figure 1 shows the changes in O_2 and CO_2 composition for the Abruzzi, Dulis, Casper, Serrano, Caprio and Nautilus varieties packaged in the same type of film (P-Plus 120, the film which had least permeability). The composition of the atmosphere inside the packages differed depending on the variety of cauliflower, owing to the differences in respiration rate of the different varieties.

Significant differences in CO_2 and O_2 concentrations were found when the same cauliflower variety was packaged in different films, owing to the differences in permeability of the films. Figure 2 shows the changes in atmosphere for Abruzzi cauliflower (one of the varieties with highest respiratory activity) when packaged in the films tested.

The O_2 and CO_2 contents in the equilibrium atmosphere inside the packages depended on the type of film and the variety of cauliflower (Table 1). The O_2 concentration ranged between a minimum of 5.1% for Abruzzi cauliflower packaged in P-Plus 120 and a maximum of 21.0% for PVC treatment, whereas the CO_2 level ranged between 0.0% for PVC treatment and 19.3% for Abruzzi in P-Plus 120. Values for the rest of the varieties tested lay between these extremes and depended on the film used.

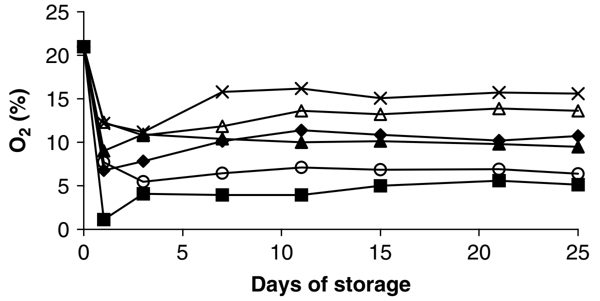

Figure 1. O_2 and CO_2 concentrations in minimally processed cauliflower varieties Abruzzi (■), Dulis (○), Casper (▲), Serrano (♦), Caprio (△) and Nautilus (×) packaged in P-Plus 120.

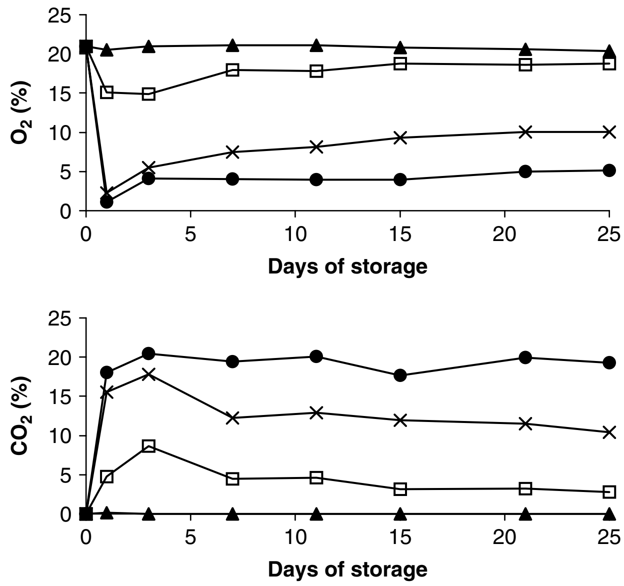

Figure 2. O_2 and CO_2 concentrations in minimally processed Abruzzi cauliflower packaged in PVC (▲), P-Plus 120 (●), P-Plus 160 (×) and P-Plus 240 (□).

The varieties that most modified the atmosphere inside the packages were Abruzzi and Dulis, indicating higher respiratory activity. These two varieties displayed very similar behaviours when packaged in the same type of film, there being no significant differences in the composition of the atmosphere inside the packages, except for the O_2 content in the case of P-Plus 160 film. Both these varieties are highly vigorous and have a large inflorescence.

Intermediate values applied with the Serrano and Casper varieties. They behaved in similar ways when

DOI: 10.1002/jsfa

Table 1. Agronomic characteristics and equilibrium atmospheres of eight varieties of cauliflower packaged in different films

			Equilibrium atmosphere	
Variety	Agronomic characteristics[a]	Film	O_2 (%)	CO_2 (%)
Abruzzi	(a) March 2004	PVC	20.8 ± 0.2d	0.0 ± 0.0a
	(b) Long (210–220)	P-Plus 120	5.1 ± 0.1a	19.3 ± 0.2d
	(c) Very high	P-Plus 160	10.0 ± 0.3b	11.5 ± 0.2c
	(d) Large (1.87 ± 0.31)	P-Plus 240	18.7 ± 0.1d	2.8 ± 0.3b
Dulis	(a) November 2004	PVC	21.0 ± 0.3d	0.0 ± 0.0a
	(b) Short (100–110)	P-Plus 120	8.8 ± 0.2ab	18.2 ± 0.2d
	(c) High	P-Plus 160	14.3 ± 0.1c	8.6 ± 0.4c
	(d) Large (1.94 ± 0.19)	P-Plus 240	18.8 ± 0.3d	3.4 ± 0.3b
Casper	(a) October 2004	PVC	20.8 ± 0.2d	0.0 ± 0.0a
	(b) Short (85–100)	P-Plus 120	9.2 ± 0.2b	10.5 ± 0.2c
	(c) Medium	P-Plus 160	15.5 ± 0.1c	6.5 ± 0.2bc
	(d) Large (1.95 ± 0.15)	P-Plus 240	19.6 ± 0.3d	1.8 ± 0.1b
Serrano	(a) May 2004	PVC	20.7 ± 0.3d	0.0 ± 0.0a
	(b) Short (85–95)	P-Plus 120	9.8 ± 0.2b	11.2 ± 0.3c
	(c) Medium	P-Plus 160	16.5 ± 0.2c	5.5 ± 0.1bc
	(d) Large (1.79 ± 0.25)	P-Plus 240	18.5 ± 0.1d	2.9 ± 0.2b
Caprio	(a) April 2005	PVC	20.1 ± 0.2d	0.0 ± 0.0a
	(b) Medium (180–190)	P-Plus 120	13.8 ± 0.3c	7.6 ± 0.1c
	(c) High	P-Plus 160	17.5 ± 0.2cd	3.2 ± 0.1b
	(d) Small (1.23 ± 0.19)	P-Plus 240	18.6 ± 0.1d	2.2 ± 0.2b
Nautilus	(a) October 2004	PVC	20.7 ± 0.1d	0.0 ± 0.0a
	(b) Short (80–85)	P-Plus 120	15.7 ± 0.1c	5.5 ± 0.3bc
	(c) High	P-Plus 160	17.4 ± 0.2cd	4.5 ± 0.2b
	(d) Small (1.32 ± 0.17)	P-Plus 240	19.5 ± 0.2d	1.7 ± 0.1b
Arbon	(a) February 2005	PVC	20.6 ± 0.1d	0.0 ± 0.0a
	(b) Medium (130–150)	P-Plus 120	1.9 (3)/16.5 (25)[b]	17.8 (3)/4.0 (25)[b]
	(c) Medium	P-Plus 160	10.3 (3)/17.2 (25)[b]	11.0 (3)/3.8 (25)[b]
	(d) Small (1.36 ± 0.23)	P-Plus 240	15.1 (1)/18.6 (25)[b]	7.7 (1)/2.6 (25)[b]
Beluga	(a) February 2005	PVC	20.2 ± 0.2d	0.0 ± 0.0a
	(b) Medium (120–140)	P-Plus 120	8.0 (1)/16.4 (25)[b]	11.0 (1)/4.0 (25)[b]
	(c) Medium	P-Plus 160	10.3 (1)/16.7 (25)[b]	10.9 (3)/4.9 (25)[b]
	(d) Small (1.28 ± 0.27)	P-Plus 240	15.0 (1)/18.5 (25)[b]	8.0 (3)/2.6 (25)[b]

Values are mean ± standard deviation. Means in the same column followed by different letters differ significantly.

[a] (a) Month and year of harvest. (b) Cycle length: short, medium or long (days). (c) Vigour: medium, high or very high. (d) Inflorescence size without leaves: small, medium or large (kg).

[b] Minimum/maximum values (day reached).

packaged in the same film, with no significant differences in the composition of O_2 and CO_2 inside the packages. It is notable that both are short-cycle varieties, are of medium vigour and have a large inflorescence.

With the Nautilus and Caprio varieties there was little change in the atmosphere inside the packages. Both produce small inflorescences in spite of their description as vigorous varieties. The contrast between the vigour of these plants and the size of their inflorescence could be due to the fact that planting density in these cases hindered greater development of the inflorescence.

The behaviour of the Arbon and Beluga varieties is significant: the atmosphere inside the packages continued to change during the whole storage period of the study and no equilibrium atmosphere was reached with any film except PVC (Fig. 3). Both varieties had similar small inflorescences in proportion to their vigour. A study of the kinetics of the atmospheric change inside the packages shows

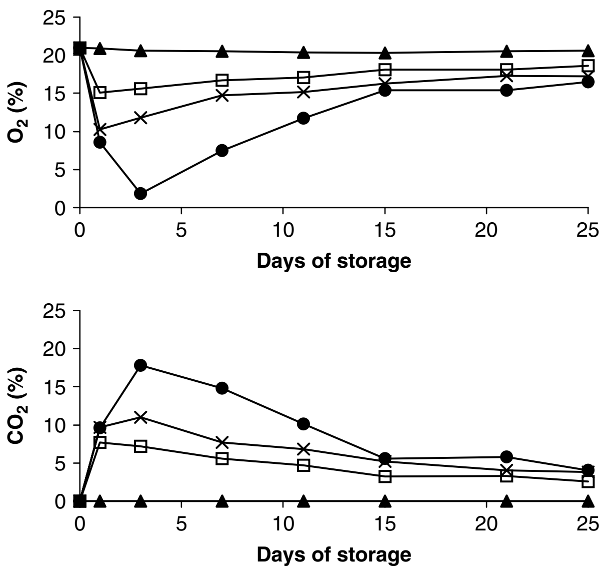

Figure 3. O_2 and CO_2 concentrations in minimally processed Arbon cauliflower packaged in PVC (▲), P-Plus 120 (●), P-Plus 160 (×) and P-Plus 240 (□).

that respiratory activity was decreasing throughout the period of the experiment, in such a way that, as from day 15, there were no significant differences in the composition of the atmosphere of the batches packaged in P-Plus films, and the concentrations of O_2 and CO_2 were clearly moving towards the same values as the batch packaged in PVC.

According to Rolle and Chism,[18] the number one priority of all living tissues is to maintain the 'energised state'. Once detached from the parent plant, energy must be supplied by utilising stored carbohydrate, lipid or protein. Respiration, the conversion of these stores of energy, is essential in order to maintain the 'energised state'. If respiration cannot supply enough energy to maintain the 'energized state', then the tissues will deteriorate rapidly and die. Practical experience has demonstrated that tissues with large energy reserves generally have longer postharvest lives.[18] In our case the different behaviours of the varieties of cauliflower studied could be explained by their different capacities for maintaining this 'energised state'.

Establishment of shelf-life

The varieties of cauliflower studied gave different values when establishing their shelf-life, depending on the film used for packaging. End of shelf-life was determined from the results of the microbiological and sensory analyses (Table 2).

Microbiological analysis

The mesophilic counts of unprocessed cauliflower samples were 5.6 ± 1.2 log CFU (colony-forming units) g^{-1}, with the exception of the Serrano variety where the initial count was higher than 7 log CFU g^{-1}. This variety was harvested at the end of May (the end of the season in the area) after a month of high temperatures, which encouraged greater development of micro-organisms.

Processing reduced the mesophilic presence by around 2 log CFU g^{-1}, in such a way that the microbial load before packaging varied from 3.04 log CFU g^{-1} for the Dulis variety to 3.92 log CFU g^{-1} for Caprio. Except for the Serrano variety, which showed a count of 5.33 log CFU g^{-1}, values for the other varieties were no higher than 3.5 log CFU g^{-1} (Abruzzi 3.13,

Table 2. Shelf-life, weight loss and variation in coordinate b^* at end of shelf-life (in bold) of eight varieties of cauliflower packaged in different films

Variety	Film	Shelf-life (days)		Weight loss (%)	Δb^*
		Microbiological	Sensory		
Abruzzi	PVC	15	**11**	1.97 ± 0.31b	4.03 ± 0.32a
	P-Plus 120	>25	>**25**	0.44 ± 0.13a	4.52 ± 0.27a
	P-Plus 160	15	**11**	0.24 ± 0.03a	6.29 ± 0.65b
	P-Plus 240	15	**7**	0.28 ± 0.17a	11.50 ± 1.88c
Dulis	PVC	>25	**7**	1.46 ± 0.38b	5.37 ± 0.46c
	P-Plus 120	>25	>**25**	0.70 ± 0.19a	0.73 ± 0.18a
	P-Plus 160	>25	**11**	0.62 ± 0.17a	0.94 ± 0.21a
	P-Plus 240	>25	**11**	0.49 ± 0.09a	2.91 ± 0.51b
Casper	PVC	>25	**11**	1.66 ± 0.35b	4.24 ± 0.89c
	P-Plus 120	>25	**21**	0.35 ± 0.12a	0.77 ± 0.28a
	P-Plus 160	>25	**15**	0.27 ± 0.08a	1.42 ± 0.62b
	P-Plus 240	>25	**7**	0.29 ± 0.02a	0.45 ± 0.19a
Serrano	PVC	**3**	15	0.84 ± 0.28b	3.77 ± 0.48b
	P-Plus 120	**21**	>25	0.65 ± 0.15ab	1.44 ± 0.51a
	P-Plus 160	**11**	21	0.53 ± 0.12ab	7.93 ± 1.16d
	P-Plus 240	**9**	15	0.36 ± 0.07a	4.65 ± 0.83c
Caprio	PVC	11	**7**	0.54 ± 0.20b	5.68 ± 1.02c
	P-Plus 120	15	**7**	0.11 ± 0.08a	2.73 ± 0.77a
	P-Plus 160	15	**7**	0.21 ± 0.15ab	6.11 ± 1.20d
	P-Plus 240	11	**7**	0.15 ± 0.04a	4.85 ± 1.17b
Nautilus	PVC	>25	**7**	0.25 ± 0.07	2.04 ± 0.92a
	P-Plus 120	>25	**7**	0.13 ± 0.05	2.79 ± 0.96a
	P-Plus 160	>25	**7**	0.12 ± 0.04	3.47 ± 1.52b
	P-Plus 240	>25	**7**	0.21 ± 0.06	3.28 ± 1.38b
Arbon	PVC	>25	**3**	0.45 ± 0.10b	−10.20 ± 0.62c
	P-Plus 120	>25	**11**	0.43 ± 0.12b	−5.68 ± 1.02a
	P-Plus 160	>25	**7**	0.28 ± 0.08ab	−9.39 ± 0.21b
	P-Plus 240	>25	**3**	0.12 ± 0.07a	−9.38 ± 0.18b
Beluga	PVC	>25	**3**	0.70 ± 0.19b	4.91 ± 0.86b
	P-Plus 120	>25	**11**	0.27 ± 0.17a	3.49 ± 0.51a
	P-Plus 160	>25	**7**	0.18 ± 0.10a	3.05 ± 0.62a
	P-Plus 240	>25	**3**	0.07 ± 0.06a	3.22 ± 0.39a

Values are mean ± standard deviation. Means in the same column and variety followed by different letters differ significantly.

J Sci Food Agric **87**:266–273 (2007)
DOI: 10.1002/jsfa

Casper 3.52, Nautilus and Arbon 3.50, Beluga 3.41 log CFU g^{-1}). These results are in line with those reported by other authors for similar vegetables and treatments.[19–22]

The legal regulations on minimally processed fresh vegetables establish a maximum total limit for microbial counts of 10^7 CFU g^{-1} (7 log CFU g^{-1}).[23] According to this, 70% of samples only exceeded the legal limit after more than of 20 days of storage. The shortest shelf-life was with the Serrano variety packaged in PVC, which reached the maximum legal limit after day 3 owing to its high initial count.

In the case of five varieties (Dulis, Casper, Nautilus, Arbon and Beluga) there were no significant differences in the development of the microbial load depending on the film used for packaging. In these cases the initial microbial loads were very similar and the composition of the equilibrium atmosphere after packaging in different films displayed no differences important enough to modify the kinetics of microbial growth. In all batches of these varieties the counts at the end of the storage period were lower than the legal maximum.

However, differences were encountered in the case of the Abruzzi variety. Here only the P-Plus 120 film proved capable of maintaining the microbial load below the legal limit for more than 25 days. This could be explained by the fact that, with this variety, there were more differences in the atmosphere inside the packages depending on the film used.

In the case of the Caprio variety (harvested in April) there was a microbial load before packaging of 3.92 log CFU g^{-1}, the highest value except for Serrano. The respiratory activity of Caprio did not modify the atmosphere inside the packages to levels of O_2 and CO_2 capable of significantly inhibiting the growth of micro-organisms.

With the Serrano variety it is to be noted that, despite the high initial count, the composition of the atmosphere inside the packages of P-Plus 120 film was enough to inhibit the growth of mesophilic micro-organisms and maintain levels lower than the legal maximum until day 21of storage.

None of the samples studied showed any signs of fungal growth.

Sensory evaluation

Scores for visual appearance, texture and odour decreased during storage in all treatments under study. Except for the Serrano variety, end of shelf-life was determined by sensory quality (Table 2). It was observed that there was a connection between the atmosphere inside the packages and the speed at which the cauliflower lost sensory quality.

With the Abruzzi, Dulis, Casper and Serrano varieties the film that best maintained sensory quality was P-Plus 120, with values higher than 3 for all attributes up to the end of the storage period (Abruzzi, Dulis and Serrano) or until day 21 (Casper). These batches were the only ones in which the composition of the equilibrium atmosphere inside the packages showed an O_2 concentration below 10% and a CO_2 concentration above 10%. These results are in line with those reported by others for non-processed cauliflower and broccoli stored in controlled atmospheres.[19,24–27]

This composition of the atmosphere was not obtained in any of the batches of Caprio and Nautilus varieties; in fact, none of the films used was capable of giving a shelf-life of more than 7 days. With these varieties the existence of discoloured patches and the darkening of the cut zones caused the judges to give marks below 3 as from day 7 of storage.

The respiratory kinetics of Arbon and Beluga after packaging only transitorily achieved levels of $O_2 < 10\%$ and $CO_2 > 10\%$ in the case of the batches packaged in P-Plus 120 film (Fig. 2). This would explain the extension of the shelf-life of these batches to 11 days. After day 11 the appearance of discoloured patches and the darkening of the cut zones, similar to the changes that had occurred with the Caprio and Nautilus varieties, caused rejection on the part of the judges.

It must be mentioned that in the case of the batches of Abruzzi and Dulis packaged in P-Plus 120 film, in which the highest CO_2 levels were obtained in the equilibrium atmosphere (19.3 and 18.2% respectively), a slight odour was noticeable on opening the package. This was described by the judges as a 'fermented cabbage', 'wine cellar' or 'damp' smell. It disappeared soon after opening the package and was not taken into account in the sensory evaluation.

Colour

Values of the colour coordinates L^*, a^*, b^* were obtained from the average of six measurements in the cut zones and from the average of six measurements on the outer zone separately.

The most significant variations occurred in the measurements in the cut zones, and these were the measurements used to quantify the results obtained by sensory evaluation.

It was noted that throughout the shelf-life of the cauliflower there was no browning of the samples. This is clear from the slight variation (less than 1 unit) in coordinate a^* (red tones).

Coordinate L^* (brightness) shows slight negative variations, indicating a darkening of the sample due to progressive deterioration of the cut zones, as was observed in the judges' sensorial evaluation. These variations are not, however, great and cannot be used to determine end of shelf-life.

It is coordinate b^* that shows more useful results. Its value increases in all varieties except Arbon, indicating a yellowing of the samples. In the case of Arbon, coordinate b^* decreases in value because of the variety's tendency towards green, due to slight variation in coordinate a^* towards negative values. Table 2 shows that, in most cases, at the end of shelf-life the increase in coordinate b^* is greater than

3 units absolute value. If we take into account the differences in shelf-life between the more vigorous varieties with large inflorescences (more than 21 days) and the smaller, less vigorous varieties (3–11 days), the larger, more vigorous varieties show less variation in coordinate b^* in comparison with the variations encountered in the case of the smaller plants.

The studies by Berrang *et al.*[19] on whole cauliflower and broccoli stored in controlled atmospheres showed little effect due to the composition of the storage atmosphere on the evolution of colour in these products. For their part, Paradis *et al.*,[28] studying the evolution of the pigments present in minimally processed broccoli, concluded that, during storage at 4 °C, vitamin C, β-carotene and chlorophyll contents were generally stable.

It can be seen in Table 2 that in the case of four varieties the lowest variation in coordinate b^* occurs when P-Plus 120 film is used. For the other varieties the difference between using this film and the one showing least variation is of no great significance.

Weight loss

As shown in Table 2, the weight losses in the different treatments under study were conditioned by the permeability to water vapour of the film used in the packaging. None of the three treatments where P-Plus films were used suffered substantial changes during storage ($<0.7\%$ at the end of shelf-life). In general, treatments with PVC film showed higher losses, since this film proved to be the most permeable to water vapour under the conditions tested. In all, weight loss was no more than 2% at the end of shelf-life.

CONCLUSIONS

The composition of the atmosphere inside packages of minimally processed cauliflower depends on both the permeability of the film used and the variety of cauliflower.

When establishing the shelf-life of minimally processed cauliflower, loss of sensory quality was the deciding factor rather than loss of microbiological quality.

Loss of microbiological quality depended more on the initial microbial load than on the composition of the atmosphere inside the packages. However, for the varieties in which microbiological evolution differed depending on the film used for the packaging, more growth was observed in the packages with a greater concentration of O_2. Microbial load in the raw material may be one of the factors most affected by the period of cultivation.

In sensory evaluation the most important aspect was colour. In instrumental evaluation of colour, coordinate b^* was the main means of estimating shelf-life.

It can be concluded from the results of these experiments that the combination of a variety of cauliflower with high respiration rate and a film of limited permeability, allowing the atmosphere inside the packages to have an O_2 level below 10% and a CO_2 level above 10%, maintains the organoleptic quality of cauliflower as a minimally processed product for more than 20 days. Although O_2 levels below 5% were not reached in any of the conditions studied, we have to take into account the findings of other authors[19,24–27] that warn of the appearance of undesirable characteristics when these vegetables are stored in atmospheres with less than 2% O_2.

In this study, these conditions were achieved using P-Plus 120 film and varieties of cauliflower of large size and great vigour, having a respiration rate sufficient to modify the atmosphere inside the packages until a composition is reached that enables extension of shelf-life, without reaching the level of O_2 at which other authors have identified undesirable behaviour. The favourable behaviour of these varieties of cauliflower packed in P-Plus 120 film is reflected in the change in colour of the product. These batches showed least variation in coordinate b^*.

The different behaviours of the cauliflower varieties make it necessary to establish packaging conditions in a specific way. Thus films with lower permeability than those used in this study, or the use of actively modified atmospheres, could be an alternative for those varieties that, owing to their characteristics, require special packaging conditions when processed using this technology.

ACKNOWLEDGEMENT

This work was supported by a research project grant (ANGI2003/16) from the Consejería de Educación, Cultura y Deportes, Government of La Rioja, Spain.

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