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Research Article

The Influence of Drying Method on Volatile Composition and Sensory Profile of *Boletus edulis*

Joanna Nöfer,[1] **Krzysztof Lech**,[2] **Adam Figiel**,[2] **Antoni Szumny**,[1] and **Ángel A. Carbonell-Barrachina**[3]

[1]*The Faculty of Food Science, Department of Chemistry, Wrocław University of Environmental and Life Sciences, Norwida 25, 53-375 Wrocław, Poland*
[2]*Institute of Agricultural Engineering, Wrocław University of Environmental and Life Sciences, Chełmońskiego 37/41, 51-630 Wrocław, Poland*
[3]*Research Group "Food Quality and Safety", Agro-Food Technology Department, Escuela Politécnica Superior de Orihuela, Universidad Miguel Hernández de Elche, Ctra. Beniel, km 3.2, 03312-Orihuela, Alicante, Spain*

Correspondence should be addressed to Joanna Nöfer; joanna.politowicz@gmail.com

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The objective of this study was to evaluate the influence of different drying methods on aroma and sensory profile of *Boletus edulis* (cepe). The drying methods tested were convective drying (CD), freeze-drying (FD), vacuum microwave drying (VMD), and a combination of convective predrying and vacuum microwave finish-drying (CPD-VMFD). Fresh and dried cepe volatiles, analyzed by SPME and GC-MS, showed the presence of 53 volatile compounds, most of them present in all dried samples but with quantitative variation. The major volatile compounds in fresh and dried cepe were 1-octen-3-ol (3405 μg 100 g^{-1}·db), 3-octanone (429 μg 100 g^{-1}·db), and hexanal (355 μg 100 g^{-1}·db). The results showed that drying of cepe mushrooms caused major losses of aroma compounds; however, the highest content of volatile compounds and the highest intensity of most of the key positive sensory attributes were found in samples after (i) CD at 80°C (3763 μg 100 g^{-1}·db), (ii) CD at 70°C (3478 μg 100 g^{-1}·db), and (iii) CPD at 60°C and VMFD at 480/240 W (2897 μg 100 g^{-1}·db).

1. Introduction

Over the last decades, the consumption of edible wild-grown mushrooms has significantly increased because they are traditionally recognized as valuable sources of nutrients [1]. Mushrooms are rich in digestible proteins, carbohydrates, dietary fibre, certain vitamins, and minerals but low in calories and fat [2]. Moreover, mushrooms contain a huge variety of bioactive compounds and proved to be effective as antioxidants, anticancer, and antimicrobial agents [3]. Among the bioactive molecules, phenolic compounds and tocopherols are the most responsible for their antioxidant activity. Apart from medicinal and nutritional properties, mushrooms are strongly appreciated for subtle flavor, aroma, texture, and unique taste [4]. Fruiting bodies are consumed as food and food-flavoring material in almost every national cuisine of many countries all over the world. For some regions of Europe, the rate of mushroom production and consumption is relatively high. In terms of value, European apparent consumption increased from €158 million in 2010 to €177 million in 2014 [5]. For instance in Poland, according to FAO statistics, mushroom production was estimated at almost 200.000 tons per year [6]. Furthermore, the annual consumption in Poland in the last two years was about 1.5 kg of fresh product by capita [7].

Boletus edulis is commonly known as cepe and king bolete in English-speaking countries. The fruiting body consists of 30 cm diameter brown cap and is 3–23 cm long and 3–11 cm thick white and/or grayish brown stripes and finely covered with delicate reticulated light brown pattern over the upper half [8]. Besides, its exceptional taste and aroma make *B. edulis* one of the most highly prized mushrooms in Poland. It was previously reported that this species is rich in nutrients and bioactive molecules, such as phenolic acids and tocopherols, that are related with their antioxidant activity.

Fresh mushrooms are very perishable products with a limited shelf life of 1 to 3 days at room temperature; thus, postharvest treatments are very important to extend their shelf life. One of the most frequently used methods of preserving mushrooms is canning, drying, or marinade. Dehydration is one of the simplest and oldest methods of preserving mushrooms, allowing them to be available throughout longer periods of time [9]. However, different dehydration methods may affect texture, nutritional value, volatile components, and sensory quality of final product [10]. Therefore, choosing the best drying method could make a significant contribution to the mushroom processing industry. Several techniques for mushroom drying have been reported; the most popular are convective and sun drying. Freeze-drying is considered as one of the best dehydration methods, providing the best structural integrity and flavor retention [9]. Due to the lack of liquid water presence, most of microbiological reactions are stopped, and the low temperatures required for the process gives a final product of excellent quality. Convective drying is still the most widely technique used to reduce the moisture content of vegetables, fruits, and herbs. However, relatively long time of the process and high temperature may negatively affect color, texture, flavor, and nutritional value of the final product [11]. An alternative way to avoid these inconveniences is vacuum microwave drying. The low temperature used during process combined with fast mass transfer conferred by vacuum and fast energy transfer by microwave heating induces very rapid and low temperature drying. Furthermore, the absence of air during drying may inhibit oxidation, and therefore, the color and nutrients content can be largely retained [12]. The combination of an initial convective predrying step (CPD) with a second and final step of vacuum microwave finish-drying (VMFD) reduces the mass to be loaded in the VMD system, resulting in a reduced total cost of dehydration process and improving the product quality [13].

In the present work, the influence of different drying methods on volatile profile of fresh cepe (*Boletus edulis*), originated from Polish forests, was examined. Furthermore, the aroma composition found in each sample was related with their descriptive sensory evaluation.

2. Materials and Methods

2.1. Materials. *Boletus edulis* (cepe) samples were collected from the forest in the region of Wrocław (Poland, 51°10′25.2″N 16°51′38.3″E) in September 2015. Moisture content of samples was determined using the vacuum dryer (SPT-200, ZEAMIL Horyzont, Krakow, Poland). The initial moisture content of all samples was 11.58 kg kg^{-1}·db. Whole mushrooms of similar size were selected and cut into cubes of 1 cm of side and dehydrated using 4 different methods: (i) freeze-drying (FD), (ii) convective drying (CD), (iii) vacuum microwave drying (VMD), and (iv) combined drying consisting of convective predrying followed by vacuum microwave finish-drying (CPD-VMFD).

2.2. Drying Methods. Freeze drying (FD) was performed in a freeze dryer OE-950 (Labor, MIM, Hungary) for 24 h at reduced pressure 65 Pa. Frozen mushrooms were placed on a heating plate, arranged in a one single layer. The temperature within the drying chamber was −60°C, while the heating plate reached 30°C.

Convective drying (CD) was carried out in a dryer designed and built at the Institute of Agricultural Engineering (Wrocław University of Environmental and Life Sciences, Poland). Mushroom samples (100 g) were placed in a tray of 100 mm diameter, arranged in one single layer, and were dried at four different temperatures: 50, 60, 70, and 80°C; the air velocity was 0.8 m s^{-1}. An increased mode of temperature 50/70°C and 50/80°C, consisting of convective finish drying at 70 and 80°C preceded by convective predrying at 50°C, was applied in order to reduce the drying time by increasing the drying rate at the final stage of CD.

Vacuum microwave drying (VMD) was done using a Plazmatronika SM 200 dryer (Wrocław, Poland). A cylindrical drum made of organic glass (18 cm of diameter × 27 cm of length) was rotated with 6 rev·min^{-1}. The drum was connected to a vacuum system consisting of a vacuum pump BL 30P ("Tepro", Koszalin, Poland), vacuum gauge MP 211 ("Elvac", Bobolice, Poland), and compensation reservoir of 0.15 m^3 capacity. In this study, 2 power levels were assayed, 240 and 480 W; a reduced mode of microwave power 480/240, consisting of VMD at 480 W followed by drying at 240 W, was also applied to assure a possible fast drying at relatively low temperature of the dried material. The maximum temperature reached by the mushroom samples was measured with an infrared camera i50 (Flir Systems AB, Stockholm, Sweden), immediately after removing samples from the VM dryer.

Combined drying (CPD-VMFD) consisted of convective predrying (CPD) at temperatures 50, 60, 70, and 80°C until a moisture content around 4.0 kg·kg^{-1} db was reached, followed by VM finishing-drying at 480/240 W. Samples of ~100 g of fresh mushrooms were used for all abovementioned drying methods.

2.3. Modeling of Drying Kinetics. The drying kinetics of CD, VMD, and CPD-VMD was performed based on the mass losses of cepe samples. During CD, weight losses were monitored every 5 min for the initial 20 min, and then, the measurement time intervals were extended to 10, 15, and 30 min after 20, 60, and 120 min of drying, respectively. On the contrary, VMD samples were monitored every 2 and 4 min for 480 and 240 W, respectively, to get a similar energy input regardless of the microwave power level. The moisture ratio (MR) was calculated using the following equation:

$$\mathrm{MR} = \frac{M(t) - M_e}{M_0 - M_e}, \quad (1)$$

where $M(t)$ is the moisture content at time τ, M_0 is the initial moisture content, and M_e is the equilibrium moisture content.

The value of the equilibrium moisture content, M_e, usually is very low, and Equation (1) is often simplified to the form of Equation (2), without a significant change in the value of MR [14, 15].

$$MR = \frac{M(t)}{M_0}. \quad (2)$$

Table Curve 2D Windows v2.03 was used to fit the basic drying models to the measured MR determined accordingly to Equation (2). There are several drying models which can be used for describing drying kinetics of plant materials including mushrooms. The good fitting of a specific model to the experimental data was evaluated using two parameters: (i) coefficient of determination (R^2) and (ii) root-mean squared error (RMSE). The model fit is better if the value of R^2 is closer to 1, and the RMSE value is closer to 0. Five drying models, such as modified Page, Henderson–Pabis, logarithmic, Midilli-Kucuk, and Weibull were considered for describing the drying kinetics. However, preliminary tests conducted in this study proved that the best fitting was obtained for the modified Page model (as given by equation (3)); consequently, only this model was used in this study:

$$MR = A \cdot \exp(-k \cdot \tau^n), \quad (3)$$

where A, n, and k are constants.

2.4. Isolation of Volatile Compounds. The isolation of the aroma compounds was performed using a headspace solid phase microextraction (HS-SPME) procedure, previously reported by Politowicz et al. [16]. A manual SPME holder (Supelco, Bellefonte, PA, USA) with a divinylbenzene/-carboxen/polydimethylsiloxane (DVB/CAR/PDMS, 50/30 μm, coating 1 cm) fiber (Supelco) was used to extract headspace volatiles from *Boletus edulis*.

2.5. GC-MS and GC-FID Analyses. The GC-MS analysis was performed on GC-MS Clarus SQ8 (PerkinElmer, MA, USA) equipped with an Elite-5 MS (PerkinElmer, MA, USA) capillary column (30 m × 0.25 μm film × 0.25 mm i.d.). Samples were injected with a splitless ratio and helium, at 1 mL·min^{-1}, was used as carrier gas. Oven temperature was held at 60°C for 3 min, raised to 120°C at 3°C min^{-1}, then to 300°C at 15°C·min^{-1}, and held for 2 min. Mass spectra were recorded in electron impact (EI) ionization mode at 70 eV, scanning the 35–550 m/z range. The injector was held at 250°C, while the detector temperature was 300°C.

The quantification was performed by gas chromatograph (GC) coupled to a flame ionization detector (FID) (PerkinElmer 580, MA, USA) with an Elite-5 MS (PerkinElmer 580, MA, USA) column (30 m × 0.25 μm film × 0.25 mm i. d.). 2-Undecanone was used as an internal standard (0.5 μg 2-undecanone in cyclohexane per each sample of cepe mushrooms (~5 g)), and comparing its concentration with that of the other compounds, by supposing a general response factor of 1 for all volatile compounds, no standard curves were conducted for each of the compounds found in the samples. The GC conditions were the same as those for GC-MS. The analyses were carried out using helium as a carrier gas.

2.6. Descriptive Sensory Analysis. Nine trained panelists belonging to the "Food Quality and Safety" research group, UMH (Universidad Miguel Hernández de Elche), use descriptive sensory evaluation to test dried samples of *B. edulis*. The panel consisted of 5 males and 4 females, with ages ranging between 26 and 55 years. The panel was selected and trained following the ISO standard 8586–1 [17], and it is specialized in descriptive sensory evaluation of fruits and vegetables and has a wide expertise in studying the effects of drying on different matrixes, such as herbs and mushrooms [16, 18].

One orientation session was conducted, and the panel evaluated different coded samples of Spanish and Polish dried and fresh mushrooms similar to *B. edulis*. During this session, the panel decided to use 10 attributes (i) appearance: inner color and piece size; (ii) flavor: mushroom ID (flavor resembling that of freshly picked mushrooms), fresh, fried, nutty, earthy, and burnt, and (iii) texture: hardness and sponginess. Reference products of these attributes, with intensity similar to those of the samples under evaluation, were prepared and provided to the panel.

Samples of *B. edulis* (coded with 3-digit numbers) were randomly presented, in 100 mL plastic cups with lids, to panelists in normalized individual booths with controlled illumination and temperature. Freeze-dried *B. edulis* sample was used as control. The intensity of the sensory attributes was scored using a scale from 0 to 10, where 0 = none or not perceptible intensity and 10 = extremely high intensity.

2.7. Statistical Analysis. To compare the experimental data, two consecutive tests were performed: (i) one-way analysis of variance (ANOVA) and (ii) Tukey's multiple range test. Homogenous groups and the least significant difference (LSD) were determined at significance level of $p \leq 0.05$. Statgraphics Plus 5.0 software (Manugistics, Inc., Rockville, MD, U.S.A.) was the program used for the statistical analyses.

3. Results and Discussion

3.1. Drying Kinetics. Figure 1 shows changes with time of the moisture ratio (MR) of cepe samples dehydrated by CD at temperatures in the range 50 to 80°C (Figure 1(a)), VMD at three magnetron powers 240, 480, and 480/240 W (Figure 1(b)), and combined (CPD-VMFD) drying consisting of CPD at 60 and 70°C and VMFD under the reduced mode 480/240 W (Figure 1(c)). The drying times, together with the final moisture content, the maximum temperatures, and the constants of the modified Page model (Equation (3)) are shown in Table 1. Because of the high values of the coefficient of determination (R^2>0.99) and low values of RMSE (<0.05), it was demonstrated that this model (modified Page) can be successfully used to describe drying kinetics of cepe dehydrated by CD, VMD, and CPD-VMFD methods. Similar to earlier research, the good fitting of modified Page model was found in the case of chanterelle and oyster mushrooms [16, 19].

In the case of CD, increasing the air temperature from 50 to 80°C shortened the drying time from 390 to 210 min,

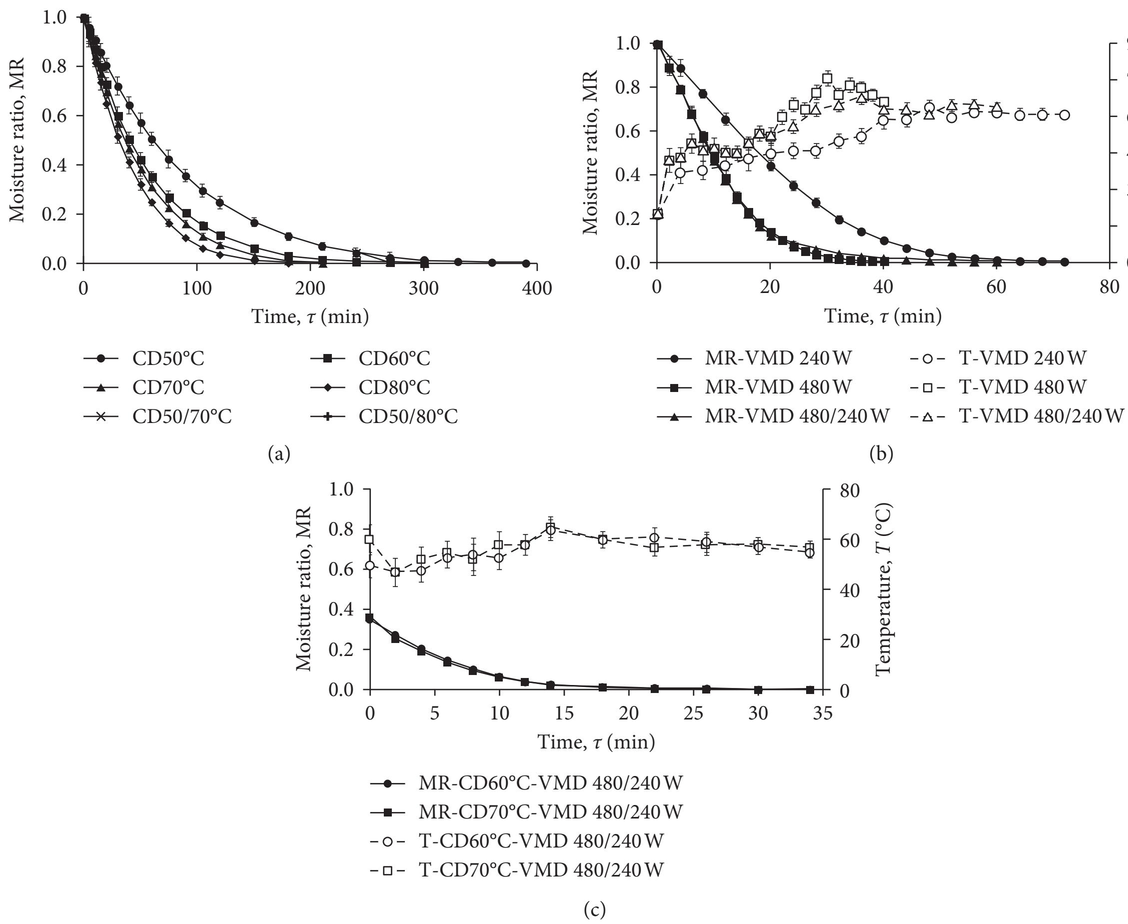

Figure 1: (a). Drying kinetics of *Boletus edulis* samples processed using convective drying (CD) at temperatures of 50, 60, 70, and 80°C, as well as convective finish drying at 70 and 80°C preceded by convective predrying at 50°C. (b) Drying kinetics of *Boletus edulis* samples processed using vacuum microwave drying (VMD) at powers of 240 and 480 W as well as vacuum microwave predrying at 480 W and finishing drying at 240 W. (c) Drying kinetics of *Boletus edulis* samples processed using vacuum microwave finish-drying (VMFD) at 480/240 W after convective predrying (CPD) at temperatures 60 and 70°C.

Table 1: Final moisture content (Mfwb), maximum temperature of the sample *T*, convective drying time (τ, τ′, time for CD steps 1 and 2, resp.), vacuum microwave drying time (τ″, τ‴ for VMD steps 1 and 2, resp.), and constants A, *k*, and *n* of the modified Page model describing the drying kinetics of cepe mushrooms as affected by the drying method.

Drying conditions	Constants			Statistics		Drying time (min)				T (°C)	M_{fwb} (%)
	A	k	n	RMSE‡	R^2	τ	τ'	τ''	τ'''		
CD 50°C	1.000	0.0084	1.070	0.0046	0.9998	390†a‡	—	—	—	50	5.98c
CD 60°C	1.000	0.0120	1.080	0.0056	0.9997	300b	—	—	—	60	6.04c
CD 70°C	1.000	0.0130	1.100	0.0052	0.9998	210c	—	—	—	70	6.23b
CD 80°C	1.000	0.0150	1.110	0.0057	0.9997	210c	—	—	—	80	5.56d
CD 50/70°C	0.046	0.0520	0.940	0.0023	0.9831	60d	240a	—	—	70	5.91c
CD 50/80°C	0.046	0.0340	1.200	0.0006	0.9999	30e	240a	—	—	80	6.29b
VMD 240 W	1.000	0.0130	1.400	0.0118	0.9986	—	—	72a	—	61	6.04c
VMD 480 W	1.000	0.0320	1.370	0.0091	0.9992	—	—	40b	—	66	6.06c
VMD 480/240 W	1.000	0.0360	1.340	0.0108	0.9989	—	—	20c	40a	64	6.68a
CD 60°C -VMD 480/240	0.358	0.1290	1.070	0.0060	0.9970	60d	—	14c	24b	55	6.70a
CD 70°C -VMD 480/240	0.368	0.1790	0.940	0.0054	0.9976	50d	—	14c	24b	57	6.40a

†Treatment means of the ANOVA test (values are the mean value of three replications). ‡Values followed by the same letter, within the same column, were not significant different ($p < 0.05$), Tukey's multiple range test.

respectively. With regard to VMD, where the conventional water diffusion occurring according to Fick's law is supported by the pressure diffusion mechanism of the Darcy type, a radical reduction of total drying time was observed [20] as compared to CD. Under VMD at 480 and 240 W, the drying time was 40 and 72 min, respectively. Calín-Sanchez et al. also observed extended drying time while decreasing the microwave power [21]. Combined CPD and VMD at a reduced mode 480/240 W reduced process duration ~4 times when compared to simple CD. It was also found that increasing hot air temperature during CPD resulted in higher temperature of VMFD samples, from 55 to 57°C (Table 1). This experimental finding may be related to the water molecules distribution constituted by CPD inside the sample as the location of water molecules effects the generation of heat energy under microwave radiation during VMFD [22].

The results of previous studies [23, 24] revealed that energy consumption for VMD of plant materials is significantly lower than that for convective drying particularly for higher microwave powers. However, from the practical point of view, combined drying consisting of convective predrying followed by vacuum microwave finish-drying (CPD-VMFD) is recommended for industrial conditions [25]. This is due to the fact that CPD is very effective at the beginning of drying process when the most of water is removed from the dried material and requires more and more time at the final stage of drying when the residual water strongly binds with the cellular structure of this material [22]. That kind of water is effectively evacuated during VMFD when the process of diffusion is assisted by the pressure transport mechanism as it was stated above. Moreover, the mass of CPD material is largely reduced, and VMFD can be performed in much smaller installations which leads to the lowering of the investment costs. Therefore, from the technical point of view, the combined drying CD 70°C -VMD 480/240 seems to be the better option than CD 60°C -VMD 480/240 taking into account shorter drying time and lower operating costs at the comparable temperature of the dried material. However, the final recommendations regarding drying conditions of cepe for industrial applications should be formed considering also the quality aspects of the dried material, such as volatile composition and sensory attributes.

3.2. Volatile Composition of Fresh and Dried Cepe. The volatile compounds of fresh and dried cepe mushrooms identified by HS-SPME are listed in Tables 2 and 3. In this context, it is also worth mentioning that the aroma profile of Polish *B. edulis* has not previously been well examined. Fifty-three volatile compounds, most of them short-chain organic compounds amounting on average 95.6% of total volatile fraction, were identified by means of GC-MS (Tables 2 and 3). Alcohols, aldehydes, and ketones, amounting on average to 69.2, 11.0, and 6.5% of total volatiles, respectively, were the dominating chemical families and represented more than 80% of individual components in fresh and dried material. It was previously found that these C_8 odorants usually represent between 44 and 98% of the total volatile fraction in mushrooms [29]. Aprea et al. reported the presence of 66 aroma components identified by HS-SPME in dried cepe, while only 25 compounds were identified in previous works where solvent extraction techniques were used [30, 31].

The total concentration of volatile compounds in the fresh *B. edulis* was 5089 μg 100 g^{-1}·db (Table 2). The main components found in cepe were (i) 1-octen-3-ol (66.9%), (ii) 3-octanone (8.43%), and (iii) hexanal (6.99%). It was previously found that 1-octen-3-ol and 3-octanone are secondary metabolites of most mushrooms and give them their typical "mushroom-like" odor [32]. According to Csóka et al., the percentage of the 8-carbon volatiles in cepe was notably high (65.41%), and 1-octen-3-ol was the predominant compound [33]. The high ratio of this "mushroom alcohol" in *B. edulis* was reported by other authors as well [1, 34].

In the present study, heterocyclic compounds were also identified, including 9 pyrazines and 1 furan. In a previous work, Thomas identified in dried cepe 12 pyrazines, 6 furans, and 9 pyrroles [35]. These compounds are products of the Maillard reaction occurring during the drying process and are responsible for typical odor notes of "dried" mushrooms [36]. Of the 13 aldehydes found in dried cepe, 11 were previously reported by Aprea et al. and only 4 (hexanal, octanal, nonanal, and benzaldehyde) by Thomas [35].

According to the literature survey, only few studies have described the influence of drying on the volatile composition of cepe mushrooms. Furthermore, there is no information about the impact of CPD-VMFD and/or VMD on their volatile composition. Table 3 shows the total volatile compounds content and the content of each individual compound, expressed as μg volatiles per 100 g db, in fresh and dried cepe mushrooms. The preliminary working hypothesis was that FD (control treatment) and CD, contrary to CPD-VMFD, will provide the best quality product, with high content of volatiles and the highest intensities of key sensory attributes [18]. With regard to the assayed drying methods, CD at 70 and 80°C can be considered as suitable dehydration methods, because these methods allowed to maintain high content of volatiles. Moreover, the increase in hot air temperature decreased the drying time which seems to more harmful to volatiles that the drying temperature.

Remarkable differences were noticed among tested drying methods as regards the total concentration of volatile compounds (Table 3). With regard to FD, it was found that, under this method, the losses of volatiles were intermediate as compared to the fresh product. For example, fresh cepe samples dried using FD lost only 56% of their characteristic aroma, contrary to adjusted modes 50/80°C and 50/70°C, where the loss of volatiles accounted for almost 80% of the initial total content of volatiles; the sublimation of water during FD is linked with the loss of water soluble volatile compounds. In the study by Baranauskiene et al., the loss of volatile components depended on the nature of aroma components; for example, the vapor pressure of a nonpolar compound is higher than that of a polar compound [37]. Accordingly, Calin-Sanchez et al. proved that reduction in pressure in the drying chamber of the freeze dryer may result in losses of volatiles into the environment [38].

In the case of CD, it can be stated that increasing the air temperature led to higher retention of the total volatile compounds from fresh cepe; however hot-air-dried mushrooms showed characteristic color deterioration and

Table 2: Identification and codification of volatile compounds in fresh, freeze-, vacuum microwave-, and convective-dried cepe mushrooms.

Compound	Code	RI†		Sensory descriptor
		Exp.	Lit.	
2-hexanone	V1	791	792	
Hexanal	V2	804	801	Fatty, green [26]
2-(*E*)-hexenol	V3	861	862	Green leafy, fresh, fatty, fruity [27]
1-hexanol	V4	875	870	Green, herbaceous, woody, sweet [26]
4-(*Z*)-hexenol	V5	878	877	Green, herbal, musty, tomato [27]
2-(*Z*)-hexenol	V6	882	885	Fruity, green, leafy [27]
2-heptanone	V7	892	889	Cheesy, fruity, ketonic, green banana [27]
Heptanal	V8	904	902	Fatty, oily, nutty, woody, fruity [26]
Methional	V9	911	909	Vegetable, earthy, oily, yeasty, bready [27]
2,4-(*E*,*E*)-hexadienol	V10	913	916	Fresh, green, herbal [27]
2,5-dimethylpyrazine	V11	916	912	Nutty, peanut, musty, earthy, cocoa, slightly roasted [27]
2,3-dimethylpyrazine	V12	925	920	Musty, nut skins, cocoa, roasted, potato, coffee [27]
1-heptanol	V13	963	966	Musty, leafy green, fruity (apple and banana) [27]
2-(*E*)-penten-1-ol	V14	968	973	Banana, green, rubbery [28]
1-octen-3-one	V15	981	977	Cucumber, green, mushroom [26]
1-octen-3-ol	V16	985	979	Cheesy, creamy, fishy, green, mushroom, herbaceous, earthy [26]
3-octanone	V17	988	983	Musty, mushroom, ketonic, moldy, cheesy, fruity [27]
2-pentylfuran	V18	992	988	Fruity, green, earthy beany with vegetable [27]
2,3,5-trimethylpyrazine	V19	996	1000	Nutty, musty, powdery cocoa, potato, musty [27]
Decane	V20	1001	1000	
Octanal	V21	1003	998	Aldehydic, waxy, citrus, orange, green, peely [27]
2-ethylhexen-2-al	V22	1007	1011	
Limonene + unidentified	V23	1034	1029	Lemon, orange, sweet [26]
2-(*E*)-Octen-1-al	V24	1043	1049	Fresh, fatty, green, herbal, banana, green leaf [27]
Benzeneacetaldehyde	V25	1048	1042	Honey, floral rose, powdery, fermented, chocolate [27]
2-(*E*)-octen-1-ol	V26	1061	1066	Green, citrus, vegetable, fatty [27]
2,3-diethylpyrazine	V27	1081	1084	Raw, nutty, green, pepper [27]
2,3,5,6-tetramethylpyrazine	V28	1089	1086	Nutty, musty, raw, vanilla, dry, cocoa, peanut [27]
2-nonanone	V29	1093	1090	Fruity, sweet, waxy, soapy, cheesy, green herbaceous, coconut [27]
Linalool	V30	1101	1096	Citrus, orange, floral, terpy, waxy, rose [27]
Nonanal	V31	1105	1100	Waxy, aldehydic, citrus, fresh, green, lemon, peely, fatty [27]
2,4-(*E*,*E*)-octadienal	V32	1115	1116	Green, fruity, melon, peely [27]
2-(*Z*)-nonen-1-al	V33	1145	1149	
2,3-diethyl-5-methylpyrazine	V34	1156	1153	Musty, nut skin, earthy, toasted, potato, green, meaty [27]
3,5-diethyl-2-methylpyrazine	V35	1159	1163	Nutty, green, meaty, vegetable [27]
2-(*E*)-nonenal	V36	1163	1161	Green, cucumber, aldehydic, fatty, citrus [27]
2-decanone	V37	1193	1192	Fermented, cheesy [27]
Dodecane	V38	1120	1120	
2-acetyl-3,5-dimethylpyrazine	V39	1273	1275	Nutty, roasted, hazelnut [27]
Nonanoic acid	V40	1276	1270	Waxy, fatty, dairy, cheesy [27]
1-tridecene	V41	1278	1290	
Unknown pyrazine derivative	V42	1289	1293	
Tridecane	V43	1306	1300	
2,5-dimethyl-5-isopentylpyrazine	V44	1325	1323	Fruity [27]
2-(*E*)-butylocten-2-al	V45	1382	1389	
2,3,5-trimethyl-6-butylpyrazine	V46	1400	1414	
Dodecanal	V47	1409	1408	Soapy, waxy, citrus, orange with floral nuances [27]
Pentadecane	V48	1501	1500	Waxy [27]
2,4-(*E*,*E*)-dodecadienal	V49	1523	1519	
Tridecanol	V50	1560	1570	
2-tridecanol	V51	1599	1593	
Tetradecanal	V52	1608	1611	Fatty, waxy, dairy, creamy, fishy, fruity, pear [27]
Isopropyl myristate	V53	1812	1812	Faint, oily fatty [27]
Pentadecane	V48	1501	1500	Waxy [27]
2,4-(*E*,*E*)-dodecadienal	V49	1523	1519	
Tridecanol	V50	1560	1570	
2-tridecanol	V51	1599	1593	
Tetradecanal	V52	1608	1611	Fatty, waxy, dairy, creamy, fishy, fruity, pear [27]
Isopropyl myristate	V53	1812	1812	Faint, oily, fatty [27]

Table 3: Content of volatile compounds (μg 100 g^{-1} db, dry basis) in fresh, freeze-, convective-, vacuum microwave-, and CPD-VMFD-dried cepe mushrooms.

Compound	ANOVA	Fresh	FD	CD (°C)						VMD (W)			CPD (°C)-VMFD (W)	
				50	60	70	80	50/70	50/80	240	480	480/240	60/480/240	70/480/240
Concentration (μg·100 g^{-1}·db)														
V1	**	12.2[†] a[‡]	1.63d	5.10c	12.1a	12.3a	11.1a	6.35c	5.51c	10.5ab	8.69b	7.55b	8.76b	7.06c
V2	***	355a	75.0b	51.9c	67.2b	73.3b	76.4b	20.7e	20.5e	33.8d	33.3d	22.7e	39.8d	39.6d
V3	NS	0.12	0.10	1.56	1.08	1.61	1.29	0.12	0.12	0.16	0.14	0.52	1.02	1.07
V4	NS	0.15	0.10	1.67	1.27	1.50	1.63	1.02	1.05	0.72	0.33	0.10	0.15	0.10
V5	*	4.31a	4.61a	4.50a	3.31b	3.72a	3.01b	3.07b	3.90a	3.00b	2.80b	2.08c	2.76b	2.06c
V6	NS	2.03	0.49	2.06	2.36	3.07	3.68	2.24	2.04	3.60	3.05	2.69	11.9	9.98
V7	NS	2.45	1.53	2.02	2.07	2.43	2.68	2.65	2.00	2.36	2.94	2.56	2.62	1.92
V8	NS	0.40	0.44	0.98	1.01	1.01	1.21	0.10	0.11	0.96	0.65	0.10	0.15	0.12
V9	NS	0.00	3.25	9.57	5.55	4.46	3.18	0.15	0.15	0.60	0.22	0.21	2.50	0.80
V10	NS	2.03	1.30	2.45	3.45	3.46	3.80	2.00	1.54	2.45	2.43	1.21	2.52	2.12
V11	***	0.00e	7.32b	8.70a	8.18a	8.56a	8.90a	6.68b	6.12c	6.11c	6.01c	6.01c	2.51d	1.81d
V12	***	0.00f	8.46a	5.74b	5.91b	7.14a	7.72a	1.59d	0.90e	1.40d	0.95e	4.36bc	3.75c	2.05d
V13	*	12.4a	8.30b	12.2a	12.0a	12.9a	12.2a	12.0a	12.6a	9.03b	7.27d	8.66b	11.9bc	10.4c
V14	**	32.5ab	20.7c	27.0b	27.2b	27.1b	20.8c	36.0a	37.1a	10.2d	5.74e	11.2d	11.1d	11.2d
V15	***	304b	300.2b	143d	164d	448ab	518a	247c	82.6e	193d	142d	111d	192d	190d
V16	***	3405a	1509b	330e	512d	1365b	1521b	567d	433e	890c	860c	803c	1913c	1888c
V17	***	429a	194.3b	118c	120c	411a	428a	184b	172b	102c	100c	100c	424a	422a
V18	NS	2.46	3.90	2.84	1.07	2.21	2.91	2.82	2.33	0.48	0.46	1.05	3.17	3.15
V19	**	0.00f	6.99a	3.19c	4.72b	4.50b	4.43b	1.74d	1.22d	1.20d	0.65e	0.42e	1.26d	0.65e
V20	NS	1.09	1.13	1.40	1.09	1.21	1.21	1.81	1.01	1.59	1.52	1.26	1.03	1.00
V21	**	52.9	24.23	20.4	20.7	23.6	26.6	35.0	24.3	10.1	10.1	11.1	12.5	10.8
V22	***	95.6a	17.64d	22.6c	28.3b	22.7bc	16.5d	33.6b	21.1c	10.8e	8.69ef	7.86f	20.8c	19.1c
V23	***	119a	59.60c	86.7b	86.1b	114a	113a	96.1b	105a	53.8c	35.3d	26.4d	62.6c	61.1c
V24	*	10.2b	1.81d	10.7b	9.99b	9.21c	9.03c	14.3a	10.5b	1.60d	1.43e	1.31e	10.7b	11.0b
V25	**	35.8a	28.5b	7.26e	7.63e	7.96e	9.97d	19.2c	15.0c	3.45f	3.45f	2.42f	39.4a	37.7a
V26	NS	14.5	12.4	13.9	15.8	16.0	16.9	13.5	13.3	18.4	12.2	11.0	12.6	12.1
V27	NS	0.00	1.33	1.86	1.18	1.04	1.04	1.18	1.66	0.96	0.87	0.73	1.04	1.02
V28	*	0.00e	0.81d	2.55b	2.27b	2.68b	3.18a	1.24c	1.12c	2.69b	2.54b	2.44b	1.13c	1.43c
V29	*	10.2a	1.81e	2.02e	2.16d	2.46d	2.65d	7.94b	5.51c	2.45d	2.55d	2.51d	2.77d	2.07e
V30	**	37.0c	29.6d	43.6c	54.1b	57.0b	57.0b	71.8a	67.0a	12.2ef	5.43f	5.14f	16.3e	14.6e
V31	NS	2.36	1.79	2.69	2.65	2.11	2.18	2.15	1.21	2.96	3.03	2.48	1.37	1.67
V32	*	6.10c	1.49e	3.25d	3.18d	3.39d	3.18d	2.77d	2.64d	18.7a	11.1b	3.35d	2.89d	1.19e
V33	NS	4.07	1.33	2.47	2.27	3.02	3.91	3.94	3.06	3.59	3.04	1.99	5.63	3.93
V34	NS	0.00	1.79	3.10	3.01	3.32	3.51	1.02	1.02	2.39	2.17	1.89	1.06	1.06
V35	**	0.00e	4.07c	3.83c	3.64c	4.43c	8.49a	7.95a	7.34ab	8.36a	6.51b	6.35b	1.68d	1.41d
V36	NS	4.79	6.34	9.57	7.91	6.25	1.86	4.86	3.06	6.22	5.43	4.93	1.63	1.60
V37	NS	4.07	2.33	8.49	8.36	8.02	7.17	7.02	5.63	8.91	8.04	3.98	2.52	2.82
V38	NS	0.12	0.10	0.12	0.12	0.12	0.10	0.12	0.12	0.10	0.08	0.12	0.11	0.10
V39	NS	0.00	4.72	4.49	4.45	4.79	4.35	0.45	0.12	0.73	0.79	0.84	2.39	2.32
V40	NS	0.89	0.95	0.70	0.73	0.79	0.81	0.15	0.10	0.91	0.81	0.81	0.25	0.26
V41	NS	1.02	1.44	1.00	0.98	0.98	0.91	1.02	1.00	0.64	0.43	0.41	1.02	1.07
V42	*	0.00	1.53	1.82	1.77	1.14	1.21	1.00	1.01	0.01	0.01	0.01	1.06	1.02
V43	NS	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02
V44	NS	0.00	1.79	1.19	1.27	1.12	1.13	0.82	0.87	0.91	0.95	0.98	1.13	1.43
V45	NS	8.13	7.22	13.4	13.5	14.5	14.9	1.00	1.00	1.01	1.02	1.00	12.9	12.2
V46	NS	0.00	0.49	0.49	1.09	1.54	2.12	0.48	0.51	3.27	2.86	1.25	1.63	0.89
V47	**	12.2a	1.98c	1.03d	0.91d	1.04d	0.98d	1.23c	1.02d	3.09b	3.05b	1.78c	1.37c	1.12bc
V48	NS	1.01	1.25	1.48	1.18	1.21	0.63	1.05	1.02	1.01	1.01	1.18	2.43	2.06
V49	NS	3.51	2.44	2.84	3.27	3.86	4.25	1.05	0.51	0.73	0.25	1.06	1.12	0.95
V50	NS	2.03	1.14	2.76	3.09	3.18	3.78	0.33	0.18	0.91	0.85	3.98	1.50	0.80
V51	**	44.73a	3.58c	3.18c	3.09c	3.09c	3.18c	8.18b	9.18b	2.64d	2.43d	8.49b	8.88b	8.18b
V52	*	14.23a	12.93b	8.29c	7.73c	6.25d	6.06d	12.7b	12.9b	1.00f	1.00f	1.00f	11.3b	10.1c
V53	**	36.6a	13.58c	2.55e	3.09e	9.64d	9.63d	15.1b	11.0c	10.0d	12.0c	15.0b	15.7b	10.3cd
Total	***	**5089a**	**2231c**	**1538d**	**1923c**	**3478b**	**3763b**	**1538d**	**1148e**	**1492d**	**1335d**	**1225e**	**2897c**	**2835c**

[†]Treatment means of the ANOVA test (values are the mean value of three replications). [‡]Values followed by the same letter, within the same row, are not significant different ($p < 0.05$), Tukey's multiple range test.

Table 4: Descriptive sensory profiles of *Boletus edulis* samples as affected by the drying method.

Attribute	ANOVA†	FD	Convective drying (°C)						Vacuum microwave (W)			CPD (°C)-VMFD (480/240 W)	
			40	50	70	80	50/70	50/80	240	480	480/240	60	70
Appearance													
Inner color	∗∗∗	10a	7.6bc	7.8c	7.8bcb	6.6bc	7.4bc	8.3b	2.8de	3.6de	2.1e	3.6de	5.2cd
Piece size	∗∗∗	9.8a	8.3b	7.7b	7.9b	7.6b	7.1b	7.8b	1.9d	4.0cd	1.8d	3.8cd	4.7c
Flavor													
Mushroom ID	∗∗∗	9.6a	8.6a	7.4ab	9.2a	8.0a	7.2ab	7.4ab	2.4c	3.2c	3.4c	5.1bc	4.4c
Fresh	∗∗∗	9.8a	8.3b	6.5bc	8.7b	7.6b	6.4bc	6.5bc	1.8d	2.2cd	2.8cd	4.4cd	2.9cd
Fried	∗∗	0c	1.7b	3.1a	1.2b	1.9b	2.4a	2.2b	3.4a	3.6a	3.8a	3.7a	2.5ab
Nutty	NS	4.7	3.3	3.1	2.6	3.2	3.6	4.3	3.0	2.3	2.3	3.9	2.3
Earthy	∗∗∗	6.2a	4.8bcd	3.6	5.1b	4.9bc	4.1bcd	4.1bcd	2.2bcd	1.6cd	1.5d	2.5bcd	2.6bcd
Burnt	∗	0.3b	0.4b	0.9ab	0.3b	0.4b	0.8ab	0.6ab	2.1ab	1.7ab	3.2a	1.8ab	1.0ab
Texture													
Hardness	∗∗∗	0.6e	3.8d	3.3d	4.2d	3.8d	4.4bc	2.9d	8.3a	8.1ab	8.8a	6.1abc	6.3abc
Sponginess	∗∗∗	9.7a	5.0bc	5.8bc	5.6bc	6.1bc	4.1bcd	7.3b	0.6e	1.2de	0.6e	3.2cde	4.0cd

†NS = not significant F ratio ($p < 0.05$); ∗,∗∗, and ∗∗∗ = significant at $p < 0.05$, 0.01, and 0.001, respectively. ‡Treatment means of the ANOVA test (values are the mean value of 9 panelists). Values followed by the same letter, within the same row, are not significantly different ($p < 0.05$), Tukey's multiple range test.

structure deformation [39]. The total concentration of aroma constituents increased from 1538 to 3763 μg 100 g^{-1}, when the air temperature increased from 50 to 80°C; a similar trend was observed for the "mushroom alcohol" 1-octen-3-ol with concentrations being significantly higher when the drying temperature was 80°C (1521 μg 100 g^{-1}·db) as compared to 50°C (330 μg 100 g^{-1}·db).

Increasing the microwave wattage from 240 to 480 W resulted in decrease in total amount of volatile components from 1492 to 1335 μg 100 g^{-1}, although differences were not statistically significant. The adjusted mode of microwave power 480/240 W provided a final product with a total volatiles concentration of 1225 μg 100 g^{-1}. It has been previously stated that the VMD method is suitable for the drying of heat-sensitive materials, such as mushrooms and herbs; however, in that study, the changes in the content of volatiles was not investigated [40].

To improve the quality of dried mushrooms, vacuum drying has been combined with microwave drying [8]. Under CPD-VMFD, the losses of volatiles were intermediate as compared to the fresh product. For instance, sample predried at 60 and 70°C and finish dried at reduced mode 480/240 W presented total volatile concentration of 2897 and 2835 μg 100 g^{-1}, respectively This indicates that using a lower temperature during CPD is a more advantageous option for combined drying. In the previous section, combined drying was recommended for the preservation of cepe from the technical point of view. In the study by Argyropoulos et al., it was reported that the combined method CPD-VMFD was proposed as an alternative method to improve the quality of dried mushrooms, especially when considering their structural and textural properties [8].

3.3. Descriptive Sensory Analysis with Trained Panel. It is clearly proven in Table 4 that the drying method significantly affected the descriptive sensory profile of dried cepe mushrooms. FD proved to be the best drying treatment, as expected, and that was why it was selected as the control treatment. But besides FD, CD gave the best results and had the highest (after FD) intensities of key sensory attributes in dried mushrooms, such as inner color, piece size, mushroom ID, and fresh mushroom (Figure 2). CPD-VMFD method showed intermediate intensities, while VMD was the worst drying method (Figure 2). These trends agreed well with previous results reported on chanterelle mushrooms [16].

Data on Table 4 are useful in selecting the best one within each type of the drying method (CD, VMD, or CPD-VMFD). In this way, CD at the highest temperatures (70 and 80°C) led to the best results in this specific drying method. There were no significant differences between the two conditions assayed in CPD-VMFD according to the sensory profile, and similar conclusions can be reached for VMD. Thus, the conclusion of this section could be that CD at high temperatures was successful in keeping high intensities of the key positive attributes in *B. edulis*, and this experiment finding must be due to the short drying time needed to reach the final moisture content.

To make a final conclusion on the grouping of all sensory attributes and volatile compounds linked to specific drying treatments, a principal component analysis (PCA) was conducted and explained 62.89% of the data variability (PCA 1 explained 46.56% and PCA 2 16.34 %). The drying treatments could be visually grouped into 3 clusters of samples (Figure 3):

(1) The first one included only the FD and CD samples at 50, 60, 70, or 80°C and was characterized by high intensities of inner color, piece size, mushroom ID, fresh and earthy notes, and sponginess and also by high contents of hexanal, 4-(Z)-hexenol, 2,5-dimethypyrazine, 2,3-dimethylpyrazine, 1-octen-3-one, and 2,3,5-trimethylpyrazine. This group consisted of the best drying treatments.

(2) The second one included samples CD at 50/70 and 50/80 and CPD-VMFD samples and was linked with 2-tridecanol. This second cluster consisted of drying

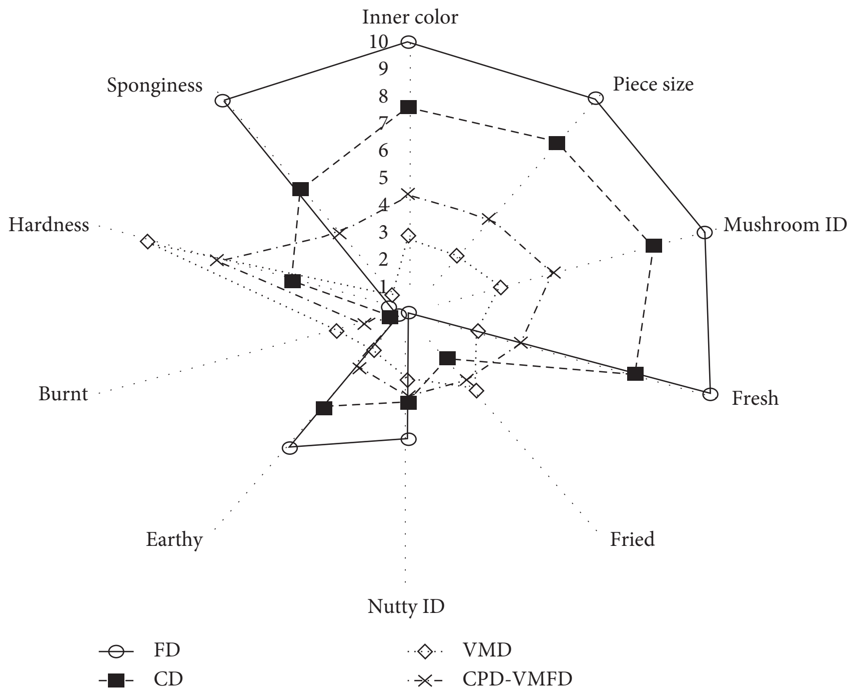

Figure 2: Descriptive sensory profiles of *Boletus edulis* samples as affected by the drying methods. Values included in this figure represent the mean value for all the conditions assayed for each drying treatment. That is, the mean of FD, 6 temperatures (40, 50, 70, 80, 50/70, and 50/80°C) in CD, 3 microwave powers (240, 480, and 480/240 W in VMD), and 2 different temperatures (60 and 70°C) in CPD for the combined method CPD-VMFD.

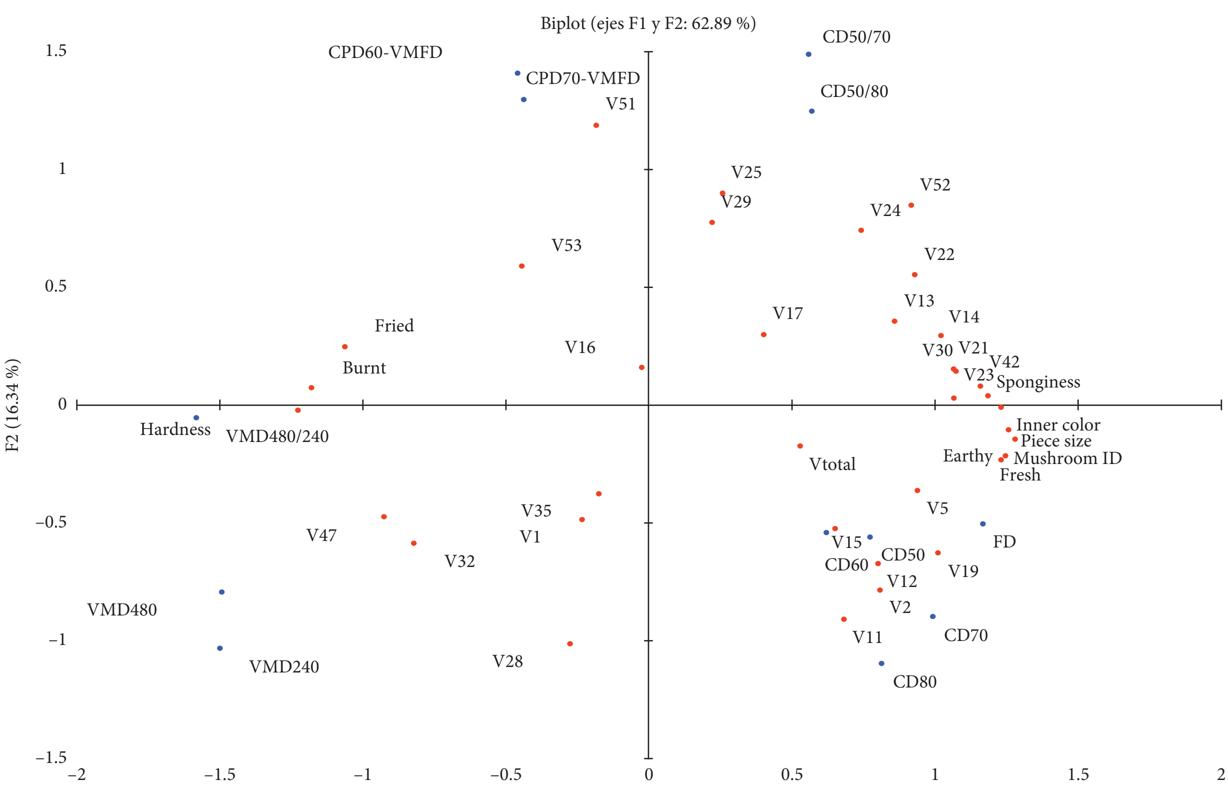

Figure 3: PCA score plots showing relationships among volatile compounds, sensory attributes, and dried *Boletus edulis* samples dehydrated by different methods.

treatments leading to dried products of intermediate quality.

(3) The third and last group included all VMD treatments and was characterized by the highest intensities of negative sensory attributes, such as hardness, burnt, and fried. This experimental finding proved that VMD cannot be recommended to dry *Boletus edulis*.

4. Conclusions

Fresh cepe was dried using the following methods: convective (CD), vacuum microwave drying (VMD), freeze-drying (FD), and CPD-VMFD (convective predrying and vacuum microwave finish-drying). The drying kinetics were successfully described with the modified Page model. Convection drying of *Boletus edulis* in 70 and 80°C gave the highest retention of key volatile compounds, which was 74 and 69%, respectively. In the case of CD in 50 and 50/80°C provides product, with loss around 70% of aromatic substances. In all conducted variants of drying, several pyrazine derivatives were found, having impact on aroma description. Combined methods of drying lead to products whose aroma descriptor was far from fresh one. Contrary to this, freeze-drying and CD in 70 and 80°C gives product with highest mushroom aroma. Eventually, CD at 80°C could be most recommended approach for *Boletus* preservation taking into account both the simplicity of drying procedure and the quality of dried product. On the contrary, combined drying of mushrooms consisted in CPD at 60°C followed by VMFD at reduced mode of microwave power 480/240 W can be considered for industrial applications due to high performance and energy efficiency with intermediate quality of the dried product.

Nomenclature

A, n:	function parameters
db:	dry basis
k:	drying constant (min^{-1})
M:	moisture content (kg kg^{-1}·db)
M_0:	initial moisture content (kg kg^{-1}·db)
M_e:	equilibrium moisture content (kg kg^{-1}·db)
M_f:	final moisture content (%)
MR:	moisture ratio
R^2:	coefficient of determination
t:	temperature (°C)
τ:	time (min)
wb:	wet basis
ANOVA:	analysis of variance
CD:	convective drying
CPD:	convective predrying
DSA:	descriptive sensory analysis
GC-MS:	gas chromatography-mass spectrometry
SPME:	headspace solid-phase microextraction
LSD:	least significant difference
RMSE:	root-mean squared error
RI:	retention index
FD:	freeze-drying
VD:	vacuum drying
VM:	vacuum microwave
VMD:	vacuum microwave drying
VMFD:	vacuum microwave finish-drying.

Data Availability

The authors declare that all results can be found in Department of Chemistry, Wrocław University of Environmental and Life Sciences.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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