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Influence of different drying methods and cold storage treatments on the postharvest quality and nutritional properties of *P. ostreatus* mushroom

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Abstract: This study was conducted to determine the effects of different drying methods and cold storage treatments on the postharvest quality and nutritional properties of *P. ostreatus* mushroom. In the study, six different treatments including natural drying, oven drying (60 °C), microwave drying (450 W), storage at -18 °C, 4 °C and 10 °C were evaluated. After drying and cold storage, pH value, ash, protein, color, total phenolic content, total flavonoid content, antioxidant activity and element contents in mushroom samples were detected. According to findings obtained from the study, drying and cold storage treatments significantly ($p < 0.01$) affected the postharvest quality and nutritional composition of *P. ostreatus*. The protein content, ash content, L* color value, total phenolic content, total flavonoid content, antioxidant activity and essential mineral contents such as potassium, magnesium, phosphorus, calcium, iron, zinc, and manganese of *P. ostreatus* decreased after drying and cold storage compared to the fresh mushroom sample. As a result, the best treatment was determined as storage at 4 °C in terms of protection the quality and nutritional value of *P. ostreatus* during postharvest storage. In addition, natural drying was the most effective treatment among drying methods, and it can be used successfully for long-term storage of this mushroom. However, it was concluded that microwave drying method was not suitable for the preservation of *P. ostreatus* since it caused significant nutrient and quality losses. The results of the present study will provide useful information about postharvest preservation and processing of *P. ostreatus* for researchers working on this issue.

Key words: Drying methods, low temperature storage, nutritional content, oyster mushroom, quality

1. Introduction

Horticulture crops include high content of nonnutritive, nutritive, and bioactive compounds such as flavonoids, phenolics, anthocyanins, phenolic acids, and as well as nutritive compounds such as sugars, essential oils, carotenoids, vitamins, and minerals (Engin and Mert, 2020; Koyuncu, 2020).

Among horticultural crops, mushrooms have also been considered as important food items because of their flavor, aroma, unique taste, high nutritional values, and several medicinal properties since ancient times. Nowadays, mushrooms constitute an integral part of the human diet. The production and consumption of edible mushrooms have increased greatly in recent times all over the world (Royse et al., 2017). Mushrooms are rich in proteins, minerals, vitamins, nonstarchy carbohydrates, and dietary fibers, and they have quite low cholesterol, calories, and fat content (Kalac, 2013). Moreover, mushroom proteins are of high quality, and they contain all essential amino acids required by humans (Kakon et al., 2012). Barros et al. (2007) have contended that the amino acid compositions of mushroom protein are comparable to that of animal proteins. Therefore, mushroom consumption may contribute considerably to overcome protein deficiency in particularly developing countries (Pokhrel, 2016). In addition, mushrooms are a natural source for functional foods or nutraceuticals due to their bioactive components, which are beneficial to human health (Zhu et al., 2015).

Mushrooms of *Pleurotus* genus are commonly known as "oyster mushroom" and popularly consumed all over the world. Oyster mushrooms are the second most widely cultivated mushrooms in the world and Turkey (Royse, 2014; Eren and Pekşen, 2019). *P. ostreatus* is the first cultivated species among the *Pleurotus* spp., and it is the most commercially produced mushroom worldwide, after *Agaricus bisporus*. *P. ostreatus* belongs to the phylum Basidiomycota, the class Agaricomycetes, the order Agaricales and the family Pleurotaceae (Phillips, 1994). *P. ostreatus* has been preferred throughout the world since long years owing to its characteristic taste, pleasant aroma, culinary quality, nutritional composition, medicinal importance, high yield, short

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life cycle, relatively easy method of cultivation (Kibar et al., 2016). Additionally, mycelia and fruiting bodies of *P. ostreatus* contain numerous bioactive compounds with antioxidant properties, including polysaccharides, polyphenols, β-carotenes, peptides, terpenoids, steroids and glycoproteins, which are proven to prevent oxidative damage related to aging and diseases and thus protect the human body (Jayakumar et al., 2011; Kortei and Wiafe-Kwagyan, 2015). For this reason, *P. ostreatus* is used in the treatment of many diseases such as hypertension, hypercholesterol, Alzheimer, and cancer (Adebayo and Oloke, 2017).

On the other hand, edible mushrooms deteriorate very quickly and lose their quality after harvest (Reis et al., 2012). The highly perishable nature of fresh mushrooms is attributed to their high moisture content (85%–95%) which favors microbial activities, high respiration rate, delicate texture, and high enzymatic activities (Jiang, 2013). Mushrooms have thin and porous epidermal structures, and they do not have cuticle layer to protect them from physical changes, microbial attacks, and water loss (Villaescusa and Gil, 2003). Enzymatic breakdown continues rapidly in the mushrooms after harvest. In addition, some mold fungi and bacteria develop on the mushrooms. In fact, fresh mushrooms' shelf life is limited to a few days at ambient temperature. The short shelf life of mushrooms causes difficulties in their distribution and marketing as fresh products and limits the amount of consumption (Singh et al., 2010). Accordingly, the extension of mushroom's shelf life is a constant quest for production and supply chain of mushrooms (Akbarirad et al., 2013). Mushroom deterioration during storage is a complex process. Various morphological and physiological changes occur after harvest, which make mushrooms unacceptable for consumption. The quality losses such as weight loss, shrinkage, elongation and thinning of stipe, opening of cap, decay, reduction in protein, sugar and soluble solid contents, formation of unwanted odor, color changes (darkening, browning, etc.), texture changes (softening, toughening, etc.) and microbial infections occur during postharvest storage of mushrooms, which often result in great economic losses and considerably reduce their commercial value (Song et al., 2019). However, the quality of mushrooms is the most important factor affecting fresh consumption. Physical parameters such as color, flavor, texture and odor, and general appearance are known to influence consumers' choices regarding fresh mushroom. Therefore, it is extremely important to determine suitable postharvest storage conditions for extending the shelf life and maintaining the quality of mushrooms. When determining the appropriate preservation methods for mushrooms, care should be taken to minimize the losses in terms of quality and nutritional properties. The methods such as cold storage, drying, freezing, modified atmosphere packaging, controlled atmosphere storage, and canning are applied to extend the shelf-life and maintain the postharvest quality of mushrooms (Kibar and Kibar, 2015). Approximately 40%–50% of edible mushrooms produced in the world are consumed fresh, and the remaining part is processed (drying, canned, etc.).

It is known that low temperature storage is an effective method to reduce losses, maintain quality, and extend the shelf life of horticultural crops including mushrooms after harvest (Candir et al., 2019; Ozdemir et al., 2019). Mushrooms cannot be stored for more than 24 h at ambient temperature, while they can be stored for 1 to 2 weeks in refrigerated conditions. Low temperature storage of mushrooms decreases respiration and transpiration, delays aging, reduce the softening, enhance the textural firmness, prevents water loss, wilting and wrinkling, and, thus, extends the shelf life. It is reported that low temperature is one of the most important parameters for extending shelf life of *Pleurotus* mushrooms. Generally, fresh oyster mushrooms can be stored for 8–11 days at 0 °C, 4–6 days at 5 °C, 2–3 days at 10 °C and 1–2 days at 20 °C (Villaescusa and Gil, 2003).

Drying is one of the most common methods for the long-term preservation of mushrooms (Walde et al., 2006; Argyropoulos et al., 2011). In the peak period of production, mushrooms that are fresh consumption surplus are preserved by drying. Drying is a simpler and cheaper method when compared to other postharvest storage methods (Walde et al., 2006). In addition, dried mushrooms can be stored in air-tight packages for more than one year, and they are convenient for transportation. Dried mushrooms are used in soups, pizzas and canned foods, and different food ingredients as mushroom powder. Mushrooms must be dried to a certain moisture level (about 12%) in order to be stored safely of mushrooms after drying. Drying prevents microbial growth, reduces water loss, slows down enzyme activity and biological reactions, and, thus, preserves the quality of mushrooms and prolongs their shelf life (Argyropoulos et al., 2011). The food quality of dried mushrooms depends considerably on drying method used. The most common drying methods for mushrooms are hot air drying, natural air drying, vacuum drying, microwave drying, sun drying, fluidized bed drying, infrared drying and freeze drying (Walde et al., 2006).

Like other mushrooms, *Pleurotus* mushrooms are highly perishable, and its quality deteriorates immediately after harvest if not stored properly. Mushroom consumers place much value quality and nutritional content of mushrooms. Therefore, investigating the effects of different postharvest techniques on the quality and nutritional properties of *Pleurotus* mushrooms is an important research subject.

Studies have predominantly been focussed on storage conditions of *A. bisporus*; however, less information is currently available concerning postharvest storage characteristics of *Pleurotus* mushrooms. The objective of this study was to study the effects of different drying methods and cold storage treatments on the postharvest quality and nutritional properties of *P. ostreatus*.

2. Materials and methods

2.1. Material

Oyster mushroom [*Pleurotus ostreatus* (Jacq. ex. Fr.) Kummer, strain HK-35] was used as material in this study. The mushrooms were grown on substrate consisting of a mixture of straw, sawdust, and bran (45% straw + 45% sawdust + 10% bran) in the mushroom growing room belong to Bolu Abant İzzet Baysal University Faculty of Agriculture. The mushrooms from the first flush were used in the study. Freshly harvested mushrooms were placed in polyethylene bags and transported to the laboratory within 1 h after harvest. The mushrooms of the same size and maturity were selected to provide homogeneity in the experiment. Fresh mushroom clusters were separated into individual mushrooms. Subsequently, damaged, injured, and crushed mushrooms were discarded. The initial moisture content of fresh oyster mushroom was 87.7 ± 2.4% (wet basis), which was determined by drying in a hot air oven at 105 °C until constant weight was obtained (Lin et al., 2019).

2.2. Methods

2.2.1 Experimental design and treatments

In the study, six different treatments were compared. Treatments are as follows: natural drying, oven drying (60 °C), microwave drying (450 W), storage at –18 °C, storage at 4 °C and storage at 10 °C. The experiment carried out in a completely randomized design (CRD) with three replications for each treatment.

Drying treatments were conducted under laboratory conditions. In drying treatments, the mushrooms were dried using three different methods. Prior to drying, the fresh mushroom samples were initially cut into slices about 5 mm thickness using stainless steel knife and then homogenized. For each replication of drying treatments, 500 g of oyster mushrooms were dried. In the natural drying method, mushroom samples were spread on perforated trays and dried at ambient temperature (24 ± 3 °C) by air flowing in the laboratory. The samples were mixed routinely to ensure uniform drying. It took 4–5 days depending on ambient air temperature during drying. The samples were periodically weighed until a constant weight was obtained. In the oven drying method, mushroom samples were laid on stainless steel perforated trays and placed in a hot air oven (MST-120, Mikrotest, Turkey) at 60 °C. The samples were periodically stirred during drying. The samples were dried until constant weight was achieved. In the microwave drying method, mushroom samples were laid on grills in a microwave oven (ME732K, Samsung, Korea) and dried at a power of 450 W. Drying samples were weighed each 15 s until a constant weight was obtained without pausing the drying process. The dried mushroom samples were placed in zip-locked plastic bags and stored in a dark place at room temperature until needed for further analyses.

The cold storage treatments were carried out in temperature controlled cold storage rooms. Mushrooms were stored whole without slicing. For each replication of cold storage treatments, 500 g of fresh oyster mushrooms were packed in zip-locked polyethylene bags (ISOLAB, 30 × 20 cm). Then, the samples were stored at different low temperatures (–18 °C, 4 °C and 10 °C) with 85 ± 5% relative humidity for 14 days.

Morphological properties, color, dry matter, pH value, ash, protein, total soluble solid content (TSSC), total phenolic, total flavonoid, antioxidant activity, and element contents of the mushroom sample before drying and cold storage were determined. After different drying and cold storage treatments, pH value, ash, protein, color, total phenolic, total flavonoid, antioxidant activity, and element contents in mushroom samples were detected.

2.2.2. Determination of morphological and nutritional properties

Morphological properties (cap length, cap width, stipe length, stipe diameter, and average fruit body weight) of fresh oyster mushrooms were determined according to Ağaoğlu et al. (1992). pH values of the samples were measured using a digital pH meter (Thermo Scientific, Orion Star A111). The total soluble solid content was measured with a hand-held refractometer (ATC-1, Atago, Japan). The dry matter, moisture, and ash contents of the samples were determined by using the procedures of AOAC (1990). The color properties (L*, a*, b*, C* and h°) of samples were measured using a colorimeter (3NH NR60CP). The total nitrogen (N) content was performed according to Kjeldahl method, and the protein content of mushrooms (Nx6.25) was calculated as described by AOAC (1990).

To determine element contents (potassium, magnesium, calcium, sodium, iron, zinc, copper, manganese, selenium, cobalt, tinnen, nickel, lead, cadmium, arsenic, and chrome), dried mushroom samples were firstly ground by using a grinder (MC23200, Siemens, Germany) and then prepared for analysis according to the microwave digestion method. Element contents were detected using inductively coupled plasma mass spectrometry (ICP-MS; Thermo Scientific, X Series, Cambridge, U.K.). Phosphorus content was determined by UV-visible spectrophotometer (UV-1800, Shimadzu, Japan). Sulphur content was detected using the

Elemental Analyzer CHNS-O (Thermo Scientific, Flash 2000). Element contents were expressed as mg kg^{-1} dry weight (DW).

2.2.3. Determination of total phenolic content, total flavonoid content, and antioxidant activity

To determine total phenolic content, total flavonoid content, and antioxidant activity, initially 15 g mushroom samples were taken for each replication of each treatment. Afterwards, samples were homogenized with the aid of a blender. After this stage, it was centrifuged (12.000 × g) for 30 min at 4 °C. Then, the resultant sample was diluted with distilled water. About 30 mL of homogenate was taken and placed into 50 ml falcon tubes. The tubes were stored at –20 °C until used for analyses. Spectrophotometric measurements for bioactive compounds were performed in a UV-Vis spectrophotometer (Shimadzu, Kyoto, Japan).

For total phenolic content, mushroom sample was extracted with a buffer (70:29.5:0.5, acetone:water:acetic acid, v/v). Resultant extracts were supplemented with Folin-Ciocalteu's phenol reagent and water, incubated at room temperature for 8 min and supplemented with 7% sodium carbonate. Subsequently, sample absorbance was measured at 760 nm in spectrophotometer as described by Singleton and Rossi (1965). Gallic acid was used as test standard and results were expressed as mg g^{-1} GAE (gallic acid equivalent).

Total flavonoid content was determined using the colorimetric method described by Chang et al. (2002). For total flavonoid content, about 0.1 g extract was dissolved in 1 mL of the solvent, and then supplemented with 10% $AlCl_3.6H_2O$ and 0.1 ml of 1 M potassium acetate (CH_3CO_2K). The absorbance of the resultant mixture was measured at 415 nm. Quercetin was used as test standard and results were expressed as mg g^{-1} QE (quercetin equivalent).

The antioxidant activity of mushroom samples was determined according to two different procedures of 1.1-diphenyl-2-picrylhydrazyl (DPPH) and Ferric Ions (Fe^{3+}) Reducing Antioxidant Power (FRAP). Free radical scavenging activity of methanol extract of samples was measured by a stable free radical, 1.1-diphenyl-2-picrylhydrazyl (DPPH) as described by Blois (1958). DPPH bleaching rate was monitored at a characteristic wavelength. About 3.0 mL extracts were supplemented with 0.5 mL of 0.1 mM ethanolic solution of DPPH and then the mixture was shaken vigorously and left still for 30 min. Mixture absorbance was measured spectrophotometrically at 517 nm. Ferric ions (Fe^{3+}) Reducing Antioxidant Power assay (FRAP) was performed as described by Benzie and Strain (1996). Portions of 120 µL were taken from the samples, 0.2 M of phosphate buffer (PO_4^{-3}) (pH = 6.6) was added to obtain a volume of 1.25 mL, and then 1.25 mL of 1% potassium ferricyanide ($K_3Fe(CN)_6$) solution was added. After vortexing, they were incubated at 50 °C for 1 h. Afterwards, 1.25 mL of 10% TCA (trichloroacetic acid) and 0.25 mL of 0.1% $FeCl_3$ were added to the samples. The absorbances of the extract solution were read at 700 nm using a UV-Vis spectrometer. Results were expressed as µmol g^{-1} TE (trolox equivalent) in both assays.

2.2.4. Statistical analysis

All analyses except for morphological properties were performed with three replications. Measurements for morphological properties carried out with ten replications. Mean values and standard deviations (SD) related to properties of the mushroom sample before different drying and cold storage treatments were calculated, and the data were expressed as mean ± standard deviation. The results were subjected to one-way analysis of variance (ANOVA) using JMP statistical software (Version 13.0). Differences among means were evaluated by Tukey's Honestly Significant Difference (HSD) test, and the significance was accepted at $p < 0.05$ level.

3. Results and discussion

3.1. Morphological and nutritional properties of the fresh *P. ostreatus* mushroom before drying and cold storage

Some morphological and nutritional properties of the fresh *P. ostreatus* mushroom before different drying and cold storage treatments are given in Table. The dry matter, ash, and protein contents of mushroom sample were 12.3, 10.34, and 20.35%, respectively. Similar results were also reported by Khan (2010), Tolera and Abera (2017) for *P. ostreatus.* Total soluble solid content and pH value determined in this study agreed with the results of Villaescusa and Gil (2003) for *P. ostreatus*. Morphological properties and color values of *P. ostreatus* were in accordance with the results detected by Kibar (2019). Our results for total phenolic and flavonoid contents were compatible with the findings of Turfan et al. (2018) for *P. ostreatus*. Mineral contents obtained in the present study were in the range detected by Khan et al. (2008) and Turfan et al. (2018) for *P. ostreatus*. The nutritional properties of edible mushrooms are directly related to their chemical composition (Kortei et al., 2017a).

3.2. Effect of drying and cold storage treatments on pH, ash, and protein contents of *P. ostreatus*

Effects of drying and cold storage treatments on pH value, ash, and protein contents of *P. ostreatus* are presented in Figure 1. There were significant differences ($p < 0.01$) in terms of the nutritional properties mentioned among the treatments. The pH values, ash and protein contents depending on the treatments ranged from 5.73 to 6.26, 8.01 to 10.22% and 16.40 to 20.19%, respectively. The highest pH values were determined in storage at 4 and 10 °C, and natural drying, while the lowest values were observed

Table. Some morphological and nutritional properties of the fresh *P. ostreatus* mushroom before drying and cold storage.

Properties	**Mean ± SD**	**Properties**	**Mean ± SD**
Dry matter (%)	12.3 ± 1.06	Potassium (mg kg^{-1})	6465.09 ± 255.56
pH	6.32 ± 0.29	Magnesium (mg kg^{-1})	2744.42 ± 144.45
Ash (%)	10.34 ± 0.83	Phosphorus (mg kg^{-1})	1617.23 ± 94.23
Protein (%)	20.35 ± 1.75	Calcium (mg kg^{-1})	1295.47 ± 75.84
Total soluble solid content (TSSC, %)	6.20 ± 0.27	Sulphur (mg kg^{-1})	2656.24 ± 140.62
L*	68.96 ± 2.25	Sodium (mg kg^{-1})	1141.46 ± 70.55
a*	7.46 ± 0.36	Iron (mg kg^{-1})	350.24 ± 13.24
b*	17.40 ± 1.16	Zinc (mg kg^{-1})	202.86 ± 7.85
C*	18.94 ± 1.20	Copper (mg kg^{-1})	52.13 ± 2.13
h°	66.75 ± 2.06	Manganese (mg kg^{-1})	20.27 ± 1.27
Cap length (cm)	11.5 ± 0.78	Selenium (mg kg^{-1})	15.47 ± 0.95
Cap width (cm)	9.6 ± 0.62	Cobalt (mg kg^{-1})	8.37 ± 0.35
Stipe length (cm)	4.3 ± 0.19	Tinnen (mg kg^{-1})	5.41 ± 0.25
Stipe diameter (mm)	16.8 ± 1.15	Nickel (mg kg^{-1})	9.70 ± 0.48
Average fruit body weight (g)	26.7 ± 1.48	Lead (mg kg^{-1})	2.96 ± 0.17
Total phenolic content (mg g^{-1} GAE)	137.25 ± 4.75	Cadmium (mg kg^{-1})	3.15 ± 0.19
Total flavonoid content (mg g^{-1} QE)	21.45 ± 1.35	Arsenic (mg kg^{-1})	4.83 ± 0.23
Antioxidant activity (DPPH, μmol g^{-1} TE)	52.64 ± 2.12	Chrome (mg kg^{-1})	1.97 ± 0.12
Antioxidant activity (FRAP, μmol g^{-1} TE)	168.53 ± 6.35		

SD: Standard deviation.

in storage at –18 °C and microwave drying. Among the treatments, storage at 4 °C had the highest ash content. However, the lowest value in terms of ash content was detected in microwave drying. The highest protein content was found in storage at 4 °C followed by storage at –18 °C, while the lowest values were recorded in microwave drying and oven drying (Figure 1). The pH values, protein, and ash contents of *P. ostreatus* decreased after drying and cold storage compared with fresh mushroom sample (Table).

The protein content is one of the most important components affecting mushroom quality. The protein content of mushrooms depends on species of mushroom, the composition of substrate, size of pileus and harvest time (Akyüz and Kırbağ, 2010). *P. ostreatus* are considered as a good source of protein (17%–42%) (Khan et al., 2008; Akyüz and Kırbağ, 2010). Decreases in the protein and sugar content of mushrooms are the most important indicators of deterioration during the postharvest stage (Meng et al., 2017). In addition, the change in the ash content of mushrooms during the storage period directly affects the change in mineral content of mushrooms (Ramdas, 2012). Similar to our results, Ramdas (2012) found that protein and ash contents of oyster mushrooms decreased as the storage period increased at different storage temperatures (0–3, 3–5 and 8–10 °C). Likewise, protein content of *P. tuoliensis* stored at 4 °C decreased with increasing of storage time (Li et al., 2021). In general, the drying process causes a significant reduction in protein content of mushrooms (Hassan and Medany, 2014). The lowest protein content in *P. eryngii* was found in microwave drying among different drying methods (Lüle, 2014), which was consistent with our findings. In another study, different drying methods (sun, solar, and oven drying) significantly affected the protein and ash contents of *P. ostreatus*. The protein content in fresh mushroom sample was found significantly higher than dried samples (Tolera and Abera, 2017). Results obtained for protein and ash contents in this study agreed with values detected by Kortei et al. (2017a) in solar dried *P. ostreatus*.

3.3. Effect of drying and cold storage treatments on color properties of *P. ostreatus*

The effects of drying and cold storage treatments on color properties (L*, a*, b*, C* and h°) of *P. ostreatus* were significant ($p < 0.01$) (Figure 2). In the present study, a considerable variation in terms of color properties was observed among the treatments. The L*, a*, b*, C* and h° values of the mushroom samples after drying and cold storage varied from 25.01 to 62.91, 5.55 to 9.47, 10.05 to 23.39, 13.96 to 23.81 and 44.49 to 75.93, respectively. The L* values of mushroom samples in microwave drying were

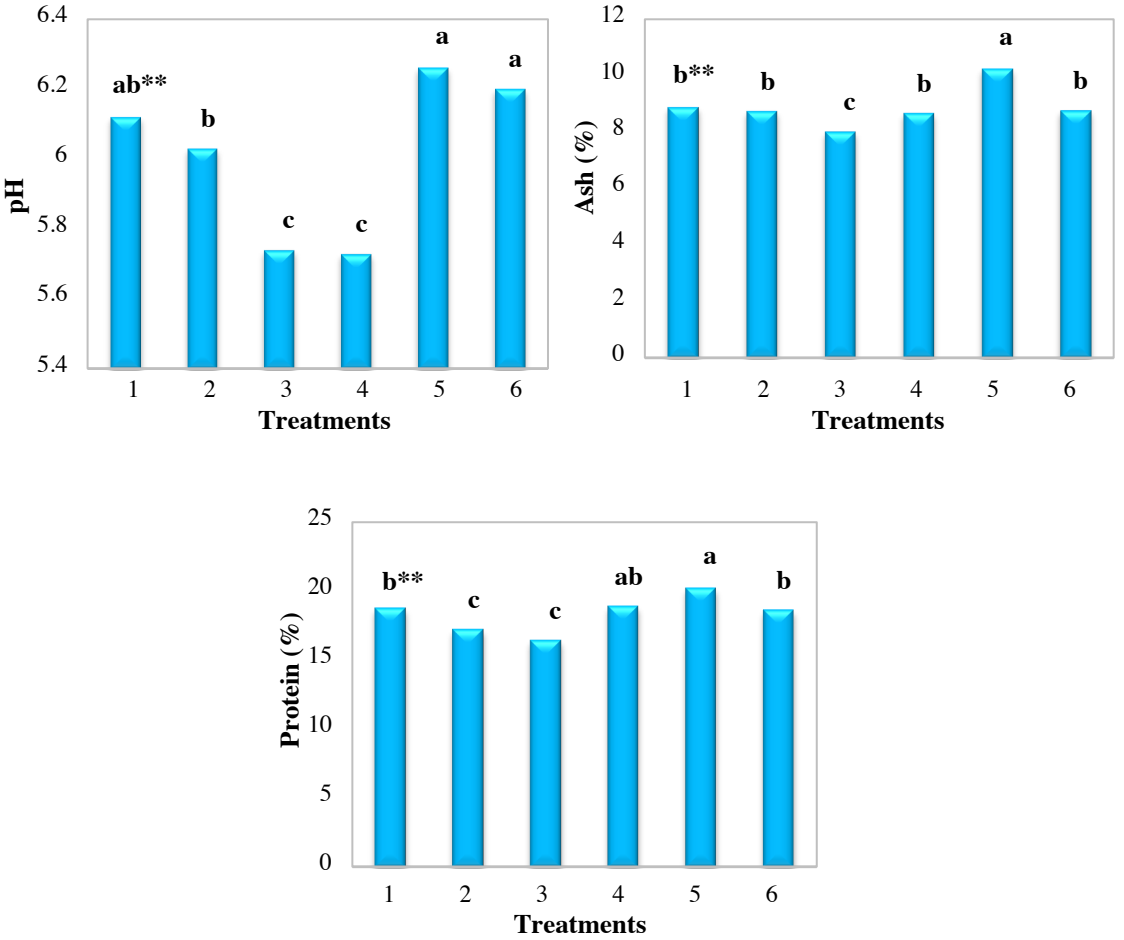

Figure 1. Effect of drying and cold storage treatments on pH, ash, and protein contents of *P. ostreatus* (1. Natural drying, 2. Oven drying, 3. Microwave drying, 4. Storage at -18 °C, 5. Storage at 4 °C and 6. Storage at 10 °C. The different letters indicate a significant difference among the treatments, **: Significant at $p < 0.01$).

significantly lower than other treatments and so they were darker compared to other treatments. The highest L* value was determined in the mushroom samples in stored at 4 °C and these mushroom samples stored at 4 °C had a lighter color. The L* values in cold storage treatments were considerably higher than drying treatments. The highest a* value was recorded in microwave drying, while the lowest a* values were determined in storage at –18 °C and natural drying. The mushroom samples in natural drying possessed the highest b*, C* and h° values. On the contrary, the lowest values in terms of b*, C* and h° were observed in microwave drying (Figure 2). The color properties of *P. ostreatus* considerably changed after drying and cold storage compared with fresh mushroom sample and L* value decreased (Table).

Color is one of the most important quality criteria affecting consumer preference for edible mushrooms. The observed changes in color during storage are the result of non-enzymatic or enzymatic darkening (Espin and Wichers, 1999). Villaescusa and Gil (2003) stated that L* value decreased significantly at the end of 11 days of storage at 0, 4 and 7 °C for *P. ostreatus*, whereas a* and b* values increased when compared with the initial values. Li et al. (2021) reported that L* value decreased significantly at the end of 12 days of storage at 4 °C and 6 days of storage at 25 °C in *P. tuoliensis*. Also, L* value of mushrooms stored at 4 °C was higher than that of 25 °C. Our results were similar to L*, a*, b*, C* and h° values reported by Kortei et al. (2015) in dried *P. ostreatus*. Similar findings to our results were detected by Piskov et al. (2020) who stated that the darkest mushrooms in *P. ostreatus* were obtained in microwave drying among different drying methods (freeze drying, hot air drying, microwave drying and sun drying). Darker color of mushrooms in microwave drying may be due to the reaction of saccharoamine condensation (Maillard reaction) during heating (Izli and Isik, 2014). The results obtained in the present study are generally consistent with the previous studies.

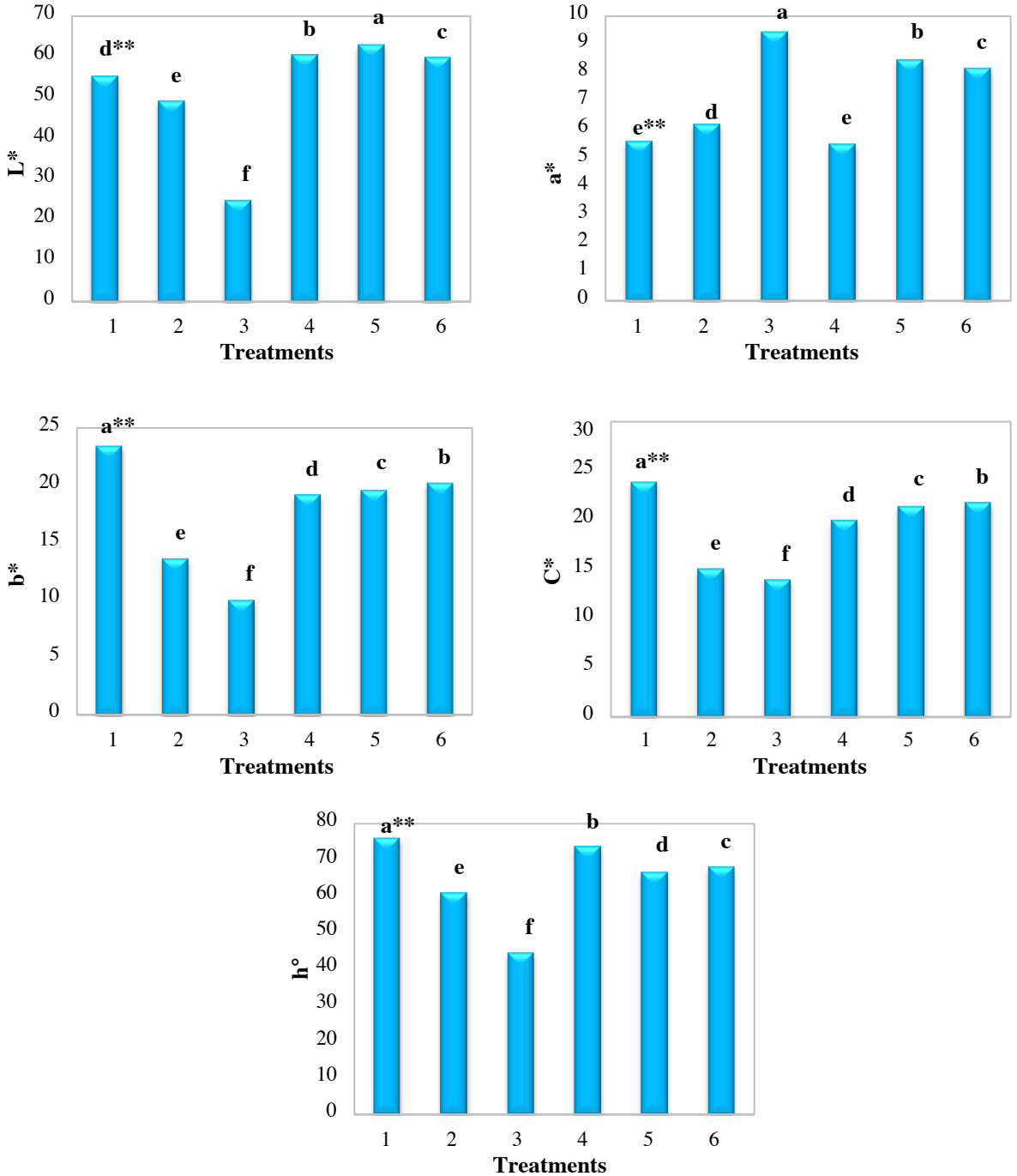

Figure 2. Effect of drying and cold storage treatments on color properties (L*, a*, b*, C* and h°) of *P. ostreatus* (1. Natural drying, 2. Oven drying, 3. Microwave drying, 4. Storage at -18 °C, 5. Storage at 4 °C and 6. Storage at 10 °C. The different letters indicate a significant difference among the treatments, **: Significant at $p < 0.01$).

3.4. Effect of drying and cold storage treatments on total phenolic content, total flavonoid content, and antioxidant activity of *P. ostreatus*

In the present study, total phenolic content, total flavonoid content, and antioxidant activity (DPPH and FRAP) of *P. ostreatus* varied significantly ($p < 0.01$) depending on drying and cold storage treatments. Among the treatments, the highest values for total phenolic content, DPPH antioxidant activity, and FRAP antioxidant activity (135.70 mg g^{-1} GAE, 50.51 µmol g^{-1} TE and 164.39 µmol g^{-1} TE, respectively) were observed in storage at 4 °C. However, microwave drying had the lowest total phenolic content

and DPPH antioxidant activity (61.14 mg g^{-1} GAE and 35.60 µmol g^{-1} TE, respectively). Total phenolic content in storage at 4 °C was almost twice that of microwave drying. The lowest values in terms of FRAP antioxidant activity were found in microwave drying and storage at 10 °C. The total flavonoid content ranged from 8.09 to 20.86 mg g^{-1} QE. The highest total flavonoid content was found in storage at –18 °C and 4 °C, whereas the lowest values were observed in microwave drying and storage at 10 °C. Total flavonoid content in storage at –18 °C and 4 °C were about 2 times higher than that of microwave drying (Figure 3). Total phenolic content, total flavonoid content, and antioxidant activity of *P. ostreatus* decreased after drying and cold storage compared with fresh mushroom sample (Table).

P. ostreatus is of great importance as a source of natural antioxidants in food biotechnology (Piskov et al., 2020). Turkoglu et al. (2007) reported that the antioxidant activity in mushrooms is closely related to the total phenolics. A similar situation was determined in our study. Antioxidant activity was also found to be high in treatments with high total phenolic content. Jafri et al. (2013) reported that the total phenolic content decreased significantly at the end of the storage period at 4 °C for 25 days in *P. florida*, which was compatible with our results. Zhang et al. (2020) found that total phenolic content increased in the first 6 days of storage and then decreased in *A. bisporus* stored at 4 °C for 12 days. Contrary to our results, it was observed that the total phenolic content increased at the end of storage period in *P. eryngii* stored at 2, 4, and 8 °C for 18 days (Li et al., 2016) and in *P. tuoliensis* stored at 4 °C for 12 days and at 25 °C for 6 days (Li et al., 2021). Researchers also stated that the total phenolic contents in mushrooms stored at low temperatures were higher than that of high temperatures. Piskov et al. (2020) reported that the highest total phenol and flavonoid contents and antioxidant activity (FRAP) in *P. ostreatus* were obtained from microwave drying among different drying methods (freeze drying, hot air drying, microwave drying and sun drying), which was not in consistency with our results. The content of biologically

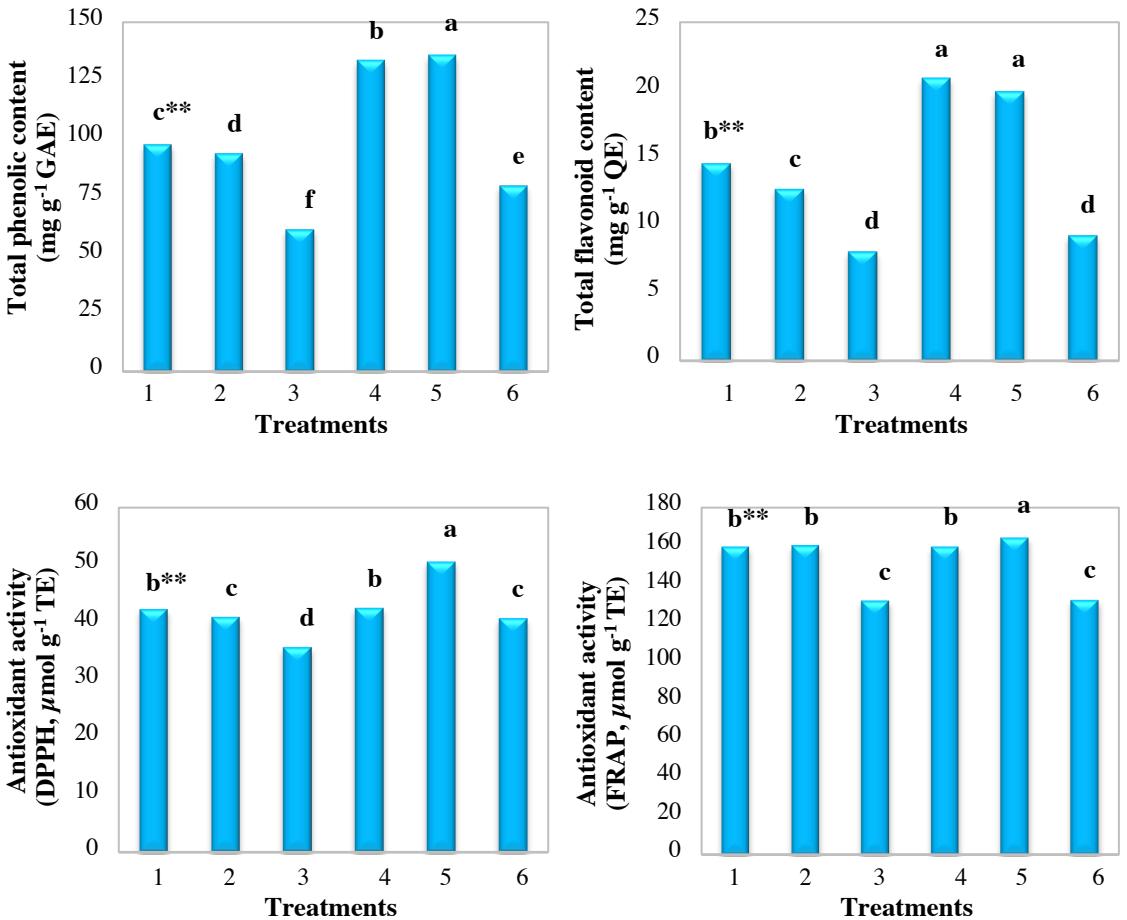

Figure 3. Effect of drying and cold storage treatments on total phenolic content, total flavonoid content, and antioxidant activity (DPPH and FRAP) of *P. ostreatus* (1. Natural drying, 2. Oven drying, 3. Microwave drying, 4. Storage at –18 °C, 5. Storage at 4 °C and 6. Storage at 10 °C. The different letters indicate a significant difference among the treatments, **: Significant at $p < 0.01$).

active compounds in mushrooms varies greatly, not only depending on genetic structure of species, physical and chemical differences in growing medium, maturity, and cultivation conditions (Koutrotsios et al., 2018) but also on storage conditions and processing methods (Ji et al., 2012).

3.5. Effect of drying and cold storage treatments on element contents of *P. ostreatus*

Effects of drying and cold storage treatments on element (potassium, magnesium, phosphorus, calcium, sulphur, sodium, iron, zinc, copper, manganese, selenium, cobalt, nickel, tinnen, arsenic, lead, cadmium, and chrome) contents of *P. ostreatus* are shown in Figures 4, 5, and 6. The analysis of variance revealed that there were significant differences ($p < 0.01$) in terms of all element contents examined among treatments.

Potassium, magnesium, phosphorus, calcium, sulphur and sodium contents of *P. ostreatus* depending on the treatments varied from 5685.74 to 6373.72 mg kg^{-1}, 2292.70 to 2686.98 mg kg^{-1}, 1381.19 to 1531.60 mg kg^{-1}, 993.58 to 1223.16 mg kg^{-1}, 1791.06 to 2838.82 mg $kg^{-1}$and 707.82 to 1223.92 mg kg^{-1}, respectively. For potassium and sulphur, the lowest values were determined in microwave drying, though the highest values were observed in storage at 4 °C. Likewise, microwave drying also possessed the lowest values for magnesium, phosphorus, calcium, and sodium. The highest magnesium content was found in storage at 4 °C followed by storage at 10 °C and natural drying. The highest values regarding phosphorus content were recorded in natural drying, storage at 4 °C and 10 °C, and oven drying. The highest calcium contents were observed in natural drying and storage at 4 °C. Among the treatments, storage at –18 °C had the highest sodium content, and it was closely followed by natural drying and storage at 4 °C (Figure 4).

The highest iron and selenium contents were obtained in storage at 4 °C (320.39 and 15.79 mg kg^{-1}, respectively) and natural drying (343.72 and 15.64 mg kg^{-1}, respectively). The zinc content was found to between 123.31 (microwave drying) and 187.72 mg kg^{-1} (storage at 4 °C). The highest copper content (56.28 mg kg^{-1}) was observed in storage at 10 °C. On the other hand, iron, zinc, copper, and selenium contents were the lowest in microwave drying. Manganese content was in the range from 16.89 to 19.19 mg kg^{-1}. Manganese content was the highest in storage at 4 °C, oven drying and natural drying, while it was the lowest in storage at –18 °C, microwave drying and storage at 10 °C. The highest cobalt content was determined in storage at –18 °C, and it was closely followed by natural drying and storage at 10 °C. The lowest cobalt contents were observed in microwave drying and oven drying (Figure 5).

The highest nickel contents were found in storage at –18 °C and natural drying, while the lowest values were observed in microwave drying and oven drying. Microwave drying had the lowest values with regard to tinnen, arsenic, lead, and cadmium contents. However, the highest values for mentioned heavy metals were recorded in storage at –18 °C, natural drying and storage at 10 °C. Storage at 10 °C had the highest chrome content. Conversely, the lowest chrome content was observed in storage at –18 °C (Figure 6). Essential mineral contents such as potassium, magnesium, phosphorus, calcium, iron, zinc, and manganese of *P. ostreatus* decreased after drying and cold storage in comparison with fresh mushroom sample. However, increases were observed in the contents of minerals such as sulphur, sodium, selenium and copper, and heavy metals such as tinnen, arsenic, lead and cadmium in some treatments compared with fresh mushroom sample (Table).

Oyster mushrooms are important sources of mineral elements (Adebayo and Oloke, 2017). Macro elements (potassium, magnesium, calcium, phosphorus, and sodium) and micro elements (iron, zinc, manganese, selenium, copper, cobalt, chromium, and molybdenum) have numerous important functions in human body, and they are essential for human health. Potassium, calcium, magnesium, sodium, phosphorus and sulphur are the minerals found in the most quantities in mushrooms (Kalac, 2009). Similar findings were also obtained in this study. In the present study, although different treatments affected mineral contents of *P. ostreatus*, the quantities determined in the study are still valuable and beneficial in the human nutrition. Similar to our results, the lowest potassium, calcium, phosphorus, and iron contents were found in microwave drying among different drying methods in *P. eryngii* (Lüle, 2014). Vetter (2003) found that potassium, magnesium, and phosphorus contents decreased after *A. bisporus* had been dried, which was consistent with our findings. Mutukwa et al. (2019) reported that drying methods (solar and oven) had no significant effect on mineral contents in *P. ostreatus*. The results obtained for element contents in this study were higher than the values determined in *P. ostreatus* dried by using a solar dryer (Kortei et al., 2017b). It is considered that the concentration of heavy metals in mushrooms is higher than in vegetables and fruits (Zhu et al., 2011). Mushrooms can easily accumulate some toxic elements or heavy metals such as cadmium, arsenic, lead, tinnen, and chromium from the environment due to their dense mycelial systems, which infiltrates the substrate (Chen et al., 2009). The effects of preservation methods on mineral contents of mushrooms differed among different researchers. Variation in mineral contents can be considerably influenced by various factors such as mushroom species, type of substrate, environmental conditions, growing conditions, stage of development, diameter of the pileus, postharvest storage conditions, and

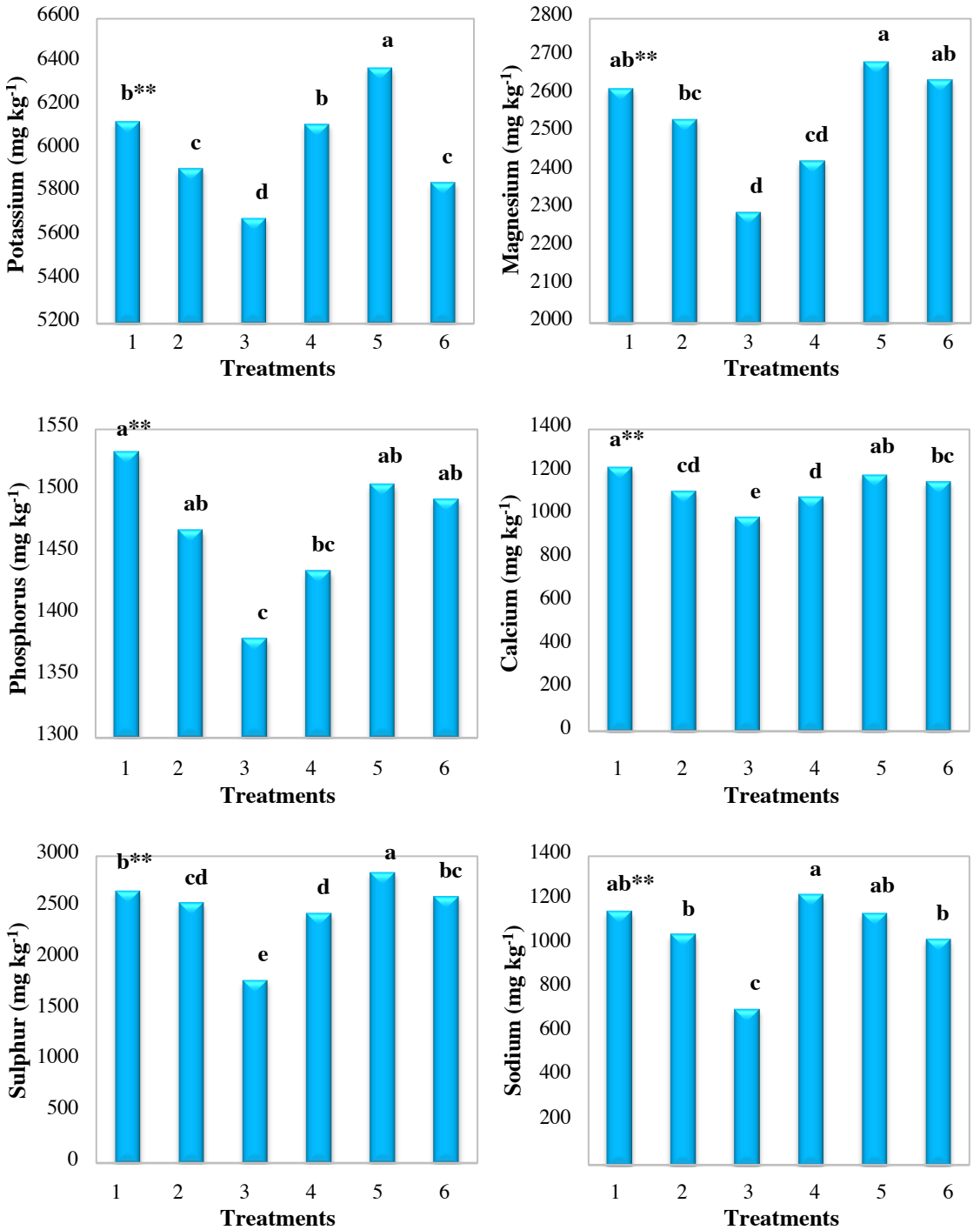

Figure 4. Effect of drying and cold storage treatments on potassium, magnesium, phosphorus, calcium, sulphur, and sodium contents of *P. ostreatus* (1. Natural drying, 2. Oven drying, 3. Microwave drying, 4. Storage at –18 °C, 5. Storage at 4 °C and 6. Storage at 10 °C. The different letters indicate a significant difference among the treatments, **: Significant at $p < 0.01$).

differences in the laboratory methods used (Manzi et al., 2001; Adejumo and Awosanya, 2005).

In the previous studies, the effects of various drying methods and storage temperatures on the quality and nutritional properties of *Pleurotus* mushrooms were investigated. Different researchers compared the effects of various drying methods in *P. eryngii*, and microwave drying was not found suitable for this species since it damaged physicochemical properties and caused losses of nutrients (Lüle, 2014; Li et al., 2015a; Yang et al., 2020). It

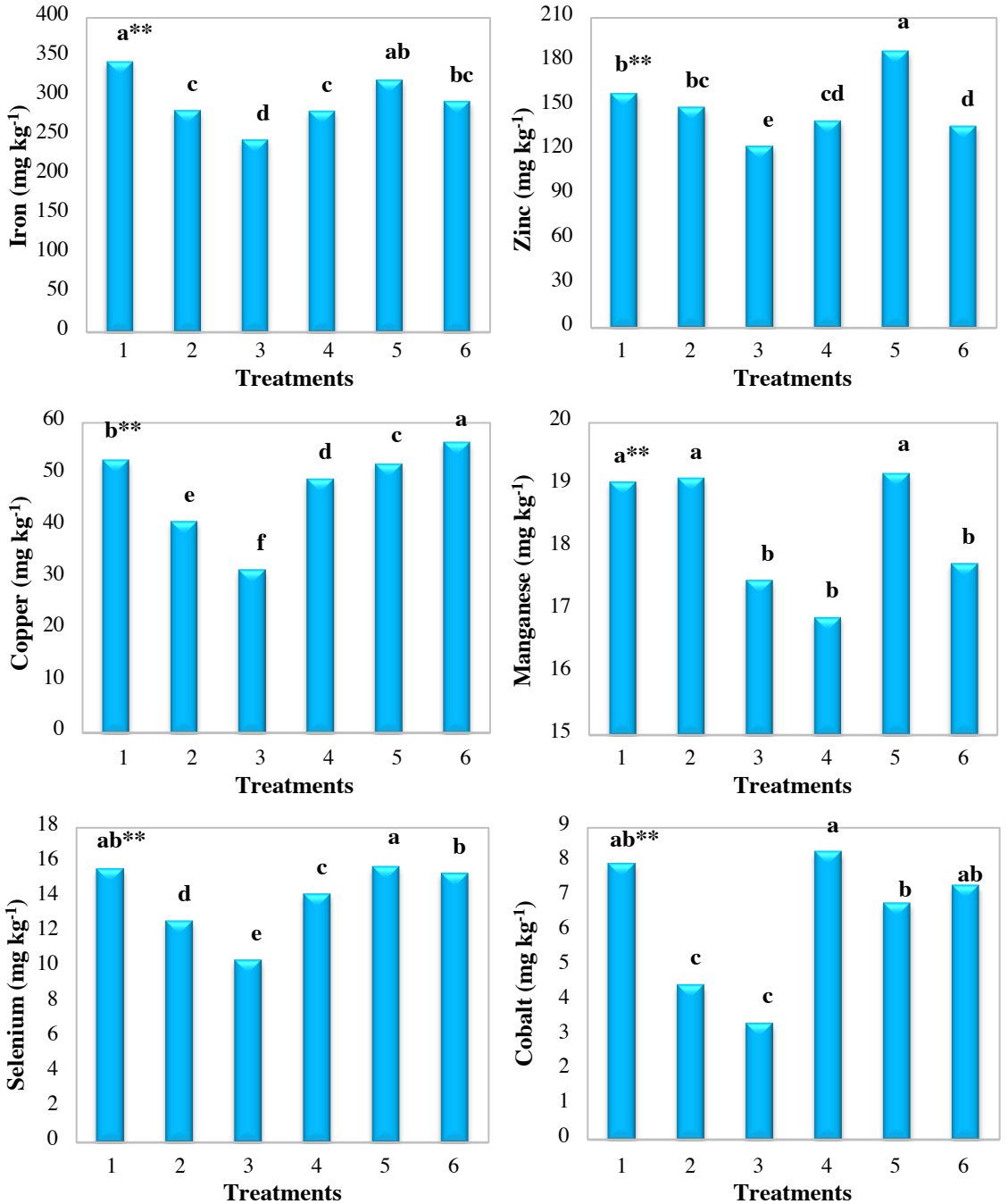

Figure 5. Effect of drying and cold storage treatments on iron, zinc, copper, manganese, selenium, and cobalt contents of *P. ostreatus* (1. Natural drying, 2. Oven drying, 3. Microwave drying, 4. Storage at –18 °C, 5. Storage at 4 °C and 6. Storage at 10 °C. The different letters indicate a significant difference among the treatments, **: Significant at $p < 0.01$).

is reported that the recommended storage temperature for quality of *P. ostreatus* stored at different temperatures (0, 4 and 7 °C) for 11 days was 0 °C (Villaescusa and Gil, 2003). Li et al. (2015b) found that the best storage temperatures were 2 and 4 °C for postharvest quality of *P. eryngii* stored at different temperatures (0, 2, 4, 6 and 8 °C). The results obtained in the present study are generally consistent with the previous studies.

4. Conclusion

Application of the best postharvest techniques to maintain the quality and extend the shelf life of

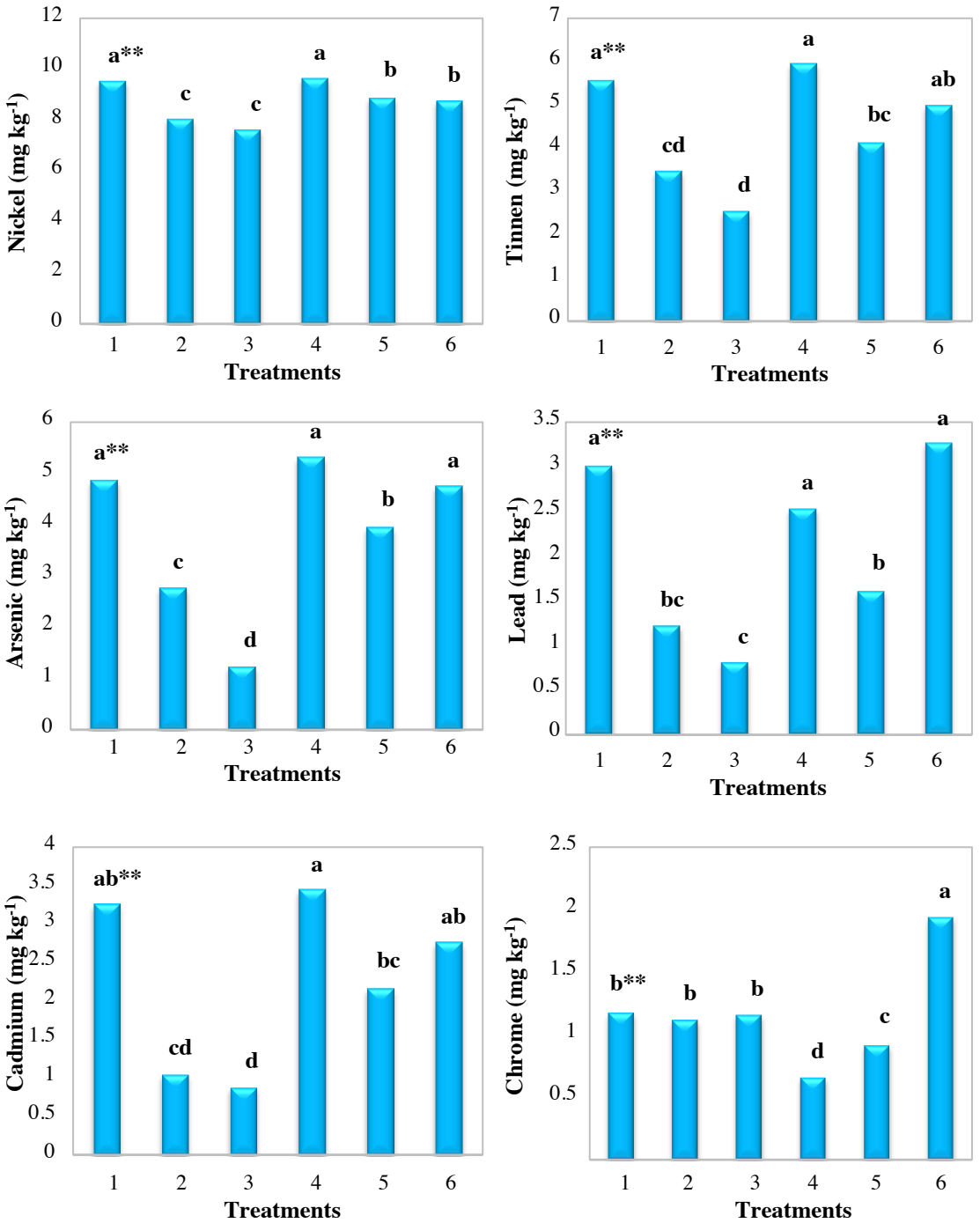

Figure 6. Effect of drying and cold storage treatments on nickel, tinnen, arsenic, lead, cadmium, and chrome contents of *P. ostreatus* (1. Natural drying, 2. Oven drying, 3. Microwave drying, 4. Storage at –18 °C, 5. Storage at 4 °C and 6. Storage at 10 °C. The different letters indicate a significant difference among the treatments, **: Significant at $p < 0.01$).

mushroom after harvest plays an extremely important role in commercialization of mushrooms. The results of the present study clearly indicated that significant differences were found among different drying and cold storage treatments in terms of all properties examined. In conclusion, the best treatment was found in the case of storage at 4 °C in terms of protecting the quality and nutritional value of *P. ostreatus* during postharvest storage. Additionally, natural drying, a simple and inexpensive method of drying, was the most effective treatment among drying methods, and it can be used successfully for long-term storage of this mushroom. However, it was concluded

that microwave drying method was not suitable for the preservation of *P. ostreatus* because it caused significant nutrient and quality losses, though it reduces the drying time. The results of this study will contribute to the food industry in terms of determining the best postharvest storage conditions to maintain the quality and nutritional components of *P. ostreatus*.

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