European Journal of Food Science and Technology
Vol.6, No.3, pp.9-23, August 2018
Published by European Centre for Research Training and Development UK (www.eajournals.org)

USE OF TEMPERATURE SENSITIVE FILM TO AVOID THE IMPACT OF TEMPERATURE FLUCTUATIONS ON MUSHROOMS (*AGARICUS BISPORUS*) MODIFIED ATMOSPHERE PACKAGES

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ABSTRACT: *A new generation of plastic film, who's the permeability increases drastically with a slight rise in temperature, were used to bulk the modified atmosphere packages of mushrooms (Agaricus bisporus cv. U3 sylvan 381) in order to prevent the lack of O_2 and the excessive accumulation of CO_2 caused by temperature fluctuations during transportation and storage. The use of thermal plastic film allowed the level of CO_2 in the modified atmosphere packages of the mushrooms (8-10%) during fluctuating period. According to the level of oxygen, this dropped from 5% to 2.6% during fluctuation from 4°C to 14°C. Final quality of mushrooms was improved by the use of a temperature sensitive film. This new film showed efficacy in preventing the accumulation of CO_2 and in compensating for the drop in O_2 in the modified atmosphere packages of mushrooms under temperature abuse conditions.*

KEYWORDS: Modified Atmosphere, temperature fluctuations, mushroom, permeability.

INTRODUCTION

Modified Atmosphere Packaging (MAP) is an efficient solution to maintain the quality of fresh fruit and vegetables and prolonging their self life as long as temperature is kept constant at the product optimum storage temperature (Tano *et al*., 1999; Tano *et al*., 2007; Shaarawi and Nagy, 2017; Liamnimitr *et al*., 2018). Most studies of modified atmosphere packaging design consider the storage temperature to be constant (Cameron *et al*., 1989; Lopez-Brionez *et al*., 1992; Giacalone and Chiabrando, 2013; Oliveira *et al*., 2015). These studies have shown that modifying the atmosphere surrounding the produce decrease the respiration metabolism slows down senescence and extend the self-life of fruit and vegetables (Exama *et al*., 1993; Cameron *et al*., 1994; Fante *et al*., 2014, Esmer and Melikoglu, 2016).

However, commercial use of modified atmosphere packaging has been limited because of the temperature fluctuations encountered in the cold chain during transportation and storage (Kader *et al*., 1989; Tano *et al*., 2007; Barrios *et al*., 2014). The fluctuations in temperature that occur in the cold chain during shipping and storage of fruit and vegetables can lead to an accumulation of CO_2 and a reduction of O_2 because of the disparity between the effect of temperature on the respiration rate of fruits and vegetables and on the permeability of the films used for modified packages design (Tano *et al*., 1999; Tano *et al*., 2007; Anurag *et al*., 2016). Beaudry *et al*. (1992) have shown that respiration in blueberries increases by a factor of 12 between 0°C and 25°C. At the same time, the permeability of the polyethylene film

ISSN 2056-5798(Print), ISSN 2056-5801(online)

increases only four times in the same temperature interval. Studies of Doyon *et al.* (1991) on the permeability of polyethylene film have shown that the Q_{10} for O_2 and CO_2 are 1.2 and 1.3, respectively between 0 and 10°C; 1.6 and 1.8 between 10 and 40°C.

Packaging with perforations system or made of micro-porous membrane, the increase in the permeability to gas as a function of temperature is slight, and this significant difference between the increased respiration of products and the permeability leads to the risk of anaerobic conditions within the packaging (Nanos *et al*., 1994; Church and Parsons, 1995; Tano *et al*., 1999; Tano *et al*., 2007, Anurag *et al*., 2016). The accumulation of CO_2 damages the cell membrane, modifies glycolysis and therefore causes physiological disorders. Further, the lack of O_2 slows down the transfer of electrons leads to the accumulation of acids. To control the pH of the tissue, anaerobic respiration is stimulated by producing acetaldehyde and ethanol (Knee and Hatfield, 1981; Lougheed, 1987; Rahman *et al*., 1995; Pesis *et al*., 2002). The accumulation of acetaldehyde and ethanol also damages the cell membrane and produces off-odours.

This problem may be solved by using, in the design of packaging, plastic films with a Q^{p}_{10} value close to the Q^{R}_{10} value of the product's respiration. Q^{p}_{10} and Q^{R}_{10} are the factors by which the film permeability and fruit respiration are multiplied for a temperature increase of 10°C. Another possibility would be to design packaging with valves that would open when the temperature increased and close when the optimal temperature for storage was restored in order to compensate the lack of O_2 and the accumulation of CO_2 in the packages (Cameron *et al*., 1993; Beaudry, 2000). Studies in this field have led to a new generation of polymers whose permeability increases drastically with only a slight increase in temperature. The permeability of the film increases with temperature above a critical temperature called the transition temperature. At temperatures below the transition temperature, permeability is very slight, but above this temperature, permeability increases drastically.

The objective of this study is to use the temperature sensitive film to compensate the lack of O_2 and the accumulation of CO_2 caused by temperature fluctuations that encounter in the cold chain during transportation and storage of mushrooms. At the end of the storage period, the quality of this product will be assessed and compared to the quality of products packaged with the commonly materials.

MATERIELS AND METHODS

Fruit and vegetables and storage conditions

Fresh flush mushrooms (*Agaricus bisporus* cv. U3 sylvan 381) at stage 2 of development were picked from a local farm of Quebec City region, Canada and held for 12 h at produce optimum temperature of 4°C before packaging. They were then sorted and packaged in various containers. These mushrooms (750g) were packaged in 4-liters Plexiglas containers fitted with diffusion windows for gas exchange.

The experiment consisted to five treatments. The first treatment consisted to three packages without temperature sensitive film stored at the optimum storage temperature of the products (4°C). The second treatment consisted to the same type of package but submitted to temperature abuse conditions (4 to 14°C). The third and fourth treatments consisted to the

ISSN 2056-5798(Print), ISSN 2056-5801(online)

packages with temperature sensitive film stored at storage optimum temperature (4^{o}C) and submitted to temperature fluctuation conditions (4 to 14^{o}C). The last treatment was the packages stored in open containers (4-liters) exposed to an appropriate temperature of the product and relative humidity of 90%, served as the control group.

For simulating the fluctuation conditions, the packages was stored at temperatures of 4°C and 14°C for two days alternatively and the sequence was repeated 3 times during the 12-days storage period.

The window for package without thermal film provided O_2 flux rate of $5.58x10^{-12}$ $mol.s^{-1}.pa^{-1}$ and CO_2 flux rate of $13.55x10^{-12}$ $mol.s^{-1}.pa^{-1}$ at 4°C. The flux rates for O_2 and CO_2 at 14°C were $5.75x10^{-12}$ $mol.s^{-1}.pa^{-1}$ and $14.48x10^{-12}$ $mol.s^{-1}.pa^{-1}$ respectively.

With the O_2 and CO_2 flux rates, steady - state modified atmosphere of 5% O_2 and 9.5% CO_2 was obtained in packages at 4°C.

The thermal valve used in this study has selectivity (PCO_2/PO_2) of 4.8 and did not vary with temperature. The temperature quotient (Q^{p}_{10}) varied between 3.2 and 4.0 for CO_2 and O_2 and the transition temperature was 10^{o}C.

Package atmosphere

The temperature of the atmosphere inside the packages was monitored using type T thermocouple probes (POD-237/236, Omega Engineering, Stamford, CT, USA) and datalogger (Model RR2-1200-2, Rustrak Ranger II, Automatic RP Inc., Quebec City, Canada). CO_2 and O_2 concentrations inside the packages was monitored as a function of time by gas chromatography (Perkin Elmer, Model 8500) using a thermal conductivity detector. Gas samples of 1 ml were drawn using polypropylene syringes through a septum from each package. The measurements were carried out in triplicate.

Fermentation products

Acetaldehyde and ethanol production in the plant tissue was measured by head- space gas chromatographic analysis. A sample of ten mushrooms and 2g of ground sample was placed in a sealed tube which was placed in a head space sampler (Hewlett Packard, Model 19395A), maintained at 90°C. After 20 minutes the vapour accumulated in the headspace was immediately analysed by gas chromatography (Hewlett Packard, Model 5890A), using a capillary column (DB-225, 30 m; 0.25 mm diameter; film thickness, 0.50 µm). The volume of the headspace gas injected in the gas chromatography (GC) was 1ml. The temperatures of the injector and the detector were 155°C and 250°C respectively. The temperature programming used was: initial temperature, 35°C for 4 min; final temperature, 75°C and heating rate, 20°C/minutes. The measurements were carried out in triplicate for each treatment.

Quality attributes

Color

Product color was evaluated, using a Tristimulus (Colorguard System 1000/05, Pacific Scientific Co., Md., U.S.A.), calibrated using white and black plates. Only the values of the

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brightness value (L) and Hunter "a" values (- green to + red) were used to evaluate product color. The measurement was made directly on mushrooms surface three times on each of ten fruits for each treatment. A mean of ten randomly selected fruit was used for each treatment.

Texture, weight loss, maturity stage and infection

Mushrooms texture was evaluated by measuring the firmness on Instron Testing machine (Model 1101, Instron Corp., Wash., U.S.A). Their stems were placed in the central opening of the metal holding plate and a 3/16 in metal plunger was applied on the mushroom cap at a speed of 10 mm/min with a chart speed of 10 min/ minute.

The firmness was the average obtained for ten randomly selected mushroom from each treatment and was expressed as the ratio of the applied force to deformation, in Newton/mm.

Weight loss was also determined during the storage by monitoring the weight of the contents of the package before and after storage period. Weight loss was expressed as the percentage of the loss of weight with respect to the initial weight and was determined in triplicate.

Mushrooms maturity (development stage) was assessed using a scale of 1 to 7, with 1 = veil intact and 7 = gill surface curving upwards (Hammond and Nichols, 1975).

The severity of bacterial blotch disease was assessed using a rating of 1 to 4, with 1 = no bacterial blotch and 4 = above 25% of the mushrooms cap area with symptoms of blotch diseases (Wong and Preece, 1982). Mushrooms maturity and the severity of bacterial blotch diseases were assessed using ten randomly selected mushrooms form each treatment.

Statistical analysis

The experiment was repeated twice. Since there was no significant difference between the 2 experiments, the results were pooled and averaged. Data on lightness (L), redness (a), weight loss, ethanol and acetaldehyde levels were submitted to an analysis of variance, followed by Neuwman-Keul's multiple comparison test (alpha = 0.05).

RESULTS

Package atmosphere

The temperature inside mushrooms subjected to both constant and fluctuating temperature conditions are shown in Figure 1. When the ambient temperature was increased from 4°C to 14°C for mushrooms, the package temperature equilibrated to the ambient temperature over a period of 10 hour.

ISSN 2056-5798(Print), ISSN 2056-5801(online)

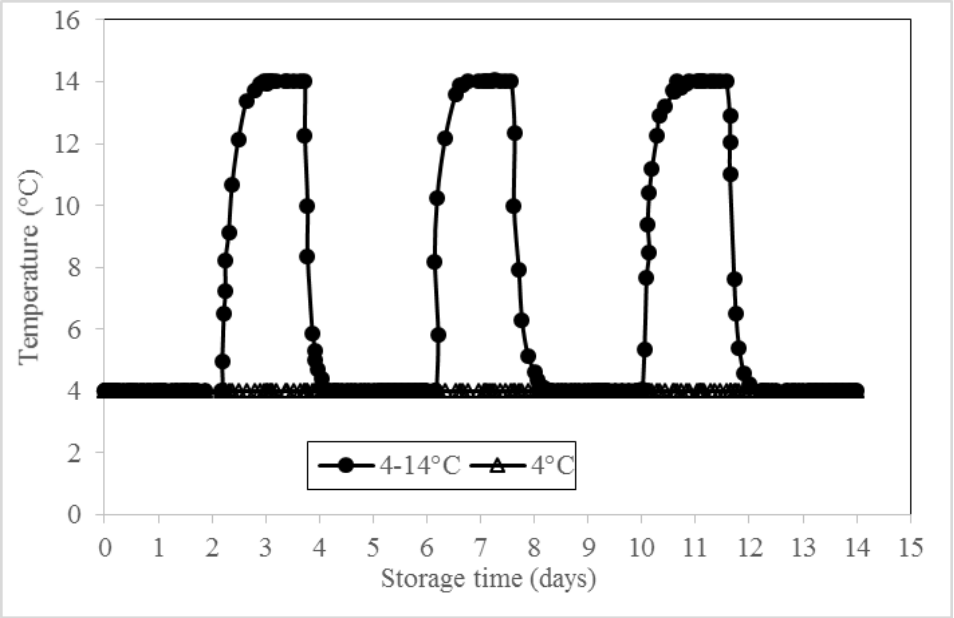

Figure 1 : changes in temperature levels inside mushroom packages at constant temperature (4°C) and under temperature fluctuating conditions (4-14°C)

Throughout the 12 days storage period, the atmosphere inside these packages, kept at constant temperature of 4°C, remained stable at the previous steady-state O_2 and CO_2 levels (Figure 2).

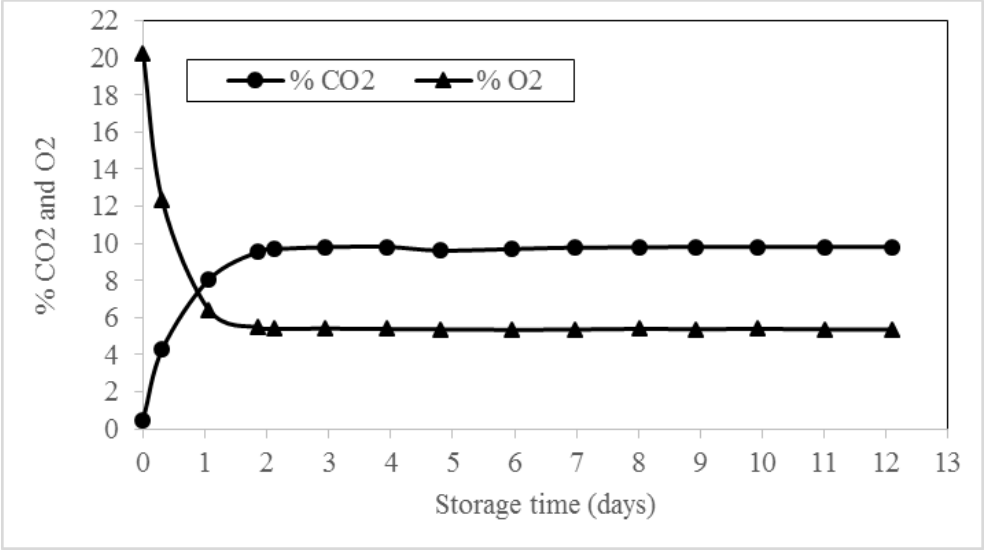

Figure 2 : changes in oxygen and carbon dioxide levels inside mushroom packages stored at constant temperature (4°C)

ISSN 2056-5798(Print), ISSN 2056-5801(online)

In the packages with and without the thermal film and submitted under temperature fluctuation conditions, the steady states were reached after 30 hour (5.4%O_2 and 8.1%CO_2) of storage (Figure 3).

However under temperature fluctuation conditions, the O_2 concentration in the packages without thermal film decreased more rapidly than those in the packages with temperature sensitive film. In the same way, the CO_2 concentration increased more quickly in the packages without thermal film (Fig. 3). In the packages without the thermal film subjected to temperature fluctuation, during a temperature increase from 4°C to 14°C in the first fluctuation cycle, the CO_2 concentration increase rapidly, reaching 13 and 16.5% after 12 hour and 24 hour respectively, while the O_2 concentration fell to 3.0 and 1.5% after 12 hour and 24 hour respectively. When the temperature was lowered to 4°C after the first two-day period at 14°C, the CO_2 concentration decreased to 11.0%, whereas the O_2 concentration increased to 3.8%.

During the temperature increase of the next fluctuation cycle, CO_2 level rose again to 14% but did not reach the previous level of 16%, while O_2 level fell again to 1.2%. Carbon dioxide levels in the mushroom packages subjected to temperature changes followed the temperature changes, but the maximum CO_2 accumulation attenuated with each subsequent cycle, whereas the O_2 concentration stayed nearly the same at 1.2% regardless of temperature changes since the second temperature fluctuation cycle.

In the temperature sensitive film packages, the O_2 concentration dropped from 5.4% to 2.6%, while the CO_2 concentration rose from 8% to 10% during the first temperature fluctuating cycle (4°C to 14°C). When the temperature was lowered to 4°C after two days at 14°C, CO_2 and O_2 returned to the previous levels of 8% and 5%, respectively. During the two following temperature fluctuations, in the thermal film packages, CO_2 concentration remains always close to the optimal concentrations of 8 to 10% whereas O_2 concentrations fell but remains over of the critical value at which the anaerobic respiration was initiated.

ISSN 2056-5798(Print), ISSN 2056-5801(online)

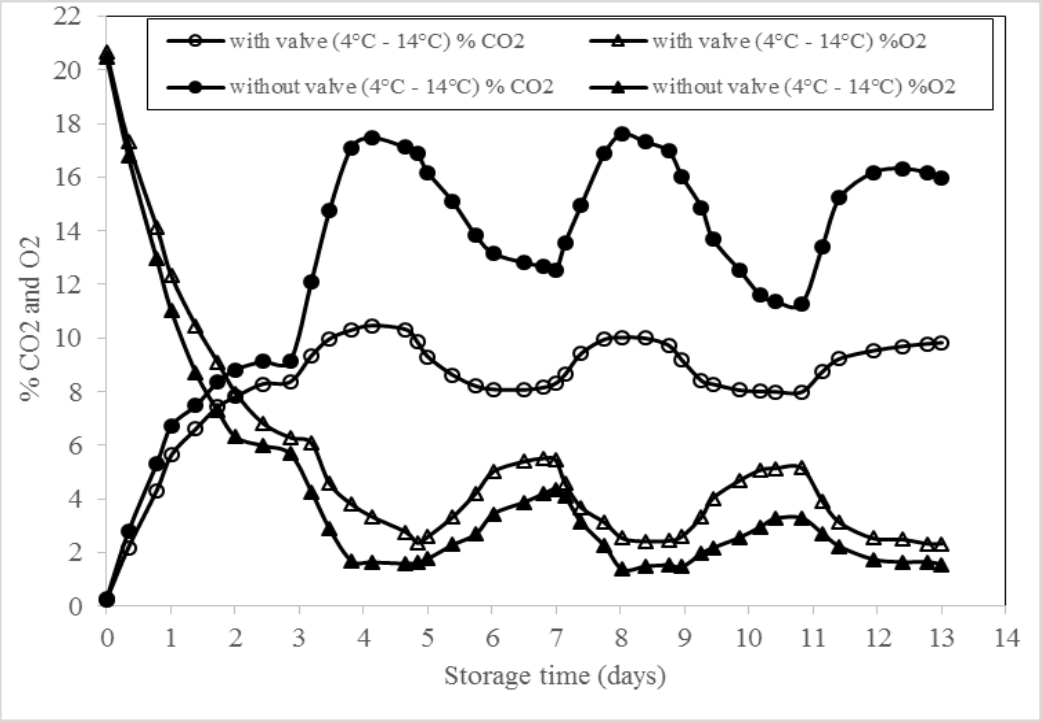

Figure 3 : changes in oxygen and carbon dioxide levels inside mushroom packages stored under temperature fluctuating conditions (4-14°C)

Acetaldehyde and ethanol production

Ethanol and acetaldehyde concentrations in the tissue packaged stored at the optimum temperature and those stored in air at the same temperature showed significant differences after the different period of storage. In the same way, significant differences appeared when these packages were submitted to temperature abuse conditions (Table 1).

With the conventional film and subjected to temperature fluctuating from 4°C to 14°C after twelve days, ethanol and acetaldehyde concentrations were 387.5 ppm and 9.1 ppm respectively. However, in packages with temperature sensitive film under fluctuating conditions, ethanol and acetaldehyde concentrations reached 178.4 ppm and 8.2 ppm (Table 1). Ethanol concentrations in non sensitive temperature packages submitted to temperature abuse conditions were 2.1-fold higher than those in thermal packages, 12.8-fold higher than modified atmosphere at constant temperature and 24.4-fold than in air at optimum storage temperature. The accumulation of ethanol was significantly ($p<0.05$) higher than that of acetaldehyde (Table 1). Furthermore, ethanol was the major product of anaerobic respiration of mushrooms under all storage conditions.

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Table 1 : quality attributes of mushrooms stored at constant temperature (4°C), under temperature fluctuating conditions in MA packages with and without valve and at air storage after 12 days storage

Quality attributes	Storage conditions				LSD à 5%
	4°C (Air)	4°C (AM)	4-14°C (without valve)	4-14°C (with valve)	
Color and appearance					
Lightness (L)	72,6±1,8	76,1±2,1	69,3±2,2	74,6±1,6	1,9
Redness (a)	4,2±0,29	1,9±0,27	4,0±0,25	3,1±0,23	0,3
Bacterial blotch index	4,0±0,1	2,9±0,05	3,8±0,1	3,3±0,1	0,1
Development stage	5,8±0,09	3,7±0,07	5,0±0,1	4,3±0,1	0,1
Texture					
Firmness (N/mm)	1,5±0,13	4,9±0,21	2,4±0,10	3,2±0,12	0,2
Weight loss (%)	15,9±0,3	2,0±0,10	2,9±0,09	2,8±0,11	0,1
Anaérobie					
Ethanol (mg/kg)	15,9±0,6	30,2±2,8	387,5±4,1	178,4±0,9	3,9
Acetaldehyde (mg/kg)	6,9±0,2	7,5±1,1	9,1±0,8	8,2±0,6	0,9

Quality attributes

Colour

Lightness (L) and the redness (a component of color) were used to compare the colour of mushrooms. Significant differences ($p<0.05$) were obtained between packages without thermal film (4°C to 14°C), with thermal film (4°C to 14°C), modified atmosphere packages stored at a constant temperature (4°C) and in air (4°C) (Table 1). At a constant temperature (4°C), the lightness values were 76.1 in modified atmosphere packages. The lightness were 72.6 and 69.3 for in air storage at a constant temperature and in modified atmosphere packages without thermal film and submitted to temperature fluctuations conditions, respectively (Table 1).

Firmness and weight loss

Table 1 showed the firmness of mushrooms. After 12 days of storage under temperature fluctuating conditions, the firmness of the mushrooms packed in temperature sensitive film was firmer (3.2 N/m) than those wrapped without thermal film (2.4 N/m). Mushroom firmness remained higher when the packages were stored at a constant temperature (4.9). With air storage at a constant temperature of 4°C, firmness decreased significantly from 4.9 to 1.5 N/mm at the end of the 12 days storage period

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Wight loss remained the same for both (with valve: 2.8%; without valve: 2.9%) (Table 1). In these conditions, weight loss was considerable. Mushrooms lost 15.9% of their initial weight (Table 1).

Under modified atmosphere (MA) storage at a constant temperature and with the two types of packages, mushrooms lost only 2% of their initial weight, while loses reached 2.9% and 2.8% without and with temperature sensitive film, respectively and submitted to temperature fluctuations conditions (4°C to 14°C).

Developmental stage of mushrooms

At a constant temperature of 4°C, the development stage of mushrooms stored in modified atmosphere packages was 3.7 after 12 days storage (Table 1). The developmental stages reached 5 and 4.3 in modified atmosphere storage under temperature fluctuations conditions without and with thermal film, respectively. Use of the temperature sensitive films improved the quality of the mushrooms when there were fluctuations in temperature.

Infection

After 12 days of storage, the bacterial infection index indicated that above 25% of the mushroom cap area had symptoms of blotch diseases for mushroom packaged in no thermal film and submitted to temperature abuse conditions (4°C to 14°C) (Table 1). With the thermal film submitted to temperature fluctuating conditions, the index showed that less 25% of the mushroom cap area had bacterial symptoms. No significant difference ($p>0.05$) was observed between unpackaged groups stored at constant temperature and no thermal film packaged groups subjected to temperature fluctuations.

DISCUSSION

Package atmosphere

At the constant temperature (4°C), the use MA packages was able to create and maintain the optimum atmospheres in the mushrooms packages. The changes in CO_2 and O_2 concentrations in MA packages and the time required to reach the optimal concentrations depend on the gas flux rates within the packaging materiel, the respiration rate of the products and the package void volume.

Establishing an optimum atmosphere in MA packages depends on the rate of product respiration and the permeability of CO_2 and O_2 films (Kader, 1989; Tano *et al*., 2007; Liamnimitr *et al*., 2018), both affected by temperature. However, the increase of respiration rate as function of temperature described the Qr10 is generally substantially greater than the increase of permeability of usually packaging material (Qp10) (Beaudry *et al*., 1992; Exama *et al*., 1993; Cameron *et al*., 1994; Tano *et al*., 2007). At a constant temperature, packaging allowed the optimal atmosphere for preserving the product studied to be created and maintained.

The rapid variation in concentrations of CO_2 and O_2 in the valveless packages, compared to those with valves, before the steady state was due to the additional permeability furnished by

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the valve. The decrease in the concentration of O_2, the increase in the concentration of CO_2 and the time required to reach the steady state depend on the available permeability of the packaging material (Renault *et al*., 1994; Giacalone and Chiabrando, 2013). Maintaining optimal concentrations of CO_2 and O_2 in packages submitted to fluctuations in temperature requires that the activation energy of the permeability of the film used be equal to that of the product's respiration in the interval of temperature variation under consideration (Beaudry *et al*., 1992; Cameron *et al*., 1994; Lee *et al*., 2014).

The low value for energy activation and the Q^p_{10} of the permeability of the films commonly used leads to a lack of O_2 and an accumulation of CO_2 in valveless packages submitted to fluctuations in temperature (Beaudry *et al*., 1992; Exama *et al*., 1993; Cameron *et al*., 1994).

CO_2 and O_2 levels during temperature fluctuations depend on the effect that the temperature has on the respiratory metabolism of the product. The level of CO_2 in the packages of mushrooms, with or without valve, is high because mushrooms have a great Q^r_{10}. The membrane used as a valve has a Q^p_{10} greater than some fruits and vegetables between 5°C and 15°C. However, using the membrane as a valve installed with a film having a very low Q^p_{10} reduces the final Q^p_{10} of the package. This would explain the slight change in concentrations of CO_2 and O_2 in the packages with valves. Adding the valve allowed the concentration of CO_2 to be maintained close to the optimum for mushrooms (Kim *et al*., 1976; Bhowmik and Pan, 1992).

For mushrooms, the level of O_2 in the packages with valves remained higher than that of valveless packages, but lower than the optimal level recommended for preservation (>5%) (Burton *et al*., 1987; Lopez-Brones *et al*., 1992; Lee *et al*., 2014).

The required selectivity of the product is very important in maintaining the optimal atmosphere. Mushrooms with a required selectivity of 1.6 in modified atmosphere require a large amount of the other film with a selectivity of 1 in order to create and maintain the optimal atmosphere at a constant temperature. This greatly reduces the Q^p_{10} resulting from mushroom packaging and causes a reduction in O_2 concentrations during fluctuations in temperature.

Products of fermentation

Compared to valveless packages, production of ethanol and acetaldehyde in the tissues of the various products stored in packages with valves decreased by over 50%. The transition from aerobic respiration to anaerobic respiration depends on the level of oxygen within the package. In valveless packages, the concentration of O_2 dropped below 2.0% to 1.5% during the increases in temperature. For those with valves, the level of O_2 approached 3%, which explains the reduced production of ethanol and acetaldehyde in the tissues of products stored in packages with valves, as compared to those without valves.

However, there is a significant difference between ethanol and acetaldehyde production in packages stored at a constant temperature and in packages with valves submitted to temperature fluctuations: this is due to the reduction in O_2 concentrations in valveless packages, but also to the effect of the temperature itself, because the level of O_2 at which anaerobic respiration is initiated increased with temperature (Beaudry *et al*., 1992; Joles *et al*., 1993).

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Similarly, the exposure time of the product to low concentrations of O_2 also affects ethanol and acetaldehyde production (Saltveit and Sharaf, 1992). In packages with valves, the decrease in concentration of O_2 from 5% to 2.7% lasts only as long as the product is kept at a high temperature. As soon as the package returns to the optimal temperature, O_2 also returns to its optimal level. In packages without valves, as soon as the temperature fluctuates, the level of O_2 no longer returns to its optimal level.

In general, exposure of products under anaerobic conditions for a short time does not cause any permanent physiological disorders. In fact, it has been shown that ethanol can be beneficial under certain conditions (Saltveit and Sharaf, 1992). Ethanol can vaporize or be metabolised if the atmosphere returns to its optimal level (Saltveit and Ballinger, 1983). In mushrooms for example, after the second increase in temperature, the level of O_2 in the valveless packages remained at 1.5% even when the temperature was restored to its optimal level of 4°C.

Attributes of quality

The concentration of CO_2 in modified atmosphere packaging is a key factor in maintaining the quality of the product. A high concentration of CO_2 leads to the browning of mushrooms (Nichols and Hammond, 1973; Burton *et al*., 1987; Ban *et al*., 2014), which eventually lead to the development of microorganisms.

Maintaining the optimal concentration of CO_2 within the package with valve reduced all these problems related to high concentrations of CO_2 considerably.

In the packages of mushrooms with valve, during the three fluctuations in temperature, the level of O_2 drops below the critical level for anaerobic respiration. When the temperature returns to the optimal, the level of O_2 returns to its optimal level. This keeps the mushrooms firmer than those stored in packages without valves. Mushroom metabolism was not damaged by these changes. Use of the valve reduced the effects of the temperature fluctuations in packages under modified atmosphere, and improved the quality of the resulting products.

In modified atmosphere packages with temperature sensitive film, the reflectance was 74.6 up to 70 which is considered an acceptable value for the color of mushrooms (Gormley, 1975; Lopez–Brones *et al.*, 1992). Mushrooms in packages stored at constant temperature had the lowest redness value (positive of color), where a high "a" value is associated with browning. Mushrooms from air storage at constant temperature, and modified atmosphere storage under temperature abuse conditions had lower lightness and higher redness values and were browner, expected the thermal film packages subjected to fluctuating temperature conditions.

Under these gas compositions, both packaging materials were able to minimize weight loss and maintain fruit quality attributes. These results are in accordance with those obtained on pomegranate by other authors (Laribi *et al*., 2012; Shaarawi and Nagy, 2017). Wang and Sugar (2013) reported same findings on 'Bartlett' pears stored up to 4 months. Kader (1995) recommended for the storage of pomegranate a gas composition of 3% to 5% for O2 and 5% to 10% for CO2, at 5 °C. Soltani *et al*. (2015) affirm that, in passive MAP respiration rate of crop, the permeability of the packaging film are the most important parameters.

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CONCLUSION

This study examined the effects of fluctuations in temperature on the atmosphere within packaging under modified atmosphere. Temperature fluctuations that occur in the cold chain during transportation and storage lead to an accumulation of CO_2 and a lack of O_2, which affect product quality. Use of a new generation of polymers whose permeability increases drastically with a slight rise in temperature as a valve in packages under modified atmosphere maintained the concentrations of CO_2 for the mushrooms.

The concentration of O_2 dropped below the optimal level, but remained above the level of O_2 in packages without the valve. Similarly, use of the valve improved the quality of the mushrooms significantly. Therefore, use of the membrane prolongs the shelf life of mushrooms, even if there are temperature fluctuations to the package under modified atmosphere.

The new valve membrane shows that it is possible to compensate for variations in CO_2 and O_2 concentrations in packages under MA submitted to temperature fluctuations. Further research into the chemistry of the polymers is necessary to improve this new membrane. This research should look at improving the selectivity of the valve to take better advantage of its high Q^{p}_{10}, its high permeability and its high activation energy.

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