**Effect of Modified Atmosphere Packaging (MAP) on the Quality of ‘Ready-To-Eat’ Shredded Cabbage**

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**Abstract**

Shredded white cabbage (Brassica oleracea L) var Banner were stored in modified atmosphere packaging (MAP) made of medium density polyethylene film with thickness of 30 \(\mu\)m. The in-package gas concentrations (O\(_2\), CO\(_2\) and C\(_2\)H\(_4\)), mass loss, texture, and superficial color were estimated. Browning of the cut surfaces, total visual quality, proliferation of the 'pepper spot' disorder and off-odors were assessed organoleptically. Shredded cabbage was stored at 0\(^\circ\)C for a period of 23 days. After 6 days of storage significant O\(_2\) depletion of the atmosphere was found. A sharp rise of ethylene concentration was recorded on the 6\(^{th}\) day of storage due to wounding, followed by a decline. Limited mass loss (0.5% of the initial mass) and increase in hardness were estimated due to the beneficial effect of packaging. The lightness L* and hue angle (h*) reduction was limited at all cases and the initial color was preserved. The visual quality of the packaged produce was assessed by six trained panelists and it was reported that control remains marketable for 12 days, while shredded cabbage can be packed in MAP for 23 days. In conclusion an atmosphere low in O\(_2\) (1.5%) and high in CO\(_2\) (17%) concentration retained quality characteristics (color, exterior appearance and organoleptic attributes), reduced the proliferation of the 'pepper spot' disorder and extended storage period up to 80% extending likewise the marketability of the end product as ‘ready to use’ salad.

**Keywords:** ready to eat shredded cabbage, storage, modified atmosphere packaging (MAP), quality.

**1. Introduction**

Marketing of ready-to-eat products has increased lately due to increased demand of consumers for these products (Ohlsson, 1994). Demand for minimally processed shredded cabbage has also expanded especially for restaurants, dining rooms, fast food outlets and retail markets due to its convenience and minimal requirements for washing, trimming, cutting or shredding with no additional preparation necessary for its use (Watada and Qi, 1999).

Processing of these products has two aims: firstly, to retain freshness of the product without deterioration of its nutritive value and secondly, to ensure satisfactory shelf-life for its smooth marketability. The suitability of these products is based on their convenience and fresh-like quality. Operations including peeling, coring, cutting and/or slicing are critical to delimit the shelf life of fresh-cut vegetables commodities. Wounding
stresses result in metabolic activation, becoming apparent with increased respiration rate and, in some cases, ethylene production (Rosen and Kader, 1989; Watada et al., 1990; Varoquaux and Wiley 1994; Cantwell, 1998; Nur Aida et al., 2007).

Minimally processed vegetables have a shorter shelf-life than their intact counterparts. Industry has to overcome these problems with limited tools, since preservation methods should avoid impairing the fresh or fresh-like attributes of the product.

Modified atmosphere packaging (MAP) is an effective tool used in the fresh-cut industry to extend shelf-life by altering the gases in the package to produce a composition different from that of air (Al-Ati and Joseph, 2002). Depleted O\textsubscript{2} and/or enriched CO\textsubscript{2} levels reduce respiration, decrease ethylene production, delay enzymatic reactions alleviate physiological disorders and preserve the product from quality losses and growth of microorganisms (Day, 1994). The equilibrium gas concentration thus developed within the package may extend the product shelf-life (McDonald et al., 1990; Omary et al., 1993). However; improper MA conditions may also adversely affect product quality. For most vegetables, modified atmospheres of between 2 and 5% O\textsubscript{2} and 3–8% CO\textsubscript{2} maximize product shelf-life (O’Beirne, 1990; Day, 1991; Moleyar and Narasimham, 1994; Rinaldi et al., 2010). The optimum oxygen concentration for storage of shredded cabbage was considered to be between 5-7.5% according to Gorny (2001) or to 2.2 and 4.3% according to Kawano et al. (1984). Kaji et al. (1993) reported the optimal concentrations for preservation of shredded cabbage as 5 - 10% of O\textsubscript{2} and 5 - 15% of CO\textsubscript{2}. Optimal levels of O\textsubscript{2} and CO\textsubscript{2} are influenced by cultivar and storage duration (Saltveit, 1997). These conditions, reduce respiration rate, retain sugar and reduce cut surface browning.

MAP systems for minimally processed products generally involve their storage within packaging films at refrigeration temperatures, ideally ≤4 °C (Cliffe-Byrnes et al., 2003). Low temperatures (≤4°C) and high relative humidity were found to be the most important post-harvest conditions necessary for maintaining the glucosinolate content of broccoli (Jones et al., 2006). Temperature control is vitally important in order for a MAP system to work effectively. Film permeability also increases as temperature increases, with CO\textsubscript{2} permeability responding more than O\textsubscript{2} permeability. Minimally processed products should be refrigerated at (0-5°C) to prolong their quality and safety (Rivera-López et al., 2005). Duration of cold storage also has an impact on final product quality (overall sensory quality declines and microbial load increases) (Gorny et al., 1999). The optimum storage temperature and atmospheric composition need to be maintained during the whole chain, from harvesting and processing to consumption.

Cabbage is an important member of cruciferous vegetables and is also an important dietary vegetable. The majority of cabbage cultivars are of the white (green) type which is considered as a versatile food where it can be eaten raw, often shredded for coleslaw, fermented to make sauerkraut, or is baked or boiled and made into dishes such as casseroles or cabbage rolls stuffed with meats or other foods (Ibrahim et al., 2004). Cabbage has antioxidant, anticarcinogenic properties (Chu et al., 2002) and containing large quantities of glucosides (Keum et al., 2004; Li et al., 2012). Recently cabbage was widely marketed as a minimally processed product. For fresh-cut products, MA packaging is a necessary supplement to lower temperature storage in order to reduce deterioration rates.

The aim of this work is to study the effect of modified atmosphere packaging at low temperature storage (0°C) on the quality characteristics (weight loss, color, hardness, organoleptic attributes, off-odours) of ready-to-eat shredded cabbage.

2. Materials and Methods
2.1 Raw Material
White cabbage (Brassica oleracea L. var capitata), Bunner variety was harvested at its commercial maturity (weight ~2 Kg, compact head compressed with moderate hand pressure) in Messinia, (south Peloponnese, Greece) during March and April 2010. After harvest, cabbages were immediately transferred to the lab and prepared during the same day. Whole cabbage was trimmed to remove deteriorated leaves, cored and washed with tap water and with chlorinated water (100 ppm available chlorine). Leaves were cut in quarters (four) and then sliced into 5mm thick strips with
sharp stainless steel knives sterilized in alcohol (95% ethanol, Sigma UK, high purity). Shredded cabbage was washed in chlorinated water (100 ppm NaOCl solution adjusted to a pH of 6.5) at a temperature of 5°C for 4 minutes (ratio of cabbage/water 1:3). Following that, it was rinsed in tap water for 4 minutes and centrifuged for 1 minute at a speed of 500 rpm to remove excess water. To minimize product heterogeneity, processed cabbage was pooled and mixed.

2.2 Packaging and Storage Conditions
A quantity of approximately 100±2 g shredded cabbage was placed in heat sealed bags (180 mm x 200 mm) which had a surface area of 720 cm², made with 30 µm thick MDPE packages (O₂ permeability 6.170±730 mL m⁻² d⁻¹ bar⁻¹ and CO₂ permeability 41.520±1830 mL m⁻² d⁻¹ bar⁻¹, according to data provided by the film manufacturer) since gas flushing was applied. Polystyrene trays with dimensions of (15.5 x 22.5 x 3 cm) and wrapped with 13 µm thick PVC film, were used as control due to the fact that it has been a normal commercial practice for packing fresh produce and minimally processed products especially on the supermarkets’ shelves.

Gas flushing was carried out using a gas mixer (MAP Mix 9000, Denmark) and a vacuum compensation chamber (Multivac A, 300/16, Germany). The groups created were: SA (MDPE packaging film, injection of a mixture with 5% O₂ -10% CO₂ balanced with N₂), SB (MDPE packaging film with one macro-perforation 3 mm in diameter) and control (polystyrene trays wrapped with PVC). Freshly shredded cabbage was prepared each with a sampling date.

In each sampling date, quality characteristics of shredded cabbage in SA, SB packages and control were compared to those of freshly-shredded cabbage prepared using the same technique from whole heads cabbages stored at 0°C and coming from the same harvesting period (March and April 2010) compared to those used to produce the minimally processed product.

All tested packages were stored at 0°C and 90% relative humidity in the dark for 23 days. For quality characteristics (texture, colour, organoleptic attributes) six packages were prepared per sampling date and treatment (SA, SB, Control, fresh). Ten bags per treatment (SA, SB and control) were prepared from these packages for gas analysis (O₂, CO₂ and C₂H₄) and weight loss estimation. These packages were kept constant throughout the experiment. Each experiment was carried out twice. Samples were removed from the low temperature storage (0±1°C; 90-95% relative humidity) at predetermined intervals (0, 6th, 12th, 19th and 23rd day) and were analysed for gas concentration in-packaged atmosphere, weight loss, hardness, colour changes, quality and sensory evaluation. All quality and sensory evaluation were conducted in a temperature controlled room at 18°C to minimize the effect of temperature variations during testing.

2.3 Gas Analysis (O₂, CO₂ and C₂H₄) of the In-package Atmosphere
The in-package atmosphere (O₂, CO₂) was measured with a headspace gas analyzer (Check-Mate 9000, PBI Densensor Co., Denmark) drawing up to 2 mL of air samples. Sampling took place with a hypodermic needle through a septum pasted on the packaging.

Ethylene was determined by injection of 1 ml gas sample into a gas chromatograph (Perkin Elmer, Auto System XL) equipped with a modified alumina F1 (mesh size 60/80) column and a flame ionization detector (Manolopoulou et al., 2012).

2.4 Weight Loss
Weight loss was calculated as (%) of the initial mass, with an electronic scale of ±0.01 g accuracy. Weighing took place at controlled air conditions to avoid moisture condensation on the packages.

2.5 Texture Analysis
Hardness was measured with a Texture Analyser TA-XT2i (SMS, UK) with a 100N load cell attached. A Kramer shear cell with five probes attached to the instrument was used. The speed of the probe was set to 1 mm s⁻¹. Hardness was evaluated as the maximum rupture force (N), defined from a typical force-distance diagram (Manolopoulou et al., 2010).

2.6 Colour Measurement
Colour was measured on the CIE L*a*b* chromatic space with a Minolta CR-300 Chromameter (Minolta Corp., Japan). The instrument was initially calibrated using a white ceramic tile (Y=92.6 X=0.313 y=0.319). The L* chromatic
variable, ranges from 0 (black) to 100 (white) and is an indicator of the lightening or darkening due to the physicochemical changes taking place during storage. The a* measures the degree of redness (+a*) and greenness (-a*) while the b* the degree of yellowness (+b*) and blueness (-b*). The measured a* and b* values were used to estimate hue angle degrees h*=arctan(b*/a*). Hue angle values greater than 90° correspond to intense green colour while values close to 90° to yellow (McGuire, 1992). Colour changes were determined by the parameters of (L*) and hue angle.

2.7 Quality Evaluation

Quality evaluation (overall visual quality, pepper spot and cut surface browning) was assessed by a panel of six trained judges adopting a hedonic scale from 1 to 5, rating with 5= very fresh with no browning on the cut surfaces, 3= slight browning on the cut surfaces with marginal marketability, 1= not to be consumed (Kim and Klieber, 1997). A score of 3 was considered as the marketable limit. The entire package contents were poured into white trays. The samples were coded with three digit numbers to mask the treatment identity in an effort to minimize test subjectivity and to ensure test accuracy.

2.8 Sensory Evaluation

Off-odours in the headspace were determined by a panel of six trained judges 2-3 min after opening the bag. Off-odours were scored at a 1 to 5 scale, where 1=none, 3=moderate and 5=severe. A score of 3 was considered as the marketable limit.

Quality and sensory evaluation were also used to determine the shelf-life of shredded cabbage, as scores below 3 were taken as unacceptable and were used to indicate the end of shelf-life (López-Galvez et al., 1997).

2.9 Statistical Analysis

The experiment was performed according to a full factorial design (treatments x storage time) and subjected to the analysis of variance (ANOVA), using Statgraphics Plus 5.1 (Statpoint Technologies, Inc, VA, USA). Mean values were subjected to Fisher’s Least Significance Difference test (LSD) at confidence level p≤0.05. The adopted test is liberal with respect to the comparison wise error rate; however it is powerful for detecting true difference (Gacula and Sign 1984) Data shown in figures is the mean values of two experimental series with no significant difference found between the series.

3. Results and Discussion

3.1 Effect of Gas Composition during Storage

Evolution of O₂ and CO₂ during the storage of shredded cabbage at 0°C is shown in Figure 1. As it was expected, the O₂ concentration was reduced during the first days, whereas CO₂ concentration increased. Oxygen and carbon dioxide evolution depended on storage time and treatments.
After 6 days of storage at 0°C the composition of the atmosphere in both packages was stabilized and remained in these levels until the end of storage (23rd day). Therefore, in package SA, O₂ concentration stabilized at 1.5% (from an initial concentration of 5%) and CO₂ concentration remained constant at 17% (from an initial concentration of 10%). In package SB, O₂ concentration remained constant at 16% (from an initial concentration of 21%) whereas CO₂ concentration remained at 4% (from an initial concentration of 0%). This change in gases could be attributed to the increase in respiratory activity of tissues due to the cutting (Surjadinata and Cinseros-Zevallos, 2003). According to Pretel et al. (2000), the modified atmosphere inside the bags (O₂ and CO₂) and the time necessary to reach equilibrium depend on the respiratory intensity (IR) of the produce and the permeability of the film. According to Hiroaki et al. (1993) and Gorny (2001), the ideal gas concentration for shredded cabbage storage is 5-7.5% O₂ and 15% CO₂, whereas Hu et al. (2007) suggested a 2% O₂ and 13% CO₂ concentration. The suitable gas mixture for modified atmosphere of minimally processed fruits and vegetables has been based on the recommendations for the whole commodity (Saltveit, 1997). In the case of whole cabbage at 0°C, low O₂ injury is seen after 2 months at 0.5% or 6 months at 1.5% O₂. CO₂ injury is seen after 2 months at 20% or 6 months at 10% (Saltveit, 2001). The sensitivity of minimally processed vegetables to modified atmospheres may be quite different than for whole product, withstanding more extreme concentrations of O₂ and CO₂ compared to whole vegetables and this is due to the fact that they find fewer obstacles in the diffusion of gases (Kader et al., 1989). In certain vegetables O₂ concentration can go down to levels below the start point of alcoholic fermentation without the appearance of injuries. Hence broccoli flowers can be stored at 0.5% O₂ concentration (Izumi et al., 1996a), zucchini slices at 0.25% O₂ concentration (Izumi et al., 1996b), spinach at 0.8% (Ko et al., 1996), and lettuce at 1% (Hamza et al., 1996). In each case, lower O₂ limit increased with temperature. Lower O₂ limits vary from 0.15% to 5% and are influenced by temperature, commodity and cultivar (Beaudry and Gran, 1993).

In our experiments, O₂ concentration in SA packages was lower whereas CO₂ concentration was higher compared to those reported in other studies (Hiroaki et al., 1993; Gorny, 2001) but was similar to those presented in many commercial salad packages (López-Gálvez et al., 1997).

3.2 Effect of Packaging on Ethylene Concentration in Shredded Cabbage during Storage at 0°C

Ethylene concentration changes in the interior of packages SA and SB are shown in Figure 2.

Figure 2 shows the effect of wounding plant tissues and type of packing on ethylene production. When commodities are cut or otherwise damaged mechanically, they start respiring more rapidly, and ethylene production is stimulated (Kader et al., 1989). Some variation in ethylene production rate was noted in the different packages (SA, SB). The general trend was a sharp rise due to wounding, followed by a decline. The marked ethylene variability was due to the fact that gas concentrations within each package (SA, SB) evolved differently (Piga et al., 2000).

Wounding caused ethylene production and this was in agreement to other studies in kiwi fruits (Agar et al., 1999), tomato (Artés et al., 1999), and strawberry (Rosen and Kader, 1989). Concentration of O₂ in the package affected the rate and quantity of ethylene. Therefore, SB packaging which had a high O₂ concentration (16% during stabilization), showed a more than double quantity of ethylene on the 6th day compared to SA packaging with a low O₂ concentration (1.5% during stabilization). SB packaging presented a maximum on the 6th day,
whereas SA packaging presented a maximum on the 9th day. There was no difference between the two packages after the 12th day, and ethylene production was zero on the 19th day. It is well known that low O2 concentration can prevent ethylene production in climacteric fruits as well as in non climacteric fruits (Abeles et al., 1992). Levels of O2 between 1 and 3% could reduce ethylene production up to 50% in stored apples (Lelievre et al., 1997). Reduced ethylene production could be attributed to a lowered activity of the enzyme EFE and the conversion of ACC to ethylene (Masia, 2003).

For whole cabbage the ethylene production rates are generally very low: <0.1µL/kg•hr at 20°C (Cantwell and Suslow, 2005).

3.3 Weight Loss

Our results showed that weight loss of the shredded cabbage, packaged with SA and SB packages was minimal, of the order of 0.5% after 23d of storage whereas that of control (PVC package) was of the order of 3% after the same storage period. No visibility of water drips and no fluid leakage was evident in the packages at all cases. Weight loss observed even in the control (3%) was not able to degrade the quality of the product because it ranged at much lower levels. The ANOVA showed that the factors affecting weight loss were type of packaging and storage time (p≤0.05).

Water loss in vegetables is determined by many factors, the most important of which is the resistance exerted by the outer periderm or cuticle to movement of water vapour due transpiration (Ben-Yehoshua, 1987). However produce cutting, results in resistance reduction of these barriers to transpiration. Fresh-cut products are highly susceptible to weight loss because internal tissues are exposed to atmosphere conditions. However, the formed relative humidity in general is very high in film bags, so dehydration is not a major problem. Kader (1983) considered transpiration as the major cause of postharvest losses and poor quality in leafy vegetables.

Weight loss adversely affects the appearance, texture, flavor, all factors that determine the quality of the fruits and vegetables. Weight loss induces wilting, shrinkage and loss of firmness, crispness all of which are components of freshness of leafy vegetables.

Maximum permissible weight loss for cabbage without quality deterioration is 7% according to Kang et al. (2002).

3.4 Hardness

Hardness changes of shredded cabbage in the different treatments during storage are shown in Figure 3.

Figure 3: Effect of SA and SB packaging on the hardness of shredded cabbage during storage at 0°C. The figure on the left shows the change during storage at 23 days, and the figure on the right shows the average change during the whole storage period (N=2 repetitions X 6 samples per repetition =12) (I =LSD).
It is shown that rupture values for minimally processed cabbage have increased at all cases from the first days of storage. SA and SB packages retained hardness constant until the 19th day when force increased again. Control as well as the fresh product made from whole cabbage in every sampling, presented a constant increase until the end of storage (23rd day). At the end of storage the smallest change (10%) in hardness was shown by the product in SA packaging, whereas there was no statistically significant change between the three other treatments whose change varied between 15-19%. ANOVA showed that treatments as well as storage time affected changes in hardness.

Barry-Ryan et al. (2009) reported a small reduction in texture during storage of shredded lettuce and cabbage. Variety plays a significant role as well as the heterogeneity of texture observed between leaves and on the same leaf (Toole et al., 2000). Finally, it should be stressed that high CO₂ concentration and low O₂ concentration kept tenderness of cabbage and made it less fibrous as it was also reported in asparagus (Wang et al., 1971).

3.5 Colour

The L* colour value and hue angle (h°) were selected as the most suitable parameters for discoloration of cut surfaces (Sapers and Douglas, 1987) (Figure 4).

Lightness of shredded and packaged cabbage showed a decrease on the 6th day but with no statistically significant changes between treatments SA, SB and control. No statistically significant difference between treatments and freshly cut cabbage was reported at the end of storage (23rd day). It could be noted that treatment SA kept lightness values close to fresh product values during storage. At the end of storage lightness change in treatments SA, SB and control varied between 3.5-5%, whereas for the freshly cut product it was approximately 0.5%.

Control showed a decrease in hue values during the whole storage period whereas packages SA and SB retained hue value at high levels until the 19th day. At the end of storage control showed the lowest hue value (p=0.05) whereas freshly cut cabbage had the highest value. The decrease in hue according to Bolin and Huxsoll (1991) could be due to chlorophyll degradation from the action of chlorophyllase. High concentrations in CO₂ keep chlorophyll in cabbage (Isenberg and Sayles, 1969) and reduce polyphenoloxidase and phenolic compounds concentration (Kaji et al., 1993; Buescher and Henderson, 1977).

3.6 Organoleptic Attributes

Changes in quality characteristics (browning of cut surfaces, appearance of ‘pepper spot’ disease and total visual quality) are shown in Figure 5.

Three (3) criteria were tested. Among the different treatments freshly shredded cabbage and package SA presented the smallest browning of cut surfaces. Hence, shredded cabbage in package SA
was judged to be marketable with respect to browning of cut surfaces until the 23rd day, whereas product stored in package SB was marketable until the 19th day and control until the 12th day. Browning of cut surface is a problem with several products such as cabbage (Yano and Saijo, 1987; Manolopoulou and Varzakas, 2011), lettuce (Bolin and Huxsoll, 1991), potato (Sapers et al., 1990).

High concentrations in CO₂ protect shredded vegetables from browning of cut surfaces because they limit the action of polyphenoloxidase (PPO) and the concentration in phenolic substances (Buescher and Henderson, 1977). Our results come in agreement with those reported by Kaji et al. (1993) according to which browning was suppressed as the CO₂ concentration increased (0% to 15%), with no influence of O₂ concentration (2.5% to 10%). Hu et al. (2007) suggested the total colour difference (ΔE) as a discoloration index. Based on this criterion organoleptic control analysis data are confirmed because package SA showed the smallest change (10.9) whereas package SB and control showed a change of 11.7 (results not reported here). Freshness is the most important criterion that consumers use to evaluate organoleptic quality of fruits and vegetables. Browning of cut surfaces is one of the most limiting factors on the shelf life of fresh-cut products and a significant factor of quality deterioration of shredded cabbage (Pirovani et al. 1997).

Freshly cut cabbage ready for each sampling showed the highest infection by ‘pepper spot’ disorder and based on this criterion it was marginally marketable on the 19th day. Package SA showed the lowest infection and retained the product as marketable until the 23rd day, whereas package SB retained the product marginally until the 19th day and control until the 12th day. ‘Pepper spot’ is a non-pathogenic disorder appearing during storage. It consists of very small to moderate size discolored lesions on the midrib and veins of the leaves (Walsh et al., 1983). The use of MAP reduces the appearance of the disorder. Atmospheres poor in O₂ (1-3%) and rich in CO₂ (10%) are capable of removal of any symptoms (Menniti et al., 1997). In our case MAP in SA package reduced the appearance of «pepper spot» disorder.

Finally according to the total visual quality control criterion, control and package SB showed the most intense deterioration of total visual quality, whereas the smallest deterioration was shown in package SA. Hence, according to this criterion product in package SA was marketable until the end of storage (23rd day), product in package SB until the 12th day, and control was marketable only until the 6th day.

### 3.7 Sensory Evaluation

Table 1 shows the effect of packaging type on off-odours scores for shredded cabbage at 0°C. This effect appeared to be directly related to the gas mixture in the packs.

Results from the analysis of ANOVA showed significant differences among the samples. Treatment and storage time affected evolution of off-odours. Generally there was an increase in values during storage mainly of SA package, which showed the highest score at the end of storage. It should be noted that, the score of SA package at the end of storage at 0°C (23 days) was less than that of the marketable limit (2.6<3). Significant differences between SA and SB packages were found at 19 days.

#### Table 1

Sensory evaluation of shredded cabbage at different gas mixtures, at 0°C

<table>
<thead>
<tr>
<th>Type of package</th>
<th>0 day</th>
<th>6 days</th>
<th>12 days</th>
<th>19 days</th>
<th>23 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>1</td>
<td>1.6a</td>
<td>1.8a</td>
<td>2.2c</td>
<td>2.6c</td>
</tr>
<tr>
<td>SB</td>
<td>1</td>
<td>1.2b</td>
<td>1.6a</td>
<td>1.8b</td>
<td>2b</td>
</tr>
<tr>
<td>Control</td>
<td>1</td>
<td>1b</td>
<td>1.2b</td>
<td>1.3a</td>
<td>1.3a</td>
</tr>
</tbody>
</table>

Values are the mean of 72 (2 repetitions x 6 samples x 6 panellists) determinations, separated by Fisher’s least significant difference (p<0.05). Values followed by different letters in the same column show difference (p<0.05).
In the present study, the development of off-odours was related to CO$_2$, up to a concentration of 17% and O$_2$, below a concentration of 2%. On the other hand, no off-odour was detected until the end of storage in PVC overwrapped samples. The organoleptic attributes and sensory evaluation influenced the shelf life of shredded cabbage. These attributes were different depending on the package used. For samples in SB and control, the practical shelf life was related to a decrease in general appearance and extent to browning. However, for samples in SA bags, the shelf life was conditioned to the development of off-odour.

According to López-Gálvez et al. (1997) high CO$_2$ (20%) resulted in a significant increase in ethanol and acetaldehyde levels. Increase in these fermentative volatiles may affect the sensory properties of the products. Hamza et al. (1996) showed that, in the case of minimally processed lettuce, an atmosphere enriched in CO$_2$ (>15%) changed the content of acetaldehyde and ethanol to a very small extent during storage and the changes did not induce off-odours. McDonald et al. (1990) reported no fermentation of cut lettuce when CO$_2$ was <20% and O$_2$ was 1-4%. In the case in which, whole cabbage was stored at 0°C in 1-3% O$_2$ and 10% CO$_2$ off flavours and odours were developed after 74 days (Menniti et al., 1997). Accumulation of CO$_2$ up to 18% and O$_2$ depletion to 1% or lower induced undesirable odours in other cruciferous (Bastrash et al., 1993). The off odours due to high CO$_2$ disappeared after aeration but those due to low O$_2$ were still detectable. If high CO$_2$ is used, the O$_2$ level should be greater than 1% (Herner, 1987). Variations in response to CO$_2$ among cultivars, developmental stages and temperature have been reported in numerous leafy vegetables (Ke et al., 1993; Paull, 1992). Storage temperature is an important factor in the occurrence of off-odours in SA package. Temperature of 0°C reduces degradation of phytochemicals such as glucosinolates which provokes some bad flavors and increases tolerance of any plant tissue at low O$_2$ tension (Gomes et al., 2010).

Based on Gacula (1975) and Shewfelt (1986) and keeping in mind that minimally processed vegetables must maintain their fresh quality, the shelf life was defined as the time of refrigerated storage at which any one of the organoleptic attributes scored below 3 and sensory evaluation up to 3 (Kader and Cantwell, 2006).

4. Conclusions

Modified atmosphere in SA packaging, low in O$_2$ (1.5%) and high in CO$_2$ (17%) retained the texture, reduced browning of the cut surfaces, retained total visual quality and sensory evaluation, and
increased shelf life of shredded cabbage to 23 days.

A sharp rise of ethylene concentration was recorded on the 6th day of storage due to wounding, followed by a decline. Limited mass loss (0.5% of the initial mass) and increase in hardness were estimated due to the beneficial effect of modified atmosphere packaging. The initial color of the products was preserved. The visual quality of the packaged produce was assessed by six trained panelists and it was reported that control remains marketable for 12 days, while shredded cabbage can be packed in MAP for 23 days.

References


common vegetables”. *Journal of Agriculture and Food Chemistry.* Vol. 50, pp. 6910-6916


refrigerated fruits and vegetables, Chapman and Hall, New–York, pp.226–268


