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Influence of Temperature on Respiration Rate of Shiitake Mushrooms under Air and 15% O_2

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ABSTRACT

Modified atmosphere packaging could be a useful technique for extending the shelf life of shiitake mushrooms (*Lentinus edodes*). The design of modified atmosphere packaging requires information about the produce's respiration rate. In this work, the influence of temperature on O_2 consumption and CO_2 production rate of shiitake mushrooms under air and 15% O_2 were studied. Respiration rate values of shiitake mushrooms under air were higher (105.4 mL CO_2 kg^{-1} h^{-1} at 5°C) than those encountered in the literature for other mushroom species, suggesting that they might be particularly perishable. The respiration quotient was independent of both temperature and gas composition within the range of those variables that were tested, and near to one in all cases. Mushrooms showed a significantly lower respiration rate under 15% O_2 than under air at 1, 5 and 10°C. On the other hand, calculated activation energies were equivalent to Q10 values of approximately 3 between 5 and 15°C.

Keywords: *Lentinus edodes*, modified atmosphere packaging

INTRODUCTION

Shiitake (*Lentinus edodes*) is the second most widely cultivated mushroom, surpassed only by *Agaricus* spp. (Boa 2004). Due to its high nutritional and medical value (Lindequist *et al*. 2005; Ares *et al.* 2007), it has a big potential market.

The shelf life of a mushroom is mainly determined by its metabolic activity. Since mushrooms are rapidly respiring and highly perishable, prolonging postharvest storage while preserving their quality would benefit the mushroom industry as well as the final consumer market. Refrigeration and modified atmosphere packaging (MAP) are commonly used techniques for extending fresh-cut product shelf life (Schlimme and Rooney 1997; Farber *et al.* 2003; Ares *et al.* 2007). The design of a MAP packaging requires knowing the influence of storage temperature and gas composition on respiration rate (Solomos 1997; Fonseca *et al.* 2002a).

Temperature has been identified as the most important external factor influencing respiration (Fonseca *et al.* 2002a). Biological reactions generally increase two or three-fold for every 10°C rise in temperature within the range of temperatures normally encountered in the distribution and marketing chain (Zagory and Kader 1988; Fonseca *et al.* 2002a). At higher temperatures, enzymatic denaturation may occur and reduce respiration rates. If temperatures are too low, physiological injury may occur, which may lead to an increase in respiration rate (Fidler and North 1967). No studies have been found reporting the relationship between respiration rate and storage temperature for shiitake mushrooms.

The aim of the present work was to analyze the influence of temperature on respiration rate of shiitake mushrooms under air and an atmosphere containing 15% O_2.

MATERIALS AND METHODS

Produce

Shiitake mushrooms (*Lentinus edodes*) cultivated on logs, grown on a commercial farm in Artigas, Uruguay, were acquired. Mushrooms were harvested on early June (late Autumn) during the first time of the day (5-7 a.m.). Within 24 hours after harvest, mushrooms were transported refrigerated at 5 ± 1°C to the School of Engineering in Montevideo, Uruguay.

Respiration rate measurement

A closed system was chosen to measure O_2 consumption and CO_2 production rates of the product. Approximately 70 g of mushrooms were held in 2.5 L airtight stainless steel jars. The jars were stored at 1, 5, 10 and 15°C in a cold room and were flushed with humidified ambient air or a gas mixture containing 15% O_2 for fifteen minutes before measurements. The gas flow was then halted and the gas stream inlet and outlet closed. A septum fixed on the lid allowed sampling of the atmosphere within the jar. Samples of 1 ml were withdrawn from the jars each 45 minutes, up to 5 hours. Two replicates were performed for each set of conditions. As CO_2 and O_2 concentrations correlated linearly with time during the first hours of the experiments (R^2 higher than 0.94, data not shown), respiration rate (expressed as CO_2 production rate, R_{CO2}, or O_2 consumption rate, R_{O2}) was calculated as the slope of the CO_2 or O_2 concentration *vs* time curve.

Gas concentration analysis

The gas samples were analyzed with a gas chromatograph (Shimadzu GC-14B) equipped with an Alltech CTR1 column and a thermal conductivity detector. The gas carrier was Helium at a flow rate of 40 ml/min and the temperature of the injector, column and the detector was set at 60ºC. Using calibration standards, a ± 0.04 % (v/v) and ± 0.05 % (v/v) error was estimated in the CO_2 and O_2 measurements respectively.

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Short Communication

Data analysis

Analysis of variance was performed on the data obtained considering temperature, atmosphere and their interaction as variation factors.

The influence of temperature on respiration rate was modelled using the Arrhenius model:

$$\text{Respiration rate} = A_0.\exp\left(\frac{E_A}{R.T}\right)$$

The model's constants were estimated by fitting the model to experimental data by non-linear regression.

Statistical analyses were performed using Genstat Discovery Edition 2 (VSN International, London, UK)

RESULTS AND DISCUSSION

O_2 consumption rates and CO_2 production rates under air and an atmosphere containing 15% O_2 are shown in **Table 1**. As shown in this table, respiration rate values under air were higher than those encountered in the literature for other mushroom species (Varoquax *et al.* 1999; Villaescusa and Gil 2003), suggesting that they might be particularly perishable. Respiration rate of shiitake mushrooms under air at 10ºC was nearly 5 times higher than for *Agaricus bisporus* at 10°C (19.8 mL O_2 kg^{-1} h^{-1}) (Varoquax *et al.* 1999), whereas respiration rate at 5°C was twice the respiration rate of *Pleurotus* spp. at 4°C (22 mL CO_2 kg^{-1} s^{-1}) (Villaescusa and Gil 2003). The high respiration rate values encountered suggest that the use of highly permeable films would be necessary for modified atmosphere packaging of shiitake mushrooms, in order to avoid anaerobic conditions inside packages.

The respiratory quotient (ratio of CO_2 production and O_2 consumption rates) were near 1 for the four evaluated temperatures, as shown in **Table 1**. These values are within the range of those reported in literature regarding aerobic respiration (Fonseca *et al.* 2002a). This result was expected due to the high O_2 atmospheric composition. Moreover, RQ showed no dependence of temperature in the range considered.

Analysis of variance showed that respiration rate under air was significantly higher than respiration rate under 15% O_2 at 1, 5 and 10°C. No significant difference was found at 15°C. Thus, the influence of oxygen concentration seems to depend on the storage temperature. As shown in **Table 1**, the influence of decreasing oxygen concentration from 21 to 15% was much lower than the effect of storage temperature. This is in agreement with results from Kader (1987) and Fonseca *et al.* (2002b).

Respiration rate increased significantly ($p<0.001$) with an increase in temperature (**Table 1**). Respiration rate (expressed as oxygen consumption rate) under air at 5°C was 1.6 times lower than at 10°C and 2.3 times lower than at 15°C, suggesting that temperature might have a great influence in shelf life of shiitake mushrooms. The increase in respiration rate with temperature was modelled using the Arrhenius equation. Model gave a good fit (R^2=0.98) for both O_2 consumption rate and CO_2 production rate. Activation energies for O_2 consumption and CO_2 production were calculated and are shown in **Table 2**. Estimated activation energies are higher than that reported by Varoquax *et al.* (1999) for *Agaricus* mushrooms under air (43.4 kJ/mol), suggesting that respiration rate of shiitake mushrooms would be more dependent of temperature. For both air and 15% O_2, activation energies for O_2 consumption and CO_2 production were similar, suggesting that both were affected in a similar way by temperature, in agreement with the lack of influence of temperature on RQ. These activation energies are equivalent to Q_{10} values of approximately 3 between 5 and 15°C. Other studies report Q_{10} values of 3-4 for other vegetables such as apple (Lakakul *et al.* 1999), shredded cabbage (McLaughlin and O'Beirne 1999), *Pleurotus* mushrooms (Villaescusa and Gil 2003), *Agaricus* mushrooms (Exama *et al.* 1993), eggplant, asparagus and broccoli (Uchino *et al.* 2004). Therefore, respiration rate of shiitake mushrooms might be similarly affected by temperature as in other vegetables. These Q_{10} values show that even mild temperature abuse might cause a major increase in respiration rate, which could lead to a decrease in O_2 concentration and an increase in CO_2 concentration within packages. This could result in unfavorable atmosphere compositions which could lead to physiological damages, the development of anaerobic conditions or an increase in deterioration rate. In order to avoid this phenomenon films with similar dependence of permeability with temperature should be used.

Activation energies under 15% O_2 were slightly higher than those under air, suggesting that the influence of temperature on respiration rate depend on atmosphere composition.

Table 1 Respiration rate (O_2 consumption and CO_2 production rate) and RQ under air and 15% O_2 at 1, 5, 10 and 15°C for shiitake mushrooms.

Atmosphere	Temperature (°C)	O_2 consumption rate ($mL.kg^{-1}.h^{-1}$)	CO_2 production rate ($mL.kg^{-1}.h^{-1}$)	RQ
Air	1	43.3	33.0	0.76
	5	69.8	54.6	0.78
	10	112.7	105.4	0.94
	15	157.6	134.8	0.86
15% O_2	1	33.4	19.5	0.58
	5	55.4	46.8	0.84
	10	86.5	85.8	0.99
	15	171.5	138.8	0.81

Table 2 Activation energies (E) and Q_{10} between 5 and 15°C for respiration rate of shiitake mushrooms under air and 15% O_2

Atmosphere	E_{O2} (kJ/mol)	Q_{10} for O_2 consumption rate	E_{CO2} (kJ/mol)	Q_{10} for CO_2 production rate
Air	60.6	2.3	67.9	2.5
15% O_2	74.7	2.8	90.0	3.4

CONCLUSIONS

The respiration rate of shiitake mushrooms was higher than values encountered in literature for other mushroom species. This suggests that the films with high permeability for modified atmosphere packaging would be necessary in order to avoid anaerobic conditions. The respiration quotient was independent of both temperature and gas composition within the range of those variables that were tested, and nearly one in all cases.

Respiration rate increased significantly with an increase in temperature and the initial respiration rates followed the Arrhenius equation. Calculated activation energies were equivalent to Q_{10} values of approximately 3 between 5 and 15°C.

A further study is necessary to study the influence of O_2 and CO_2 concentrations on the respiration rate of shiitake mushrooms in order to properly design modified atmosphere packaging of this produce.

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