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ORIGINAL PAPER

Impact of drying methods on the quality of grey (*Pleurotus sajor caju*) and pink (*Pleurotus djamor*) oyster mushrooms

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Abstract

The aim of this study was to determine proximate composition, minerals, vitamins (B_3 and B_6) and browning index of *Pleurotus sajor caju* (i.e. grey oyster mushrooms, GOM) and *Pleurotus djamor* (i.e. pink oyster mushrooms, POM), which were subjected to cabinet, microwave and vacuum drying. Electric cabinet-dried POM yielded higher protein (29.94% ± 0.60), fat (0.79% ± 0.07), vitamin B_3 (0.25 mg/100 g ± 0.04) and most of the minerals content. However, cabinet-dried GOM yielded higher carbohydrate (64.75% ± 1.05) and significantly higher K, Mg, Zn, Fe, and vitamin B_6 ($p < 0.05$). Meanwhile, internal microstructure resulted in severe damages for vacuum-dried mushroom. Microwave-dried POM yielded the highest value for browning index (75.11 ± 0.18) ($p < 0.05$). Among the three drying methods investigated, cabinet drying is the optimal choice as the low-cost postharvest treatment, as it reduced microstructure degradation of the mushrooms, retained more nutritional components, increased shelf-life and yield of the produce that can alleviate the threat of global food security.

Keywords Oyster mushroom · Drying · *Pleurotus sajor caju* · *Pleurotus djamor*

Introduction

Mushrooms are widely used food ingredients due to their nutritional value and characteristic flavor profile for various human dietary trends such as vegan, vegetarian, low-carbo, low-calorie, low fat, ketogenic and Mediterranean. Specifically, oyster mushrooms are rich in proteins composed of nine essential amino acids required by humans, enabling their use as a substitute for meats. It contains low amount of fat (~ 1–3%); nevertheless it contains a large amount of poly-unsaturated fatty acids (72–85%), mainly linoleic acid, which makes mushrooms categorized as healthy food [1, 2]. Protein malnutrition in Bangladesh was reduced tremendously through the development of biscuits fortified with oyster mushroom [3]. High amounts of Fe, Cu, Mg and K were found in bread, which contains 20% of dried shiitake mushroom [4]. This is in line with the United Nation's Sustainable Development Goals (SDG), "SDG 3: Good Health & Wellbeing" that can be practiced and enforced by developed and developing countries for better food product quality and security involving health benefits. Development of functional food from dried mushroom in the recent years could be one of the major breakthroughs towards progression of good health and healthy eating lifestyle.

Pink oyster mushroom (POM, *Pleurotus djamor*) has a light to dark pink coloured cap depending upon the strain and growing conditions as indicated in Fig. 1a. POM is one of the fastest growing *Pleurotus* species and can readily colonize adjacent plantations or any kind of agricultural

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waste including wheat or paddy straw, sawdust and sugarcane bagasse [5]. However, there is limited information on health benefits of the pink oyster mushroom. Generally, in ASEAN countries, grey oyster mushrooms are consumed and are available readily as shown in Fig. 1b. One of the literatures that highlighted on the potential health benefit of oyster mushroom is the radical scavenging activity of grey oyster mushroom (GOM, *Pleurotus sajor caju*), which was up to 89.29% against DPPH assay [1]. This indicates strong antioxidant activities that can possibly prevent diseases among consumers.

Mushroom has a short shelf life due to its high-water content compared to most vegetables at ambient temperature. High-water content and rapid metabolic activity are two major factors that lead to quality degradation of mushrooms during post-harvest life, which is limited to less than a week. Thus, the commercial value of the mushroom could be reduced. Therefore, it is necessary to apply preservation technologies to prolong the shelf life of mushrooms. The most suitable method for high water content and rapid metabolic activity of vegetables that tend to be served fresh or stir fried on low heat, drying is one of the most important preservation methods employed [4]. Drying allows mushroom growers to generate additional income from both fresh and dried products, which is in line with the SDG 10: Reduced Inequality. The Covid-19 pandemic situation across the world, with fluctuations of alarming cases had affected the normal routine which eventually has deepened existing inequalities leading to financial crisis among vulnerable small scale mushroom growers. Increased unemployment and lower economic stability has risk for both mushroom growers and their supplier counterparts. It is highly important for mushroom growers to up-keep with the pandemic and endemic situation, while keeping their mushroom business afloat, hence, continuous flow of income generation is highly necessary. Furthermore, drying technique could eliminate the problems usually faced by growers, especially when mushrooms did not grow to the specified size, uniformity and colour variation. For example, consumers do not prefer to consume POM due to the colour pigment. Hence, wastage within the farm could be eliminated and this is in line with the SDG 12: Responsible Consumption & Production. In agriculture practises, an estimated of 1.3 billion tonnes (worth USD1 trillion) waste are being generated annually, which is equivalent to one-third (1/3) of total food being produced globally. These wastes are generated from harvesting practises, improper storage conditions, poor transportation and spoilage at retail itself.

Common low-cost drying method involves hot air dryer, microwave and vacuum dryer. However, the effect of different drying methods on the quality parameters of mushrooms is not clear. Dehydrated mushrooms can be stored in airtight packages for more than one year. The final products obtained from these methods may vary in physicochemical or nutritional properties and microstructure characteristics. Preservation methods such as drying, freezing, ultrasound and pulsed electric field application have been applied on several mushrooms; however, drying techniques carried out on grey oyster mushrooms (GOM) and pink oyster mushrooms (POM) has not been conducted yet. Hence, in this work, the impact of different drying techniques (i.e. cabinet drying, microwave drying and vacuum drying) on the quality attributes (browning index and microstructure) and nutritional values (proximate composition, selected mineral content, vitamin B_3 and vitamin B_6) of GOM and POM was investigated.

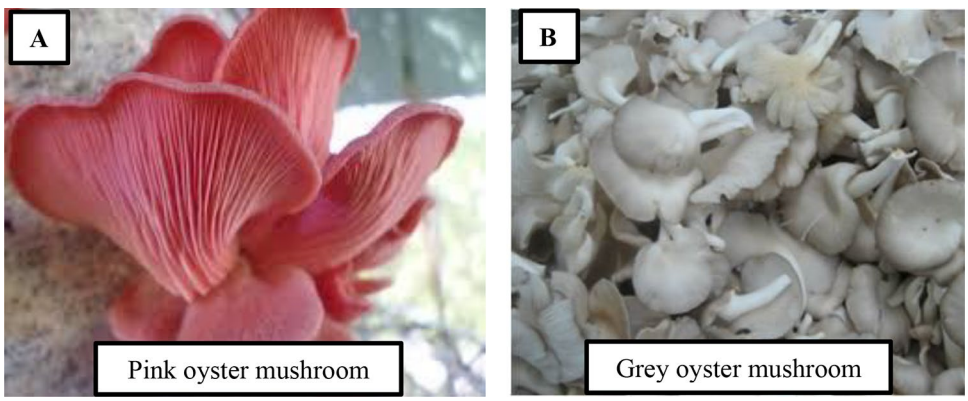

Fig. 1 Images of **a** pink oyster mushroom (GOM) and **b** grey oyster mushroom (Color figure online)

Materials and methods

Materials

Freshly harvested grey oyster (GOM, *Pleurotus sajor caju*) and pink oyster (POM, *Pleurotus djamor*) mushrooms, respectively, were purchased from Nas Agro Farm in Jenderam Hulu, Sepang, Selangor, Malaysia. All mushroom samples were placed in a box containing ice pack and transported to lab and stored at 4 °C before used for experimentation. All samples used for drying were purchased from the same batch. Raw oyster mushrooms were washed and cleaned from impurities such as dirt and sand. Then, they were placed on an absorbent paper to remove excess surface water. Mushrooms (1500 ± 5 g) were selected at random and subjected to the following treatments; cabinet drying (CD), vacuum drying (VC) and microwave drying (MW). Independent replication was carried out for each drying method. All chemicals used in this study were analytical grade and procured from

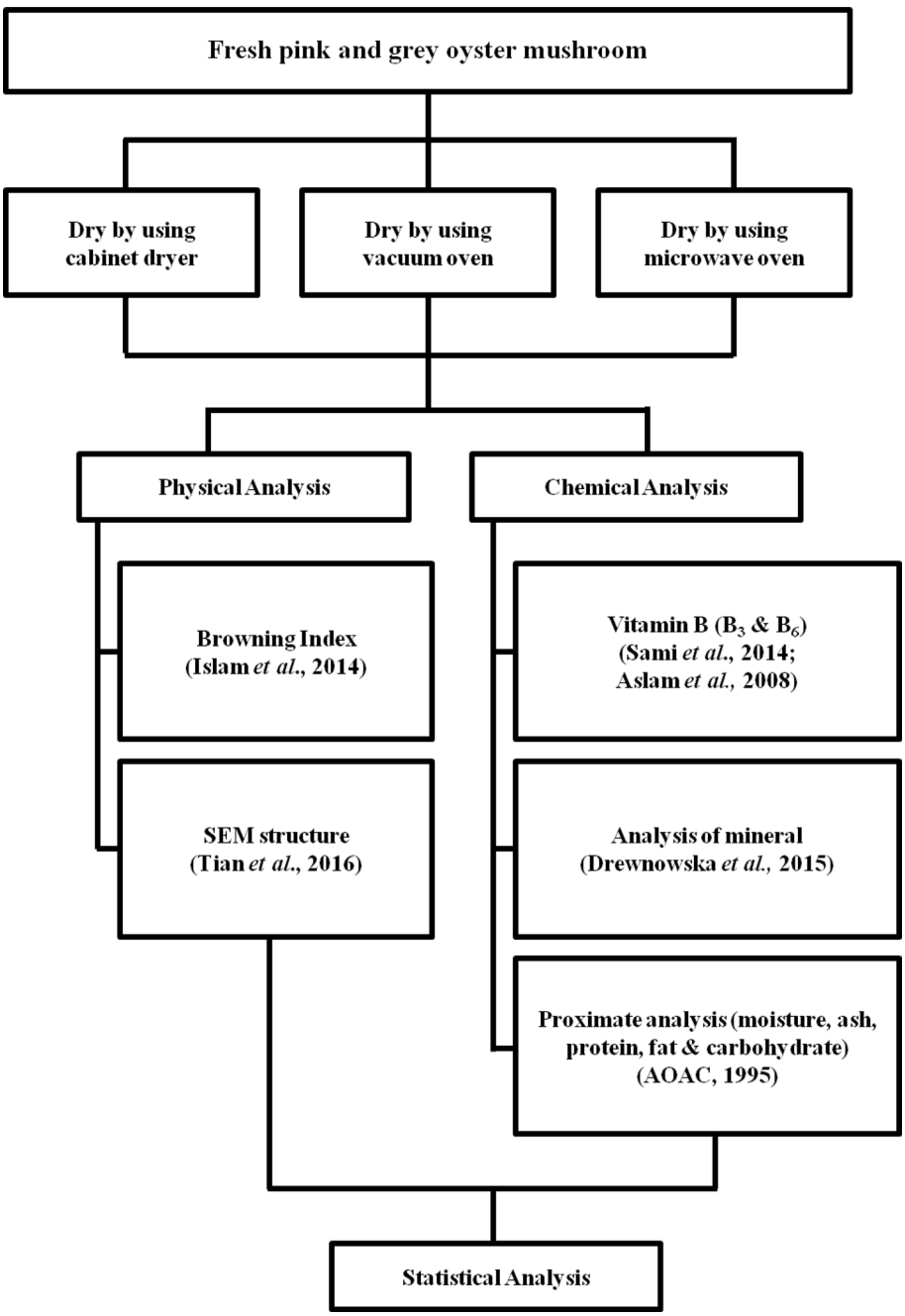

Fig. 2 Overall research activity (Color figure online)

Sigma Aldrich, USA. Overall research activity carried out in this study are depicted in Fig. 2.

Drying of mushrooms

Cabinet drying

The samples were hot air dried using an electric cabinet dryer (FSD 380, Protech, Malaysia) at 60 °C overnight as described previously [6]. Samples were spread in a single layer on the tray.

Vacuum drying

The samples were spread in a single layer on an aluminum dish and dried at 60 °C for 15 h by using vacuum drying oven (Vacucell 22, Germany) equipped with a vacuum pump based on previous work [6] as indicated in Fig. 3.

Microwave drying

Microwave drying was conducted according to Tian et al. [6], by a microwave oven (Samsung, Model: MW71E, Malaysia) with a maximum power output of 1150 W and 2450 MHz. The samples were spread in a single layer on a glassy culture dish, and dried at 539 W within 6 min.

Proximate analysis

Moisture content, protein, fat, ash and carbohydrate content were determined based on AOAC standard [7]. Several proximate analyses were done on the mentioned parameters through several methods: (i) the crude protein content (N × 4.38) of the samples were estimated by Kjedahl method; (ii) the crude fat was determined by extracting a known weight of powdered sample with petroleum ether, using a Soxhlet (EAM 9202-06, Mtops, Korea) apparatus; (iii) the ash content was determined by an incineration; (iv) total carbohydrates were calculated using Eq. 1 below.

$$\text{Total carbohydrate } (\%) = 100 \quad (1)$$

Analysis of minerals

Dried mushroom samples were analysed for mineral content using an Inductively Coupled Argon Plasma Optical Emission Spectrometer (ICP-OES, Optima 2100 DV, Perkin Elmer, Germany). Dried samples were digested using nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) solution. Then, 0.5 g of samples was added to 10 mL of HNO_3 and left overnight before further heating until no red fume produced. After cooling, 1 mL H_2O_2 was added into the solution. The solution was heated for a few minutes until completely homogenized then diluted with 50 mL deionized water to meet instrument conditions (Varian, Model Vista—MPX CCD, USA).

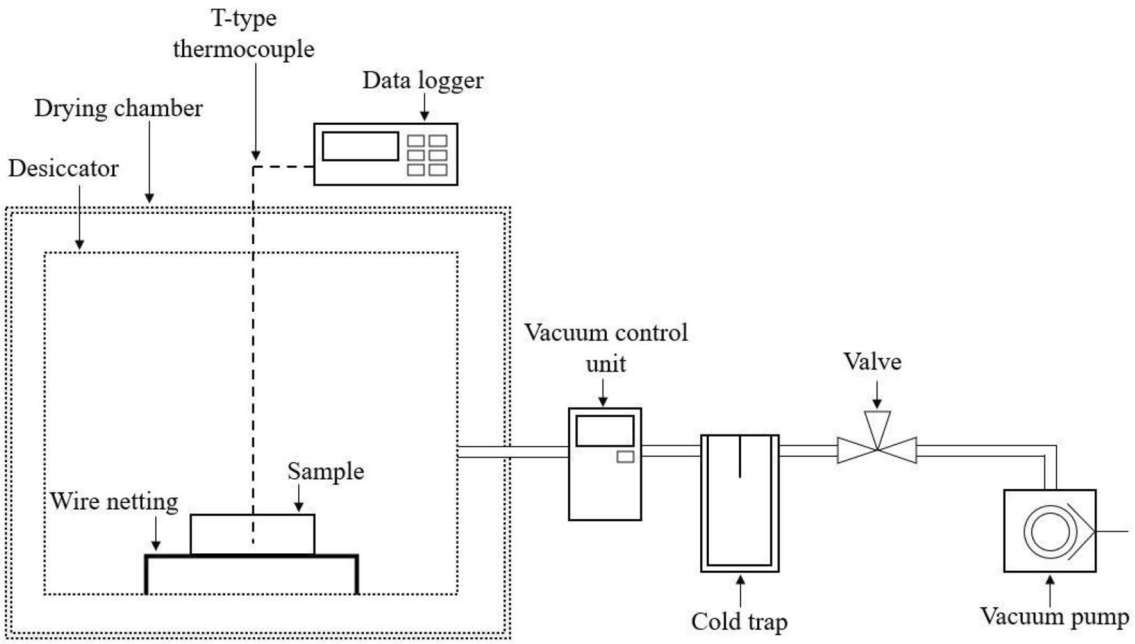

Fig. 3 Schematic diagram of vacuum oven system (Color figure online)

The analysed elements were Zn, Fe, Ca, Mg, Na and K. A standard solution was prepared from 1000 ppm stock solution of multi-element standard with deionized water. After proper dilution, content of elements was determined by ICP-OES [8].

Analysis of vitamin B_3 and B_6

Vitamins were analysed according to Sami et al. [9], whereby, powder sample (2 g) was placed in 25 mL of sulfuric acid (H_2SO_4) (0.1 N) solution and incubated for 30 min at 121 °C. Then, the contents were cooled and adjusted to pH 4.5 with 2.5 M sodium acetate. After that, 50 mg Takadiastase enzyme was added. The preparation was stored at 35 °C overnight. The mixture was then filtered through a Whatman No. 4 filter, and the filtrate was diluted with 50 mL pure water and filtered again through a micropore filter (0.45 µm). Approximately around 20 µL of the filtrate was injected into the HPLC–DAD (Model 1200, Agilent Technologies, USA).

Quantification of vitamin B content was accomplished by comparison to vitamin B standards. Standard stock solutions for vitamin B_3 and B_6 were each prepared by dissolving the standard and marked up with double distilled water. Chromatographic separation was achieved on a reversed phase (RP-) HPLC column (Agilent ZORBAX Eclipse Plus C18; 250 × 4.6 mm i.d., 5 µm) through the isocratic delivery mobile phase (A/B 33/67; A: MeOH, B: 0.023 M H_3PO_4, pH = 3.54) at a flow rate of 0.5 mL/min. Ultraviolet (UV) absorbance was recorded at 270 nm at room temperature [10].

Browning index determination

The colour measurement was carried out using a chroma meter (CR 400, Konica Minolta Optics, Inc. Osaka, Japan). The colour parameters, Luminosity, L^*; redness or greenness, a^*; yellowness or blueness, b^* were recorded. The browning index (BI) represents the intensity of brown colour. Browning index was calculated using Eq. 2 according to previous studies [11, 12].

$$BI = 581.395\left[\left(\frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^{*2}}\right) - 0.31\right] \quad (2)$$

Microstructure of dried mushrooms

Scanning Electron Microscopy (SEM, Model TM3030 Plus, Hitachi, Japan) was used to visualize the microstructure of gill and stem of dried mushrooms. Dried samples were attached onto SEM stubs using two-sided adhesive tape and coated with gold using Mini Sputter Coater (Model: Bal-Tec SCD 005, Quorum Technologies, UK). The specimens were then photographed using a SEM (Quanta 200 FEI (2004) in magnification of (× 500), (× 1500) and (× 2000) [6].

Statistical analysis

All data on dried mushrooms were presented as means ± standard deviations. The statistical analysis was carried out using analysis of variance (ANOVA) by Duncan's multiple test at ($p < 0.05$) and independent t-test procedure by using the SPSS (Statistical Package for the Social Science, version 20) software. Principal component analysis (PCA) based on correlation matrix was carried out using Minitab statistical software (Minitab 20.4, Minitab LLC, PA, USA).

Results and discussions

Proximate composition of mushrooms

Table 1 demonstrates the proximate composition of mushroom samples based on different drying methods. The results exhibited that both GOM and POM processed by cabinet drying method had the lowest ($p < 0.05$) moisture content compared to microwave and vacuum drying. Dried POM had

Table 1 Proximate composition of dried oyster mushrooms

Composition (%)	Grey oyster mushroom (*Pleurotus sajor caju*)			Pink oyster mushroom (*Pleurotus djamor*)		
	Cabinet dryer oven	Microwave oven	Vacuum oven	Cabinet dryer oven	Microwave oven	Vacuum oven
Carbohydrate	$64.75 \pm 1.05^{a,A}$	$59.85 \pm 0.26^{b,A}$	$59.22 \pm 1.25^{b,A}$	$50.75 \pm 0.70^{b,B}$	$48.36 \pm 0.82^{c,B}$	$52.37 \pm 0.70^{a,B}$
Protein	$15.26 \pm 0.78^{a,B}$	$13.50 \pm 0.37^{b,B}$	$12.89 \pm 086^{b,B}$	$29.94 \pm 0.60^{a,A}$	$24.05 \pm 0.73^{b,A}$	$18.90 \pm 0.19^{c,A}$
Moisture	$13.14 \pm 0.30^{c,A}$	$20.61 \pm 0.12^{b,A}$	$23.41 \pm 019^{a,A}$	$11.54 \pm 0.36^{c,B}$	$21.06 \pm 0.42^{b,A}$	$22.97 \pm 0.44^{a,A}$
Ash	$6.27 \pm 0.24^{a,B}$	$5.58 \pm 0.42^{b,A}$	$4.27 \pm 0.28^{c,B}$	$6.98 \pm 0.22^{a,A}$	$5.92 \pm 0.15^{b,A}$	$5.24 \pm 0.41^{c,A}$
Fat	$0.58 \pm 0.05^{a,B}$	$0.46 \pm 0.08^{a,A}$	$0.20 \pm 0.03^{b,B}$	$0.79 \pm 0.07^{a,A}$	$0.61 \pm 0.02^{b,A}$	$0.52 \pm 0.05^{b,A}$

Analysis data were obtained from three triplicate samples. Values are expressed as mean ± standard deviation. Means with different lower case letter indicate a significant difference using ANOVA ($p < 0.05$) for different drying treatment and means with different capital letter indicate a significant difference using independent t-test ($p < 0.05$) for different type of oyster mushroom respectively

a lower moisture content than GOM. Besides, hot air-drying causes severe shrinkage and lower bulk density. Compared to microwave and vacuum drying method, cabinet drying has reduced the moisture rapidly without changing the physical structure of the mushrooms. Water molecules vibrates and undergoes friction, while reducing the moisture content more rapidly [13].

It was found that protein content of POM was higher ($p < 0.05$) compared to GOM in all drying treatments. Protein content was higher for both mushrooms dried using cabinet dryer compared to other methods. Similar to our findings, previously, POM had higher protein content (26.6%) compared to GOM (21.30%) [14, 15]. An increase of proteins possibly due to low moisture content and removal of water allows the bioactive compound to be concentrated. The factors affecting protein content is strains, physical and chemical differences in growing medium, composition of the substrate, size of the pileus and harvest time.

Table 1 also indicates that cabinet drying exhibited higher ($p < 0.05$) fat content compared to other drying methods for both mushrooms. Between GOM and POM, the later had higher fat: GOM and POM contain 2.3% and 0.56% fat content, respectively [14, 15]. Lipid composition maybe affected by drying conditions. Vacuum oven drying decreased lipid content in both mushrooms possibly due to increased lipase activity, which cause hydrolysis of triglycerides into glycerol and fatty acids [16]. This complex event leads to oxidation of lipids in which unsaturated fatty acids can react with molecular oxygen that can be initiated by the thermal decomposition of a peroxide such as free radical chain-forming peroxides.

The carbohydrate content of GOM was higher ($p < 0.05$) compared to POM as shown in Table 1. However, carbohydrate in GOM dried using cabinet dryer was higher, while POM indicated higher carbohydrate content when dried using a vacuum oven. The carbohydrate contents in GOM and POM are about 68.35% and 52.7%, respectively [14, 15]. During heat treatment, starch may turn to dextrin and drying methods affects available carbohydrate content. Besides, the conversion degree of crystalline structure of the starch granule and gelatinization rate occurs depending on the temperature used, proportions of amylose and amylopectin and water content in the mushroom samples (Wang et al.) [17]. The importance of starch gelatinization and retrogradation is important in case food industrialist want to apply dried mushroom as functional food.

The data in Table 1 indicated that ash content was significantly different between dried grey and pink oyster mushrooms, except for microwave drying ($p < 0.05$). Dried mushrooms from cabinet drying had the highest amount of ash followed by microwave and vacuum drying. Pink oyster mushrooms had higher ash content compared to grey oyster mushrooms (Table 1). Previously, grey oyster mushrooms and pink oyster mushrooms are composed of ash at 7.27% and 5.81%, respectively [14, 15]. The range of ash content for dried grey oyster mushrooms was about 4–10 g/100 g dried mushrooms [18]. On the other hand, Rahman et al. [19] stated that the range of ash content for pink oyster mushrooms is between 6.7 and 7.2 g/100 g of dried mushroom sample. The ash content in mushroom samples are greatly influenced by the drying temperature and duration of exposure. This study indicated that shorter exposure time resulted in lower ash content, which is relatively important for mineral content in samples.

Mineral and vitamin B content of mushrooms

The mineral content analysed in different types of oyster mushrooms dried through different methods was shown in Table 2. From the results, K is the major mineral content in both types of mushroom followed by Mg, Na, Ca, Zn and Fe. *Pleurotus* species contain high K to Na ratio, which makes mushrooms an ideal food for patients suffering from hypertension & heart diseases. The substrate material used during

Table 2 Mineral composition of dried oyster mushrooms

SAMPLE	K	Mg	Na	Ca	Zn	Fe
GCD	$550.60 \pm 2.12^{a,A}$	$90.24 \pm 0.37^{a,B}$	$9.07 \pm 0.27^{b,B}$	$8.14 \pm 0.07^{b,B}$	$7.72 \pm 0.11^{b,B}$	$4.81 \pm 0.006^{a,B}$
GMW	$427.45 \pm 1.91^{b,B}$	$63.26 \pm 0.29^{c,B}$	$7.23 \pm 0.21^{c,B}$	$3.35 \pm 0.20^{c,B}$	$0.72 \pm 0.10^{c,B}$	$1.65 \pm 0.01^{b,B}$
GVC	$398.80 \pm 0.42^{c,A}$	$88.49 \pm 0.27^{b,B}$	$14.33 \pm 0.11^{a,B}$	$36.24 \pm 2.16^{a,A}$	$13.33 \pm 0.006^{a,B}$	$2.28 \pm 0.02^{c,B}$
PCD	$558.25 \pm 1.77^{a,A}$	$134.27 \pm 0.06^{a,A}$	$10.10 \pm 0.34^{c,A}$	$9.04 \pm 0.18^{b,A}$	$45.08 \pm 0.55^{a,A}$	$5.04 \pm 0.04^{a,A}$
PMW	$241.25 \pm 2.90^{c,B}$	$124.83 \pm 0.38^{b,A}$	$12.08 \pm 0.11^{b,A}$	$9.87 \pm 0.34^{b,A}$	$38.67 \pm 0.34^{c,A}$	$4.82 \pm 0.03^{b,A}$
PVC	$439.35 \pm 1.35^{b,A}$	$118.73 \pm 1.06^{c,A}$	$16.38 \pm 0.17^{a,A}$	$18.26 \pm 0.75^{a,B}$	$41.56 \pm 0.55^{b,A}$	$4.73 \pm 0.05^{c,A}$

Concentration in mg/100 g sample, mean ± standard deviation)

Analysis data were obtained from three triplicate samples. Values are expressed as mean ± standard deviation. Means with different small letter indicate a significant difference using ANOVA ($p < 0.05$) for different drying treatment and means with different capital letter indicate a significant difference using independent t-test ($p < 0.05$) for different type of oyster mushroom respectively

GCD grey oyster mushroom cabinet dried, *GMW* grey oyster mushroom microwave dried, *GVC* grey oyster mushroom vacuum dried, *PCD* pink oyster mushroom cabinet dried, *PMW* pink oyster mushroom microwave dried, *PVC* pink oyster mushroom vacuum dried

the growth of mushroom influences the mineral content in the mushroom. The least element found in the mushroom is Fe and Zn. There is significant difference ($p < 0.05$) for every element for each sample in different drying treatment, except for Ca in POM. For element K, Mg, Zn and Fe, cabinet dried samples have retained most of their minerals compared to other drying treatments. However, for Na and Ca, vacuum dried samples have retained most of their minerals. However, the whole mineral level depends, among other things like the species and age of the mushrooms, the diameter of the pilei and on the substratum [20]. The data showed that POM has higher content of all the elements determined. POM has indicated high amount of K and Mg. It is very common for both *Pleurotus* mushrooms to exhibit different mineral composition with higher content of K [15, 21]. *Pleurotus* usually extracts its nutrients from the substrate, usually agricultural by-products, through the mycelium to assist the growth of mushroom by receiving carbon, nitrogen, vitamins and minerals [22]. Hence, major elements such as K and Mg are efficiently being transferred from cultivation substrate into the fruiting body of mushroom. Meanwhile, peptides have preference to form complexes with transition elements such as Zn and Fe. Thus, the chelating of these elements could be an explanation for the high uptake of Zn in the POM [23].

Based from the results indicated in Table 3, vitamin B_3 was significantly higher for GOM and POM dried using cabinet oven compared to other drying techniques. According to Mattila et al. [24], the abundant vitamin contained in *Pleurotus* mushroom particularly thiamine, riboflavin, niacin, pyridoxine, pantotene acid, nicotinic acid, nicotinamide, folic acid and cobalamin. For both vitamin B_3 and B_6, POM has higher vitamin content compared to GOM counterpart. Extended drying time and high temperatures could degrade vitamin B content, however, drying at 50 °C had reasonable retention of vitamin [25]. GOM contains more folacine, vitamin B_1 and vitamin B_3, but less vitamin B_{12} than other mushroom species [6, 26]. Lower temperature, high vacuum and shorter drying time of combination of microwave-vacuum drying may protect vitamin B from being destroyed [6]. Meanwhile Mosuro and Ogunwole [27] found that air drying at room temperature (up to 72 h) retained more vitamin B_3 and vitamin B_6 compared to oven drying (55 °C) and freeze drying. However, low rate of heat transfers in vacuum drying lead to extended drying time and uneven energy distributed by microwave drying may cause lower vitamin content [6]. Moreover, the vacuum oven dried mushrooms had the highest moisture contents (Table 1). Therefore, the same sample weight, vacuum oven dried samples had relatively

Table 3 Vitamin B_3 and B_6 composition of dried oyster mushrooms

Vitamin B_3			Vitamin B_6	
Drying treatment	Grey oyster mushroom (*Pleurotus sajor caju*)	Pink oyster mushroom (*Pleurotus djamor*)	Grey oyster mushroom (*Pleurotus sajor caju*)	Pink oyster mushroom (*Pleurotus djamor*)
Cabinet dryer oven	$0.2196 \pm 0.01^{a,A}$	$0.2521 \pm 0.04^{a,A}$	$0.0251 \pm 0.002^{a,B}$	$0.1136 \pm 0.001^{a,A}$
Microwave oven	$0.1272 \pm 0.03^{b,B}$	$0.1946 \pm 0.01^{b,A}$	$0.0252 \pm 0.005^{a,A}$	$0.0274 \pm 0.001^{b,A}$
Vacuum oven	$0.0777 \pm 0.0006^{c,B}$	$0.1142 \pm 0.001^{c,A}$	$0.0175 \pm 0.003^{b,B}$	$0.0261 \pm 0.0006^{c,A}$

Concentration in mg/100 g sample, mean ± standard deviation). Means with different small letter indicate a significant difference using ANOVA ($p < 0.05$) for different drying treatment and means with different capital letter indicate a significant difference using independent t-test ($p < 0.05$) for different type of oyster mushroom respectively

Table 4 Browning index of oyster mushroom by different drying treatments

Browning index (cap)			Browning index (stem)		Browning index (gill)	
Treatment	Grey oyster mushroom (*Pleurotus sajor caju*)	Pink oyster mushroom (*Pleurotus djamor*)	Grey oyster mushroom (*Pleurotus sajor caju*)	Pink oyster mushroom (*Pleurotus djamor*)	Grey oyster mushroom (*Pleurotus sajor caju*)	Pink oyster mushroom (*Pleurotus djamor*)
Fresh mushroom	$36.8854 \pm 0.52^{d,A}$	$37.9061 \pm 0.68^{c,A}$	$13.9774 \pm 0.43^{c,B}$	$17.7366 \pm 1.23^{d,A}$	$16.3789 \pm 1.06^{c,B}$	$38.9890 \pm 0.71^{d,A}$
Cabinet dryer oven	$43.1501 \pm 0.64^{c,B}$	$48.5244 \pm 0.37^{b,A}$	$50.0895 \pm 1.20^{b,A}$	$42.1206 \pm 0.97^{c,B}$	$51.2078 \pm 0.46^{a,B}$	$84.3482 \pm 1.83^{a,A}$
Microwave oven	$70.5871 \pm 1.55^{a,A}$	$67.2938 \pm 4.07^{a,A}$	$55.8556 \pm 0.50^{a,B}$	$75.1082 \pm 0.18^{a,A}$	$50.0591 \pm 2.72^{a,B}$	$66.2368 \pm 0.57^{b,A}$
Vacuum oven	$62.7124 \pm 0.89^{b,A}$	$63.3091 \pm 0.98^{a,A}$	$50.3531 \pm 1.34^{b,A}$	$46.5465 \pm 0.85^{b,B}$	$29.2522 \pm 1.31^{b,B}$	$56.9718 \pm 0.56^{c,A}$

Values are expressed as mean ± standard deviation. Meanswith different small letter indicate a significant difference using ANOVA ($p < 0.05$) for different drying treatment whilecapital letters indicate independent t-test ($p < 0.05$) for different types of oyster mushroom (grey and pink) respectively

low solid contents, which resulted in a lowered Vitamin B content (Table 3).

Browning index and microstructure of mushrooms

Table 4 shows the results of browning index. POM showed that it is more likely to degrade colour and undergo browning compared to GOM. POM has resulted to intense colour, which could cause the mushroom to degrade more and has darker brown compared to GOM. From the data, the browning index for three different drying treatments that resulted to dried mushrooms is significantly different ($p < 0.05$) with the browning index of the fresh oyster mushroom. For cap and stem of the mushroom, cabinet dried mushroom has lowest browning index. The brighter colour possibly were retained due to lower temperature usage in cabinet drying method compared to other methods [25]. While, microwave dried mushroom has the highest colour degradation and browning index. The microwave dried products were more influenced by browning reactions than the hot-air dried products due to uneven heating in microwave ovens because variations in the power density over the volume in a microwave oven makes heating uniformity difficult to achieve [28]. Higher browning index occurred due to moisture evaporation that could alter and increase the absorption in the electromagnetic spectrum (Tian et al. [6]. However, pulse-spouted microwave vacuum drying (60 °C, 600 W) resulted in similar colour characteristics with fresh edamame [13]. While, the gill of GOM that undergo vacuum drying has the least colour degradation compared to microwave and cabinet dried mushroom. The availability of oxygen molecules is lower in vacuum drying chamber that may have limited the browning reaction, hence resulting in minimal colour changes [29]. Meanwhile, the colour is more intense at gills part especially for POM and most of the mushrooms has inconsistent colour and caused the browning index to be higher.

Scanning electron microscopy (SEM) of the microstructure of dried GOM and POM on the stem surface and gill

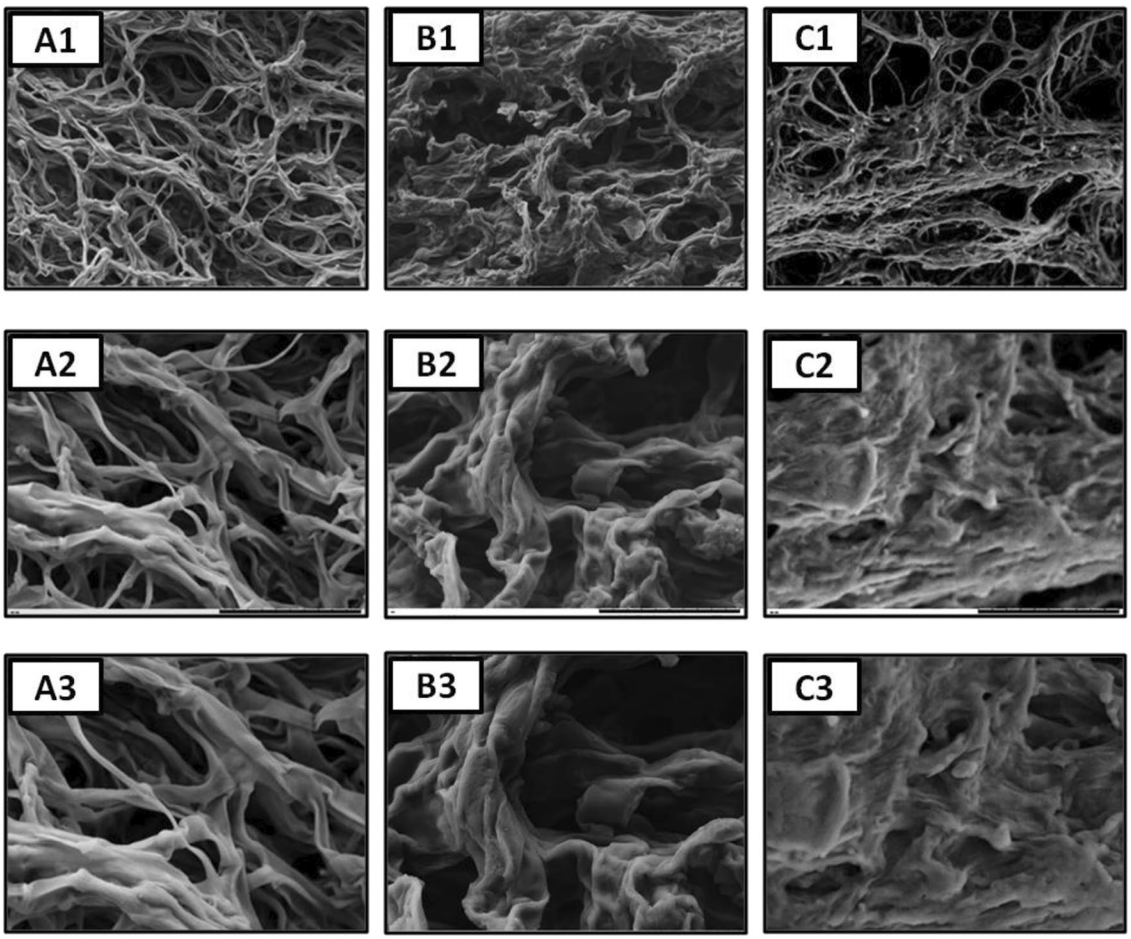

Fig. 4 Scanning electron micrograph (SEM) of dried grey oyster mushroom (GOM) of different drying treatments at stem surface of the mushroom. Scanning electron microscopy, image of *Pleurotus sajor caju* (grey oyster) stem surface heated by different methods, **A** cabinet dryer, **B** microwave oven, and **C** vacuum oven. (A1, B1, C1: 500×), (A2, B2, C2: 1500×) and (A3, B3, C3: 2000×) (Color figure online)

surface can be compared visually by referring to Figs. 4, 5, 6, 7. From the SEM results obtained, stem surface of cabinet drying mushroom exhibited the highest porosity. The gill surface images of cabinet dried POM were more rigid compared to GOM counterpart. While vacuum dried mushroom stem surface showed bigger pore size due to the observation that vacuum conditions created a larger vapour pressure difference between the product and the drying chamber [6]. The vast difference of vapour pressure between the product and the drying chamber has caused a rapid moisture transfer, which has led to swelling of cell and larger channels being formed inside the sample [30]. This explains why the size of the pore of vacuum dried mushroom is bigger compared to the other dried mushroom. There is less pore can be seen on stem of microwave dried mushroom, but it has rough and gritty surface. In the microwave drying, due to the rapid conversion of microwave radiation, the inner moisture was difficult to evaporate outside which caused cellular structures cross linked together [29]. This might be due to the action of high temperature and the dielectric strength with higher penetrating ability, leading to an uneven distribution of water diffusion and electromagnetic properties [13]. This may lead to the texture changes of the mushroom, in terms of hardness, cohesiveness, springiness and chewiness. This would be an extensive study to explore on the textural and optical properties of the POM and GOM during different drying methods.

Relationship between drying methods and mushroom characteristics

The relationship between various drying method investigated in this study, namely, cabinet drying, vacuum oven drying and microwave oven drying was established using Principal Component Analysis (PCA) using quality attributes (browning index and microstructure) and nutritional values (proximate composition, selected mineral content, vitamin B_3 and vitamin B_6) for GOM and POM, as the variables, concurrently. PCA results are presented in score

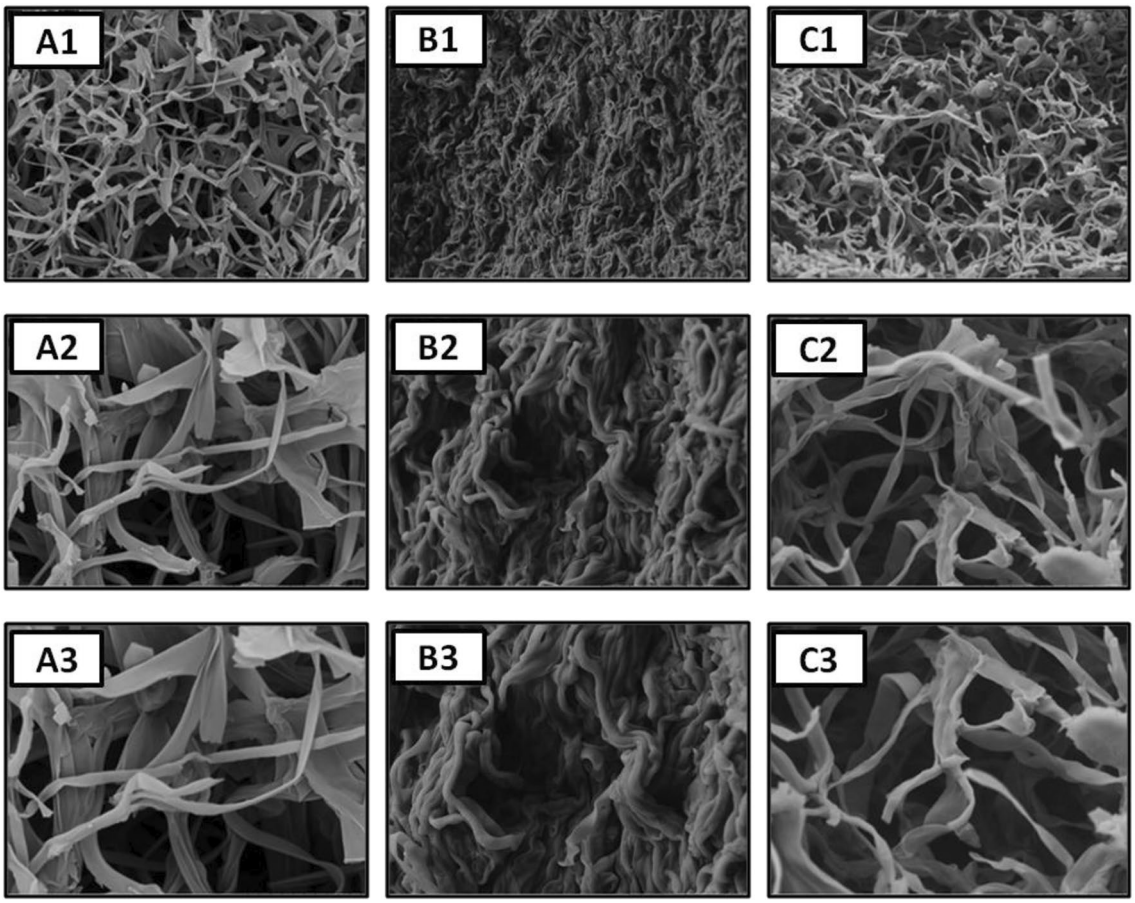

Fig. 5 Scanning electron micrograph (SEM) of dried pink oyster mushroom (POM) of different drying treatments at stem surface of the mushroom. Scanning electron microscopy, image of *Pleurotus sajor caju* (grey oyster) stem surface heated by different methods, **A** cabinet dryer, **B** microwave oven, and **C** vacuum oven. (A1, B1, C1: 500×), (A2, B2, C2: 1500×) and (A3, B3, C3: 2000×) (Color figure online)

plot and biplot depiction and the eigenanalysis of the correlation matrix showed that the cumulative PC1 and PC2 is of 73.9% (PC1: 49.3% and PC2: 24.5%). The PCA results showed a clear discrimination of different types of oyster mushrooms dried using different techniques based on both nutritional characteristics and browning effects (Tables 1, 2, 3, 4). The same type of drying technique showed some similarity between different types of mushrooms. For instance, samples regardless of the type of mushroom dried by using cabinet dryer oven (indicated as blue and purple in Fig. 8a) and vacuum oven (indicated as green and orange in Fig. 8a) were well discriminated from each other (based on PC1) and from samples were dried by microwave oven (based on PC2). The samples dried by microwave oven showed significant differences between GOM and POM. Further, microwave dried samples were different from other samples dried using other different techniques (both cabinet drying and vacuum drying).

The biplot of principal component analysis (Fig. 8b) showed that cabinet dryer resulted in higher contents of K, fat, vitamins (vitamin B_3 & vitamin B_6), whereas vacuum oven dried samples had relatively higher contents of Ca, Na, moisture and browning index (cap). Pink oyster mushroom seemed to yield relatively higher protein content. In general, pink oyster mushroom resulted in higher contents of both macro- & micro nutrients and higher browning indexes in comparison with grey oyster mushroom except carbohydrates and K.

Conclusion

In conclusion, cabinet drying grey oyster mushrooms (GOM) has yielded the highest carbohydrate, protein, fat, vitamin B_3, vitamin B_6, essential elements such as K, Mg, Zn & Fe. While, vacuum dried mushrooms yielded

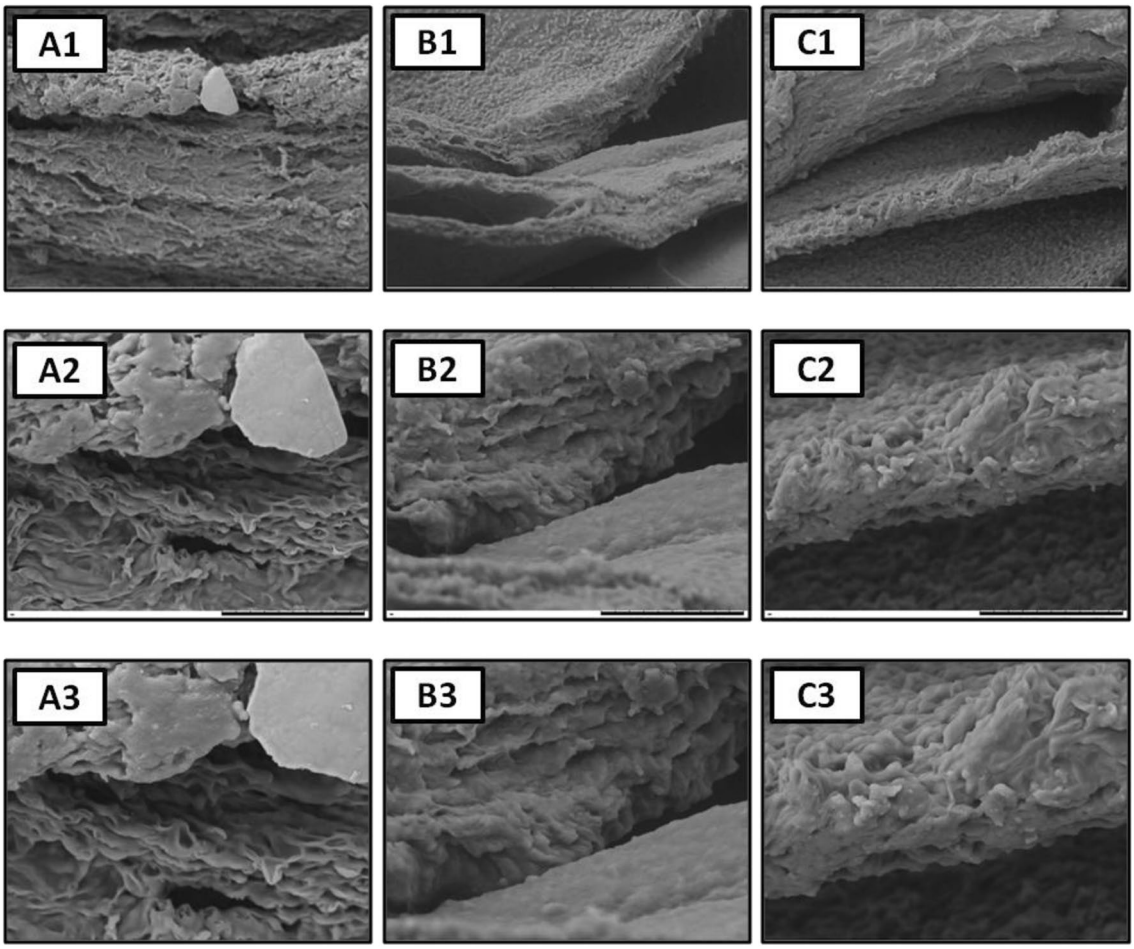

Fig. 6 Scanning electron micrograph (SEM) of dried grey oyster mushroom (GOM) of different drying treatments at gill surface of the mushroom. Scanning electron microscopy, image of *Pleurotus sajor caju* (grey oyster) gills surface heated by different methods, **A** cabinet dryer, **B** microwave oven, and **C** vacuum oven. (A1, B1, C1: 500×), (A2, B2, C2: 1500×) and (A3, B3, C3: 2000×) (Color figure online)

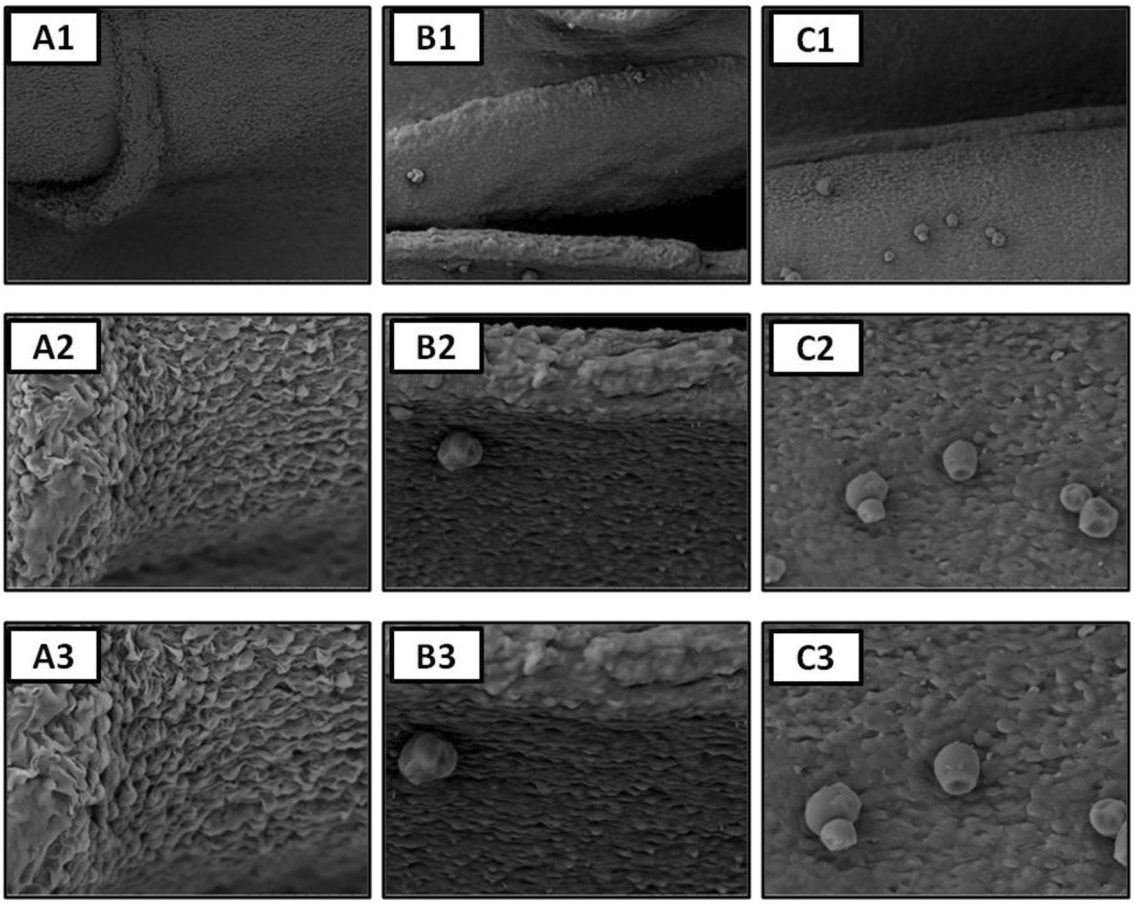

Fig. 7 Scanning electron micrograph (SEM) of dried pink oyster mushroom (POM) of different drying treatments at gill surface of the mushroom. Scanning electron microscopy, image of *Pleurotus sajor caju* (grey oyster) gills by different methods, **A** cabinet dryer, **B** microwave oven, and **C** vacuum oven. (A1, B1, C1: 500×), (A2, B2, C2: 1500×) and (A3, B3, C3: 2000×) (Color figure online)

significantly higher Ca for both GOM and pink oyster mushrooms (POM), however, vacuum drying caused severe damage on cell structure of the mushroom. On the other hand, microwave drying treatment mushroom has the highest post-drying browning index. Generally, POM had higher protein, fat, vitamin B_3 and most of the mineral content, while GOM had higher carbohydrate. Based on principal component analysis, cabinet drying is more likely to be chosen as the best postharvest treatment as it causes least degradation and it is low-cost and easy for maintenance. Conclusively, cabinet drying produced higher nutritional content in mushrooms compared to microwave and vacuum oven. Dried mushroom that has been produced should be further developed into food product that can be accepted by consumers. Further study could explore the effect of food processing on the product nutrient quality, textural and optical properties of the POM and GOM.

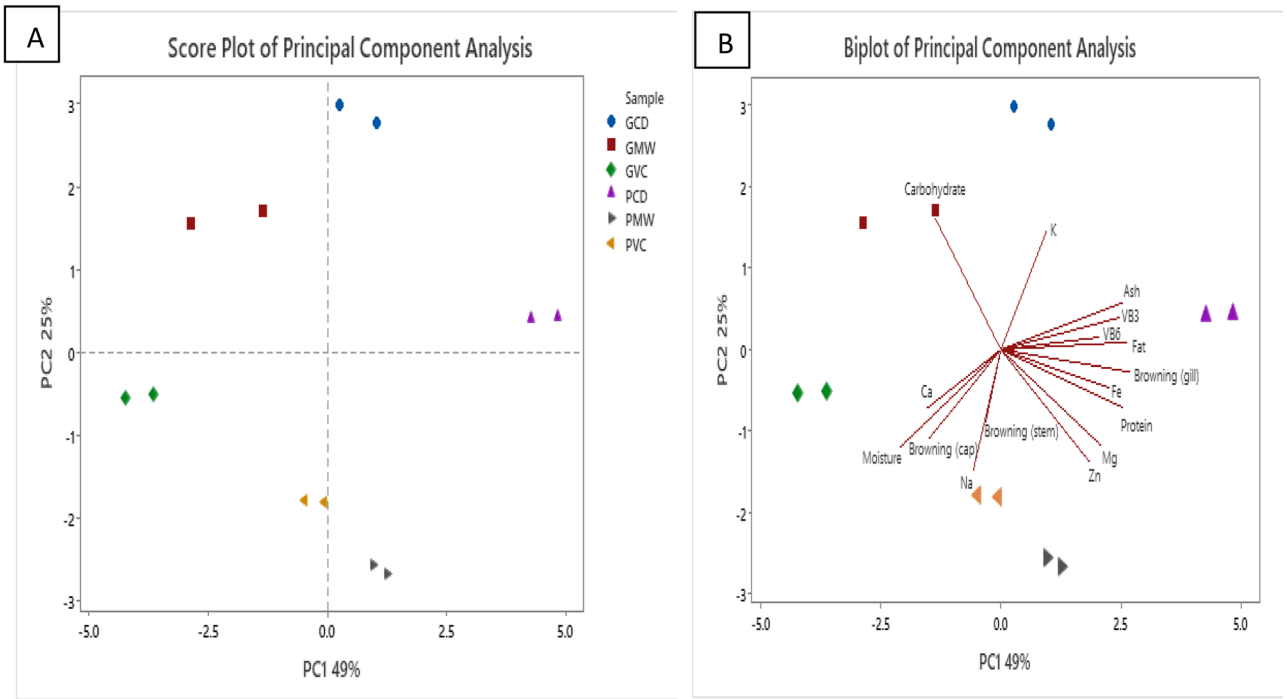

Fig. 8 Principal component analysis (PCA) indicates **A** score plot diagram dried GOM and POM using different drying treatments and **B** biplot diagram of quality attributes (browning index) and nutritional values (proximate composition, selected mineral content, vitamin B_3 and vitamin B_6). (*GCD* grey oyster mushroom cabinet dried, *GMW* grey oyster mushroom microwave dried, *GVC* grey oyster mushroom vacuum dried, *PCD* pink oyster mushroom cabinet dried, *PMW* pink oyster mushroom microwave dried, *PVC* pink oyster mushroom vacuum dried) (Color figure online)

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Declarations

Conflict of interest There are no conflict of interest among authors.

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