Evaluation of 1-methylcyclopropene (1-MCP) treatment combined with nano-packaging on quality of pleurotus eryngii

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Abstract The aim of the present study was to investigate the effect of 1-methylcyclopropene (1-MCP) combined with nano-packaging on quality of pleurotus eryngii stored at 4 ± 1 °C for 12 days. Texture, respiration rate, soluble protein, soluble sugar, weight loss, soluble solid, malondialdehyde (MDA) content, polyphenol oxidase (PPO), superoxide dismutase (SOD) and catalase (CAT) activity of treated pleurotus eryngii were determined. The results suggested that 1-MCP treatment combined with nano-packaging reduce respiration rate, weight loss and MDA content, delayed the decrease of soluble protein content, and maintained soluble sugar and soluble solid content of treated pleurotus eryngii during the storage at 4 ± 1 °C compared with the untreated samples. The efficiency of the combined treatment (1-MCP + nano-packaging) was better than that of 1-MCP or nano-packaging alone. Moreover, 1-MCP plus nano-packaging treatment effectively improved SOD and CAT activities, and suppressed the increase of PPO activity in pleurotus eryngii. Therefore, present results indicated that 1-MCP plus nano-packaging treatment may be an effective technology on maintaining commercial quality and lengthening shelf life of pleurotus eryngii.

Keywords 1-Methylcyclopropene (1-MCP) · Nano-packaging · Pleurotus eryngii · Quality

Introduction

In recent years, pleurotus eryngii is widely cultivated in China. Pleurotus eryngii has also been a popular topic among food microbiologist because of its value of high nutrition and medicine (Gu 2009; Sheng and Fang 2009). However, the storage period of harvested pleurotus eryngii is especially short. The commercial quality of pleurotus eryngii will decline 1 or 2 days after harvest at 20 ± 2 °C. The surface of pleurotus eryngii will brown, stink, and become soften and sticky, which seriously affect its nutritional and commercial value (Xing and Liu 2010). Therefore, it is extremely urgent to seek an effective and practicable technique to keep the internal and external quality and prolong the postharvest lifetime of pleurotus eryngii.

Primary reasons of deterioration and senescence of postharvest pleurotus eryngii are respiration, oxidation, moisture loss and browning under the external environment. As a kind of cyclopropenes, 1-methylcyclopropene (1-MCP) has been extensively applied and demonstrated to suppress ethylene action of respiration climacteric fruits by competitively binding to ethylene receptors (Xu et al. 2014; Xu et al. 2016a, b). Studies have shown that the fresh-keeping effect of 1-MCP for various harvested climacteric fruits is noticeable. For example, 1-MCP has an obvious effect on pear (Escribano et al. 2016), mango (Faasema et al. 2014), banana (Zhu et al. 2015), avocado (Adkins et al. 2005), actinidia arguta (Wang et al. 2015), apple (DeEll et al. 2016), tomato (Guillén et al. 2007), persimmon (Luo 2007) and blueberry (Xu et al. 2016a, b) for postponing maturity and senescence. Moreover, its effect on postharvest physiological and biochemical changes of climacteric fruits is connected with maturity stage (Villalobos-Acuña et al. 2011), concentration applied

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(Chriboga et al. 2012) and ambient temperature (Guillén et al. 2007).

Nano-packaging material is a novel type of packing material, which added molecules or nano-particles of 1–100 nm based on the traditional packaging materials. Application of nano-packaging can prolong the lifetime and maintain original color and taste of postharvest edible fungus (Li et al. 2009). In addition, nano-packaging material will not produce anaerobic diseases, though its permeability is poor compared with other general packaging materials (Avella et al. 2005; Liu and Ma 2016). In recent years, nano-packaging material have attracted increasing attention and widely applied to food industry due to the influence on a broad market, such as apple (Li and Wang 2006), jujube (Zhong and Xia 2007) and green tea (Hu and Fu 2003). Studies have shown that nano-packaging significantly reduces respiration intensity, nutrition and moisture loss, thereby maintain the storage quality of *flammulina velutipes* (Yang et al. 2009). Silver ions with their semiconductor photocatalysis, photoactivity, antibacterial activity and nanocrystallites, have attracted the interest of some researchers (Guz et al. 2007). The antimicrobial ability of nano-Ag is more efficient than Ag^+ , due to their little quanta, dimension and wide external regional effect. In addition, nano-Ag can absorb and decompose ethylene (Hu and Fu 2003).

So far, there have been no reports on the efficacy of 1-MCP combined with nano-packaging on preservation of *pleurotus eryngii*. The objective of this study is to evaluate the efficacy of 1-MCP combined with nano-packaging treatment for maintaining commercial quality and lengthening shelf life of *pleurotus eryngii*, which provides theoretical reference for preservation of *pleurotus eryngii*.

Materials and methods

Sample preparation

Fresh *pleurotus eryngii* were purchased from a local market in Shenyang, China, immediately transported to the laboratory of Shenyang Normal University. Samples were chose for uniform size (120 ± 5 g), equal color and absence of diseases and mechanical damage for our analysis. Samples were divided into four groups of 20 each at random for treatment in triplicate and immediately kept at 4 ± 1 °C for experiments.

Sample treatments

1-MCP and nano-packaging material (nano-Ag PE bag) were in a ready to use form that purchased from Sinopharm Chemical Reagent Co., Ltd., China. In our preliminary

study, 0.1, 0.3, 0.5 and 1.0 $\mu\text{L L}^{-1}$ 1-MCP solutions were applied which were equal to the treated time of 18, 20, 22, 24 and 26 h, respectively. On the basis of our preliminary results (preservation effect), the optimum concentration of 1-MCP was 0.3 $\mu\text{L L}^{-1}$ and the optimum fumigated time was 24 h. Samples of the four groups were respectively treated as follows: (1) untreated, (2) 1-MCP (0.3 $\mu\text{L L}^{-1}$, 24 h), (3) nano-packaging, and (4) 1-MCP (0.3 $\mu\text{L L}^{-1}$, 24 h) + nano-packaging. The combined treated samples were first fumigated with 1-MCP and then with nano-packaging. Subsequently, four groups of samples were stored at 4 ± 1 °C and 90–95% RH for measured on day 0, 3, 6, 9 and 12 during storage. In addition, three replicates from each group were taken and the mean value was reported.

Texture analysis

Texture indexes were determined using a texture analyzer (TMS-PRO, USA) fitted with a 6 mm diameter columnar probe. The metering mode was texture profile analysis (TPA). TPA parameters: force initiation 0.3 N; test rate 90 mm min^{-1} ; rate of before and after test 200 mm min^{-1} ; deformation quantity 50%; interval time 5 s; data acquisition rate 200 times s^{-1} .

Respiration rate and weight loss

Samples (approx. 100 g) were put into a 1000-mL closed container at 4 ± 1 °C and 90–95% RH for 30 min prior to gas sampling. CO_2 was assessed by a portable infrared CO_2 analyzer (GXH-3010E1, Beijing XiLinZi Technology Development Co., Ltd., China), and respiration rate result was expressed as $\text{mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$.

Weight loss of *pleurotus eryngii* was assessed by the following formula and the results were reported as a relative percentage: weight loss (%) = (initial weight – final weight)/initial weight $\times 100$.

Soluble protein and soluble sugar

Soluble protein was assessed with coomassie brilliant blue G250 staining method. Samples (approx. 0.5 g) was weighed and homogenized with 5 mL distilled water, subsequently centrifuged at $10,000 \times g$ for 20 min at 4 °C. Supernatant (1 mL) was collected in a 25-mL volumetric flask, then dilute with distilled water to volume, and blended. 1 mL of diluent was taken, and 5 mL of coomassie brilliant blue G250 was added. The sample was mixed for 2 min and the absorbency at 595 nm wavelength was assessed, then referred to bovine serum albumin solution standard curve. Results of soluble protein content was expressed as: soluble protein (mg g^{-1}) = (standard

curve value $\times$ extract total volume)/(extract measure volume $\times$ sample weight).

Soluble sugar was measured with anthrone colorimetric method. *Pleurotus eryngii* (approx. 0.5 g) was weighed and cut into pieces, then put into a 50-mL triangular flask. Whereafter, 5 mL of 85% ethanol was added and the triangular flask was placed into a water bath at 80 °C for 1 h. Sample after heated was centrifuged at 4000 $\times$ g for 10 min, and the extracting process was repeated three times. Finally the supernatant was collected into a 50-mL flask, to which 85% ethanol was added to volume. Solution (1 mL) was inhaled into a centrifuge tube with 1.5 mL of distilled water, and then anthrone reagent (6.5 mL) was added. The mixture was incubated at 20 ± 2 °C for 20 min for color developing. After it cooling, the absorbency at 620 nm wavelength was assessed, then referred to glucose standard curve. Results of soluble sugar content was expressed as: soluble sugar (mg g^{-1}) = (standard curve value $\times$ extract total volume)/(extract measure volume $\times$ sample weight).

Soluble solids and MDA content

Approximately 50 g sample was homogenized and diluted with distilled water (50 mL), then mixed for 1 min. The mixture was centrifuged at 6000 $\times$ g for 5 min. Whereafter, a drop of supernatant was assessed by a refractometer (WAY-2S, Shanghai INESA Physico optical instrument Co., Ltd., China) (Liew and Lau 2012).

Sample (approx. 2 g) was homogenized in 10 mL trichloroacetic acid solution (10%) with 0.5 g of quartz sand. 2 mL of thiobarbituric acid (0.6%) was added into the supernatant (2 mL), and then centrifuged at 6000 $\times$ g for 5 min. Mixture after heated for 15 min was quickly cooled, and further centrifuged. Afterwards, absorbances of supernatant at 450 and 532 nm were determined by a spectrophotometer (UV-4802, Unico, China) were measured. Malondialdehyde (MDA) was calculated as: $\text{MDA} (\text{nmol g}^{-1}) = 6450 \times A_{532} - 560 \times A_{450}$ (Martinez-Solano et al. 2005).

PPO, SOD and CAT activity

Polyphenol oxidase (PPO, EC 1.14.18.1) activity was assessed by a spectrophotometer (UV-4802, Unico, China). The reaction mixture included 0.1 mL of enzyme, 0.9 mL of citrate buffer (0.1 M, pH 3.0), and 0.5 mL of catechol or 4-methylcatechol. Then 0.5 mL of 6% trichloroacetic acid was added to stop the reaction, and one unit of PPO activity (U g^{-1} FW) was defined as an increase of 0.001 in absorbance per minute at 294 nm under the determination conditions (Gauillard et al. 1993).

Superoxide dismutase (SOD, EC 1.15.1.1) activity was determined referring to the method of Wang and Chen (2010). 0.5 mL of enzyme was added into 3 mL of assay reagent consisting of 130 mM methionine, 100 μM EDTA, 750 μM NBT, and 20 μM riboflavin in sodium phosphate buffer (0.05 M, pH 7.8). Then, the reaction lasted for 15 min under 4000 lux illumination. The absorbance was determined by a spectrophotometer (UV-4802, Unico, China) at 560 nm, and sodium phosphate buffer (0.05 M, pH 7.8) was used as a comparison. One unit of enzyme activity (U g^{-1} FW) was defined as the amount of enzyme that caused 50% inhibition of NBT reduction.

Catalase (CAT, 1.11.1.6) was determined referring to the method of Change and Maehly (1995). The assay mixture included 2.8 mL of 15 mM H_2O_2 prepared from sodium phosphate buffer (0.05 M, pH 7.8) and 0.2 mL of enzyme solution. An increase in absorbance at 240 nm was recorded at 25 °C for 3 min. One unit of CAT activity (U g^{-1} FW) was defined as the amount of the enzyme that caused a change in absorbance of 0.01 min^{-1} .

Statistical analysis

Analyses of data were carried out by one-way ANOVA in SPSS 16.0 for Windows (SPSS Inc., Chicago, IL, USA). Statistic differences were considered to be significant at $P < 0.05$. All results were expressed as the mean $\pm$ SE.

Results and discussion

Texture indexes

Texture indexes have a direct relation with moisture content of *pleurotus eryngii*. In general, the indexes describing texture of edible fungus are firmness, elasticity, cohesiveness and chewiness (Rahman and Al-Farsi 2005). Firmness represents the internal binding force of keep food shape. Elasticity refers to the ability of deformed food to restore the original state after removing external force. Cohesiveness is a sign of internal structure compaction degree of food, which reflects close connection degree when food is chewed. Chewiness is the comprehensive reflection of firmness, elasticity and cohesiveness, which is defined as the work done when chews food to swallow (El-Magoli et al. 1996). In the present study, no significant difference ($P > 0.05$) in the four texture indexes was noticed between 1-MCP and nano-packaging treatment comparing with the untreated *pleurotus eryngii* during storage period at 4 ± 1 °C (Table 1). Though the four texture indexes of *pleurotus eryngii* slowly decline, the combination of 1-MCP plus nano-packaging treatment suppressed the decrease of firmness, elasticity, cohesiveness and

Table 1 Effects of 1-MCP, nano-packaging and their combination on texture index of *pleurotus eryngii* during storage at 4 ± 1 °C

Texture index	Treatment	Storage time (d)				
		0	3	6	9	12
Firmness (N)	Untreated	28.75 $\pm$ 0.62Aa	28.12 $\pm$ 0.31Aa	27.36 $\pm$ 0.59Ab	25.59 $\pm$ 0.26Ac	21.15 $\pm$ 0.18Ad
	1-MCP	28.75 $\pm$ 0.62Aa	28.36 $\pm$ 0.29Aa	27.59 $\pm$ 0.45Ab	26.20 $\pm$ 0.67Ac	22.12 $\pm$ 0.26Ad
	Nano-packaging	28.75 $\pm$ 0.62Aa	28.25 $\pm$ 0.38Aa	27.48 $\pm$ 0.37Ab	26.18 $\pm$ 0.04Ac	22.09 $\pm$ 0.34Ad
	1-MCP + nano-packaging	28.75 $\pm$ 0.62Aa	28.62 $\pm$ 0.17Aa	28.46 $\pm$ 0.28Ba	26.98 $\pm$ 0.15Bb	23.54 $\pm$ 0.19Bc
Elasticity (N)	Untreated	20.18 $\pm$ 0.57Aa	20.01 $\pm$ 0.27Aa	18.15 $\pm$ 0.17Ab	16.86 $\pm$ 0.15Ac	15.01 $\pm$ 0.35Ad
	1-MCP	20.18 $\pm$ 0.57Aa	20.13 $\pm$ 0.59Aa	18.32 $\pm$ 0.26Ab	16.98 $\pm$ 0.63Ac	15.27 $\pm$ 0.17Ad
	Nano-packaging	20.18 $\pm$ 0.57Aa	20.11 $\pm$ 0.07Aa	18.29 $\pm$ 0.84Ab	16.92 $\pm$ 0.09Ac	15.34 $\pm$ 0.29Ad
	1-MCP + nano-packaging	20.18 $\pm$ 0.57Aa	20.15 $\pm$ 0.41Aa	19.95 $\pm$ 0.35Ba	17.75 $\pm$ 0.42Bb	16.35 $\pm$ 0.08Bc
Cohesiveness (Ratio)	Untreated	0.34 $\pm$ 0.21Aa	0.27 $\pm$ 0.54Aab	0.20 $\pm$ 0.15Ab	0.16 $\pm$ 0.15Ac	0.11 $\pm$ 0.14Ac
	1-MCP	0.34 $\pm$ 0.21Aa	0.29 $\pm$ 0.25Aa	0.25 $\pm$ 0.61Aab	0.20 $\pm$ 0.34Ab	0.15 $\pm$ 0.25Ab
	Nano-packaging	0.34 $\pm$ 0.21Aa	0.28 $\pm$ 0.14Aa	0.26 $\pm$ 0.45Aab	0.19 $\pm$ 0.59Abc	0.14 $\pm$ 0.57Ac
	1-MCP + nano-packaging	0.34 $\pm$ 0.21Aa	0.31 $\pm$ 0.03Aab	0.27 $\pm$ 0.36Aab	0.26 $\pm$ 0.05Bab	0.22 $\pm$ 0.43Bb
Chewiness (mJ)	Untreated	70.23 $\pm$ 0.27Aa	70.06 $\pm$ 0.16Aa	68.05 $\pm$ 0.25Ab	66.12 $\pm$ 0.53Ac	65.01 $\pm$ 0.21Ad
	1-MCP	70.23 $\pm$ 0.27Aa	70.19 $\pm$ 0.58Aa	68.56 $\pm$ 0.11Ab	66.77 $\pm$ 0.09Ac	65.45 $\pm$ 0.04Ad
	Nano-packaging	70.23 $\pm$ 0.27Aa	70.11 $\pm$ 0.36Aa	68.64 $\pm$ 0.08Ab	66.84 $\pm$ 0.15Ac	65.59 $\pm$ 0.08Ad
	1-MCP + nano-packaging	70.23 $\pm$ 0.27Aa	70.21 $\pm$ 0.12Aa	69.05 $\pm$ 0.02Aa	67.89 $\pm$ 0.33Bb	66.67 $\pm$ 0.45Bc

^aAll means in the same column followed by different letters (A–C) are significantly ($P < 0.05$) different by Duncan's multiple range test

^bAll means in the same row followed by different letters (a–d) are significantly ($P < 0.05$) different by Duncan's multiple range test

chewiness of *pleurotus eryngii*, and there was significant difference ($P < 0.05$) in firmness and elasticity after 6 days of storage and cohesiveness and chewiness after 9 days of storage, as compared with the untreated *pleurotus eryngii* (Table 1). Our results showed that texture indexes gradually decreased during the whole storage because of the moisture evaporation, which due to the cell turgor decrease and organization structure wilting of *pleurotus eryngii*. The results indicated that the texture indexes of *pleurotus eryngii* significantly ($P < 0.05$) increased by treated with 1-MCP plus nano-packaging, which probably by reducing moisture evaporation and suppressing respiration intensity of *pleurotus eryngii* (Table 1).

Respiration rate and weight loss

Nutrient and water consumption of postharvest fruits and vegetables during storage is mainly due to the respiration and transpiration (Chen et al. 2011). Figure 1a suggested that respiration rate of untreated *pleurotus eryngii* gradually increased to maximum on 6th day, and dropped from day 6 to 12 days of storage period at 4 ± 1 °C. Treatment with 1-MCP or nano-packaging inhibited the respiration rate in varying degrees, but the effect of 1-MCP treatment

was not obvious ($P > 0.05$). On day 6 of storage period, 1-MCP or nano-packaging treatment inhibited respiration rate of 8 and 20% as compared with the untreated samples, respectively (Fig. 1a). However, maximal inhibition of respiration rate in *pleurotus eryngii* was observed with the combined treatment. In particular, respiration rate in *pleurotus eryngii* of the combined treatment was 160 mg CO₂ kg⁻¹ h⁻¹ with an inhibition of 36% on day 6 of storage, and a significant difference ($P < 0.05$) was observed compared to the untreated samples (Fig. 1a).

Weight loss is one of the basic physiological indexes for determining senescence of edible fungus (Wang et al. 2015). As shown in Fig. 1b, weight loss of *pleurotus eryngii* for all treatments gradually increased with increasing storage time at 4 ± 1 °C. The untreated samples exhibited serious weight loss from day 0 to 12 and ranged from 0 to 10.02%. 1-MCP or nano-packaging treatment inhibited the increase of weight loss and significant difference ($P < 0.05$) was observed after day 6 during the storage, as compared with the untreated *pleurotus eryngii* (Fig. 1b). In particular, the most effective treatment was the combination of 1-MCP and nano-packaging with an inhibition of 48% on day 12, which was better than that of 1-MCP (18%) or nano-packaging (27%) treatment alone

Fig. 1 Effects of 1-MCP, nano-packaging and their combination on respiration rate (a), weight loss (b), soluble protein (c), soluble sugar (d), soluble solid (e) and MDA content (f) of *pleurotus eryngii* during storage at 4 ± 1 °C

(Fig. 1b). The results suggested that postharvest application of 1-MCP plus nano-packaging to *pleurotus eryngii* delayed the increase of weight loss, and a significant difference ($P < 0.05$) was found between the combined treatment and the untreated samples (Fig. 1b), consistent with results reported by Chen et al. (2001).

Soluble protein and soluble sugar

During the postharvest storage of edible fungus, most of the soluble protein is decomposed to meet the demand of metabolic. So the soluble protein content of *pleurotus eryngii* gradually declined with the extension of storage time. Figure 1c showed that 1-MCP or nano-packaging treatment delayed the decreasing of soluble protein content at varying degrees compared to the untreated *pleurotus eryngii*. Treatment with 1-MCP plus nano-packaging comparing with the untreated samples significantly

($P < 0.05$) improved the content of soluble protein by 60% on day 12 of storage. No significant difference ($P > 0.05$) was observed between the single treatment of 1-MCP or nano-packaging (Fig. 1c).

Soluble sugar is one of the substrates of respiration in edible fungus. The enhancement of respiration caused gradual decrease in soluble sugar content, which due to the quality and flavour deterioration of postharvest edible fungus (Yang et al. 2009). As shown in Fig. 1d, the soluble sugar content of *pleurotus eryngii* rose initially and then decreased with the increase in storage because of the respiration. Soluble sugar content of untreated *pleurotus eryngii* reached a peak of 360 mg g^{-1} on day 6. In our present study, 1-MCP or nano-packaging treatment maintained soluble sugar content in *pleurotus eryngii* and the value on day 6 was 380 mg g^{-1} with an increase of 5.6% comparing with the untreated samples (Fig. 1d). But no significant difference ($P > 0.05$) in soluble sugar was

noticed between 1-MCP and nano-packaging treatments compared to the untreated pleurotus eryngii during storage period at 4 ± 1 °C. Moreover, the combined treatment maintained soluble sugars and the value increased by 29.6% compared with the untreated samples on 12 days (Fig. 1d).

Soluble solid and MDA content

Another characteristic of ripening and senescencing is the change of soluble solids content in postharvest pleurotus eryngii. Figure 1e indicated that soluble solids content of pleurotus eryngii gradually increased up-to day 9, and decreased thereafter during the whole storage period at 4 ± 1 °C. In the present study, the soluble solids content of treated pleurotus eryngii was higher than that of the untreated samples. Furthermore, the soluble solids content of pleurotus eryngii treated with 1-MCP plus nano-packaging at the most effective peak on day 9, and the peak value was 31.1% higher than that of the untreated samples (Fig. 1e). The results suggested that the combination of 1-MCP and nano-packaging treatment was found to be the most potent than that of 1-MCP or nano-packaging alone. Also, there was significant difference ($P < 0.05$) between the effect of the combination and the untreated group (Fig. 1e).

MDA is the final product of lipid peroxidation of cell membranes caused by reactive oxygen species accumulation, and its content reflects stress tolerance of plants (Zhou et al. 2014). As shown in Fig. 1f, MDA content in pleurotus eryngii gradually increased, which indicated cellular oxidative damage aggravate during the postharvest storage of pleurotus eryngii. Treatments with 1-MCP, nano-packaging or their combination suppressed the increasing of MDA content in pleurotus eryngii to varying degrees comparing to the untreated samples (Fig. 1f). In particular, MDA content of pleurotus eryngii treated with the combination was 0.13 nmol g^{-1} on day 12 of storage at 4 ± 1 °C, which was significantly ($P < 0.05$) inhibited by 18.8% when compared with the untreated pleurotus eryngii (Fig. 1f).

Enzyme activity

PPO widely exists in animals and plants which can cause browning of edible fungus during the postharvest storage. In our present study, PPO activity of pleurotus eryngii gradually increased from day 0 to day 12 during the whole storage period at 4 ± 1 °C. 1-MCP or nano-packaging treatment suppressed the increasing of PPO activity and the value on day 12 was $12.0 \text{ U g}^{-1} \text{ FW}$ with an inhibition of 7.7% compared to the untreated pleurotus eryngii (Fig. 2a), which probably by inhibiting lipid peroxidation and

enzymatic browning reaction. In addition, the PPO activity of the combined treatment was lower than that of 1-MCP or nano-packaging treated pleurotus eryngii, which was significant different ($P < 0.05$) from the untreated samples with an inhibition of 26.9% (Fig. 2a).

Fig. 2 Effects of 1-MCP, nano-packaging and their combination on PPO (a), SOD (b) and CAT (c) activity of pleurotus eryngii during storage at 4 ± 1 °C

SOD is an effective scavenger of free radicals that can cause senescence of body, and high SOD activity has been related to stress tolerance in plants because it neutralizes the reactivity of superoxide radical, which is over-produced under stress (Bowler et al. 1992; Se villano et al. 2009). As shown in Fig. 2b, the SOD activity of *pleurotus eryngii* gradually increased from day 0 to day 3, and declined thereafter with the extension of storage time. 1-MCP or nano-packaging treatment delayed the decreasing of SOD activity and the peak value on day 3 was 1.8 and 9.1% higher than that of the untreated samples, respectively (Fig. 2b). But there was no significant difference ($P > 0.05$) between the effect of 1-MCP and nano-packaging treatment comparing to the untreated *pleurotus eryngii*. However, the SOD activity peak value of combined treatment appeared on day 3 with 23.6% higher than that of the untreated samples and significant difference ($P < 0.05$) was observed during the storage at 4 ± 1 °C (Fig. 2b).

Another main enzyme of defense system of active oxygen is CAT, which is the sign of quality aging of plants. Figure 2c indicated that the CAT activity of *pleurotus eryngii* gradually increased. The maximum on day 6, and then decreased during the storage at 4 ± 1 °C, which was similar to the results of Yang et al. (2009). Treatments with 1-MCP, nano-packaging or their combination maintained the MDA content in *pleurotus eryngii* in different degrees comparing to the untreated samples. However, no significant difference was observed between the single treatment of 1-MCP or nano-packaging (Fig. 2c). Moreover, treatment with 1-MCP plus nano-packaging significantly ($P < 0.05$) improved the CAT activity by 24.1% on day 6 of storage comparing to the untreated samples. The finding indicated that 1-MCP plus nano-packaging can significantly ($P < 0.05$) avoid the accumulation of activated oxygen and enhance antioxidant activity of *pleurotus eryngii*.

Conclusion

The present study indicated that 1-MCP plus nano-packaging treatment was an effective method, which maintained postharvest quality and extended storage time by inhibiting respiration rate, weight loss, MDA content and the increase of PPO activity, delaying the decrease of soluble protein content, maintaining soluble sugar and soluble solid content and improving SOD and CAT activities of *pleurotus eryngii* at 4 ± 1 °C during storage. Furthermore, the results of the combined treatment was significantly ($P < 0.05$) more effective than that of 1-MCP or nano-packaging treatments alone. Even though our study showed that 1-MCP plus nano-packaging treatment was a

potent method and potential to be applied to the postharvest storage and preservation of *pleurotus eryngii*, the responses of other edible fungi using different dosages could be various. Further researches is necessary to explore if combining 1-MCP or nano-packaging with other preservation technologies would have a more effective role in improving the quality of edible fungi. Additionally, the gene expression regulation related to ethylene biosynthesis enzymes of *pleurotus eryngii* need to be further studied.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interests to report.

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