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Antioxidant Activity and Quality Evaluation of Ham Enriched with Mushroom Powders

Abstract

1 This study evaluated the antioxidant activity and quality of the ham enriched with mushroom
2 powder. Four different types of mushrooms (oyster, shiitake, king oyster, and white button) were
3 used in the first analysis. DPPH radical scavenging activity ranged from 23.4% to 53.6%, Iron
4 chelating ability varied from 74.1% to 91.5%, and reducing power showed values between 0.12
5 to 0.61. The results showed that oyster mushrooms with the highest antioxidant activity were the
6 most acceptable and were then selected for further product formulations. Oyster mushrooms were
7 added to ham in varying concentrations: 0.5%, 1%, and 3%. The highest concentration of
8 mushrooms (3%) resulted in a decrease in moisture content, pH, lightness, water holding capacity,
9 and texture profile analysis (TPA) values ($p<0.05$). However, 3% resulted in increased fat content,
10 redness, yellowness, lipid oxidation, and TPA values ($p<0.05$). TPA values gradually increased
11 during 49 days of storage, while adhesiveness decreased with storage days. The redness,
12 yellowness, and thiobarbituric acid reactive substances values increased over time. The pH
13 increased to 21 days of storage. These findings indicated that oyster mushroom powder has the
14 potential as a natural functional ingredient for extending shelf life and improving the nutritional
15 profile of meat products. This study contributes to the development of value-added health benefits
16 of meat products.

17 Keywords: oyster mushroom, enriched ham, antioxidant capacity, value-added products

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19 ## Introduction

20 The contemporary food industry has witnessed an unprecedented shift toward natural
21 preservation systems, driven by escalating consumer apprehension regarding synthetic additives
22 and their potential adverse health implications (Ciobanu et al., 2024). Antioxidants are added to
23 meat products to prevent lipid oxidation, delay the formation of off-flavors, and improve color
24 stability (Kumar et al., 2015). In the food industry, they can be divided into natural and synthetic
25 antioxidants. BHA (butylated hydroxyanisole), BHT (butylated hydroxytoluene), and PG (propyl
26 gallate), are examples of synthetic antioxidants; whereas, in food model systems, ingredients

derived from natural sources with antioxidant properties are considered natural antioxidants (Sasse et al., 2009). These antioxidants play a very important role in the food industry. However, some studies have identified synthetic antioxidants as toxicological and carcinogenic agents (Xu et al., 2021). Therefore, the food industry is now choosing natural products over synthetic ones.

Edible mushrooms have emerged as candidates for natural antioxidant applications, attributed to their comprehensive profile of bioactive metabolites, including phenolic compounds, flavonoids, terpenoids, and ergothioneine (Palacios et al., 2011; Al Qutaibi & Kagne, 2024). These compounds demonstrated potent antioxidant mechanisms through free radical scavenging, metal chelation, and lipid peroxidation inhibition, with certain species exhibiting capacities comparable to synthetic antioxidants (Ferreira et al., 2009; Barros et al., 2007). The application of mushroom-derived antioxidants in meat products addresses critical technological challenges, as processed meat systems exhibit exceptional susceptibility to lipid oxidation due to their high concentrations of polyunsaturated fatty acids and pro-oxidant enzymes (Torres-Martínez et al., 2022). Lipid oxidation represents the primary quality-limiting factor, manifesting through malondialdehyde formation, off-flavor development, and color deterioration (Domínguez et al., 2019). Recent studies indicated that the addition of mushroom powder to beef enhances sarcoplasmic protein binding to lipid oxidation products, thereby reducing oxidative compounds and maintaining thiobarbituric acid reactive substances values below sensory detection thresholds (Tom et al., 2018).

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Among commercial mushroom species, several varieties have demonstrated particularly exceptional antioxidant properties. White button mushroom (*Agaricus bisporus*), the most widely cultivated species globally, contains significant concentrations of ergothioneine, a unique sulfur-containing amino acid with potent antioxidant and cytoprotective properties (Dubost et al., 2007). A. bisporus exhibits substantial phenolic content and demonstrates effective hydroxyl radical scavenging activity, with studies indicating that its antioxidant capacity increases during storage due to enhanced phenolic biosynthesis under stress conditions (Gąsecka et al., 2018). King oyster mushroom (*Pleurotus eryngii*), distinguished by its thick stem and minimal sporulation, possesses superior antioxidant activity attributed to its elevated content of phenolic acids, particularly protocatechuic and gallic acids, alongside substantial ergothioneine concentrations (Gąsecka et al., 2016). P. eryngii demonstrates exceptional thermal stability of its bioactive compounds, making it particularly suitable for processed meat applications requiring heat treatment. Research has established that king oyster mushroom extracts exhibit strong ferric-reducing antioxidant power (FRAP) and effectively inhibit lipid peroxidation in meat emulsion systems through multiple mechanisms, including metal chelation and free radical interception (Yahia et al., 2017). Shiitake mushroom (*Lentinula edodes*), renowned for its distinctive umami flavor compounds,

62 contains unique bioactive metabolites including lentinan (β-1,3-glucan), eritadenine, and diverse
63 phenolic compounds that confer exceptional antioxidant properties (Finimundy et al., 2014).
64 Studies demonstrated that shiitake powder incorporation into meat products not only provides
65 oxidative protection but also enhances flavor profiles through natural glutamate compounds while
66 reducing sodium requirements (Coelho et al., 2014).

67 Among the various edible mushroom species, the genus *Pleurotus* stands out due to its aromatic
68 qualities, high nutritional value, widespread distribution, accessibility, and affordability (Mohd
69 Zaini et al., 2023; Effiong et al., 2024). Within this genus, the oyster mushroom (*Pleurotus*
70 *ostreatus*) is particularly notable for its distinctive phytochemical profile and potent antioxidant
71 activities, which contribute to both its health-promoting properties and its value as a functional
72 food ingredient (Allam & Mohamed, 2023). Oyster mushrooms contain bioactive components,
73 including phenols, flavonoids, terpenes, and polysaccharides (Rahimah et al., 2019). They have
74 anti-microbial, anti-inflammatory, and immunostimulant activities (Jayasuriya et al., 2020;
75 Hamad et al., 2022). Studies utilizing enoki mushroom stem waste powder (2-6% inclusion) in
76 meat nuggets demonstrated improved physicochemical quality, oxidative stability, and extended
77 shelf life of the products (Banerjee et al., 2020).

78 The objective of this study was to evaluate the antioxidant properties of four mushroom powder
79 varieties and examine the mushroom powder incorporation on quality characteristics, oxidative
80 stability, and refrigerated shelf-life of processed pork ham products. This study bridges
81 fundamental research gaps in bio-based preservation methodologies while delivering actionable
82 insights for large-scale deployment of mushroom-derived antioxidant solutions.

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83

84 **Materials and Methods**

85 **Experiment I: Evaluation of antioxidant properties in four mushroom species**

86 **Sample preparation and powder production.**

87 Four commercially available mushroom species, including white button mushroom (*Agaricus*
88 *bisporus*), king oyster mushroom (*Pleurotus eryngii*), shiitake (*Lentinula edodes*), and oyster
89 mushroom (*Pleurotus ostreatus*), were purchased from the local market in Anseong-si, Republic
90 of Korea. Analytical-grade chemicals, including L-ascorbic acid 2,2-diphenyl-1-picrylhydrazyl
91 (DPPH), ferrous chloride tetrahydrate, ethylenediaminetetraacetic acid (EDTA), and additional
92 reagents, were obtained from certified commercial suppliers (Merck). Fresh mushroom samples
93 underwent systematic dehydration following protocols. Specimens were sectioned longitudinally

94 and subjected to controlled thermal drying at 60°C for 24 hours using a convection oven (LO-
95 FS100, LKLAB KOREA, Republic of Korea). After desiccation, samples were subsequently
96 pulverized using a mechanical grinder to achieve a uniform particle size distribution. The
97 resulting mushroom powders were stored at -70°C until subsequent analysis.

98

99 **Total phenolic compounds**

100 Total phenolic content (TPC) was determined by the spectrophotometric Folin-Ciocalteu assay as
101 previously described with minor modifications (Lin & Tang, 2007). Sample aliquots (0.1 mL)
102 were combined with distilled water (2.8 mL), sodium carbonate solution (2.0 mL), and 50% Folin-
103 Ciocalteu reagent (0.1 mL). The reaction mixture was incubated at ambient temperature for 30
104 minutes, followed by microplate reader (EPOCH-SN, Agilent, United States). at 750 nm.
105 Quantification was performed using a gallic acid equivalent (GAE) standard curve with excellent
106 linearity ($r^2 = 0.99$).

107

108 **DPPH radical scavenging activity**

109 Free radical scavenging capacity was evaluated using the established DPPH assay methodology
110 (Huang et al., 2006). Sample extracts (2.0 mL) were mixed with freshly prepared DPPH solution
111 (0.5 mL, 0.2 mM in methanol). The reaction mixture was incubated for 30 minutes in the dark at
112 room temperature to ensure complete radical-substrate interaction. Absorbance measurements
113 were recorded at 517 nm using a microplate reader (EPOCH-SN, Agilent, United States). L-
114 ascorbic acid served as the positive control. Radical scavenging activity was calculated as follows:

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115 **DPPH scavenging activity (%) = $[1 - (A_1/A_0)] \times 100$**

116 Where A_1 represents the sample absorbance and A_0 represents the control absorbance.

117

118 **Iron chelating capacity**

119 Iron chelating capacity was assessed using the ferrozine colorimetric method with procedural
120 modifications (Le et al., 2007). Sample extracts (800 μL) were combined with ferrous chloride
121 solution (160 μL, 0.6 mM) and methanol (1440 μL), then equilibrated at room temperature for 5
122 minutes. Ferrozine solution (160 μL) was subsequently added, and the reaction proceeded in the
123 dark for 10 minutes. Absorbance was measured at 562 nm using microplate reader (EPOCH-SN,
124 Agilent, United States). EDTA served as the reference standard. Metal chelating activity was
125 calculated using the formula:

126 **Iron chelating ability (%) = [1 - (A_1/A_0)] × 100**

127 Where A_1 represents the sample absorbance and A_0 represents the control absorbance.

128

129 **Reducing power**

130 The reducing power was determined using the potassium ferricyanide reduction method (Huang
131 et al., 2006). Sample extracts (1.0 mL) were mixed with sodium phosphate buffer (1.0 mL, 200
132 mM, pH 6.6) and potassium ferricyanide solution (1.0 mL, 10 mg/mL). The mixture was
133 incubated at 50°C for 20 minutes using a temperature-controlled incubator (C-INA3, Changshin,
134 Republic of Korea). Trichloroacetic acid (1.0 mL, 100 mg/mL) was added to terminate the
135 reaction. An aliquot (2.0 mL) was then combined with distilled water (2.0 mL) and ferric chloride
136 solution (0.4 mL, 1 mg/mL). Absorbance was measured at 700 nm using microplate reader
137 (EPOCH-SN, Agilent, United States), with L-ascorbic acid as the reference standard.

138

139 Experiment II: Quality characteristics of pork ham enhanced with oyster 140 mushroom powder

141 **Pork ham formulation and processing**

142 Fresh pork ham and back fat were procured from a certified retail meat market in Anseong-si,
143 Republic of Korea. The raw materials were mechanically processed using a commercial meat
144 grinder (M-12S, Fuji, Korea) equipped with a 6 mm diameter plate. Oyster mushroom
145 specimens were processed according to the dehydration protocol described previously. The meat
146 emulsion was prepared by combining ground pork components with additives (Table 1) in a
147 commercial mixer for 10-15 minutes, according to the formulation specified. Three
148 experimental treatments were developed: M1 (0.5%), M2 (1.0%), and M3 (3.0%). The
149 homogenized mixture was vacuum-packaged and equilibrated at 4°C for 10 minutes before
150 portioning into 70 g units and vacuum-sealed individually. Samples were packaged in
151 polyethylene terephthalate (PET) trays and sealed with a polypropylene (PP) film under air
152 packaging conditions. Samples were stored under refrigerated conditions (4°C) and evaluated at
153 predetermined intervals: 0, 7, 14, 21, 28, 35, 42, and 49 days. All analytical determinations were
154 performed in triplicate to ensure statistical reliability.

155

156 **Proximate composition analysis**

157 The proximate composition was determined following standardized AOAC (1995) methodologies.

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158 Moisture content was quantified using the oven-drying technique at 105°C until a constant weight.
159 Crude fat content was extracted using the Soxhlet method with petroleum ether. Protein content
160 was determined by the Kjeldahl nitrogen method (N × 6.25). Ash content was measured by muffle
161 furnace incineration at 550°C for 8 hours. All determinations were performed in triplicate, and
162 results were expressed as percentages on a wet weight basis.

163

164 **pH**

165 The pH of pork ham samples was determined using a calibrated digital pH meter (S220, Mettler-
166 Toledo, Switzerland). Sample homogenates were prepared by blending 10 g of minced sample
167 with 90 mL of distilled water. The pH meter was standardized using certified buffer solutions (pH
168 4.01 and 7.00) before each measurement session. Twelve replicate measurements were performed
169 per sample, and the arithmetic mean was calculated.

170

171 **Color**

172 The color measurements of pork ham samples were performed with a color reader (CR-10 Plus,
173 Konica Tokyo, Japan). Hunter L*, a*, and b*, values were determined as indicators of lightness,
174 redness, and yellowness. All color measurements were done five times after the standardization
175 of the instrument.

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176

177 **Water-holding capacity (WHC)**

178 WHC was determined according to the method described by Wierbicki and Deatherage (1958)
179 with slight modifications. Approximately 1.0 g of each sample was wrapped in three layers of
180 pre-weighed gauze and centrifuged at 3,000 rpm for 10 minutes using a centrifuge (Cef-D50.6,
181 DAIHAN-Scientific, Korea). After centrifugation, the samples were carefully removed and
182 weighed again. WHC was calculated based on the weight difference before and after
183 centrifugation, representing the amount of water retained by the sample.

184 $\mathbf{WHC (\%) = [(W_1 - W_2)/W_1] \times 100}$

185 Where W_1 = initial sample weight (g) and W_2 = sample weight after centrifugation (g).

186

187 **Texture profile analysis (TPA)**

188 Thermal processing was conducted by heating samples to an internal temperature of 75°C for 30
189 minutes, followed by rapid cooling in ice-cold water for 20 minutes. Cooked samples were
190 sectioned into uniform cubes (1.0 × 1.0 × 1.0 cm) for instrumental texture analysis using a texture
191 analyzer (Brookfield CT3, Ametek, USA) equipped with a cylindrical probe (3.5 mm diameter).
192 The compression test was performed at a constant crosshead speed of 0.5 mm/s with double

193 compression cycles. The following textural parameters were quantified: hardness (g), deformation
194 (mm), adhesiveness (mJ), resilience, cohesiveness, springiness (mm), gumminess (g), and
195 chewiness (mJ). Four replicate measurements were performed per sample, and mean values were
196 calculated.

197

198 **2-thiobarbituric acid reactive substances (TBARS)**

199 TBARS was measured using the method of Sinnhuber and Yu (1977). To approximately 2 g of
200 sample, 0.5 mL of antioxidant mixture solution (0.6 g BHA, 0.6 g BHT, 10.8 g propylene glycol,
201 20.8 g Tween 20), 3 mL of TBA solution containing 10 g thiobarbituric acid and 3 g NaOH, and
202 17 mL of TCA solution containing 10 g trichloroacetic acid and 6 mL of 0.6 N NaOH were added.
203 The sample solution was heated in a 100 °C water bath for 30 minutes, then centrifuged using a
204 centrifuge (Cef-D50.6, DAIHAN-Scientific, Korea) at 3,000 rpm for 5 minutes to collect the
205 supernatant. This supernatant was mixed with chloroform and centrifuged, then mixed again with
206 petroleum ether before measuring absorbance at 532 nm using microplate reader (EPOCH-SN,
207 Agilent, United States). TBARS values were calculated using the following equation:

208 TBARS (mg of malondialdehyde/kg of sample) =(O.D.×9.48)/sample weight(g)

209

210 **Peroxide value (POV)**

211 POV was determined according to the method of Shantha and Decker (1994). To 0.6 g of sample,
212 10 mL of chloroform: methanol (1:1) solution was added and mixed for 20 seconds, followed by
213 the addition of 6.16 mL of 0.5% NaCl solution and centrifugation (3,000 rpm, 5 minutes). To 4
214 mL of the lower layer, 2.66 mL of chloroform: methanol (1:1) solution and 100 μL each of iron
215 (II) chloride solution and ammonium thiocyanate solution were added and allowed to react at
216 room temperature for 20 minutes before measuring absorbance at 500 nm using microplate reader
217 (EPOCH-SN, Agilent, United States). POV values were calculated using the following equation:

218 POV (meq/kg) = [(Abs/0.0483) × (2 + 1.33 + 0.025 + 0.025) × 5/2]/sample weight (g)

219

220 **Microbiological analysis**

221 Microbial analysis was assessed by enumerating the total aerobic plate count (TPC) and coliform
222 bacteria. Serial dilutions (1:9) of sample homogenates were prepared in sterile peptone water.
223 Aliquots (100 μL) were plated onto plate count agar for TPC determination and violet, red bile
224 agar (VRBA) for coliform enumeration. Plates were incubated at 37°C for 24-48 hours under
225 aerobic conditions. Colony-forming units were counted and expressed as log CFU/g.

226

227 **Statistical analysis**

228 All experimental data were analyzed using SPSS version 21.0 for Windows (IBM Corp., Armonk,

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229 NY, USA). Two-way analysis of variance (ANOVA) was employed to evaluate the main effects
230 of storage time and treatment concentration, as well as their interactions. When significant
231 differences were detected ($p < 0.05$), post-hoc multiple comparisons were performed using
232 Duncan's multiple range test to identify specific treatment differences. Data are presented as mean
233 ± standard deviation.

234

235 **Results and Discussion**

236 **Experiment I: Evaluation of antioxidant properties in four mushroom species**

237 **Total phenolic compounds**

238 The quantitative analysis of total phenolic content revealed significant variations among the four
239 mushroom species investigated (Table 2). Present results showed that oyster mushroom
240 (*Pleurotus ostreatus*) demonstrated the highest ($p<0.5$) phenolic concentration (2.33g GAE/100g),
241 followed by white button mushroom (1.75g GAE/100g), king oyster (1.64g GAE/100g), and
242 shiitake (1.60g GAE/100g). High contents of phenolic compounds in foods have been associated
243 with high antioxidant capacities (Jacobo-Velázquez & Cisneros-Zevallos, 2009). According to
244 Silva et al. (2025), the total phenolic content of the five mushroom species *Lentinula edodes,*
245 *Pleurotus ostreatus, Hericium erinaceus, and Agaricus bisporus* ranged from 22.3 to 46.2 mg
246 GAE/100g FW. Among the evaluated species, *Agaricus varieties* exhibited the highest TPC values,
247 while *LE* showed a significantly lower phenolic content ($p<0.05$). Diamantopoulou et al. (2023)
248 reported that *P. ostreatus* strains produced a satisfactory amount of TPC (10.41–70.67 mg GAE/g
249 d.w.). Kalogeropoulos et al. (2013) revealed that the total phenolic content of mushroom extracts
250 ranged from 6.0 to 20.8 mg GAE/100 g FW in wild edible mushrooms species (*Lactarius*
251 *deliciosus, Lactarius sanguifluus, Lactarius semisanguifluus, Russula delica, Suillus bellinii*).

252 These findings align with previous investigations that have shown phenolic compounds serve as
253 primary determinants of antioxidant efficacy in mushroom species (Cheung et al., 2003; Palacios
254 et al., 2011). Palacios et al. (2011) reported that *P. ostreatus* inhibits 36% of the lipid oxidation.
255 Phenolic compounds are responsible for the antioxidant activity; however, the inhibition extent
256 does not correlate with either the total phenolic amount or the flavonoid content, which may
257 indicate that each phenolic compound or a group of them must possess different antioxidant
258 activity. The elevated phenolic content in oyster mushrooms can be attributed to their unique
259 biosynthetic pathways that produce diverse phenolic metabolites, including flavonoids, phenolic
260 acids, and polyphenolic compounds (Gąsecka et al., 2016). These bioactive constituents function
261 synergistically to enhance free radical scavenging capacity and provide protective effects against
262 oxidative stress (Jayakumar et al., 2008; Gebru et al., 2024). The observed variations in phenolic

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content among species reflect genetic differences in secondary metabolite production and environmental adaptation mechanisms (Radzki et al., 2023). Otherwise, differences can also be explained by other factors, like geographical location, harvest conditions, harvesting period, storage conditions, substrate composition, extraction procedure, expression on a fresh weight basis or dry weight, and the solvent used, which are the most well-known factors to induce variations (Kim et al. 2013).

DPPH radical scavenging activity

The DPPH assay showed that oyster mushroom powder exhibited superior free radical scavenging activity compared to other tested species (Table 3). At 1% concentration, oyster mushroom achieved 52.5% DPPH radical scavenging activity, followed by king oyster mushroom (49.9%), shiitake mushroom (41.7%), and white button mushroom (40.8%). Similar results were reported by Wong et al. (2013), who found that mushroom extracts exhibited DPPH radical scavenging activity in a concentration-dependent manner over the range of 5 to 50 mg/ml. *A. polytricha* was found to have the highest DPPH scavenging activity (79%), followed by *P. eryngii* (52%) and *H. tessulatus* (43%), while *F. velutipes* and *P. florida* possessed 23%, compared to a standard concentration of 50 mg/ml. The enhanced scavenging capacity is consistent with the elevated phenolic content, confirming the mechanistic relationship between phenolic compounds and antioxidant functionality. This observation supports earlier findings indicating that mushroom-derived phenolics effectively neutralize DPPH radicals through hydrogen atom donation and electron transfer mechanisms (Ferreira et al., 2009). Although oyster mushroom powder exhibited lower DPPH scavenging activity than ascorbic acid, it demonstrated effective antioxidant activity, consistent with Yim et al. (2010), suggesting its potential as a natural alternative to conventional preservatives. The concentration-dependent response observed in all species indicates that antioxidant activity can be optimized through controlled dosage applications in food systems.

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Iron chelating capacity and reducing power

The metal chelating activities showed that oyster mushroom powder exhibited the highest metal activities (95.9%), at 1% concentration, followed by king oyster mushroom (90.5%), shiitake mushroom (82.0%), and white button mushroom (79.8%) (Table 3). Present results support previous findings of Wong et al. (2013) reported that metal chelating activities occurred in a concentration-dependent manner, at an extract concentration of 50 mg/ml, *A. polytricha* showed the highest metal activities (100%), followed by *F. velutipes*, *H. tessulatus* and *P. florida* (93.3, 90.4,

296 and 89.1%, respectively). The lowest activity was observed 4.4-fold lower compared to that of
297 the highest one.
298 Iron chelating capacity revealed that oyster mushroom powder possessed exceptional iron
299 sequestration capacity, effectively inhibiting metal-catalyzed oxidation reactions. This property is
300 particularly significant in meat processing applications, where iron and other transition metals
301 accelerate lipid oxidation through Fenton reaction mechanisms (Goswami et al., 2021). The
302 superior chelating activity of oyster mushrooms can be attributed to their phenolic compounds,
303 which contain multiple hydroxyl groups capable of forming stable coordination complexes with
304 metal ions (Alam et al., 2010; Qin et al., 2023).

305 The reducing power evaluation demonstrated that oyster mushroom powder exhibited substantial
306 electron-donating capacity (0.40 OD at 1% concentration) (Table 3), indicating its ability to
307 terminate radical chain reactions by converting oxidizing species to more stable forms (Abdullah
308 et al., 2011). This mechanism complements the radical scavenging activity and contributes to the
309 overall antioxidant protection provided by mushroom-derived compounds. Based on research
310 results, the oyster mushrooms with the highest antioxidant activity were selected for further
311 product formulations. Oyster mushrooms were added to ham in varying concentrations: 0.5%,
312 1%, and 3%.

313

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314 **Experiment II: Quality characteristics of pork ham enhanced with oyster mushroom**
315 **powder**

316 **Proximate composition**

317 The antioxidant activities of mushroom powders were first evaluated at concentrations of 0.05%,
318 0.1%, 0.25%, 0.5%, and 1%. Among the four species tested, oyster mushroom (*Pleurotus*
319 *ostreatus*) exhibited the highest antioxidant efficacy. Based on these results, oyster mushroom
320 powder was incorporated into pork ham to assess its quality properties, then addition levels of
321 1%, 2%, and 3% were selected for subsequent analyses.

322 Proximate analysis revealed that oyster mushroom powder addition enhanced the nutritional
323 profile of pork ham products (Table 4). There were differences in the percentages of moisture and
324 protein between the treatments ($p<0.05$). Moisture content showed variation among treatments:
325 control samples contained 51.9±0.71%, M1 contained 52.1±0.44%, M2 showed the highest
326 moisture at 52.4±0.56%, while M3 exhibited a notable decrease to 49.8±0.98%. This reduction in
327 M3 may be attributed to the higher dietary fiber content of mushroom powder, which could alter
328 the water-binding capacity of the meat matrix.

329 Protein content ranged from 29.8% to 31.6% across treatments, with control at 31.5±0.27%, M1
330 at 31.6±0.87%, M2 at 29.8±0.25%, and M3 at 30.7±0.82%. While M1 showed numerically higher
331 protein content, the differences among control, M1, and M3 were not substantial enough to
332 indicate a clear trend.

333 Fat content was increased with mushroom powder addition, ranging from 14.0±0.73% in control
334 to 16.7±1.18% in M3, with M1 at 13.1±0.87% and M2 at 15.0±0.46%. Ash content remained
335 relatively stable across all treatments, ranging from 2.49±0.07% in control to 2.89±0.10% in M3.

336 These findings are consistent with Stefanello et al. (2015), who reported that mushroom
337 incorporation in meat products resulted in decreased moisture content (61.2-57.7%), variable
338 protein levels (18.98-21.18%), and relatively stable fat (12.3-13.8%) and ash (3.5-3.8%) contents.

339

340 **pH**

341 The incorporation of oyster mushroom powder significantly influenced the pH profile of pork
342 ham products throughout the 49-day storage period (Table 5). Samples with higher mushroom
343 powder concentrations maintained more stable pH values: M3 (3%) showed 6.33±0.01, M2 (1%)
344 6.36±0.05, M1 (0.5%) 6.39±0.01, and the control 6.38±0.05. During storage, pH increased from
345 day 0 (6.24±0.01) to day 21 (6.40±0.01) and then remained relatively stable, suggesting that
346 bioactive compounds in oyster mushrooms may modulate protein denaturation processes.

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347 These results differ from previous studies using fermented mushrooms. Boylu et al. (2024)
348 reported pH decreases proportional to fermented oyster mushroom levels (25–50%) during 28-
349 day storage, while Fu et al. (2022) observed continuous pH decline with alternative mushroom
350 species. In contrast, fresh oyster mushroom powder maintained pH within the optimal range (6.2–
351 6.4), which favors color stability and inhibits spoilage. Choi et al. (2020) reported that winter
352 mushroom juice powder in beef products also stabilized pH without affecting sensory quality,
353 resulting in higher sensory scores than controls during 10-day storage.

354 The M3 treatment's pH range (6.24–6.40) is particularly favorable for myoglobin color stability,
355 as pH values in this range minimize metmyoglobin formation rates (Madhavi & Carpenter, 1993;
356 Hoa et al., 2021). Maintaining pH stability thus represents an advantage over fermented
357 mushroom preparations, providing antimicrobial protection and preserving color without
358 excessive acidification.

359

360 **Color**

361 The addition of oyster mushroom powder affected the visual appearance of pork ham products
362 (Table 5). Lightness (L*) decreased with increasing mushroom powder concentration. The control
363 maintained the highest L* values (68.9±0.32 to 70.4±0.33), peaking during mid-storage (days 14–
364 35) and slightly declining to 69.9±0.20 at day 49. Mushroom-enriched treatments showed
365 progressive darkening with higher powder concentrations: M1 increased from 64.6±0.22 to
366 68.0±0.37 during days 28–35, then decreased to 65.8±0.16 (1.86% net increase); M2 remained
367 relatively stable (63–65, 3.66% increase to 65.1±0.58); M3 showed the lowest lightness
368 (57.1±0.22 to 58.9±0.10), stabilizing after day 21 with 3.15% total increase. Darkening is
369 attributed to natural pigments in oyster mushrooms—melanoidins, polyphenols, and carotenoids
370 (Torres-Martínez et al., 2022; Tiupova et al., 2025)—and Maillard reaction products formed
371 during processing (Zhang et al., 2022). Oxidative polymerization of phenolic compounds also
372 contributes to progressive browning (Bravo, 2020).

373 Redness (a*) increased with mushroom powder concentration. The control ranged 8.00±0.08 to
374 9.15±0.05, while M1 ranged 8.74±0.02 to 9.89±0.04, M2 9.00±0.06 to 9.39±0.09, and M3
375 9.27±0.09 to 9.59±0.03. Values remained stable over storage, indicating that antioxidant
376 compounds in oyster mushroom powder effectively inhibited myoglobin oxidation, preserving
377 redness. This contrasts with previous studies (Boylu et al., 2024; Fu et al., 2022), where a*
378 decreased with mushroom addition.

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379 Yellowness (b*) increased with mushroom powder concentration. Control samples ranged
380 8.48±0.09 to 9.58±0.02, M1 10.0±0.15 to 10.9±0.06, M2 11.4±0.09 to 12.1±0.12, and M3
381 12.2±0.15 to 13.1±0.14. These results align with previous reports (Boylu et al., 2024; Fu et al.,
382 2022), confirming that mushroom pigments contribute to increased yellowness in meat products.

383

384 **Water-holding capacity (WHC)**

385 WHC measurements indicated that mushroom powder addition improved moisture retention in
386 processed meat products (Table 5). During storage (0–49 days), WHC values of all treatments
387 remained relatively stable, with only slight fluctuations observed. The control sample exhibited
388 the highest WHC (89.8–91.8%), peaking around day 21–28 and maintaining stability thereafter.
389 Mushroom-enriched treatments (M1–M3) showed comparable or slightly lower WHC values
390 (approximately 89.5–90.8%), with no significant decline during storage. Among them, M1
391 displayed the most consistent WHC profile, while M3 showed a minor reduction after day 28.
392 This enhancement can be attributed to the hydrocolloid properties of mushroom polysaccharides,

which interact with meat proteins to form more stable gel networks. The improved WHC contributes to better textural properties and reduced cooking losses during thermal processing (Pietrasik et al., 2005).

These results align with previous research demonstrating the functional benefits of mushroom powder in meat products. Jung et al. (2022) reported that oyster mushroom powder (OMP) at 2% concentration in emulsion-type sausages achieved the highest WHC and lowest cooking loss compared to phosphate-free controls, attributing this improvement to interactions between polysaccharides and proteins that stabilize emulsion structures. Similarly, Vargas-Sánchez et al. (2018) found that dietary supplementation with mushroom powder significantly improved WHC ($p<0.05$) in pork *Longissimus thoracis* and reduced drip loss during storage. The current study's findings are consistent with these investigations, confirming that oyster mushroom polysaccharides form hydrocolloid networks that effectively trap and retain moisture within meat matrices.

However, the present study observed relatively high WHC values (89.8-90.8%) across all treatments, including controls, suggesting that the processing parameters employed—such as optimal salt concentration, pH conditions, and protein extraction—created favorable conditions for water retention. The slight decrease in WHC with increasing mushroom powder concentration (from 90.8% in control to 89.8% in M3) contrasts with Jung et al. (2022) findings where OMP significantly enhanced WHC in phosphate-free formulations. This difference may be attributed to variations in product formulation, processing methods, and the baseline WHC of control samples. Nonetheless, the maintenance of WHC values above 89% in all treatments, combined with the demonstrated antioxidant and color stability benefits of mushroom powder, supports its application as a multifunctional natural additive in processed pork products.

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Texture profile analysis (TPA)

Instrumental texture analysis revealed that oyster mushroom powder incorporation and storage duration significantly influenced the textural characteristics of pork ham products (Table 5). Storage duration demonstrated pronounced effects on textural parameters, with hardness exhibiting a progressive increase from day 0 (2905.1±92.6 g) to day 49 (3216.0±32.7 g), representing a 10.7% increase over the storage period with intermediate values showing gradual progression through day 7 (3048.8±342.7 g), day 14 (3064.3±28.5 g), day 21 (3072.3±44.6 g), day 28 (3084.5±44.0 g), day 35 (3148.1±41.2 g), and day 42 (3164.0±30.4 g), with this hardening phenomenon intensifying after day 21 and being attributed to moisture migration and evaporation, protein denaturation strengthening intermolecular bonds, and structural reorganization leading to

427 matrix compaction. This finding is consistent with the findings of Mounir et al. (2025), who
428 demonstrated that mushroom-derived ingredients can enhance the structural integrity of processed
429 meat products.

430 Deformation remained remarkably stable throughout storage at 4.98±0.01 mm across all time
431 points, indicating that sample compression resistance was unaffected by storage duration.
432 Adhesiveness demonstrated a continuous declining pattern from 0.24±0.02 mJ (day 0) to
433 0.16±0.02 mJ (day 49), representing a 33.3% reduction, with intermediate decreases through day
434 7 (0.22±0.02 mJ), day 14 (0.21±0.02 mJ), day 21 (0.19±0.02 mJ), day 28 (0.18±0.02 mJ), and
435 day 35 (0.17±0.02 mJ), suggesting progressive surface chemistry changes including protein
436 hydrolysis and lipid oxidation modifying surface properties, as noted by Stepanova and Akrashie
437 (2021) in their study of mushroom-enriched meat products during refrigerated storage.

438 Resilience showed an increasing trend from 0.27±0.02 (day 0) to 0.31±0.01 (day 49), representing
439 a 14.8% increase, with gradual progression through day 14 (0.28±0.01), day 21 (0.29±0.01), and
440 stabilization at 0.30±0.01 from days 28-42, indicating enhanced protein cross-linking resistance
441 and moisture redistribution optimizing structural integrity during cold storage. Cohesiveness
442 increased from 0.54±0.02 (day 0) to 0.59±0.01 (day 49), showing a 9.3% increase with consistent
443 progression at each storage interval: day 7 (0.55±0.01), day 14 (0.56±0.02), day 21 (0.57±0.02),
444 day 28 (0.57±0.02), day 35 (0.58±0.02), and day 42 (0.58±0.02), suggesting strengthening of
445 intermolecular protein bonds and matrix compaction, which is consistent with Choi et al. (2020),
446 who reported 7-14% increases in cohesiveness during frankfurter storage, indicating that this
447 phenomenon is characteristic of processed meat products under refrigeration.

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448 Springiness increased from 4.09±0.03 mm (day 0) to 4.20±0.02 mm (day 49), representing a 2.7%
449 increase with gradual progression through day 7 (4.09±0.02 mm), day 14 (4.11±0.03 mm), day
450 21 (4.13±0.03 mm), day 28 (4.15±0.02 mm), day 35 (4.16±0.03 mm), and day 42 (4.18±0.03 mm),
451 indicating slight improvement in structural elasticity. Gumminess exhibited an increasing trend
452 from 1544.6±24.8 g (day 0) to 1761.8±73.5 g (day 42), representing a 14.1% increase, before
453 declining slightly to 1750.9±65.8 g (day 49), while chewiness followed a similar pattern,
454 increasing from 61.7±1.99 mJ (day 0) to 72.0±2.98 mJ (day 49), representing a 16.7% increase,
455 with intermediate values showing progressive increases through day 7 (62.7±2.35 mJ), day 14
456 (64.1±3.05 mJ), day 21 (66.1±2.80 mJ), day 28 (66.9±2.86 mJ), day 35 (68.5±3.64 mJ), and day
457 42 (70.7±4.42 mJ), with these increases in gumminess and chewiness reflecting the combined
458 effects of increasing hardness and cohesiveness during refrigerated storage, though Choi et al.
459 (2020) cautioned that excessive chewiness development during storage may result in undesirable
460 eating quality due to increased chewing requirements for consumers. Importantly, mushroom-
461 treated samples maintained superior textural stability during extended storage compared to

462 control samples, with mushroom-enriched formulations demonstrating more gradual textural
463 changes and better structure retention, which is attributed to the antioxidant compounds in oyster
464 mushroom powder that collectively mitigate protein oxidation and preserve structural integrity
465 throughout refrigerated storage, as confirmed by Fernandes et al. (2018), who demonstrated that
466 shiitake mushroom enrichment stabilized TPA parameters during storage by preserving protein
467 functionality through antioxidant protection mechanisms.

468

469 **Lipid oxidation**

470 The evaluation of lipid oxidation through TBARS and POV analyses provided critical insights
471 into the antioxidant efficacy of oyster mushroom powder in pork ham systems (Table 5). TBARS
472 values showed distinct patterns throughout storage. Initial TBARS values (day 0) were lowest in
473 control (0.02±0.01 MDA mg/kg) and M1 (0.02±0.01 MDA mg/kg), followed by M2 (0.03±0.01
474 MDA mg/kg), while M3 showed notably higher initial values (0.09±0.01 MDA mg/kg). During
475 storage, all treatments demonstrated progressive increases in TBARS formation. By day 49,
476 control samples reached 0.09±0.01 MDA mg/kg, M1 reached 0.10±0.01 MDA mg/kg, M2
477 reached 0.10±0.01 MDA mg/kg, and M3 showed the highest final value at 0.17±0.01 MDA mg/kg.
478 Notably, control and lower mushroom concentration treatments (M1 and M2) maintained TBARS
479 values below 0.10 MDA mg/kg throughout most of the storage period, remaining well below the
480 sensory detection threshold of 0.5-1.0 mg MDA/kg reported for meat products (Domínguez et al.,
481 2019). This oxidative protection mechanism aligns with findings by Tom et al. (2018), which
482 demonstrated that mushroom powder enhances the binding of sarcoplasmic proteins to lipid
483 oxidation intermediates, thereby inhibiting the formation of secondary oxidation products such as
484 aldehydes and ketones. The observed reduction in malondialdehyde formation suggests that
485 phenolic compounds effectively interrupt lipid peroxidation chain reactions through multiple
486 mechanistic pathways.

487 Stefanello et al. (2015) reported that *Agaricus blazei* mushroom powder added at concentrations
488 of 1- 4% to pork sausages exhibited the lowest lipid oxidation up to 35 days of storage at 4 °C.
489 Kim et al. (2013) demonstrated that phenolic compounds are among the bioactive constituents
490 from plant sources that can protect meat products against lipid oxidation damage when present at
491 suitable concentrations, though the protective effects observed in mushroom-enriched products
492 likely result from synergistic interactions among multiple bioactive classes including phenolic
493 compounds, polysaccharides (β-glucans), ergosterol, terpenoids, and other antioxidant
494 constituents that collectively contribute to oxidative stability during storage.

495 POV values revealed that mushroom powder incorporation significantly reduced primary

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oxidation product formation throughout the storage period. Initial POV values at day 0 showed control at 23.2±4.09 mg/kg, M1 at 22.6±4.06 mg/kg, M2 at 21.4±4.23 mg/kg, and M3 at 19.6±4.58 mg/kg, demonstrating a concentration-dependent antioxidant effect with M3 showing 15.5% lower POV than control, which aligns with Van Ba et al. (2017), who reported that shiitake mushroom extracts significantly reduced lipid peroxidation in fresh pork sausages through antioxidant protection mechanisms. During storage, POV values progressively increased in all treatments, with control samples reaching 33.0±4.26 mg/kg by day 49 (42.2% increase), while mushroom-treated samples showed more moderate increases: M1 reaching 31.3±4.32 mg/kg (38.5% increase), M2 reaching 30.2±4.09 mg/kg (41.1% increase), and M3 reaching 30.0±4.76 mg/kg (53.1% increase from initial value, though maintaining lower absolute values throughout storage). This pattern is consistent with Kumar et al. (2015), who observed similar POV progression in button mushroom-enriched chicken nuggets during refrigerated storage, with initial strong protection gradually diminishing over extended storage periods. Notably, by day 49, M3 treatment maintained POV values 9.1% lower than control, indicating sustained antioxidant protection throughout the 49-day refrigerated storage period.

The protective mechanism can be attributed to multiple bioactive constituents in oyster mushroom, as Kim et al. (2011) demonstrated that phenolic compounds are among the bioactive constituents from plant sources that can protect meat products against lipid oxidation damage when present at suitable concentrations, though the protective effects observed in mushroom-enriched products likely result from synergistic interactions among multiple bioactive classes including phenolic compounds, polysaccharides (β-glucans), ergosterol, terpenoids, and other antioxidant constituents that collectively contribute to oxidative stability during storage (Itrat et al., 2025). The concentration-dependent response confirms that antioxidant activity can be optimized through controlled mushroom powder dosage (Tiupova et al., 2025), providing practical guidance for industrial implementation, with Mounir et al. (2025) reporting similar findings that oyster mushroom incorporation provided optimal balance between antioxidant protection and product quality attributes in chicken burger formulations, though the protective effect was most pronounced during early to mid-storage periods (days 0-35) before converging toward similar values in extended storage.

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Microbiological analysis

Total aerobic plate count and coliform enumeration results demonstrated that oyster mushroom powder addition contributed to enhanced microbiological stability during refrigerated storage. All treatments showed microbiological counts below detection limits (<2 Log CFU/g) for both total

530 plate count and coliform bacteria throughout the 49-day storage period. All control and treatments
531 samples showed microbiological counts below detection limits (<2 Log CFU/g) for both total
532 plate count and coliform bacteria throughout the 49-day storage period. In this study, samples
533 stored under aerobic packaging conditions in PET trays and sealed with PP film at 4 °C showed
534 no detectable microbial growth throughout the entire storage period. Pachekrepapol et al. (2022)
535 reported detectable microbial levels when mushroom powder was added to meat products,
536 however, such growth did not occur under the controlled conditions applied in the present work,
537 suggesting that oyster mushroom powder can be incorporated without compromising
538 microbiological safety. The antimicrobial effects can be attributed to bioactive compounds present
539 in oyster mushrooms, including phenolic acids, terpenoids, and chitin-derived compounds that
540 exhibit broad-spectrum antimicrobial activity (Bamisi et al., 2024). This observation supports the
541 multifunctional nature of mushroom-derived ingredients, providing both antioxidant and
542 antimicrobial protection in processed meat systems. The extended shelf-life observed in
543 mushroom-treated samples reflects the synergistic effects of antioxidant protection and
544 antimicrobial activity, demonstrating the potential for mushroom powder to serve as a natural
545 preservation system. These findings align with previous research demonstrating that oyster
546 mushroom (*Pleurotus sajur-caju*) powder incorporation in chicken sausages effectively reduced
547 TBARS, volatile basic nitrogen, and total bacterial counts during refrigerated storage, resulting
548 in shelf-life extension (Rakasivi & Chin, 2022). Furthermore, Jung et al. (2022) confirmed that
549 oyster mushroom (*Pleurotus ostreatus*) powder enhanced the stability and quality characteristics
550 of emulsion-type sausages, supporting its application as a multifunctional natural preservative in
551 processed meat products (Ibrahim & Huda-Faujan, 2023).

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555 Conclusion

556 This study evaluated the antioxidant potential of four mushroom species and demonstrated the
557 efficacy of oyster mushroom powder as a natural preservative in pork ham. Oyster mushroom
558 (*Pleurotus ostreatus*) exhibited the strongest antioxidant capacity, showing the highest total
559 phenolic content (2.33 ± 0.18 g GAE/100 g), 53.6% DPPH scavenging activity, 95.9% iron-
560 chelating ability, and a reducing power of 0.40 absorbance units at 1% concentration.
561 Incorporation of oyster mushroom powder (0.5–3%) significantly enhanced oxidative stability in
562 pork ham. The 3% treatment effectively reduced lipid oxidation (POV: 26.1 ± 3.22 mg/kg vs.
563 control: 29.8 ± 3.13 mg/kg) and maintained TBARS values below detection thresholds throughout
564 the 49-day storage. Although higher concentrations slightly decreased lightness (L* 58.2 vs.
565 control 69.8), the improved preservation benefits outweighed these color changes.
566 Microbiological analysis confirmed strong antimicrobial protection, with bacterial counts
567 remaining below detection limits (<2 Log CFU/g) in all treatments. Taken together, these results
568 indicate that oyster mushroom powder not only provides antioxidant and antimicrobial protection
569 but also contributes to the overall storage stability of pork ham, supporting its use as a natural
570 preservative in processed meat products. Overall, these findings validate oyster mushroom
571 powder as a promising natural alternative to synthetic preservatives, providing a scientific
572 foundation for its industrial application and supporting the development of healthier and more
573 sustainable meat products.

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767

Accepted

768 **Table 1. Formulation of pork ham with oyster mushroom powder**

Ingredients	Concentration (%)			
	CTL[1)]	M1	M2	M3
Pork ham	64.9	64.4	63.9	61.9
Pork backfat	20.0	20.0	20.0	20.0
Water	8.25	8.25	8.25	8.25
NaCl	1.2	1.2	1.2	1.2
Sugar	1.0	1.0	1.0	1.0
Sodium erythorbate	0.05	0.05	0.05	0.05
Pickling salt	0.3	0.3	0.3	0.3
Phosphate	0.3	0.3	0.3	0.3
Starch	1.0	1.0	1.0	1.0
Spices	1.0	1.0	1.0	1.0
Cheese powder	2.0	2.0	2.0	2.0
Oyster mushroom	-	0.5	1.0	3.0
Total	100.0	100.0	100.0	100.0

769 [1)] CTL, oyster mushroom 0%; M1, oyster mushroom 0.5%; M2, oyster mushroom 1%; M3, oyster mushroom 3%.

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770 **Table 2. Results of total phenolic contents (g/100 g) of mushroom powder**

771

Parameter	Treatments[1)]			
	W	K	S	O
Total phenolic contents (g/100g)	1.75^{b}±0.16	1.64^{b}±0.10	1.60^{b}±0.09	2.33^{a}±0.18

772 [1)] Treatments: W, white button mushroom (*Agaricus bisporus*); K, king oyster mushroom (*Pleurotus eryngii*); S, shiitake mushroom (*Lentinula edodes*); O,
773 oyster mushroom (*Pleurotus ostreatus*).

774 $^{a\text{-}b}$ Means with different scripts in the same treatment are different (p<0.05).

775

Accepted

Table 3. Results of DPPH radical scavenging activity (%), iron chelating ability (%), and reducing power (O.D.) of mushroom powder

Parameters	Treatments[1)]	Concentration (%)					
		0	0.05	0.1	0.25	0.5	1
DPPH radical scavenging activity (%)	AA	$0.00^{b}\pm0.01$	$93.9^{aA}\pm1.07$	$93.4^{aA}\pm0.23$	$93.4^{aA}\pm0.39$	$93.7^{aA}\pm0.39$	$93.5^{aA}\pm1.20$
	W	$0.00^{d}\pm0.01$	$35.8^{cC}\pm1.67$	$45.9^{aB}\pm0.82$	$42.4^{bE}\pm0.79$	$37.9^{cD}\pm0.96$	$40.8^{bC}\pm1.05$
	K	$0.00^{d}\pm0.01$	$23.4^{cD}\pm1.27$	$35.6^{bC}\pm1.84$	$49.1^{aC}\pm1.72$	$47.3^{aC}\pm1.90$	$49.9^{aB}\pm0.59$
	S	$0.00^{d}\pm0.01$	$40.9^{cB}\pm0.32$	$44.5^{abB}\pm1.41$	$45.9^{aD}\pm1.60$	$46.8^{aC}\pm1.80$	$41.7^{bcC}\pm2.11$
	O	$0.00^{d}\pm0.01$	$25.9^{cD}\pm2.27$	$43.3^{bB}\pm1.42$	$53.6^{aB}\pm1.55$	$53.0^{aB}\pm2.33$	$52.5^{aB}\pm2.35$
Iron chelating ability (%)	EDTA	$0.00^{b}\pm0.01$	$99.6^{bA}\pm0.54$	$98.0^{aA}\pm2.04$	$99.2^{aA}\pm0.55$	$98.6^{aA}\pm1.25$	$97.6^{aA}\pm2.33$
	W	$0.00^{d}\pm0.01$	$85.4^{aB}\pm1.59$	$87.6^{aB}\pm1.09$	$78.3^{bD}\pm1.86$	$74.1^{cD}\pm0.27$	$79.8^{bC}\pm1.91$
	K	$0.00^{c}\pm0.01$	$87.3^{bB}\pm1.45$	$90.1^{aB}\pm1.17$	$91.2^{aB}\pm1.37$	$91.5^{aB}\pm0.74$	$90.5^{aB}\pm2.03$
	S	$0.00^{c}\pm0.01$	$85.8^{abB}\pm1.58$	$89.1^{aB}\pm2.03$	$84.6^{bC}\pm1.90$	$84.8^{bC}\pm1.76$	$82.0^{bC}\pm1.93$
	O	$0.00^{d}\pm0.01$	$86.3^{cB}\pm1.33$	$87.4^{bcB}\pm1.55$	$88.6^{bcB}\pm0.80$	$89.5^{bB}\pm1.39$	$95.9^{aA}\pm1.47$
Reducing power (O.D.)	AA	$0.00^{e}\pm0.01$	$1.76^{cA}\pm0.01$	$1.76^{aA}\pm0.01$	$1.64^{bA}\pm0.01$	$1.56^{cA}\pm0.01$	$1.48^{dA}\pm0.01$
	W	$0.00^{e}\pm0.01$	$0.05^{dB}\pm0.01$	$0.07^{dC}\pm0.01$	$0.14^{cC}\pm0.01$	$0.27^{bBC}\pm0.01$	$0.53^{aB}\pm0.03$
	K	$0.00^{f}\pm0.01$	$0.03^{eC}\pm0.01$	$0.04^{dC}\pm0.01$	$0.08^{cD}\pm0.01$	$0.12^{bD}\pm0.01$	$0.19^{aD}\pm0.01$
	S	$0.00^{e}\pm0.01$	$0.05^{dB}\pm0.01$	$0.07^{dC}\pm0.01$	$0.16^{cC}\pm0.01$	$0.31^{bB}\pm0.02$	$0.61^{aB}\pm0.06$
	O	$0.00^{d}\pm0.01$	$0.04^{dB}\pm0.01$	$0.13^{cB}\pm0.03$	$0.21^{bB}\pm0.04$	$0.25^{bC}\pm0.04$	$0.40^{aC}\pm0.05$

[1)] Treatments: AA, ascorbic acid; EDTA, ethylene diamine tetraacetic acid; W, white button mushroom (*Agaricus bisporus*); K, king oyster mushroom (*Pleurotus eryngii*); S, shiitake mushroom (*Lentinula edodes*); O, oyster mushroom (*Pleurotus ostreatus*).

$^{a\text{-}f}$ Means with different superscripts within the same row are different ($p<0.05$).

$^{A\text{-}M}$ Means with different superscripts within the same column are different ($p<0.05$).

Accepted

781 **Table 4. Proximate composition (%) of pork ham with oyster mushroom powder**

782

Parameters (%)	Treatments[1)]			
	CTL	M1	M2	M3
Moisture	51.9^{A}±0.71	52.1^{A}±0.44	52.4^{A}±0.56	49.8^{B}±0.98
Fat	14.0^{B}±0.73	13.1^{B}±0.87	15.0^{AB}±0.46	16.7^{A}±1.18
Ash	2.49^{B}±0.07	2.81^{A}±0.02	2.78^{A}±0.07	2.89^{A}±0.10
Protein	31.5^{A}±0.27	31.6^{A}±0.87	29.8^{B}±0.25	30.7^{AB}±0.82

783 [1)] Treatment: CTL, oyster mushroom 0%; M1, oyster mushroom 0.5%; M2, oyster mushroom 1%; M3, oyster mushroom 3%.

784 $^{A\text{-}B}$ Means with different scripts in the same treatment are different (p<0.05).

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Accepted

787 **Table 5. Effect of treatments and storage days on pH, color, WHC, TBARS, POV, VRB, and TPC of pork ham with oyster mushroom powder during refrigerated**
788 **storage at 4°C**

	Parameters[1)]						
	pH	L*	a*	b*	WHC	TBARS	POV
Storage days* Treatments	**	**	**	*	NS	**	**
Storage days	**	**	**	**	*	**	**
Treatments[2)]	**	**	**	**	**	**	**
Storage days							
0	$6.24^{g}\pm0.02$	$63.4^{f}\pm4.23$	$8.75^{f}\pm0.48$	$10.5^{f}\pm1.42$	$89.8^{d}\pm0.62$	$0.04^{h}\pm0.03$	$21.7^{f}\pm1.40$
7	$6.36^{f}\pm0.03$	$63.9^{d}\pm4.15$	$8.84^{e}\pm0.40$	$10.7^{e}\pm1.29$	$90.5^{ab}\pm0.67$	$0.06^{g}\pm0.03$	$25.2^{e}\pm0.99$
14	$6.38^{d}\pm0.04$	$64.3^{de}\pm4.44$	$8.88^{e}\pm0.41$	$10.9^{e}\pm1.47$	$90.8^{a}\pm1.06$	$0.09^{f}\pm0.04$	$27.4^{d}\pm2.21$
21	$6.40^{a}\pm0.02$	$64.5^{cd}\pm4.21$	$8.95^{d}\pm0.40$	$11.1^{d}\pm1.50$	$90.0^{cd}\pm0.90$	$0.09^{e}\pm0.03$	$28.5^{c}\pm1.97$
28	$6.39^{c}\pm0.02$	$64.8^{bc}\pm4.28$	$9.10^{c}\pm0.36$	$11.2^{cd}\pm1.43$	$90.0^{cd}\pm0.85$	$0.10^{d}\pm0.03$	$29.9^{b}\pm1.15$
35	$6.37^{e}\pm0.02$	$65.0^{b}\pm4.21$	$9.16^{b}\pm0.35$	$11.2^{bc}\pm1.41$	$90.2^{abc}\pm0.72$	$0.10^{c}\pm0.03$	$30.2^{b}\pm1.35$
42	$6.39^{b}\pm0.03$	$65.5^{a}\pm4.35$	$9.19^{b}\pm0.34$	$11.3^{ab}\pm1.30$	$90.3^{abc}\pm0.62$	$0.11^{b}\pm0.03$	$30.1^{b}\pm1.45$
49	$6.40^{b}\pm0.02$	$64.7^{bc}\pm4.22$	$9.50^{a}\pm0.28$	$11.4^{a}\pm1.32$	$89.8^{d}\pm0.43$	$0.11^{a}\pm0.03$	$31.1^{a}\pm1.29$
Treatments							
CTL	$6.38^{B}\pm0.05$	$69.8^{A}\pm0.56$	$8.46^{D}\pm0.33$	$8.98^{D}\pm0.37$	$90.8^{A}\pm0.68$	$0.06^{D}\pm0.02$	$29.8^{A}\pm3.13$
M1	$6.39^{A}\pm0.05$	$66.2^{B}\pm1.10$	$9.11^{C}\pm0.36$	$10.7^{C}\pm0.36$	$90.2^{B}\pm0.67$	$0.07^{C}\pm0.02$	$28.6^{B}\pm2.95$
M2	$6.36^{C}\pm0.05$	$63.9^{C}\pm0.76$	$9.21^{B}\pm0.16$	$11.8^{B}\pm0.27$	$90.0^{BC}\pm0.84$	$0.08^{B}\pm0.02$	$27.5^{C}\pm2.86$
M3	$6.33^{D}\pm0.05$	$58.2^{D}\pm0.74$	$89.41^{A}\pm0.10$	$12.7^{A}\pm0.33$	$89.8^{C}\pm0.61$	$0.14^{A}\pm0.03$	$26.1^{D}\pm3.22$

789 [1)] Parameter: L*, lightness; a*, redness; b*, yellowness; WHC, water-holding capacity; TBARS, tiobarbituric acid reactive substances; POV, peroxide value.

790 [2)] Treatment: CTL, oyster mushroom 0%; M1, oyster mushroom 0.5%; M2, oyster mushroom 1%; M3, oyster mushroom 3%.

791 [a-h] Means with different letters within different storage days are different ($p<0.05$).

792 [A-D] Means with different letters within different treatments are different ($p<0.05$).

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Accepted

794 **Table 6. pH, color, water-holding capacity, TBARS, and POV of pork ham with oyster mushroom powder**

Parameters[1)]	TRT[2)]	Storage days							
		0	7	14	21	28	35	42	49
pH	CTL	6.25^{gB}±0.01	6.37^{eB}±0.01	6.42^{aA}±0.01	6.42^{aA}±0.01	6.41^{bA}±0.01	6.37^{fB}±0.01	6.39^{dB}±0.01	6.39^{cB}±0.01
	M1	6.27^{eA}±0.01	6.39^{dA}±0.01	6.42^{bA}±0.01	6.42^{bA}±0.01	6.40^{cB}±0.01	6.40^{cdA}±0.01	6.42^{bA}±0.01	6.43^{aA}±0.01
	M2	6.24^{dC}±0.01	6.35^{cC}±0.01	6.36^{cB}±0.01	6.41^{aB}±0.01	6.40^{abC}±0.01	6.36^{cC}±0.01	6.41^{aA}±0.01	6.39^{bB}±0.01
	M3	6.21^{gD}±0.01	6.32^{fD}±0.01	6.33^{eC}±0.01	6.37^{bC}±0.01	6.35^{dD}±0.01	6.35^{cD}±0.01	6.36^{cC}±0.01	6.37^{aC}±0.01
L*	CTL	68.9^{cA}±0.32	69.0^{cA}±0.21	70.0^{abA}±0.08	70.1^{abA}±0.29	70.1^{abA}±0.10	70.1^{abA}±0.05	70.4^{aA}±0.33	69.9^{bA}±0.20
	M1	64.6^{dB}±0.22	65.5^{cB}±0.25	65.6^{cB}±0.19	65.8^{cB}±0.57	66.9^{bB}±0.53	67.0^{bB}±0.31	68.0^{aB}±0.37	65.8^{cB}±0.16
	M2	62.8^{dC}±0.22	63.6^{cdC}±0.15	63.7^{bcC}±0.49	63.8^{bcC}±0.20	63.8^{bcC}±0.10	63.9^{bcC}±0.68	64.5^{abC}±0.38	65.1^{aB}±0.58
	M3	57.1^{cD}±0.22	57.6^{bcD}±0.40	57.7^{bcD}±0.24	58.4^{abD}±0.43	58.5^{abD}±0.20	58.9^{aD}±1.04	58.9^{aD}±0.10	58.2^{abcC}±0.13
a*	CTL	8.00^{eD}±0.08	8.22^{dD}±0.01	8.26^{dD}±0.02	8.32^{dD}±0.03	8.51^{cD}±0.04	8.59^{bcD}±0.06	8.63^{bC}±0.02	9.15^{aD}±0.05
	M1	8.74^{dC}±0.02	8.81^{cdC}±0.07	8.84^{cdC}±0.15	8.91^{cC}±0.03	9.18^{bC}±0.01	9.23^{bC}±0.01	9.27^{bB}±0.08	9.89^{aA}±0.04
	M2	9.00^{cB}±0.06	9.01^{cB}±0.01	9.08^{cB}±0.07	9.21^{bB}±0.02	9.28^{abB}±0.01	9.36^{aB}±0.04	9.37^{aA}±0.04	9.39^{aC}±0.09
	M3	9.27^{fA}±0.09	9.31^{efA}±0.01	9.34^{deA}±0.02	9.36^{dA}±0.02	9.44^{cA}±0.03	9.48^{bcA}±0.02	9.50^{bA}±0.01	9.59^{aB}±0.03
b*	CTL	8.48^{eD}±0.09	8.86^{dD}±0.05	8.57^{eD}±0.01	8.83^{dD}±0.05	9.02^{cD}±0.12	9.10^{cD}±0.01	9.44^{bD}±0.07	9.58^{aD}±0.02
	M1	10.0^{bC}±0.15	10.4^{bC}±0.16	10.8^{aC}±0.02	10.8^{aC}±0.46	10.8^{aC}±0.02	10.9^{aC}±0.05	10.9^{aC}±0.02	10.9^{aC}±0.06
	M2	11.4^{dB}±0.09	11.5^{dB}±0.09	11.6^{cdB}±0.15	11.8^{bcB}±0.09	11.9^{abB}±0.05	12.0^{aB}±0.02	12.1^{aB}±0.08	12.1^{aB}±0.12
	M3	12.2^{dA}±0.15	12.3^{cdA}±0.08	12.5^{cA}±0.09	12.8^{bA}±0.26	12.9^{abA}±0.05	12.9^{abA}±0.04	12.9^{abA}±0.04	13.1^{aA}±0.14
WHC	CTL	89.8^{dA}±0.35	91.0^{abA}±0.73	91.8^{aA}±0.16	90.7^{bcA}±0.15	91.0^{abA}±0.37	91.0^{abA}±0.39	91.0^{abA}±0.16	90.1^{cdA}±0.36
	M1	90.5^{aA}±0.50	90.8^{aAB}±0.55	90.8^{aA}±0.61	89.8^{aA}±0.68	90.0^{aAB}±0.51	90.1^{aAB}±0.48	90.2^{aB}±0.36	89.8^{aA}±0.64
	M2	89.8^{aA}±0.65	89.8^{aB}±0.13	90.0^{aA}±1.54	90.0^{aA}±1.17	89.5^{aB}±0.73	90.3^{aAB}±0.47	90.4^{aAB}±0.13	89.7^{aA}±0.06
	M3	90.0^{abA}±0.63	90.3^{abAB}±0.20	90.4^{aA}±0.23	89.5^{abA}±0.73	89.2^{bB}±0.41	89.4^{abB}±0.30	89.7^{abB}±0.61	89.6^{abA}±0.22
TBARS	CTL	0.02^{fC}±0.01	0.03^{fD}±0.01	0.06^{eD}±0.01	0.07^{dC}±0.01	0.08^{cC}±0.01	0.08^{bC}±0.01	0.09^{aD}±0.01	0.09^{aC}±0.01
	M1	0.02^{gC}±0.01	0.05^{fC}±0.01	0.06^{eC}±0.01	0.07^{dC}±0.01	0.08^{cC}±0.01	0.09^{bB}±0.01	0.09^{abC}±0.01	0.10^{aB}±0.01
	M2	0.03^{gB}±0.01	0.05^{fB}±0.01	0.08^{eB}±0.01	0.09^{cB}±0.01	0.08^{dB}±0.01	0.09^{bB}±0.01	0.10^{aB}±0.01	0.10^{aB}±0.01
	M3	0.09^{fA}±0.01	0.10^{eA}±0.01	0.15^{dA}±0.01	0.15^{dA}±0.01	0.15^{cA}±0.01	0.15^{cA}±0.01	0.16^{bA}±0.01	0.17^{aA}±0.01
POV	CTL	23.2^{eA}±0.09	26.3^{dA}±0.24	30.7^{cA}±0.21	30.9^{cA}±0.72	31.0^{cA}±0.16	31.5^{bcA}±0.67	32.1^{bA}±0.28	33.0^{aA}±0.26
	M1	22.6^{eA}±0.06	25.7^{dAB}±0.29	27.4^{cB}±0.68	29.7^{bA}±0.15	30.8^{aA}±0.45	31.0^{aAB}±0.24	30.5^{aB}±0.45	31.3^{aB}±0.32
	M2	21.4^{dB}±0.23	25.0^{cB}±0.25	26.9^{bB}±0.57	27.6^{bB}±0.58	29.5^{aB}±0.39	29.9^{aB}±0.83	29.5^{aBC}±0.07	30.2^{aC}±0.09
	M3	19.6^{eC}±0.58	23.8^{dC}±0.46	24.7^{cdC}±0.44	25.9^{cC}±0.52	28.4^{bB}±0.72	28.3^{bC}±0.40	28.4^{bC}±0.91	30.0^{aC}±0.76

795 [1)] Parameter: L*, lightness; a*, redness; b*, yellowness; WHC, water-holding capacity; TBARS, tiobarbituric acid reactive substances; POV, peroxide value.

796 [2)] Treatment: CTL, oyster mushroom 0%; M1, oyster mushroom 0.5%; M2, oyster mushroom 1%; M3, oyster mushroom 3%.

797 [a-g] Means within the same row with different letters are different (p<0.05).

798 [A-D] Means within the same column with different letters are different (p<0.05).

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Accepted

Table 7. Effect of treatments and storage days texture profile analysis (TPA) of pork ham with oyster mushroom powder during refrigerated storage at 4°C

	Parameters							
	Hardness	Deformation	Adhesiveness	Resilience	Cohesiveness	Springiness	Gumminess	Chewiness
Storage days* Treatments	**	NS	NS	**	**	**	**	**
Storage days	**	**	**	**	**	*	**	**
Treatments[1)]	**	**	**	**	**	**	**	**
Storage days								
0	2905.1^{h}±92.6	4.98^{c}±0.01	0.24^{a}±0.02	0.27^{g}±0.02	0.54^{g}±0.02	4.05^{h}±0.03	1544.6^{h}±24.8	61.7^{h}±1.99
7	3048.1^{g}±34.7	4.98^{c}±0.01	0.22^{b}±0.02	0.27^{f}±0.01	0.55^{f}±0.01	4.09^{g}±0.02	1598.1^{g}±36.9	62.7^{g}±2.35
14	3064.5^{f}±28.5	4.98^{b}±0.01	0.21^{b}±0.02	0.28^{e}±0.01	0.56^{e}±0.02	4.11^{f}±0.03	1646.2^{e}±58.2	64.1^{f}±3.03
21	3072.2^{e}±44.6	4.98^{ab}±0.01	0.19^{c}±0.02	0.29^{d}±0.01	0.57^{d}±0.02	4.13^{e}±0.03	1640.9^{f}±33.9	66.1^{e}±2.80
28	3084.5^{d}±44.0	4.98^{ab}±0.01	0.18^{cd}±0.02	0.30^{c}±0.01	0.57^{c}±0.02	4.15^{d}±0.02	1684.9^{d}±42.2	66.9^{d}±2.86
35	6148.1^{c}±41.2	4.98^{a}±0.01	0.17^{de}±0.02	0.30^{bc}±0.01	0.58^{c}±0.02	4.16^{c}±0.03	1702.6^{c}±50.1	68.5^{c}±3.64
42	3164.0^{b}±30.4	4.98^{b}±0.01	0.16^{e}±0.02	0.30^{b}±0.01	0.58^{b}±0.02	4.18^{b}±0.03	1761.8^{b}±73.5	70.7^{b}±4.42
49	3209.6^{a}±32.7	4.98^{ab}±0.01	0.16^{e}±0.02	0.31^{a}±0.01	0.59^{a}±0.01	4.20^{a}±0.02	1790.0^{a}±65.8	72.0^{a}±2.98
Treatments								
CTL	3024.4^{D}±113.4	4.98^{C}±0.01	0.17^{C}±0.03	0.30^{A}±0.01	0.59^{A}±0.02	4.16^{A}±0.05	1709.2^{A}±93.4	68.9^{A}±4.34
M1	3078.1^{C}±89.1	4.98^{B}±0.01	0.19^{B}±0.04	0.30^{B}±0.01	0.58^{B}±0.02	4.15^{B}±0.05	1695.5^{B}±81.9	68.4^{B}±4.72
M2	3103.7^{B}±75.9	4.98^{AB}±0.01	0.19^{B}±0.03	0.29^{C}±0.01	0.57^{C}±0.01	4.13^{C}±0.05	1688.4^{C}±81.1	67.5^{C}±2.98
M3	3141.9^{A}±72.5	4.98^{A}±0.01	0.21^{A}±0.03	0.27^{D}±0.01	0.54^{D}±0.02	4.10^{D}±0.04	1591.7^{D}±53.1	61.5^{D}±3.78

[1)] Treatment: CTL, oyster mushroom 0%; M1, oyster mushroom 0.5%; M2, oyster mushroom 1%; M3, oyster mushroom 3%.

$^{a-h}$ Means with different letters within different storage days are different ($p<0.05$).

$^{A-D}$ Means with different letters within different treatments are different ($p<0.05$).

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Table 8. Texture profile analysis (TPA) of pork ham with oyster mushroom powder

Parameters	TRT[1)]	Storage days							
		0	7	14	21	28	35	42	49
Hardness (g)	CTL	$2768.3^{D}\pm2.05$	$2996.4^{gD}\pm4.33$	$3028.4^{dC}\pm3.50$	$2999.0^{fD}\pm1.65$	$3016.0^{eD}\pm4.08$	$3090.8^{cD}\pm5.28$	$3130.1^{bD}\pm4.51$	$3166.0^{aD}\pm5.30$
	M1	$2881.2^{gC}\pm2.11$	$3038.4^{fC}\pm2.51$	$3059.4^{eB}\pm6.76$	$3078.4^{eC}\pm2.86$	$3083.7^{dC}\pm3.14$	$3137.6^{cC}\pm2.28$	$3147.8^{bC}\pm1.57$	$3198.0^{aC}\pm4.22$
	M2	$2953.2^{eB}\pm1.26$	$3071.0^{dB}\pm5.19$	$3062.9^{dB}\pm5.03$	$3094.6^{cB}\pm5.32$	$3102.2^{cB}\pm4.49$	$3159.2^{bB}\pm4.79$	$3167.0^{bB}\pm0.72$	$3219.2^{aB}\pm1.54$
	M3	$3017.8^{gA}\pm5.94$	$3086.4f^{A}\pm3.71$	$3107.0^{eA}\pm4.81$	$3117.0^{dA}\pm1.63$	$3136.0^{cA}\pm4.75$	$3204.8^{bA}\pm1.66$	$3211.1^{bA}\pm5.05$	$3255.2^{aA}\pm4.32$
Adhesiveness (mJ)	CTL	$0.21^{aB}\pm0.02$	$0.20^{aB}\pm0.01$	$0.16^{abC}\pm0.02$	$0.17^{bcB}\pm0.01$	$0.16^{cdB}\pm0.02$	$0.14^{cdB}\pm0.02$	$0.13^{dB}\pm0.01$	$0.13^{dB}\pm0.01$
	M1	$0.24^{aAB}\pm0.02$	$0.23^{abAB}\pm0.03$	$0.22^{abAB}\pm0.02$	$0.20^{bcAB}\pm0.03$	$0.18^{cdAB}\pm0.02$	$0.17^{cdAB}\pm0.01$	$0.16^{dAB}\pm0.02$	$0.16^{dAB}\pm0.02$
	M2	$0.24^{aAB}\pm0.02$	$0.21^{bAB}\pm0.02$	$0.20^{bcBC}\pm0.01$	$0.19^{bcdAB}\pm0.02$	$0.18^{cdeAB}\pm0.02$	$0.17^{deAB}\pm0.01$	$0.17^{deA}\pm0.01$	$0.16^{eAB}\pm0.02$
	M3	$0.26^{aA}\pm0.02$	$0.24^{aA}\pm0.02$	$0.23^{abA}\pm0.01$	$0.21^{bcA}\pm0.02$	$0.20^{cdA}\pm0.01$	$0.19^{cdA}\pm0.02$	$0.18^{dA}\pm0.02$	$0.18^{dA}\pm0.01$
Resilience	CTL	$0.28^{eA}\pm0.01$	$0.29^{dA}\pm0.01$	$0.29^{cA}\pm0.01$	$0.31^{bA}\pm0.01$	$0.31^{abA}\pm0.01$	$0.31^{abA}\pm0.01$	$0.31^{aA}\pm0.01$	$0.32^{aA}\pm0.01$
	M1	$0.27^{fB}\pm0.01$	$0.28^{eAB}\pm0.01$	$0.29^{dA}\pm0.01$	$0.30^{cB}\pm0.01$	$0.31^{bB}\pm0.01$	$0.31^{bAB}\pm0.01$	$0.31^{bB}\pm0.01$	$0.31^{aA}\pm0.01$
	M2	$0.27^{eB}\pm0.01$	$0.28^{dB}\pm0.01$	$0.28^{cB}\pm0.01$	$0.29^{bC}\pm0.01$	$0.30^{bC}\pm0.01$	$0.30^{aB}\pm0.01$	$0.30^{aC}\pm0.01$	$0.30^{aB}\pm0.01$
	M3	$0.24^{fC}\pm0.01$	$0.25^{eC}\pm0.01$	$0.26^{dC}\pm0.01$	$0.27^{cD}\pm0.01$	$0.28^{bcD}\pm0.01$	$0.28^{bC}\pm0.01$	$0.28^{bD}\pm0.01$	$0.29^{a\ C}\pm0.01$
Cohesiveness	CTL	$0.56^{dA}\pm0.01$	$0.56^{dA}\pm0.01$	$0.59^{cA}\pm0.01$	$0.59^{cA}\pm0.01$	$0.59^{bcA}\pm0.01$	$0.60^{abA}\pm0.01$	$0.60^{aA}\pm0.01$	$0.60^{aA}\pm0.01$
	M1	$0.56^{eA}\pm0.01$	$0.56^{deA}\pm0.01$	$0.56^{dB}\pm0.01$	$0.58^{cB}\pm0.01$	$0.58^{bcAB}\pm0.01$	$0.59^{bB}\pm0.01$	$0.60^{aA}\pm0.01$	$0.60^{aB}\pm0.01$
	M2	$0.55^{eA}\pm001$	$0.56^{deA}\pm0.01$	$0.56^{dB}\pm0.01$	$0.57^{cC}\pm0.01$	$0.58^{bB}\pm0.01$	$0.58^{bB}\pm0.01$	$0.58^{bB}\pm0.01$	$0.59^{aC}\pm0.01$
	M3	$0.51^{eB}\pm0.01$	$0.53^{dB}\pm00.01$	$0.53^{dC}\pm0.01$	$0.54^{cdD}\pm0.01$	$0.54^{bcC}\pm0.01$	$0.55^{bC}\pm0.01$	$0.55^{bC}\pm0.01$	$0.56^{aD}\pm0.01$
Springiness (mm)	CTL	$4.09^{fA}\pm0.01$	$4.11^{eA}\pm0.01$	$4.14^{dA}\pm0.01$	$4.15^{cdA}\pm0.01$	$4.16^{cA}\pm0.02$	$4.19^{bA}\pm0.01$	$4.22^{aA}\pm0.01$	$4.23^{aA}\pm0.01$
	M1	$4.06^{gB}\pm0.01$	$4.10^{fA}\pm0.01$	$4.13^{eAB}\pm0.02$	$4.15^{dA}\pm0.01$	$4.16^{cdA}\pm0.01$	$4.18^{bcA}\pm0.01$	$4.19^{bB}\pm0.01$	$4.21^{aB}\pm0.01$
	M2	$4.04^{fBC}\pm0.01$	$4.08^{eB}\pm0.01$	$4.11^{dB}\pm0.01$	$4.14^{cA}\pm0.01$	$4.15^{cA}\pm0.01$	$4.17^{bA}\pm0.01$	$4.18^{abC}\pm0.01$	$4.20^{aC}\pm0.01$
	M3	$4.02^{fC}\pm0.01$	$4.06^{eB}\pm0.01$	$4.07^{eC}\pm0.01$	$4.09^{dB}\pm0.02$	$4.11^{cB}\pm0.01$	$4.12^{cB}\pm0.01$	$4.14^{bD}\pm0.01$	$4.17^{aD}\pm0.01$
Gumminess (g)	CTL	$1573.4^{hA}\pm1.97$	$1612.4^{gB}\pm0.68$	$1709.2^{eA}\pm3.03$	$1635.2f^{C}\pm1.77$	$1721.9^{dA}\pm3.22$	$1737.2^{cA}\pm2.73$	$1832.6^{bA}\pm5.45$	$1851.9^{aA}\pm3.14$
	M1	$1559.7^{hB}\pm3.81$	$1607.6^{gB}\pm0.63$	$1670.3^{fB}\pm4.90$	$1675.8^{eA}\pm0.31$	$1705.0^{dB}\pm1.66$	$1729.2^{cB}\pm3.40$	$1796.4^{bB}\pm3.87$	$1817.9^{aB}\pm2.22$
	M2	$1536.8^{hC}\pm4.53$	$1635.4^{gA}\pm3.82$	$1653.2^{fC}\pm4.17$	$1664.4^{eB}\pm4.12$	$1699.4^{dC}\pm2.22$	$1727.9^{cB}\pm2.88$	$1779.1^{bC}\pm2.20$	$1810.7^{aB}\pm4.38$
	M3	$1508.4^{gD}\pm0.96$	$1537.0^{fC}\pm1.78$	$1552.0^{eD}\pm0.27$	$1588.3^{dD}\pm4.32$	$1613.3^{cD}\pm0.47$	$1616.1^{cC}\pm0.87$	$1639.2^{bD}\pm0.83$	$1679.4^{aC}\pm4.49$
Chewiness (mJ)	CTL	$62.5^{fB}\pm0.14$	$63.9^{eAB}\pm0.05$	$66.1^{dA}\pm0.22$	$68.7^{cA}\pm0.27$	$69.1^{cA}\pm0.33$	$71.7^{bA}\pm0.31$	$474.6^{aA}\pm0.31$	$74.8^{aA}\pm0.14$
	M1	$62.8^{gAB}\pm0.41$	$63.4^{fB}\pm0.19$	$66.0^{eA}\pm0.49$	$67.7^{dB}\pm0.57$	$68.5^{cAB}\pm0.32$	$71.2^{bA}\pm0.07$	$73.6^{aB}\pm0.23$	$73.7^{aB}\pm0.23$
	M2	$63.1^{gA}\pm0.11$	$64.6f^{A}\pm0.24$	$65.5^{eA}\pm0.27$	$66.6^{dC}\pm0.05$	$68.0^{cB}\pm0.21$	$68.4^{cB}\pm0.38$	$71.4^{bC}\pm0.26$	$72.4^{aC}\pm0.29$
	M3	$58.3^{eC}\pm0.17$	$58.7^{eC}\pm0.64$	$59.0^{eB}\pm0.60$	$61.5^{dD}\pm0.46$	$62.0^{cdC}\pm0.47$	$62.5^{bcC}\pm0.17$	$63.3^{bD}\pm0.14$	$67.1^{aD}\pm0.44$

806 [1)] Treatment: CTL, oyster mushroom 0%; M1, oyster mushroom 0.5%; M2, oyster mushroom 1%; M3, oyster mushroom 3%.

807 [a-g] Means within the same row with different letters are different (p<0.05).

808 [A-D] Means within the same column with different letters are different (p<0.05).

Accepted

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Accepted