Can Tho University Journal of Science
website: sj.ctu.edu.vn

PREDICTIVE CONTROLLED-ATMOSPHERE-MODEL FOR THE OPENING OF CAPS AND SENSORY QUALITY OF FRESH MUSHROOMS (*Agaricus bisporus*)

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ARTICLE INFO

Received date: 03/08/2015
Accepted date: 26/11/2015

KEYWORDS

Mushroom, controlled atmosphere, sensory quality, opening of cap

ABSTRACT

Fresh mushrooms (Agaricus bisporus) have a short shelf-life. The effects of O_2 and CO_2 concentrations and of storage temperature on the opening of caps and the sensory quality were studied. Eight different gaseous atmospheres were set up with combinations of O_2 concentrations (3, 12, 16.5 and 21%) and CO_2 concentrations (0, 3, 6 and 12%). The storage temperatures for each gas condition were 1, 6 and 12°C. The opening of caps and the sensory quality were modelled on the basis of a generalized logits model. As results, the various O_2 and CO_2 concentrations did not give any effect on the quality of mushrooms stored at temperatures below 6°C up to 9 days. Different temperatures were the greatest influence on the opening of the caps, and decreasing the sensory quality. At temperature of 12°C, a gas combination of 12% O_2 and 6% CO_2 provided the best conditions but the shelf-life was less than 7 days.

Cited as: Que, P.T.T, Verlinden, B. And Nicolaï, B., 2015. Predictive controlled-atmosphere-model for the opening of caps and sensory quality of fresh mushrooms *(Agaricus bisporus)*. Can Tho University Journal of Science. 1: 89-95.

1 INTRODUCTION

In modern life, consumers prefer more and more fresh fruits and vegetables, which provide indispensable substances (vitamins, fiber, etc) to the body. Mushrooms provide daily important elements for human via diet. However, mushroom is a produce with a short shelf-life. Biochemical and physiological characteristics of this mushroom are easily changed after picking, and are detrimental to the commercial quality of the commodity. The quality becomes unacceptable for consumers after 3 days of storage at 18^{o}C. A way to prolong the shelf-life in supermarkets is to cool the mushrooms down to 8°C. Controlled atmosphere storage plays an important role in maintaining the organoleptic quality parameters of mushrooms at an acceptable level. Optimization of temperature and humidity conditions, O_2 and CO_2 concentrations can be used to reduce quality losses during storage of the fresh produce. However, the relative concentrations of O_2 and CO_2 at the different temperatures of storage play hereby a key role.

There is little published focusing on the optimum controlled atmosphere (CA) conditions to increase the shelf-life of mushrooms. Sveine *et al.* (1967) investigated the storage life of mushrooms, reported that high CO_2, low O_2 and low temperature prevented cap opening. In addition, Murr and Morris (1975) reported that browning was slowed down due to tyrosinase inhibition by high CO_2 levels. Another study by Lopez - Briones *et al.* (1992)

suggested that storage atmospheres should contain 2.5% to 5% CO_2 and 5% to 10% O_2.

To define quality, a set of instrumental and sensory quality attributes must be selected. Consumers rarely choose fruits and vegetables according to their nutritional value. On the contrary, their choices are strongly influenced by sensorial and price considerations. Thus, colour and general appearance of mushrooms strongly influence the decisions of buyers. Colour and the opening of caps were chosen as the most proper parameters for sensory quality. The design of controlled atmosphere for mushrooms requires an adequate model for the prediction of quality changes as a function of both temperature and gas combination. The main model objective of this study was to define an optimal gas concentration and to develop a predictive controlled atmosphere model for the opening of caps and sensory quality of fresh mushrooms. The opening of caps and sensory quality were modelled on the basis of a generalized logits model.

2 MATERIALS AND METHODS

2.1 Sample

Cultivated mushrooms (*Agaricus bisporus*) were bought from a local grower in Leuven, Belgium as fresh mushrooms. Immediately after transport, the mushrooms were sorted for sizes and appearance then kept in a cool room at 1°C before using them in the experiments. Diseased, damaged, open veiled and extremely large (cap diameter > 40mm) or small mushrooms (cap diameter < 25mm) were discarded.

2.2 Experimental design and procedure

In order to study the effect of O_2 and CO_2 concentrations at the different storage temperatures, thirty mushrooms were put in jars in which a controlled atmosphere was established by flushing a certain gas mixture through them.

The jars with the samples were connected to one of the gas mixtures with different concentrations of O_2 (%), CO_2 (%); the gaseous nitrogen was employed as a "balance gas" to make up the required volume in a gas mixture. Eight different gas combinations (21% O_2 + 0% CO_2; 12% O_2 + 0% CO_2; 3% O_2 + 0% CO_2; 16.5% O_2 + 3% CO_2; 21% O_2 + 6% CO_2; 12% O_2 + 6% CO_2; 3% O_2 + 12% CO_2 and 21% O_2 + 12% CO_2) were used and each combination was carried out at three different temperatures: 1°C, 6°C and 12°C. The arrangement of the experiment in the storage room is illustrated in Figure 1.

The gas mixture was first introduced in the jar (1). This jar was filled with water so as to create the required equilibrium relative humidity in the gas mixture in order to avoid shriveling and (or) drying of the mushrooms. The mushrooms in jars (2), (3) and (4) were used to evaluate the variation in the opening of caps and sensory quality during storage. Since we did not know the effect of humidity on the quality of the mushrooms and the extent of which humidity would affect the quality of the mushrooms, a temperature-humidity logger was placed in the second last jar (5) to monitor both the temperature and humidity of the gas flow. At the end of the series, another jar (6) was filled with water to act as an air lock in order to avoid air from coming into the jars in case of a shutdown and also to help in detecting a problem in the gas flow during the experiment by visually checking the bubbling.

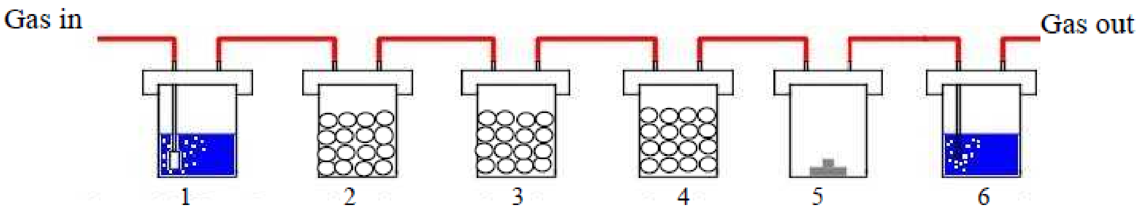

Fig. 1: Arrangement of the experiment in storage room

2.3 Measurement of quality characteristics

2.3.1 Development stage

The development stage was assigned to mushrooms based on the extent of cap opening on a 4 point scale as described by Burton *et al.* (1987) and as shown in Table 1.

Table 1: Classification of development stage (class)

Stage	Description	Illustration
0	Button	
1	Stretched veil	
2	Broken veil	
3	Open veil	

2.3.2 Sensory quality

Fresh mushrooms were taken randomly to evaluate the sensory quality on day 0, 2, 4, 7, 9 and 11 days of storage, 30 mushrooms out of each gas combination at the given temperatures were taken from 3 jars and placed in a test box; 15 test boxes of each day storage were evaluated. The sensory quality (colour, opening gills) of controlled atmospheres mushrooms was evaluated over a period of 11 days by an untrained taste panel consisting of 15 persons. A numerical score 1 (= acceptable) and 0 (unacceptable) was given for each property to describe the sensory quality of mushrooms. All sensorial tests were performed in a cool room at 1°C.

2.4 Statistical analysis

Statistical Analysis Systems, version 6.11 (SAS Institute, Inc., Cary, NC, USA) and Matlab software (The Mathworks Inc., Natick, Massachusetts) were used to compare effect of O_2 and CO_2 concentrations and the temperatures of storage on the development stage and sensory quality. The data with respect to the opening of caps and the sensory quality were analysed by a logistic regression. Logistic regression is a statistical method used to analyse binary and binomial response data. It is based on the construction of a statistical model describing the relationship between the observed response and explanatory variables, also called independent variables (Hosmer and Lemeshow, 1989; Collett, 1991). The dependency of the probability that the event occurs (opening, acceptability) on explanatory variables is modelled as follows:

$$logit(p_i) = \log\text{-}odds = \ln\left(\frac{p_i}{1-p_i}\right) = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots\ldots + \beta_j x_{ij} \quad (1)$$

A batch is a set of mushrooms with the same values x_{ij}, for the set of j explanatory variables (e.g. 12% O_2, 6% CO_2, 1°C, 7 days of storage, etc.); i and j indicate the number of the batch and the number of the explanatory variable, respectively; p_i is the probability defined by the proportion of the events occurring in batch i (opening, acceptability), and α is an intercept parameter. The β_1 to β_j parameter relates to the first to the jth explanatory variable; it describes the importance of the explanatory variable.

To study the hypothesis that the quality change (opening of caps, sensory quality) is followed in time by the effect of controlled atmosphere conditions and storage temperature, a generalized logits model needs to be fitted. The logit model is a linear model in the log-odds. It can also be transformed as non-linear model of the probabilities

$$p_i = \frac{1}{1+\exp\left(-\alpha - \beta_1 x_{i1} - \beta_{i2} - \ldots\ldots - \beta_j x_{ij}\right)} \quad (2)$$

A coding system was described to evaluate the quality of mushrooms. Opening gills (quality characteristic) or unacceptability (sensory quality) was coded as 1; button or acceptability was coded as 0. The probability of those events is always ∈ [0, 1].

3 RESULTS

3.1 Model for opening of caps

For mushrooms stored at 1°C and 6°C cap development was not observed during storage, whereas for mushrooms stored at a temperature of 12°C, the rate of cap development was rapid and reached maximum of open veil after a short time of storage. It was relative to the model at a temperature of 12°C was analysed. Beside O_2 concentration and

CO_2 concentration, storage time was also correlated with the incidence of cap opening.

By fitting the generalized logits model (Equation 2) on the experimental data, the model parameters were estimated and summarised in Table 2. The model was tested for its predictive quality for the eight different gas combinations shown in Figure 2. During the storage period of 12 days with CO_2 concentration had significant effects on the occurrence of cap opening. The probability for opening of the caps increased with decreasing CO_2 concentration and with increasing storage time. However, the strength of this relation depended on the O_2 concentration. At high O_2 concentration (21%), a decrease in CO_2 always corresponded to more opening, while high O_2 and high CO_2 concentrations prevented opening. However, this effect was more pronounced at low CO_2 concentration (0%) and long storage times. For example, the opening of veil was not observed for the gas combination 21% O_2+12% CO_2 after a long time of storage, as the model predicts, while for all simulations under 0% CO_2 maximum open veil was reached at day seven.

Table 2: Estimates for the model parameters, opening gills, of mushrooms at 12°C

Explanatory variables	Model parameters	Estimate	95% Confidence intervals	
Intercept	α	-3.081	-3.370	-2.792
Time (days)	β_1	1.057	0.915	1.198
O_2 (%)*time (days)	β_2	0.011	0.002	0.020
CO_2 (%)*time (days)	β_3	-0.068	-0.082	-0.055
O_2 (%)*CO_2 (%)*time (days)	β_4	-0.0044	-0.0058	-0.0031

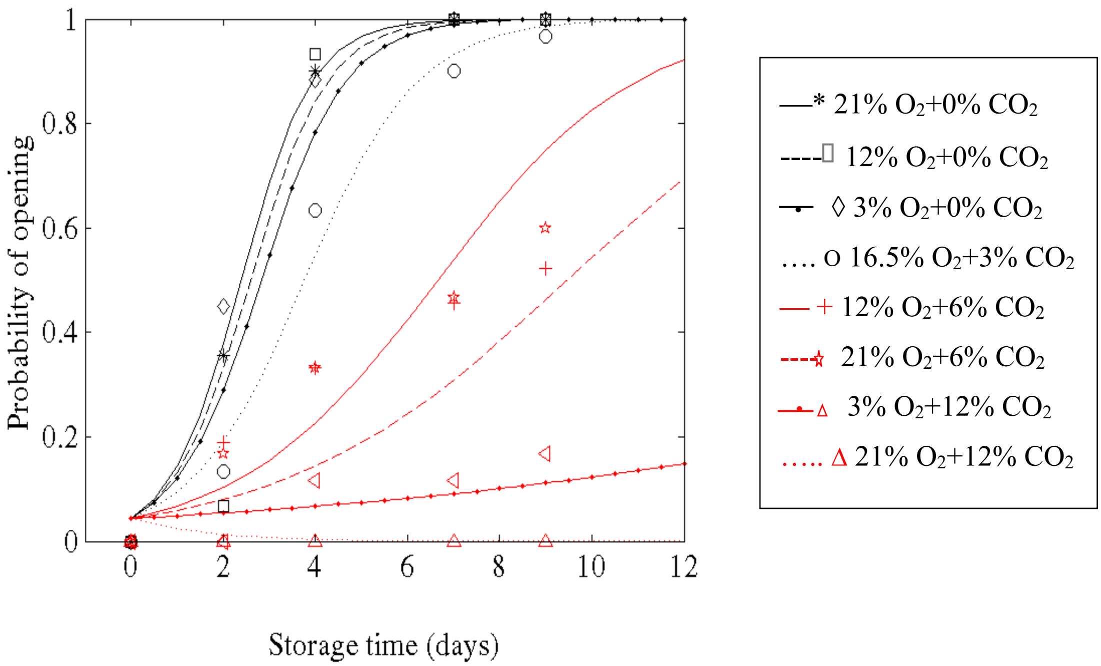

Fig. 2: The probability of opening gills of mushrooms at 12°C, plotted against storage time, at eight different gas concentrations of O_2 and CO_2. The symbols denote the means of the experimental observations. The model solution is shown by the lines

3.2 Models for sensory quality

By fitting the generalized logits model (Equation 2) on the experimental data, the model parameters were estimated and summarized in Table 3.

Figure 3 shows the fitted model together with the experimental data of consumer acceptability as a function of storage time. The symbols denote the acceptability of 15 consumer's panel. The solution of the model calculations is shown by the lines in the graph. The acceptability by consumers decreased with increasing storage temperature. The maximum in the 'unacceptability' parameter was reached at low CO_2 concentrations (0% and 3%) after 7 days of storage at 12°C. At 1°C, the sensory quality of mushrooms started to decrease after 11 days, independently of the gas combinations.

Table 3: Estimate for the model parameters of sensory quality of mushrooms

Explanatory variables	Model parameters	Estimate	95% Confidence intervals	
Intercept	α	15.71	13.40	18.02
O_2 (%)	β_1	-0.086	-0.144	-0.027
Time (days)	β_2	-0.867	-0.987	-0.748
Temperature (°C)	β_3	-0.9641	-1.1161	-0.8122
O_2 (%)*CO_2 (%)	β_4	-0.0160	-0.0281	-0.0040
O_2 (%)*CO_2 (%)*Temperature	β_5	0.0031	0.0017	0.0045

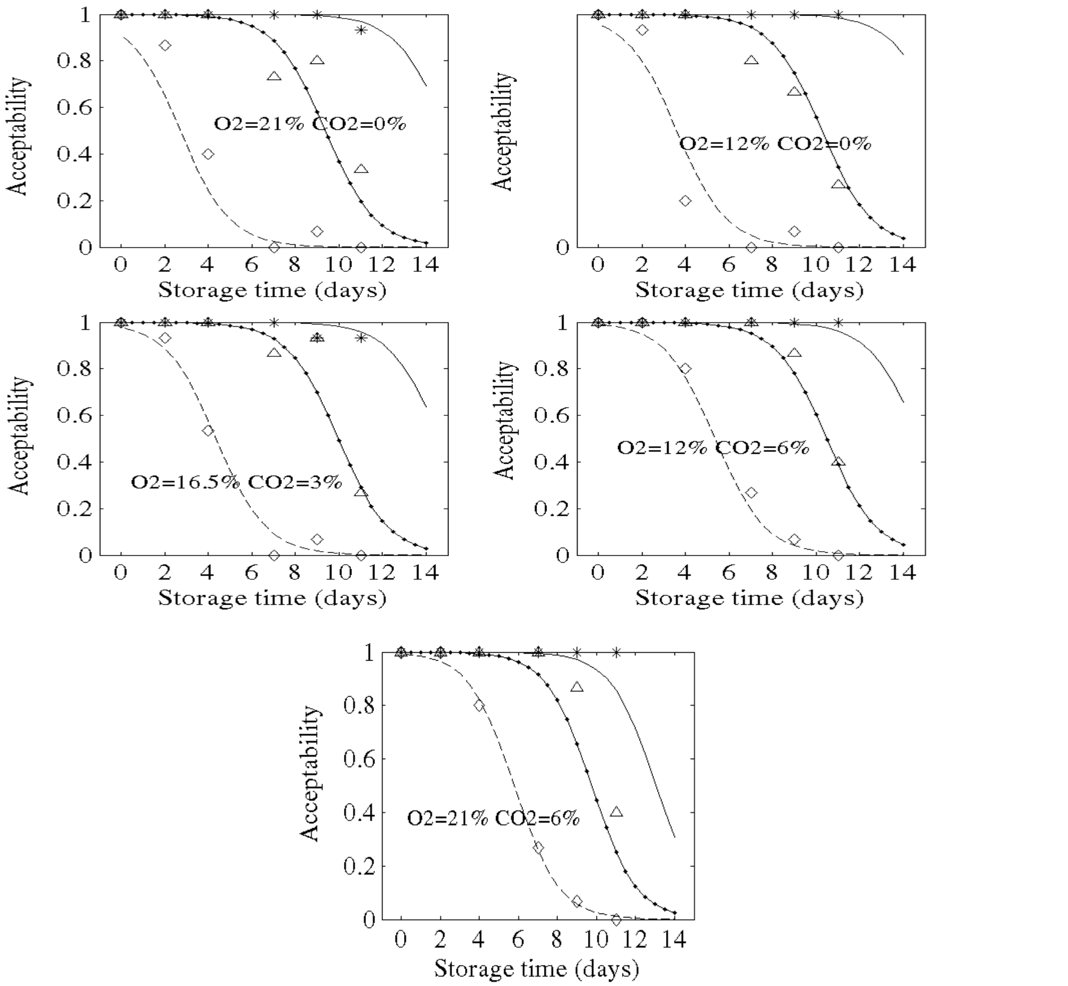

Fig. 3: The sensory quality of mushrooms expressed as 'acceptability' by consumers plotted against storage time at temperature of 1°C (—*), 6°C (-•—Δ) and 12°C (---- ◊) for the five different gas combinations

4 DISCUSSION

From the results of modelling and the experimental data in Figure 2, it can be deduced that the effect of O_2 concentration on the rate of cap opening is negligible. However, storing mushroom in such low O_2 concentrations could create a favorable micro-atmosphere at the center of mushrooms for growth and toxic production by anaerobic spore formers and therefore this is not recommended. Increasing the CO_2 concentration did slow down the rate of cap opening. These results confirm the findings of Burton *et al.* (1987) showing that CO_2 exhibits a marked effect on mushroom development stage. In the present study, mushrooms stored for 9 days at 12°C under 12% CO_2 did not break their veil, whereas for mushrooms stored under 0% CO_2 the opening of caps was reached 100% at the same number of storage day. Lopez-Briones *et al.* (1992) reported also retardation in cap development of mushrooms stored at 10°C in chamber at 15% CO_2, and the effect was not influenced by the O_2 in the chamber. However, they pointed out that CO_2 concentrations below 5% seemed to exhibit phytotoxicity as shown by increased respiration rate at the end of storage in high CO_2. Therefore, the effect of reduced cap development due to high CO_2 might be a physiological response to CO_2 stress rather than regulatory action of CO_2 in mushroom morphogenesis (Lopez-Briones *et al.*, 1992). The kinetics also confirmed that the higher the CO_2 concentration the slower the opening of the cap. So, CO_2 concentration in the market storing of mushrooms should be maintained at the highest level compatible with the preservation of whiteness.

Mushrooms are highly perishable crops and there is a need to store them properly to have a prolonged shelf-life. In order to know the exact concentrations of O_2 and CO_2 needs to have optimal storage conditions, the storage time expressed as shelf-life was calculated on the basis of Equation 1. The shelf-life of mushrooms was different under different storage conditions. For example at temperatures below 6°C and 21% O_2 and 0% CO_2 (air) mushrooms were marketable for about 9 to 15 days, but at 12°C for the same controlled atmosphere conditions, shelf-life was reduced to less than 3 days. The limit of shelf-life was derived from an acceptability test by consumers. Acceptability was fixed at a value of 0.5. A value above 0.5 was considered as an acceptable sample.

Figure 3 shows the good relationship between the experimental data and the logistic regression model. In all five cases, the model was able to predict the overall trend of the acceptability. In gas combination of 21% O_2 and 0% CO_2, the predicted and experimental data did not fit well. It is possible that the untrained evaluation panel caused part of this problem.

In order to maintain the sensory quality for a long time under controlled atmosphere, mushrooms should be stored at temperatures below 6°C. At higher temperatures, CO_2 concentration must be maintained at the highest level compatible with the preservation of whiteness. Tomkin (1966) stressed that the beneficial effect of modified atmosphere depends on temperature control and this statement was confirmed by Sveine *et al.* (1967). Ryall and Lipton (1979) proposed controlled atmosphere storage of mushrooms at temperatures should not higher than 10°C.

Table 4: Estimate of acceptability for colour level by consumers with probability 0.5

O_2 (%)	CO_2 (%)	Temperature (°C)	Model prediction shelf-life of mushroom
21	0	1	14.93
		6	9.37
		12	2.69
12	0	1	15.82
		6	10.26
		12	3.59
3	0	1	16.71
		6	11.15
		12	4.48
16.5	3	1	15.37
		6	9.81
		12	3.14
12	6	1	14.75
		6	10.47
		12	5.35
21	6	1	13.05
		6	9.74
		12	5.77
3	12	1	16.18
		6	11.26
		12	5.36
21	12	1	11.18
		6	10.12
		12	8.86

In general, the effect of O_2 concentration on the quality was less pronounced as compared to the effect of CO_2 and temperature. Temperature was the variable with the greatest influence on sensorial quality and the effect of gas composition was found to increase with temperature. This stresses the importance of refrigeration and suggests that the use of modified atmosphere packaging is more important when mushrooms are handled at temperatures above optimum temperature. High CO_2 concentrations caused an increase in enzymatic browning and tissue injury. Higher temperatures accelerate browning discoloration, development stage, and weight loss and decrease consumer acceptability. In contrast, the results of this study have demonstrated that high CO_2 concentrations prevent the opening of the caps.

5 CONCLUSIONS

Subjecting mushrooms to controlled atmosphere storage at temperatures of 1°C, 6°C and 12°C can lead to a deterioration of quality. Under the conditions studied, the quality change was not the same. From the prediction models for an appropriate controlled atmosphere for mushrooms it can be concluded that, at temperatures < 6°C and within the range of O_2 and CO_2 concentrations studied, there was no effect on quality during storage up to 9 days. At high storage temperature (12°C), the effect of O_2 and CO_2 atmospheres on quality was much more pronounced. However the shelf-life of mushrooms stored at 12°C under the best gaseous conditions was still shorter than those stored under normal air at low temperature. Therefore, the extension of the shelf-life of mushroom cannot be reached through modified atmosphere packaging at high temperature (12°C).

ACKNOWLEDGEMENTS

The authors would like to thank the Flemish Inter-university Council (VLIR) for providing the financial support.

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