ISSN 1330-9862 *original scientific paper*
(FTB-1711)

Regulation of Metabolic Changes in Shredded Cabbage by Modified Atmosphere Packaging

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Received: May 3, 2006
Accepted: June 26, 2008

Summary

The influence of different storage conditions on the storability of packaged shredded cabbage has been studied. The cabbage cultivar Fieldrocket was cut and packaged in glass jars and in polyethylene (PE) or polypropylene (PP) film. Several initial atmospheres were established within the packaged cut cabbage: 100 % N_2, 5 % O_2/95 % N_2, 10 % O_2/90 % N_2, normal atmosphere (NA), 70 % O_2/30 % N_2 and 100 % O_2. Samples were stored at two different temperatures of 0 and 10 °C for 7 days. Variation in CO_2 and O_2 concentrations was higher at 10 °C compared to 0 °C and the highest at the atmosphere consisting of 70 % O_2/30 % N_2. A decrease of O_2 below 3–5 % and an increase of CO_2 above 2–5 % in the packed product resulted in the appearance of anaerobic metabolism. An initial atmosphere consisting of 100 % O_2, and a storage temperature of 0 °C resulted in delayed anaerobic metabolism compared to other atmospheric conditions and storage temperature of 10 °C. Rinsing of fresh cut cabbage also resulted in lower accumulation of acetaldehyde and ethanol. A higher variation in CO_2 and O_2 concentrations, and consequent accumulation of anaerobic metabolites had a negative influence on the sensorial properties of the cut cabbage. The higher permeability of PE film compared to PP and glass enabled faster exchange of CO_2 and O_2, which resulted in lower accumulation of anaerobic metabolites. However, a higher O_2 concentration had a negative influence on the colour of fresh-cut cabbage. The best results were achieved by packing the fresh-cut cabbage in PE film with an initial atmosphere of 100 % O_2 and stored at 0 °C.

Key words: cabbage, modified atmosphere, packaging, polyethylene, polypropylene, respiration, anaerobic metabolism

Introduction

Nowadays, there is an increasing demand in food technology toward ready-to-eat, *i.e.* minimally processed foods, in order to meet consumer demands. Freshly cut fruits and vegetables are known to deteriorate quite quickly and have a limited shelf life. Major problems associated with fresh-cut vegetables are the development of strong off-odours and decay, tissue softening and discolouration (*1–3*). The factors influencing the shelf life of fresh-cut fruits and vegetables include respiration intensity, temperature and O_2 concentration. Today, the modified atmosphere is a widely used tool to reduce the deterioration and prolong the shelf life of fresh-cut fruits and vegetables.

Respiration of fruits and vegetables is a metabolic process that provides the energy for biochemical processes in plants. Aerobic respiration consists of oxidative breakdown of organic reserves to simpler molecules such as CO_2 and H_2O and release of energy. The ratio of

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CO_2 produced to O_2 consumed, known as RQ, is normally 1 in case of carbohydrates. RQ is much greater than 1 during anaerobic respiration. Anaerobic respiration involves production of ethanol as the final product due to pyruvate decarboxylation to CO_2 without O_2 uptake (*4*). Carlin *et al.* (*5*) found grated carrots packed in low permeability film to have an RQ of 6.

Temperature, as well as the concentration of oxygen and carbon dioxide, is one of the most important parameters influencing fruit and vegetable quality during storage and also determines their shelf life (*6–9*). Beside temperature and atmospheric composition, maturity and the physiological state of the produce also dictate the shelf life. Recent research includes the application of increased O_2 concentration around and within fresh fruits and vegetables (*10*). High O_2 concentration produces more free radicals that damage plant tissues (*11*).

The purpose of cooling and modified atmosphere packaging (MAP) is to inhibit the physiological processes that are more intensive in fresh-cut fruits and vegetables due to tissue wounding. Operations like peeling or slicing limit the shelf life of products due to physiological stress caused by physical damage or wounding (*12*). Stress provoked by wounding results in increased respiration rates of a fresh-cut produce, and is related to changes in colour, flavour, texture and sensory properties (*13*).

Slowing the respiration rate results in longer storability of commodities, as well as enabling better stability of gas concentration within the packaged product. Polyethylene (PE) and polypropylene (PP) are commonly used films for packaging of a fresh-cut produce. Film thickness, its transmission of O_2 and CO_2, in combination with respiration activity and the temperature of produce define the storage atmosphere within the modified atmosphere (MA) package. Gas transmission of packaging materials enables the establishment of dynamic equilibrium of oxygen and carbon dioxide, and thus the proper gas ratio to provide the desired atmosphere (*14*). Unsuitable MA conditions arising as a consequence of very intensive respiration or inappropriate initial MA conditions can cause anaerobic respiration. Accumulation of anaerobic respiration products, such as acetaldehyde and ethanol, leads to sensorial deterioration of produce.

Cut cabbage (*Brassica oleracea* var. *capitata* L. *forma alba*) is a very perishable biological commodity due to the high degree of damaged tissue. The use of an appropriate initial modified atmosphere (MA) and packaging material with suitable permeability can significantly prolong the shelf life of packaged fresh-cut cabbage. The presence of anaerobic metabolites in the package can provide a means for control of the metabolic intensity of the packaged commodity. In our study we have explored the optimal storage conditions for cut cabbage produce. Two different storage temperatures, three different packaging materials, several initial modified atmospheres and two different prepackaging treatments were compared. Conditions for packaged fresh-cut cabbage similar to those in refrigerators in shops were created.

The goal of this work is to study the effect of packaging material and initial storage atmosphere on the variation in CO_2 and O_2 concentrations in the headspace of stored fresh-cut cabbage. The effect of the accumulation of anaerobic metabolites (acetaldehyde and ethanol) on the sensory properties and colour of fresh-cut cabbage is also determined.

Materials and Methods

Material

White cabbage (*Brassica oleracea* var. *capitata* L. *forma alba*) cultivar Fieldrocket was obtained from a farm near Ljubljana, Slovenia. The cabbage was stored at 0 and 10 °C for 24 hours. After 24 hours the shredded cabbage was prepared as follows: outer and damaged leaves and the core were removed, and the remaining leaves were sliced to about 1-mm thick strips with an electric kitchen slicer (Gorenje S 201 food processor, Slovenia). A certain quantity of shredded cabbage was dipped three times in cold water (5 °C) for 5 min and then centrifuged at 40×*g* in a bucket-type centrifuge, all other samples were not rinsed.

Packaging of shredded cabbage

Shredded cabbage was put either in glass jars or in 30-μm thick polyethylene (PE) and 30-μm thick polypropylene (PP) film bags. The permeability coefficients of the PE and PP films are summarised in Table 1.

Table 1. Water vapour transmission, O_2, N_2 and CO_2 permeability coefficients of PE and PP films of 25 μm thickness at 25 °C according to Greengrass (*15*)

	Water vapour transmission g/(m^2·day) at 38 °C and 90 % RH	O_2	N_2	CO_2
		Permeability coefficient/(cm^3/(m^2·day·Pa))		
PE	18	0.077	0.028	0.414
PP	6–7	0.020	0.004	0.079

A mass of 830 g of cut cabbage was put in either glass jars (*V*=2.5 L) or in plastic film bags (dimensions 30×27.5 cm). All plastic bags allowed the volume of 2.5 L if maximally inflated. Ratio of cut cabbage to headspace was the same in the glass jars and in the film packages. The desired initial atmosphere (100 % N_2, 5 % O_2/95 % N_2, normal atmosphere (NA), 70 % O_2/30 % N_2 and 100 % O_2) was established by blowing each atmosphere through the units of packaged cabbage. The packages were then stored at 0 or 10 °C. Lids with valves on the packages were taken out for online atmosphere composition monitoring and sampling.

Determination of CO_2 and O_2 in packaging atmosphere

Online monitoring of CO_2 and O_2 in packages was performed every 12 hours with a gas analyser equipped with an IR detector and a Clark's ion sensitive electrode.

Gas analyser was calibrated to standard gas samples and afterwards it was connected to the inlet and outlet tube of each package. The actual atmosphere composition in the package was determined in a flow in closed system at a flow rate of 200 mL/min. The readings of CO_2 and O_2 concentrations (by volume) were recorded after reaching the equilibration period.

Determination of acetaldehyde and ethanol in cabbage tissue

The acetaldehyde and ethanol content in cabbage tissue were analysed according to the method described by Bonghi *et al.* (*16*) on the GC apparatus as follows: a mass of 15 g of shredded cabbage was frozen with liquid nitrogen, then homogenised with 20 g of distilled water. The homogenised sample was then centrifuged for 10 min at 1200×*g*. The liquid part of the sample was removed and centrifuged again for 10 min at 1200×*g*. A volume of 3 mL of supernatant was transferred to a 15-mL vial and held in a water bath at 55 °C for 45 min. A volume of 1 mL of headspace sample was taken with syringe and injected into the GC injector. GC (Hewlett Packard 5890 II) was equipped with an HP-FFAP (50 m× 0.2 mm×0.3 µm) column (isothermal programming at 100 °C) and an FID detector (260 °C).

Sensory evaluation

Four trained panellists performed a sensory evaluation test for texture, colour, smell and taste after 7 days of storage under storage conditions described above. For the purpose of evaluating sensory qualities, the panel composed of four qualified and experienced panellists in the field of fresh fruits and vegetables was appointed.

All testing posts in the sensory laboratory had identical conditions. The room temperature was approx. 20 °C and relative humidity was between 60 and 75 %. Lightning of the room was also the same throughout the experiment. Sensory descriptors of shredded cabbage after 7 days of storage under storage conditions described above were as follows: texture – easiness of chewing; colour – intensity of yellow-green colour; smell – characteristics of the smell of differently stored shredded cabbage; and taste – overall impression in the mouth.

Data analysis

The data for sensory properties were analysed by the method of the least squares using the GLM procedure (*17*). The statistical model for the analysed parameters of cabbage included the effect of package atmosphere (100 % O_2 PE, 0 °C; NA, PE, 0 °C; NA, PP, 0 °C; rinsed, NA, PE, 0 °C; NA glass jar, 0 °C; 5 % O_2, PE, 0 °C; 70 % O_2, glass jar, 0 °C; 10 % O_2, glass jar, 0 °C; NA glass jar, 10 °C; 70 % O_2, glass jar, 10 °C; 100 % N_2, glass jar, 0 °C; 100 % N_2, glass jar, 10 °C). The mean values of the experimental groups were obtained using Duncan's test (*17*).

Results and Discussion

Storage at low temperature was the first technique used commercially to prolong the storage life of agricultural commodities. In this work, cabbage samples with different MA gas composition inside PE and PP bags and glass jars were stored at 0 and 10 °C. A higher storage temperature (10 °C) caused higher respiration activity in all samples, resulting in a rapid decrease of O_2 and a corresponding increase of CO_2 inside the packaged units (Figs. 1 and 2). The O_2 concentration in the headspace of shredded cabbage stored at 10 °C reached 0 % after no later than 36 hours, regardless of the initial O_2 concentration or the packaging material (Figs. 2 and 3). Among the samples stored at 0 °C, the samples stored in glass jars in an initial NA reached 0 % O_2 after 30 hours, while samples stored in NA in PP film consumed all their O_2 after 36 hours (Fig. 3). The CO_2 concentration was very similar in glass jars and PP film (Figs. 4 and 5). In PE film packages the O_2 concentration stabilised around 2 %, which seems to be an equilibration point for MA packaging. Regarding the storage temperature, similar results were obtained by Escalona *et al.* (*18*), who reported an increase of respiration on

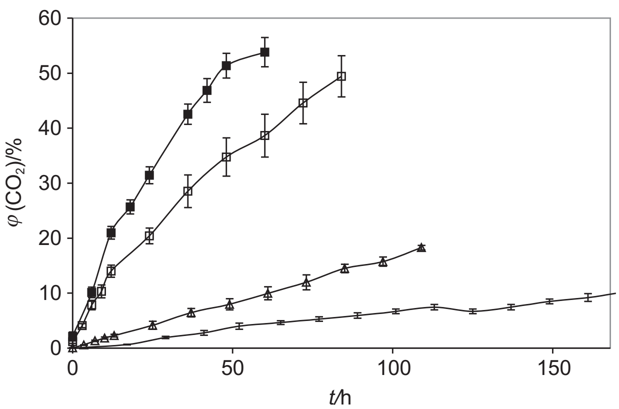

Fig. 1. Variation in CO_2 volume concentration in packages of fresh-cut cabbage stored under different conditions in glass jars: (— intact cabbage leaves, NA, 0 °C; △ fresh-cut cabbage, NA, 0 °C; □ fresh-cut cabbage, NA, 10 °C; ■ fresh-cut cabbage, 70 % O_2/30 % N_2, 10 °C). Vertical bars indicate means of three replicates±SD

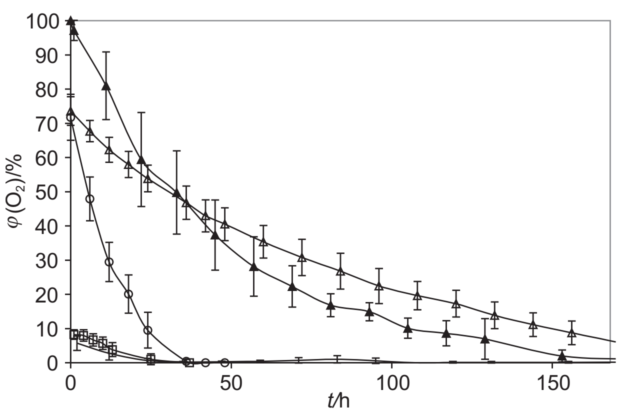

Fig. 2. Variation in oxygen volume concentration in fresh-cut cabbage packages stored under different conditions: — 5 % O_2/95 % N_2, 0 °C, PE; □ 10 % O_2/90 % N_2, 0 °C, glass jar; △ 70 % O_2/30 % N_2, 0 °C, glass jar; ▲ 100 % O_2, 0 °C, PE; ○ 70 % O_2/30 % N_2, 10 °C, glass jar. Vertical bars indicate means of three replicates±SD

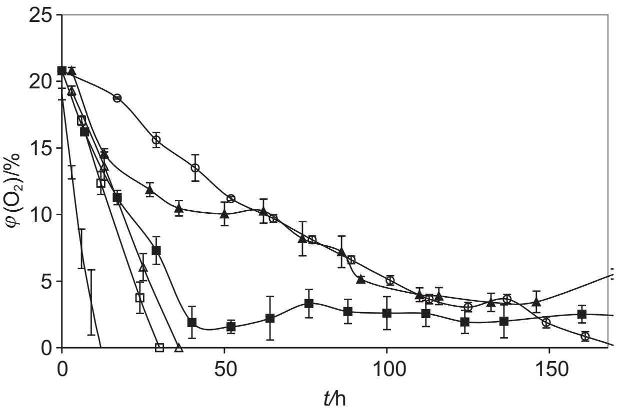

Fig. 3. Variation in oxygen volume concentration in fresh-cut cabbage packages stored at different conditions: — glass jars, NA, 10 °C; □ glass jars, NA, 0 °C; ■ NA, 0 °C, PE; △ NA, 0 °C, PP; ▲ rinsed cabbage (NA, 0 °C, PE); ○ cabbage leaves, glass jars, NA, 0 °C. Vertical bars indicate means of three replicates±SD

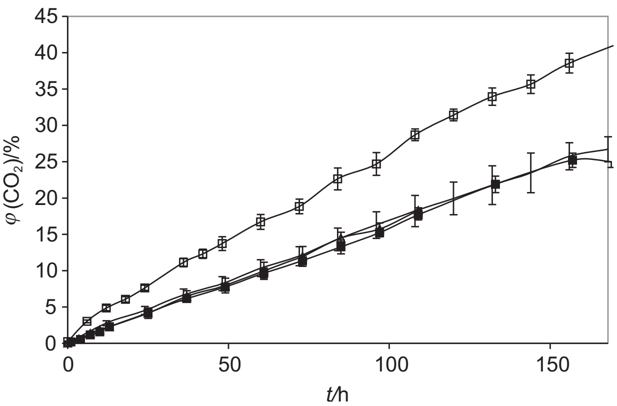

Fig. 4. Influence of different initial oxygen concentration in MA on CO_2 volume concentration in fresh-cut cabbage packages stored at 0 °C in glass jars: (— 100 % N_2, ■ 10 % O_2/90 % N_2, △ NA, □ 70 % O_2/30 % N_2). Vertical bars indicate means of three replicates±SD

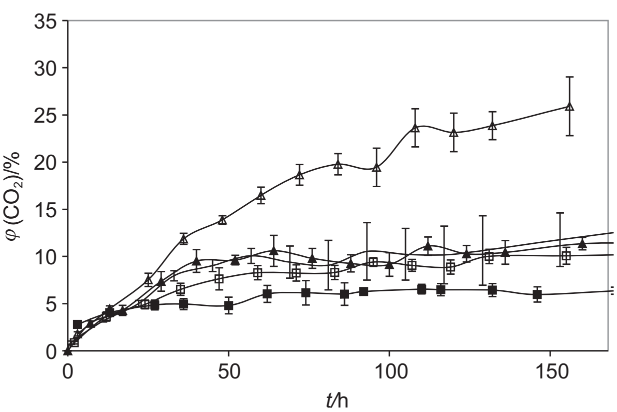

Fig. 5. Variation in CO_2 volume concentration in fresh-cut cabbage package stored at 0 °C as a consequence of different MA packaging, different film transmission rates and prepackaging treatment: (□ 5 % O_2/95 % N_2 (PE), ▲ NA (PE), — 100 % O_2 (PE), ■ rinsed cabbage (NA, PE), △ NA (PP)). Vertical bars indicate means of three replicates±SD

fresh-cut butterhead lettuce at higher temperature. There was a constant increase of CO_2 in glass jars packed with shredded cabbage.

Kader and Ben-Yehoushua (*19*) reported that high O_2 concentration atmospheres may either stimulate, have no effect or reduce the respiration rate and ethylene production, depending on the commodity, ripeness stage, storage time, temperature and concentration of CO_2 and ethylene in the atmosphere.

Shredded cabbage showed a higher respiration activity compared to intact cabbage leaves due to stress metabolism. Wounded tissue generally increases metabolic activity; Lakakul *et al.* (*20*) reported a 2–3 times higher respiration rate for apple slices compared to intact apple. Mechanical damage, *i.e.* bruising, cutting and insect attack, provokes increased respiration and ethylene production in many commodities (*21*). Fresh-cut cabbage samples stored in an atmosphere containing 70 % O_2/30 % N_2 showed higher respiration activity than other atmospheres. Gorny (*22*) found that high levels of O_2 in packages of fresh-cut spinach were beneficial in maintaining product quality. Allende *et al.* (*23*) found a high O_2 atmosphere beneficial regarding the sensory quality of fresh-cut spinach. High O_2 atmosphere treatment helped to maintain quality under extremely high CO_2 conditions (*24*).

Lower respiration activity was observed in cut cabbage previously rinsed with water compared to the non--rinsed cabbage (Fig. 5). We suspect that the reason is probably a partial or complete loss of nutrients and enzymes.

A decrease of O_2 below 3–5 % and an increase of CO_2 above 2–5 % in packed units resulted in the occurrence of anaerobic metabolism, which also depended on temperature, atmosphere composition, maturity and the overall physiological state of the commodity. Anaerobic metabolism resulted in the accumulation of acetaldehyde and ethanol within cabbage tissue.

Atmosphere composition considerably influenced the respiration rate of the stored cabbage. The atmosphere composition in MA packaged foods depends on the respiration intensity of the commodity and film permeability. PE and PP films have different permeabilities (Table 1) and thus influence the atmosphere composition of fresh-cut cabbage. Higher permeability of PE film compared to those of PP and glass enabled faster exchange of CO_2 and O_2 (Figs. 3 and 5), which resulted in a higher O_2 concentration and lower CO_2 concentration, and consequently lower accumulation of anaerobic metabolites.

Higher storage temperature accelerates the accumulation of anaerobic metabolites such as acetaldehyde and ethanol. Higher concentration of acetaldehyde and ethanol was found in cabbage tissue stored at 10 °C compared to 0 °C (Figs. 6 and 7). Due to the fact that acetaldehyde is an intermediate product, its concentration in cabbage tissue is much lower than that of ethanol, which is the final product of anaerobic metabolism. Regarding interaction effects of CO_2 and O_2 on the regulation of acetaldehyde and ethanol, Burdon *et al.* (*25*) reported similar accumulation of acetaldehyde in avocado fruit under 2–20 % CO_2 as stored under 0.1 % of O_2. CO_2 con-

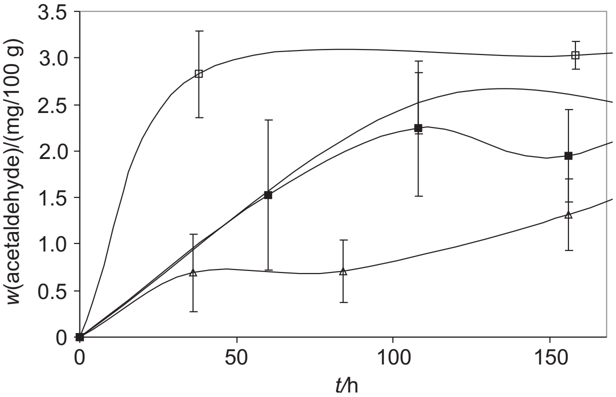

Fig. 6. Accumulation of acetaldehyde (mg/100 g) in fresh-cut cabbage tissue stored under different atmospheres at 0 and 10 °C in glass jars: (— 100 % N_2 (0 °C), △ NA (0 °C), ■ 70 % O_2/30 % N_2 (0 °C), □ 100 % N_2 (10 °C)). Vertical bars indicate means of three replicates±SD

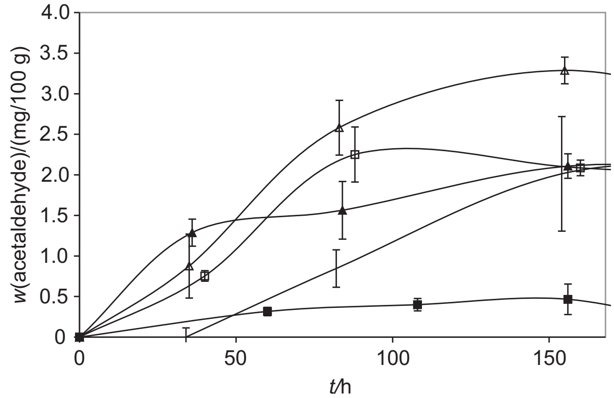

Fig. 8. Acetaldehyde accumulation in fresh-cut cabbage tissue stored at 0 °C as a consequence of different MA packaging, different film transmission rates and prepackaging treatment: △ 5 % O_2/95 % N_2 (PE), □ NA (PE), — 100 % O_2 (PE), ■ rinsed cabbage (NA, PE), ▲ NA (PP)). Vertical bars indicate means of three replicates±SD

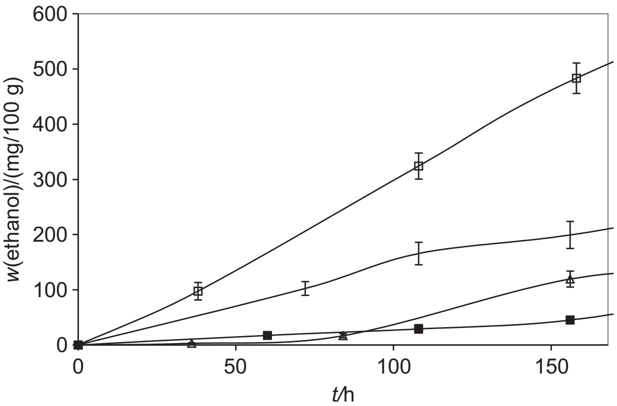

Fig. 7. Ethanol accumulation in fresh-cut cabbage tissue stored under different conditions in glass jars: (— 100 % N_2 (0 °C), △ NA (0 °C), ■ 70 % O_2/30 % N_2 (0 °C), □ 100 % N_2 (10 °C)). Vertical bars indicate means of three replicates±SD

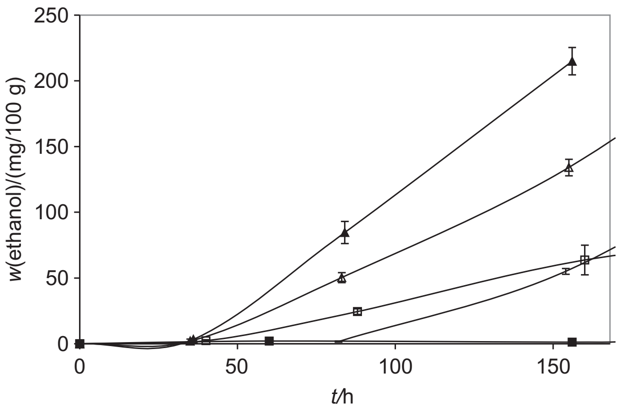

Fig. 9. Ethanol accumulation in fresh-cut cabbage tissue stored at 0 °C as a consequence of different MA, different film transmission rates and prepackaging treatment: △ 5 % O_2/95 % N_2 (PE), □ NA (PE), — 100 % O_2 (PE), ■ rinsed cabbage (NA, PE), ▲ NA (PP)). Vertical bars indicate means of three replicates±SD

centrations in the range of 1 to 5 % gave the largest effect on acetaldehyde. Bonghi *et al.* (*16*) found an additional effect of high CO_2 concentration (30 %) on the accumulation of acetaldehyde and ethanol in peach fruit. High CO_2 concentration has been shown to lower the pH of fruit tissue and thus provide conditions for fermentative metabolism (*26*).

The presence of anaerobic metabolites, especially acetaldehyde has negative influence on the sensorial properties of food in general. Cut cabbage stored in an initial atmosphere of 100 % O_2 at 0 °C exhibited an anaerobic metabolism approx. 36 hours later compared to other atmospheres employed. When a high O_2 concentration was applied as an initial storage atmosphere, both metabolites were detected in much lower concentrations than in the samples with other initial storage atmospheres after seven days of storage (Figs. 8 and 9). A high O_2 atmosphere is known to maintain better sensory properties as long as the atmospheric conditions do not induce fermentative metabolism. Ayala-Zavala *et al.* (*10*) demonstrated that the storage of strawberries under high O_2 concentration significantly affects aroma and phenolic compounds as well as overall quality.

As far as packaging film is concerned, more ethanol accumulated in the cabbage stored in an NA atmosphere in PP film bags (Fig. 9); the concentration of acetaldehyde was similar regardless of the type of film (Fig. 8). Anaerobic metabolism appeared first in the cabbage stored in PP bags. PP has lower permeability than PE and anaerobic metabolism appeared later in PE packed cabbage. Smyth *et al.* (*27*) used headspace ethanol measurement to estimate ethanol accumulation within packages of various stored fresh-cut vegetables. Ethanol concentration measurement represents a basis for dynamic atmosphere control for pome fruits and may reduce the risk of inferior or unsafe product supply to consumers. In our study the best storage conditions were achieved by packing the cut cabbage in PE film with an initial atmosphere of 100 % O_2 and storage temperature of 0 °C. PP film did not have sufficient O_2 transmission rates to maintain an adequate O_2 concentration in the packages and to preserve product quality. Low O_2 atmosphere and/or high CO_2 conditions are associated with off-flavours, which were also observed by Mateos *et al.* (*28*).

For that reason some fresh-cut vegetables are packed with perforated films.

As far as sensory evaluation is concerned, lower storage temperature (0 °C) always gave higher score compared to 10 °C. The highest score for sensory evaluation was achieved by packaging of cut cabbage in an initial atmosphere of 100 % O_2 in PE film at 0 °C, followed by cabbage stored under NA conditions in PE film at 0 °C (Table 2). The sensory score of the above mentioned high O_2 and NA conditions did not differ significantly ($p<0.05$). Under the same atmosphere and temperature conditions (NA, 0 °C), PE film gave better statistically significant score (Table 2). Higher permeability of packaging material influenced positively the sensory score, which is the most evident in case of PE film and impermeable glass jars. Combined storage conditions that include low temperature, initial high O_2 concentration and to some degree permeable packaging material contributed to higher sensory score.

Table 2. Sensory properties of fresh-cut cabbage stored under different temperature and atmosphere conditions. Data represent means of four panellists

	Texture (0–2)	Colour (0–4)	Smell (0–6)	Taste (0–8)	Total (0–20)
100 % O_2 PE, 0 °C	2.0^{a}	4.0^{a}	5.9^{a}	8.0^{a}	19.9^{a}
NA, PE, 0 °C	2.0^{a}	3.8^{a}	5.7^{ab}	7.9^{a}	19.4^{a}
NA, PP, 0 °C	2.0^{a}	3.9^{a}	5.1^{de}	7.6^{b}	18.6^{b}
washed, NA, PE, 0 °C	2.0^{a}	4.0^{a}	5.5^{bc}	7.0^{cd}	18.5^{bc}
NA, glass jar, 0 °C	2.0^{a}	4.0^{a}	5.1^{de}	7.2^{bc}	18.3^{bc}
5 % O_2, PE, 0 °C	2.0^{a}	3.7^{a}	5.4^{cd}	7.0^{cd}	18.1^{bc}
70 % O_2, glass jar, 0 °C	2.0^{a}	3.9^{a}	5.0^{e}	7.1^{c}	18.0^{c}
10 % O_2, glass jar, 0 °C	2.0^{a}	3.9^{a}	4.4^{f}	7.0^{cd}	17.3^{d}
NA, glass jar, 10 °C	2.0^{a}	3.7^{a}	3.9^{g}	6.2^{e}	15.8^{e}
70 % O_2, glass jar, 10 °C	2.0^{a}	2.9^{b}	3.5^{h}	6.7^{d}	15.1^{f}
100 % N_2, glass jar, 0 °C	1.5^{a}	2.6^{b}	4.4^{f}	5.6^{f}	14.1^{g}
100 % N_2, glass jar, 10 °C	0.7^{c}	2.1^{c}	2.5^{i}	4.1^{g}	9.5^{h}

Conclusions

Modified atmospheres containing high initial O_2 concentrations showed higher respiration activities compared to those with lower O_2 concentrations. A decrease of O_2 below 3–5 %, and an increase of CO_2 above 2–5 % in packed units resulted in the appearance of anaerobic metabolism. The intensity of anaerobic metabolism depends on the atmosphere composition in the package and film permeability. Unlike PP film, the PE film enabled O_2 in the headspace of packed cabbage to equilibrate between 2.0 and 3.0 %.

PE and PP films have different permeability and thus influenced differently the metabolic activity of fresh-cut cabbage. The best results were obtained by packing the cut cabbage in PE film with an initial atmosphere of 100 % O_2 and storage temperature of 0 °C. Higher permeability of packaging material, low storage temperature and high initial O_2 concentration also influenced positively the sensory score.

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