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Postharvest Biology and Technology 41 (2006) 56–61
Postharvest Biology and Technology
www.elsevier.com/locate/postharvbio

Prediction of sugar consumption in shredded cabbage using a respiratory model

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Received 17 October 2005; accepted 20 February 2006

Abstract

The relationship between respiration and sugar consumption of shredded cabbage was examined. Respiration rate (RR) of shredded cabbage was determined at 5 °C for 96 h and 20 °C for 48 h, and total CO_2 production estimated by integrating RR. Glucose, fructose and sucrose of shredded cabbage were also determined, and total sugar obtained as the sum of these sugars. The decrease in total sugar with time at both temperatures was recorded. Total CO_2 production was calculated from the decrease in total sugar, which was assumed to be caused by oxidation of sugar in a respiratory reaction. Experiments were carried out twice. Total CO_2 production obtained by integrating RRs was approximately equal to that calculated from the decrease in total sugar. Accordingly, it was confirmed that CO_2 emitted from shredded cabbage was mostly derived from sugar.

To predict sugar consumption, a previously developed respiratory model was applied. The model could sufficiently predict RRs of shredded cabbage at varying temperatures (15 → 25 → 15 °C). Therefore, the decrease in total sugar was predicted from total CO_2 production, obtained using the respiratory model. In addition, the predicted total sugar content agreed well with experimentally determined values. Therefore, it was considered that sugar consumption of shredded cabbage could be predicted by applying the respiratory model.

Keywords: Respiration rate; Sugar; Shredded cabbage; Temperature

1. Introduction

Consumption of fresh-cut vegetables has increased over the past decade, with eating habits being determined by time-saving, convenience and waste reduction (Jacxsens et al., 1999; Kim et al., 2005a,b). Consumers require fresh-cut produce not only to be convenient and attractive, but also to be of high quality in terms of taste and/or nutritional value. In contrast to other foods, active metabolism of fresh produce is on-going, which is related to postharvest quality loss. Fresh-cut produce are more perishable than intact vegetables because they have been subjected to severe physical stress, such as cutting, slicing, peeling, shredding, trimming, coring or removal of protective epidermal cells (Guerzoni et al., 1996; Watada et al., 1996; Roura et al., 2000). This stress causes an acceleration in physiological breakdown and shortened shelf-life (Bolin et al., 1977). Accordingly, maintenance of quality is especially important for fresh-cut produce.

Respiration is one of the main factors accelerating quality loss of fresh-cut produce because respiratory substrates, such as sugars and/or acids, are consumed in the respiratory reaction. The physical stresses mentioned above cause increased respiration rates (RR) in fresh-cut produce. Kim et al. (2004) indicated that both white and violet fresh-cut salad savoy had higher RRs than intact savoy. Similar results have been reported for bamboo shoots, kohlrabi and kiwifruit (Watada et al., 1990; Escalona et al., 2003; Lu and Xu, 2004). It is important to reduce the high RR of fresh-cut produce during distribution and short-term storage. Temperature is the principal environmental factor affecting the RR of fresh-cut pro-

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doi:10.1016/j.postharvbio.2006.02.008

duce (Hong and Kim, 2001). Although a cold-chain has been developed in many countries, constant low temperatures cannot be assured in the actual distribution chains (Brecht et al., 2003). For example, a rapid temperature increase can occur on transfer from temperature-controlled vehicles to ambient conditions during unloading at the distributors (Jacxsens et al., 2002). Respiratory models, which include the effect of temperature, have proven valuable in predicting the RR of fresh-cut produce during distribution and storage. Jacxsens et al. (2000) expressed the RR of 10 types of fresh-cut produce as functions of temperature, O_2 and CO_2. Uchino et al. (2004) developed a respiratory model with functions of temperature and time. Respiratory models are effective in predicting the RR of fresh-cut produce in many situations where time–temperature conditions are known. However, few studies have examined the relationship between respiration and consumption of respiratory substrates, although quality loss is known to be related to respiration. Lu and Xu (2004) considered that the initial decrease in reducing sugars of bamboo shoots during storage at 4 °C was due to consumption for respiration. Bolin and Huxsoll (1991) suggested that the decrease in soluble solids of cut lettuce was caused by carbohydrate utilization via respiration. If the relationship between respiration and consumption of the substrates is quantitatively clarified, quality loss of fresh-cut produce could be quantitatively predicted by using respiratory models.

In this study, the RR and sugar levels of shredded cabbage were determined during short-term storage at two temperatures. Assuming that sugar is the main substrate used in the respiratory reaction of shredded cabbage, the quantitative relationship between respiration and decrease in sugar was examined. Moreover, it was verified that sugar consumption could be predicted using the respiratory model. The results of this study could supply useful data to estimate the quality loss of shredded cabbage by applying respiratory models.

2. Materials and methods

2.1. Materials

Cabbage (*Brassica oleracea var. capitata* cv. Teruyoshi) was obtained from a wholesale market in Fukuoka city, Japan. It was shredded by hand (about 3 mm shred width), then 170 g was packed in a respiratory chamber which was used for a flow-through system to determine RR according to Uchino et al. (2004), while another 170 g sample was enclosed in a sample chamber for measuring sugars. An impermeable polymeric laminated film package (Kureha Chemical Industry), made of OPP (oriented polypropylene), acrylic-coat film and LLDP (linear low density polyethylene), was used as the respiratory and sample chamber, which was then placed in an incubator. Experiments were carried out at low temperature (5 °C) and room temperature (20 °C). The shredded cabbage was kept in storage for 96 and 48 h at 5 and 20 °C, respectively.

2.2. Measurement of RR

The RR was measured by a flow-through method according to Uchino et al. (2004) with hourly measurements for 6 h after the start of experimentation, then at 12 h intervals thereafter. The flow rate of air was 0.5 l min^{-1} depending on the temperature. The RR was expressed as the CO_2 production rate which was the mean of two experiments, and standard deviations are given. Total CO_2 production (CP_R) was obtained by integrating RRs.

2.3. Measurement of sugars

Total sugar contained in shredded cabbage was determined every 12 h at 20 °C, and daily measurements were carried out at 5 °C according to Hu et al. (2002). For measurement of sugars, three samples of 5 g of shredded cabbage were removed from the sample chamber. Each 5 g was homogenized with 20 ml of 75% acetonitrile and the suspensions filtered. Glucose, fructose, and sucrose contents were determined by HPLC (Shimadzu Co., Tokyo, Japan; LC10-AD, and detector: RID-10A, column: Shodex Asahipak NH2P). The column temperature was kept at 45 °C; 75% acetonitrile was used as mobile phase; flow rate was 1.0 ml min^{-1}. Total sugar content was the sum of these sugars. Total sugar content was converted to reducing sugar content: sucrose was regarded as being reduced to monosaccharide. Experiments at each temperature condition were performed twice and data are represented as the means of two experiments with standard deviations. An assumption was made that the decrease in sugars of shredded cabbage was caused only by oxidation for respiration. Total CO_2 production (CP_S) was calculated from the consumption of monosaccharides, following reaction (1):

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad (1)$$

2.4. Prediction of sugar consumption using the respiratory model

In this study, the respiratory model, developed by Uchino et al. (2004), was applied to calculate RR. The model is represented as Eq. (2):

$$R_c = K_1 \exp\left(\frac{-E_a}{RT}\right)\{1 + K_2 \exp(-k_d t)\} \quad (2)$$

where K_1 and K_2 are parameters in mmol kg^{-1} h^{-1} and dimensionless, respectively. E_a is the apparent activation energy (J mol^{-1}), k_d the rate constant for decomposition of enzyme (h^{-1}), R the ideal gas constant (J mol^{-1} K^{-1}), and T is the absolute temperature (K).

Shredded cabbage was kept in storage for 36 h at varying temperatures (15 → 25 → 15 °C). The experimental values