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Improved postharvest quality and respiratory activity of straw mushroom (*Volvariella volvacea*) with ultrasound treatment and controlled relative humidity

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ABSTRACT

The present study proposed a synergistic method to extend the postharvest quality of straw mushroom (*Volvariella volvacea*) by controlling the conditions of ultrasound treatment and relative humidity (RH). Results showed that 10-min ultrasound treatment combined with storage at 95% RH prolonged the postharvest quality of straw mushroom from 24 h or 48 h to 72 h. The appearance of straw mushroom was maximally kept with original odor, minimum weight loss of 28.83%, malonaldehyde (MDA) content of 5.06 nmol g^{-1}, and higher total soluble sugar (TSS) of 28.32 g kg^{-1} and total soluble protein (TSP) of 30.27 g kg^{-1}. The ultrasound treatment also inhibited the browning and respiratory rates *via* inactivating the browning-related PPO activity to 236.52 U g^{-1}, and PGI to 0.038 U g^{-1}, SDH to 3.62 U mg^{-1} Pro, CCO to 9.29 U mg^{-1} Pro and G-6-PDH/6-PGDH to 69.87 μmol NADP g^{-1} min^{-1} activities of involved in respiratory pathways after 72 h of storage. Our results suggest that ultrasonic treatment with the control of relative humidity could potentially reduce the quality deterioration of straw mushroom.

1. Introduction

The straw mushroom (*Volvariella volvacea*) is a typical tropical/subtropical species of edible mushrooms presenting highly tasty and nutritional values with an estimated annual production of 330,000 tons in China occupying over 80% of global production (Cai et al., 1999; Bao et al., 2013). The straw mushroom grows at the relatively high temperatures (28–35 °C) and high moisture contents (80–90% relative humidity) for 4–5 week of vegetative growth and fruiting (Yen, 1992), and is harvested at the button or egg phase (Chang and Yau, 1971). However, fresh straw mushroom button rapidly loses its general quality and marketability within 48 h due to the chilling damage and fruit body autolysis at below 10 °C or high levels of respiration rate, metabolic activity and water content at over 25 °C (Chang and William, 2013). Hence, increase of straw mushroom shelf-life to benefit its long-distance distribution is still an urgent problem and extremely difficult issue to be dissolved. However, only few methods, such as combination of $CaCl_2$ (0.5%) treatment with 40-perforation packages, have been proposed to extend the shelf life of paddy straw mushroom up to 6 d with acceptable contents of total phenolic, antioxidants and protein, and total bacterial counts (Dhalsamant et al., 2015).

Mushroom shelf-life is closely related to its respiration rate during postharvest period, which metabolizing the nutrients such as carbohydrates, proteins and fats in the fruiting bodies with O_2 to simple end products such as organic acid or CO_2, which results in the mushroom ripening and senescence (Cliffe-Byrnes and O'Beirne, 2007). Generally, the maturity stage at harvest, ageing (time), temperature, gas composition, and cutting (mechanical damages) are the main internal and external factors affecting the respiration rate of fresh products. Therefore, methods such as modified atmosphere packaging (MAP) that reduce product respiration by creating a suitable atmosphere within a package can help in extending quality and shelf-life of mushrooms (Villaescusa and Gil, 2003). Some enzymes including succinic dehydrogenase (SDH), cytochrome C oxidase (CCO), glucose-6-phosphate dehydrogenase (G-6-PDH) and 6-phosphogluconate dehydrogenas (6-PGDH) are closely related to the respiration pathways. For example, respiration rate of peach fruit treated with ultraviolet-C could be inhibited *via* reducing SDH and CCO activity (Yang et al., 2014).

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Treatment with 50% O_2 + 50% CO_2 led to an obvious decrease in respiration rate of broccoli by inhibiting activities of SDH, CCO (cytochrome C oxidase), and activating the combined activities of G-6-PDH and 6-PGDH (Li et al., 2016). Straw mushroom has the significantly higher respiration during growing or after harvesting than majority of mushrooms. Industrial practice and our primary experiments have proved that the closed packaging accelerated the undesirable appearance changes of straw mushroom possibly due to its higher respiration rate and water release than other commercially cultivated mushrooms such as *lentinus edodes* and *Pleurotus eryngi*. Hence, inhibiting the respiration-related enzymes in the straw mushroom is a potential method to pro-long its shelf life.

Ultrasound has been increasingly applied for food processing and preservation due to its promising advantages of improved quality, reduced chemical damage and physical risks (Mizrach, 2008; Lagnika et al., 2013). For example, 30–40 min ultrasound (33 kHz, 60 W) treatment of strawberry gave the stable shelf quality during all the storage days (Gani et al., 2016). Ultrasound also has been applied to the preserve the physicochemical characteristics of white mushrooms (*Agaricus bisporus*) by slowing respiration rate and lowering polyphenol oxidase (PPO) activity (Lagnika et at., 2013). To date, there are few published references available to improve the quality retention of straw mushroom (*Volvariella volvacea*) by applying ultrasound and controlling storage humidity. Therefore, the objectives of present study were: 1) to maximize the postharvest quality of straw mushroom by using ultrasound treatment at 75% and 95% of relative humidity conditions, and 2) to elucidate the activity changes of enzymes involved in the respiration and deterioration of straw mushroom.

2. Materials and methods

2.1. Sample preparation, ultrasonic treatment and storage

Straw mushroom (*Volvariella volvacea*) was cultivated at 32 ± 2 °C and 90% of relative humidity in Jiangnan Biotech Co., Ltd (Zhenjiang, China). The fruiting body at egg stage was harvested after 4-week cultivation, transported to our laboratory within 1 h, selected for uniformity without any damage, and then randomly divided into 8 experimental groups.

Ultrasound equipment consisted of an ultrasonic reaction chamber (internal dimensions: 240 mm × 207 mm × 215 mm (width × length × height), Shangjia Biotechnology Co., Wuxi, Jiangsu, China) equipped with 3 alternate dual-frequency plates (Fig. 1), water bath for balancing the treatment temperature, and PLC control panel. The ultrasound generators were installed at three sides of bath reactor. The maximum output acoustic power of each plate is 600 W.

About 250 g mushroom samples were kept in a valve bag (20 × 30 × 0.12 mm), placed in the ultrasonic reactor chamber, and treated with 40 kHz frequency and 300 w power for 0, 3, 10 and 30 min, respectively. The experimental groups were set as follows,

(1) Control-75%: Mushrooms conditioned at relative humidity of 75%;
(2) Control-95%: Mushrooms conditioned at relative humidity of 95%;
(3) US-3-75%: Mushrooms treated by ultrasound for 3 min at relative humidity of 75%;
(4) US-3-95%: Mushrooms treated by ultrasound for 3 min at relative humidity of 95%;
(5) US-10-75%: Mushrooms treated by ultrasound for 10 min at relative humidity of 75%;
(6) US-10-95%: Mushrooms treated by ultrasound for 10 min at relative humidity of 95%;
(7) US-30-75%: Mushrooms treated by ultrasound for 30 min at relative humidity of 75%;
(8) US-30-95%: Mushrooms treated by ultrasound for 30 min at relative humidity of 95%.

Each experimental group had 15 replicates containing the untreated or ultrasonic-treated mushroom samples, and was stored at 75% or 95% of relative humidity and 15 °C for 96 h. Samples were taken on at every 12 or 24 h for collecting data including appearance, respiration rate, nutrients contents, and activities of enzymes involved in respiration and deterioration.

The crude extraction of straw mushrooms was prepared by homogenizing with 1:2 (w/v) of 50 mM sodium phosphate buffer (pH 7.8) and obtaining the supernatant fraction with centrifugation of 6800*g* for 20 min at 4 °C for subsequent analysis.

2.2. Respiration rate

Respiration rate was measured in accordance with Wang et al. (2015). The untreated or ultrasonic-treated mushrooms (100 ± 5 g) were weighed and placed in 1 L glass jars at 15 °C for 96 h. The glass jars were sealed by an impermeable film. Carbon dioxide concentration was measured at the 0 h, 12 h, 24 h, 48 h, 72 h and 96 h of storage period using an O_2 and CO_2 analyser (Cyes-II, Jiading federation Instrument, Shanghai, China). Gas samples were taken from the jars with a 20 mL syringe. CO_2 production was calculated as follows:

$$\Delta CO_2\ (mg\ kg^{-1}\ h^{-1}) = CO_{2f} - CO_{2i}$$

Where CO_{2i} represents the gas concentration on the first hour and CO_{2f}

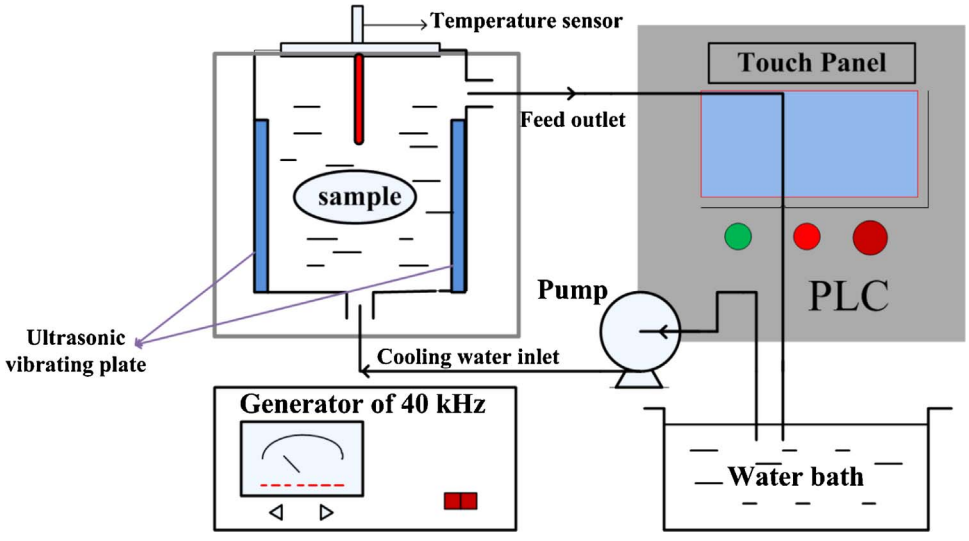

Fig. 1. Schematic diagrams of the Dual-frequency ultrasound equipment.