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Quality characterization of gamma-irradiated fresh oyster mushrooms (*Pleurotus ostreatus*) during low temperature storage

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Abstract

Fresh oyster mushrooms (*Pleurotus ostreatus*) were gamma-irradiated at 0, 1, 2, and 3 kGy. The effects on various quality attributes were determined during storage at 5 ± 1℃. Color changes were more prominent in the cap region than the stem part. At the start of storage increase of Hunter's *L*-value (lightness) was observed in the caps of 2 and 3 kGy-irradiated samples. The *L*-value was higher in the all irradiated samples during storage. The trend was different in the case of stem region, where *L*-value decreased upon irradiation, but remained high throughout storage. The *a*-value declined, whereas the *b*-value increased following irradiation. Irradiation showed a dose-dependent effect on the firmness, which was clearer during storage, but the samples irradiated at 1 kGy maintained an overall better texture than other irradiated samples. The weight loss was also higher in the all irradiated samples during storage. The samples irradiated at 1 kGy showed good physical appearance without any fungal attack at the end of storage; however color change in cap region was quite apparent. The ultra-structural drastic effect of irradiation was understandable using scanning electron microscopy. E-nose analysis demonstrated a clear change in the volatile profiles of all irradiated samples. Although the effect of irradiation on quality characteristics was quite clear but the all irradiated samples were free from fungal attack that was observed in the case of control sample.

Key words : **Gamma irradiation; Oyster mushroom; Quality Storage; Volatile profile E-nose analysis**

Introduction

Food irradiation is most extensively studied food preservation technique. Several well-reputed health authorities examined the related safety concerns and endorsed the wholesomeness of this advanced technique (WHO 1999; Farkas & Mohácsi-Farkas 2011). Food irradiation, serving as modern postharvest technologies, can increase marketability of fresh agricultural commodities with the extension of storage period and improved hygienic quality. Considering the technical applicability and nutritional safety, more than 55 countrieshave permitted the commercial use of this wholesome technology (Farkas & Mohácsi-Farkas 2011). Fresh agricultural products are usually exposed to low dose of irradiation aiming improved hygienic quality with reduced enzyme activity and respiration rate (Arvanitoyannis 2010).

Mushrooms have high market demand all over the world due to their unique taste and exclusive functional properties(Cheung 2008). *Pleurotus spp.* is third most produced variety of mushroom in the world (Royse 2003). Various scientific reports have demonstrated the high consumer demand due to its functional characteristics (Lo 2008; Oke & Aslim 2011) and need of advanced preservation technology for an increased marketability (Xiao *et al.* 2011). The short post-harvest life of fresh mushrooms due to its perishable nature and poor hygienic quality are main constraints for cost-effective long distance supply to different consumer markets (Akram & Kwon 2010). Different preservation methodologies, including modified atmosphere packaging (Gonzalez-Fandos *et al.* 2001; Jacxsens *et al.* 2001) and chemical treatments (Brennan et al. 2000) were developed to maintain postharvest quality of fresh mushrooms (Koorapati *et al.* 2004). Recently, Xiao *et al.* (2011) reported the combined effect of chemical treatment and modified atmosphere to extend shelf-life of *Pleurotus ostreatus* mushrooms.

In several countries, including Korea, fresh and dried mushrooms are permitted for food irradiation. Allowed dose ranges for fresh mushrooms is generally 1 – 3 kGy and that of dried ones is 1 – 10 kGy (Akram & Kwon 2010). *Agaricus bisporus* (Byun *et al.* 1990; Beaulieu *et al.* 2002; Akram & Kwon 2010), *Lentinus edodes* (Jiang *et al.* 2010), and *P. eryngii* (Akram *et al.* 2012) showed the improved postharvest quality and enhanced shelf life following irradiation. However, other mushrooms still need detailed investigation providing the basic scientific data for general applicability of irradiation technology.

In this study the appearance, color, texture, and weight loss of gamma-irradiated *Pleurotus ostreatus* mushrooms were evaluated during storage. The changes upon irradiation in the volatile compound profile and micro-structure were also investigated using E-nose analysis and scanning electron microscopy (SEM), respectively.

Materials and methods

Mushrooms, irradiation, and storage

Fresh oyster mushrooms (*Pleurotus ostreatus*) of uniform size and free of physical damage, were filled in polystyrene trays (about 300±10 g) and wrapped with food grade polyvinylchloride film. 48 mushroom trays were grouped for each irradiation treatment and control. The samples were stored at 5 ±1℃ before irradiation treatment. The next day, gamma irradiation treatment (0, 1, 2, and 3 kGy) was performed using a Co-60 gamma-ray source (AECL, IR-79, MDS Nordion International Co. Ltd., Ottawa, ON, Canada) at the Korean Atomic Energy Research Institute (Jeongeup, Korea). The treatment was conducted at room temperature with a dose rate of 2.1 kGy/h and alanine dosimeters of a diameter of 5 mm (Bruker Instruments, Rheinstetten, Germany) were attached with the samples to calibrate the absorbed doses. All irradiated and control samples were stored at 5 ±1℃ in a laboratory refrigerator for 4 weeks. Three sample trays were randomly selected from each group for different analysis as described below.

Color determination during storage

Chromameter (Model CR-200, Minolta Camera Co., Osaka, Japan) was used to determine the color changes upon irradiation and during subsequent storage. Color characteristics (L^* representing lightness, a^* redness to greenness, and b^* yellowness to blueness) were determined for each sample group (n = 9). The total change in color (ΔE) with respect to that of control group at day first was also determined using the expression $\Delta E = \sqrt{\Delta L^{2} + \Delta a^{2} + \Delta b^{2}}$.

Textural changes and weight loss during storage

Six samples were analyzed from each treatment group and controlto determine the change in firmness using a Sun rheometer (Compac-100, Sun Scientific Co., Ltd., Tokyo, Japan) as described earlier by Akram *et al.* (2012). Nine sampletrays from each group were marked with their respective weight and the changes were confirmed by weighing weekly during storage. The percentage weight loss with respect to the initial weight was reported.

Scanning electron microscopy

Ultra-structural determinations were conducted upon small pieces (n=3) of the mushroom stem surface and internal tissue sections as described Akram *et al.* (2012). Hitachi scanning electron microscope (Model S-570, Tokyo, Japan) at 1000 × magnification was used for the SEM investigation.

Evaluation of volatile profile

The volatile compound profiles of control and irradiated samples were investigated using a zNose (Electronic Sensor Technology, Newbury Park, CA, USA), equipped witha surface acoustic wave (SAW) sensor and VaporPrint^{TM} (Misrosense 4.88) software. Crushed sample (2 g) was filled in a 40 mL vial (Supelco, Bellefonte, PA, USA) that was sealed using a cap fitted with a Teflon septum (PTFE/silicone septa, Supelco). The headspace equilibrium was attained by leaving sample at room temperature for 4 hr. The analysis was performed at a SAW sensor temperature of 30℃; column, 60℃; valve, 120℃; inlet, 150℃; and trap, 220℃ (Akram *et al.* 2012). To find a trend in E-nose numerical data, principal component analysis (PCA) was used as described by Keshri *et al.* (2003).

Results and Discussion

Color attributes during storage

Tables 1 and 2 are demonstrating the changes in the key color parameters, upon irradiation and subsequent storage, in the stem and cap parts of mushrooms, respectively. At the same day after irradiation, the decrease in Hunter's *L*-value (lightness) following irradiation was observed in the stem region that was most prominent in 2 and 3 kGy-irradiated samples, whereas 1 kGy-irradiated samples had about similar values as that of control group (Table 1). The effect of irradiation was most prominent during storage, where all irradiated samples showed increased *L*-values. The control samples showed a decrease in *L*-value (lightness)during storage. Similar effect was observed in case of b-value, whereas a-value showed a negligible effect upon irradiation and during subsequent storage.

The cap region (Table 2) showed more differences than the stem part of the mushrooms following irradiation treatment. At the same day after irradiation treatment, the control and 1 kGy-irradiated samples showed similar color characteristics. However, the differences were prominent in 2 and 3 kGy-irradiated samples, which showed a decrease in a-value and increase in b-value as compared to the control group. All irradiated samples showed higher *L*-values with slight decrease in a-values during storage. Most significant differences were observed in case of b-value, which was much higher for cap parts of irradiated samples during storage. Microbial spoilage and different physiological actions (enzyme activity and respiration) can affect the color properties of non-irradiated samples (Simon *et al.* 2005). Irradiation can improve hygienic quality and can retard different physiological processes leading better color attributes. However, irradiation can also bleach the color pigment (Moreno *et al.* 2007) and effect cell structure resulting in changed color properties of a sample. Koorapati *et al.* (2004) showed that 1 kGy gamma irradiation improved *L*-values in slices of *A. bisporus* however the drastic effect was apparent at higher doses (3.1 and 5.2 kGy).

Physical appearance, firmness, and weight loss during storage

No noteworthy apparent differences were found in the treated samples with respect to the control group (Fig. 1) at the same day after irradiation treatment. However, irradiated samples were easily distinguishable during storage due to the cap color that turned yellowish from original green color. In the control samples, the green color became darker during storage making the color difference more prominent. However, the mold attack was also observed on the non-irradiated samples at the third week of storage, which was absent in the all irradiated samples. Microbial spoilage during storage in non-irradiated samples of *A. bisporus* slices (Koorapati *et al.* 2004) and P. eryngii (Akram *et al.* 2012) was also reported previously. Dose-dependent softening in the mushrooms was observed for all

Table 1. Effect of gamma irradiation on color characteristics in the stem region of *Pleurotus ostreatus* mushrooms during storage.

Hunter parameter†	Storage(day)	Irradiation dose (kGy)			
		0	1	2	3
L	0	83.23±3.01‡ax	82.05±2.56axy	75.18±2.67bz	79.10±3.35by
	7	80.84±4.73abx	80.19±5.14ax	81.18±2.37ax	83.64±2.49ax
	14	76.86±5.86bcy	81.98±3.27ax	79.08±2.91axy	81.53±4.28abxy
	21	74.59±4.27cy	79.13±2.94ax	81.92±5.22ax	79.28±2.89bx
	28	77.43±3.54bcy	80.79±2.44axy	79.39±2.92ay	84.01±2.76bx
a	0	-1.21±0.22cx	-1.41±0.37bx	-1.23±0.39dx	-2.01±0.32by
	7	-0.97±0.36cy	-0.52±0.46ax	-0.80±0.36cdxy	-0.69±0.19axy
	14	-0.39±0.37bx	-0.34±0.41ax	-0.25±0.29abx	-0.59±0.21ax
	21	0.30±0.39ax	-0.18±0.29ayz	0.04±0.44axy	-0.51±0.43az
	28	-0.16±0.62bx	-0.39±0.29ax	-0.71±0.59bcx	-0.68±0.28ax
b	0	10.20±0.54by	11.74±1.23axy	12.11±2.51bx	10.14±0.77by
	7	9.05±1.39bcx	12.57±1.07ay	10.08±0.76bx	10.04±1.58bx
	14	7.90±2.04cz	12.48±1.31ax	11.56±1.78bxy	9.68±1.67byz
	21	10.59±2.37bx	9.27±1.16bx	12.05±3.39bx	10.43±1.77bx
	28	15.65±2.37ax	11.83±0.76ay	17.49±1.98ax	17.27±2.78ax
ΔE	0	0.00±0.00cy	1.96±1.18by	8.27±2.07ax	4.20±5.42abx
	7	3.75±4.03bxy	5.89±1.55ax	2.76±1.57cy	2.44±1.52cy
	14	6.82±77.81ax	4.12±1.24aby	5.03±2.35bcy	3.88±2.77bcy
	21	9.09±4.17ax	4.65±2.59aby	5.60±3.19bxy	4.46±2.70abcy
	28	8.76±2.04ax	3.34±2.10by	8.78±1.56ax	7.73±2.24ax

† L^* represents lightness, a^* redness to greenness, b^* yellowness to blueness and ΔEtotal difference with respect to a control group.
‡Mean ± standard deviation (n=9).
a-e Values within the same columnwith different superscript letters are significantly different at $\rho < 0.05$.
w-z Values within the same rowwith different superscript letters are significantly different at $\rho < 0.05$.

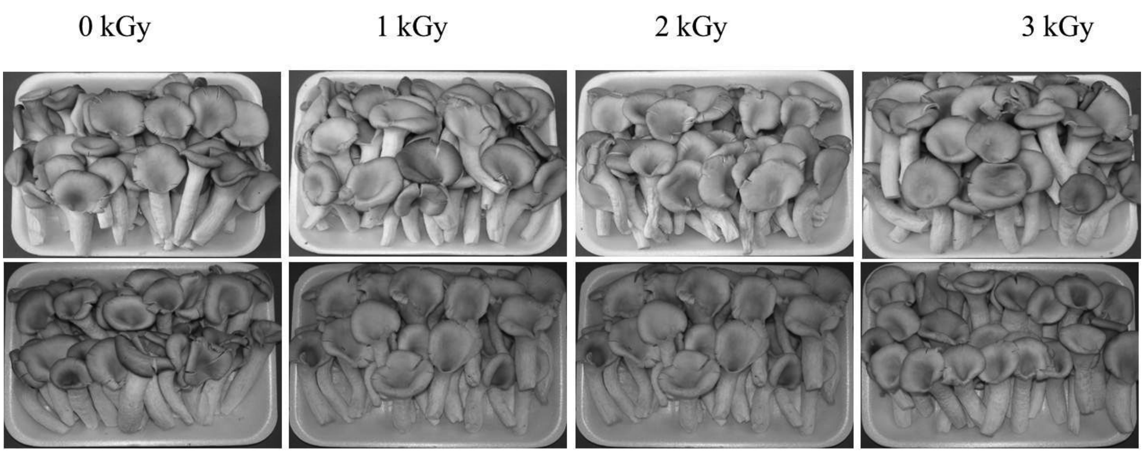

Fig. 1. Physical appearance of *Pleurotus ostreatus* mushrooms upon gamma irradiation (0-day; above) and storage (28-day; below).

Color changes weremost prominent in mushroom caps.

Table 2. Effect of gamma irradiation on color characteristics in the cap region of *Pleurotus ostreatus* mushrooms during storage.

Hunter parameter†	Storage(day)	Irradiation dose (kGy)			
		0	1	2	3
L	0	68.67±3.30^{‡bx}	68.72±4.13^{bx}	71.36±1.27^{bx}	70.55±2.72^{bx}
	7	73.83±2.81^{ax}	76.41±2.56^{ax}	75.71±3.80^{ax}	75.00±4.35^{ax}
	14	63.04±3.82^{ay}	70.78±2.97^{bx}	73.30±2.90^{abx}	74.08±5.15^{abx}
	21	68.00±2.92^{by}	75.27±4.87^{ax}	74.10±1.89^{abx}	76.65±2.36^{ax}
	28	68.57±4.58^{bz}	77.22±2.17^{ax}	72.88±2.96^{aby}	74.57±3.41^{abxy}
a	0	0.55±0.83^{bx}	0.58±0.93^{ax}	0.13±0.69^{bx}	0.22±0.67^{bx}
	7	0.95±0.50^{abx}	0.99±0.56^{ax}	-0.01±0.52	0.82±0.62^{abx}
	14	0.96±0.49^{abx}	1.01±0.59^{ax}	1.09±0.46^{ax}	1.28±0.71^{ax}
	21	1.47±0.97^{ax}	0.89±1.00^{ax}	1.08±0.53^{ax}	1.15±0.59^{ax}
	28	1.80±0.72^{ax}	0.17±0.59^{ay}	0.56±0.53^{aby}	0.74±0.69^{aby}
b	0	11.43±1.48^{by}	12.35±0.57^{cy}	13.54±1.38^{bx}	11.66±0.43^{cy}
	7	10.07±1.12^{bcz}	15.02±2.40^{bx}	11.01±0.75^{cyz}	12.25±1.25^{cy}
	14	9.05±2.04^{cy}	14.58±2.04^{bcx}	13.87±2.21^{bx}	15.58±1.79^{bx}
	21	11.29±1.51^{bz}	14.31±3.03^{bcxy}	12.85±1.03^{byz}	16.03±1.93^{bx}
	28	14.63±2.08^{ay}	19.93±2.07^{ax}	17.64±2.19^{ax}	18.52±1.85^{ax}
ΔE	0	0.00±0.00^{cy}	3.88±1.29^{cdx}	3.73±1.24^{bx}	2.60±2.10^{bx}
	7	5.56±2.61^{abx}	8.76±2.87^{bx}	7.23±3.58^{ax}	7.02±3.30^{ax}
	14	6.13±4.13^{ax}	4.41±2.78^{dx}	5.83±2.45^{abx}	7.44±4.54^{ax}
	21	2.91±1.84^{bz}	7.98±4.47^{bcxy}	5.83±1.54^{abyz}	9.31±2.81^{ax}
	28	5.51±2.05^{abz}	12.17±2.54^{ax}	7.64±3.37^{byz}	9.54±2.91^{axy}

†L*represents lightness, a* redness to greenness, b* yellowness to blueness and ΔEtotal difference with respect to a control group.
‡Mean ± standard deviation (n=9).
$^{a-e}$Values within the same column with different superscript letters are significantly different at ρ < 0.05.
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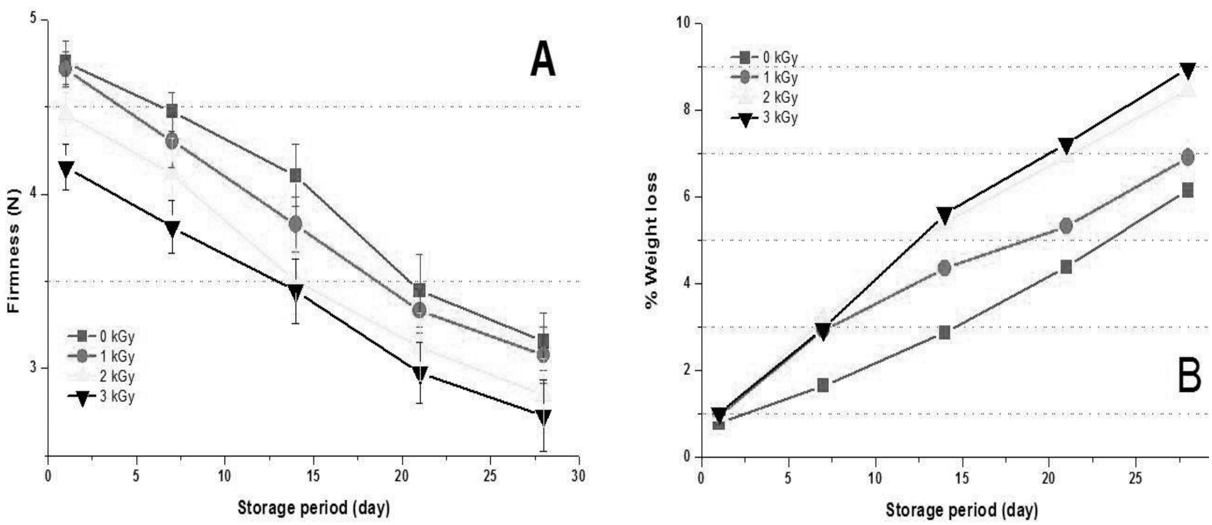

Fig. 2. Effect of gamma irradaition on firmness (above) and weight loss (below) of *Pleurotus ostreatus* mushrooms during storage.

irradiated samples (Fig. 2A). The change in firmness was apparent at the same day after irradiation treatment; however, differences were more prominent during storage. All samples, including the control group soften during storage, where the samples irradiated at 1 kGy showed a comparable firmness to that of control group during storage. Textural changes were most prominent in 2 and 3 kGy-irradiated samples. Irradiation can effect enzymatic and microbial actions (Byun *et al.* 1990) thatmight be the major causes of textural changes in the control samples during storage (Zivanovic *et al.* 2000). However, irradiation can disturb the membranous cell structures resulting in leakage of cell fluid and collapse of cell integrity (Koorapati *et al.* 2004). The loss of cell turgidity and overall poor product firmness werealso noted by other scientists, studying irradiated fresh mushrooms (Beaulieu et al. 2002 Akram *et al.* 2012).

All irradiated samples showed increased weight lossduring storage, where the effect was dependent upon the applied irradiation dose (Fig. 2B). The effect of irradiation on cell membrane resulting in easy escape of water from the mushroom surfaces might be responsible for this observation. The collapsed physical texture (shrinkage), which was visible in stems of 2 and 3 kGy-irradiated samples during storage, also support these results. Our results were contrary to those provided by Rivera *et al.* (2011) and Akram *et al.* (2012) for other mushrooms, which showed beneficial effect of 1 kGy irradiation providing a lower weight loss and higher firmness. The small size of *Pleurotus ostreatus* mushrooms with an increased surface area exposed for water evaporation and difference in physiological processes might be the cause of this variation (Akram & Kwon 2010).

Micro-structural evaluation

The scanning electron microscopy (SEM) was conducted to investigate the effect of irradiation treatment on micro-structure of mushrooms. Irradiation caused enlarged intercellular spaces due to the breakdown of fibrous structure depending upon the applied irradiation dose. The clear discrimination was possible for the samples subjected to 3irradiation treatment with respect to the control group (Fig. 3). The cell structures can collapse due to radiation-induced degradation of cell membranes producing enlarged spaces (Evered & Burton 1995 Beaulieu *et al.* 2002). The comparable micro-structural changes were found in stem skin and internal tissue samples, where more clear discrimination was possible using internal tissue micrographs. The ultra-structural evaluation provided the better understanding of radiation-induced drastic changes in physical appearance, color, firmness and weight loss observations, where the detrimental quality characteristics were also related to the applied irradiation dose. Gamma-irradiated *P. eryngii* (Akram *et al.* 2012) and electron-beam irradiated blueberries (Maria *et al.* 2007) also provided the similar micro-structural characteristics.

Changes in volatile compound profile

Radiation-induced subtle changes in sensory characteristics of mushrooms are difficult to predict by sensory panelists due to low threshold of flavoring compounds in different mushrooms (Lai *et al.* 1994; Mau *et al.* 2006). The effect of irradiation treatment was investigated using E-nose analysis and numerical data were subjected to PCA technique to find a trend in the experimental results (Keshri *et al.* 2003). Figure 4 demonstrates the PCA results of the control and irradiated samples. All samples followed different patterns as circled in Fig. 4. The results showed that the volatile compound profiles of mushrooms were not only sensitive for irradiation treatment but also depend upon applied irradiation dose, as dose-dependent discrimination was also possible. The results were in good agreement with those of reported earlier for gamma-irradiated *P. eryngii* mushrooms (Akram et al. 2012).

In conclusion, gamma irradiation showed dose-dependent effect upon the qualitycharacteristics of the mushrooms. The effect became more significant during storage. The 1 kGy-irradiated samples provided

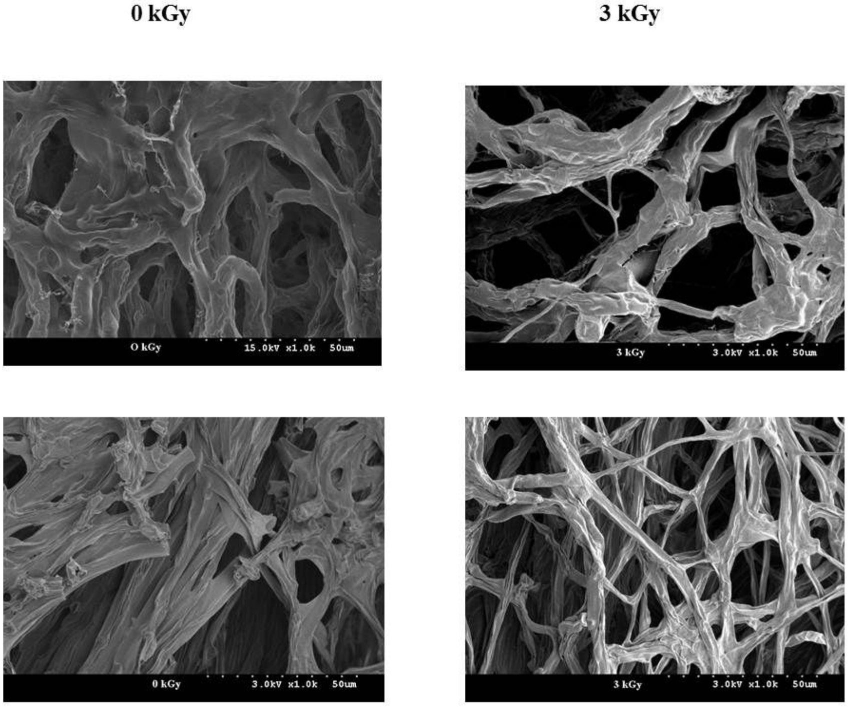

Fig. 3. Scanning electron microscopy (above: internal tissue; below: surface tissue) showing the effect of gamma irradiation on micro-structure of *Pleurotus ostreatus* mushrooms.

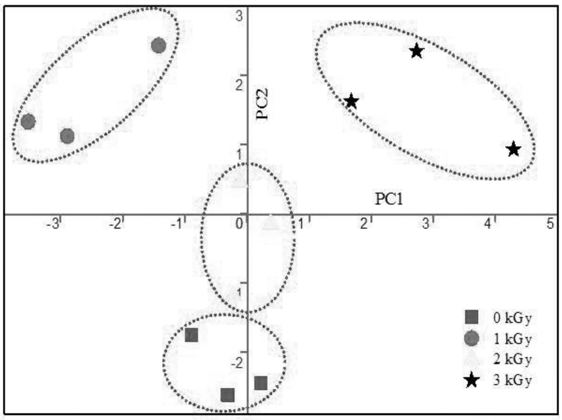

Fig. 4. Principal component analysis of E-nose data demonstrating the dose-dependent discrimination in volatile profiles of *Pleurotus ostreatus* mushrooms following gamma irradiation.

comparable results to those of control samples. The color bleaching effect of irradiation that was quite apparent in the cap region of all irradiated mushrooms and fungal attack in non-irradiated samples were important observations. The different quality attributes, such as changed color, soft texture, and increased weight loss were explainable through SEM analysis showing drastic dose-dependent effect of irradiation on mushroom micro-structure. Irradiation treatment also changed the volatile compound profiles of mushrooms. The results showed that further investigations are needed for providingbetter methodology to get improved hygienic quality by irradiation with minimum quality losses.

Acknowledgements

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