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Physico-chemical Properties and Drying Kinetic Evaluation of Hot Air and Vacuum Dried Pre-Treated Oyster Mushroom under Innovative Multi-mode Developed Dryer

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ABSTRACT

Mushrooms are characterized as the fruiting bodies of fungi and are fruitful source of high-quality protein and vitamins with low calories. Among the three most cultivated species, the oyster mushroom stands with limited shelf life (2-3 days at refrigerated conditions). Elevated quotients of browning reaction and restricted shelf life obliges the preservation of species as a matter of concern. A suitable pre-treatment along with the drying method is very important to retain the bioactive compounds of oyster mushroom. Pre-treatment optimization prior to oyster mushroom drying was carried out in two steps which involved individual and combined effects of blanching (70 to 90 °C) and chemical treatments. Thereafter, it was dried in a recently developed multi-mode novel drying unit under hot air and vacuum drying (50-70°C) conditions. Pre-treatment with citric acid and blanching at 80 °C for 2 min resulted in the lowest residual activity of polyphenol oxidase. Retention of phenolics, flavonoids, ascorbic acid and antioxidant compounds were higher in the samples dried using vacuum drying. Increase in temperature from 50 to 70 °C significantly decreased the bioactive compounds and colour of vacuum dried samples. In samples dried using hot air-drying, the higher retention of bioactive compounds and colour was obtained at 60 °C as compared to 70 °C and 50 °C. Page model was found to be the best fitted model among the different models studied. Analysis inferred the usefulness of optimised pre-treatment and vacuum drying technique at low temperature for drying of oyster mushrooms.

Abbreviations: AA, Ascorbic acid; **BI**, Browning index **CA**, Citric acid; **FRAP**, Ferric reducing antioxidant power; **KMS**, Potassium metabisulphite; **MR**, Moisture ratio; **PPO**, Polyphenol oxidase; **RR**, Rehydration ratio; **RSA**, Radical scavenging activity; **TFC**, Total flavonoid content; **TPC**, Total phenol content

Introduction

Mushrooms are the healthy and complete foods which contain all the nutritional characteristics and immense health benefits (Bernaś et al., 2006). Button (*Agaricus bisporous*), shitake (*Lentinus edodes*), oyster (*Pleurotus spp*), paddy straw (*Volveralla volvacea*) and milky mushrooms (*Calocybe indica*) are most common edible mushrooms. In India, commonly grown and available mushroom species includes button and oyster mushrooms followed by paddy straw and milky mushrooms (Akbarirad et al., 2013). Out

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of the total mushroom production, the percentage of mushroom consumed in fresh form involves only 45% due to their limited shelf life. Remaining 55% of the production is in a processed form which helps in the long-term storage and availability of the product (Ares et al., 2007). Oyster mushrooms has earned viable amount of consumer demand in last few years in India. Compared to the other common species, the shelf life of oyster mushrooms is very limited, and this signifies the importance of proper postharvest treatments. Soon after harvest, it starts to undergo physiological disorders like shrivelling, wilting, browning, and textural and weight loss, and flavour changes. Respiration rate and browning reaction are two of the major concerning elements pertaining to the postharvest storage and handling of mushrooms. Various techniques have been involved in the extension of shelf life of mushrooms including chemical treatments, cooling, modified and controlled atmospheric storage, radiation, drying etc. Among the different techniques involved, drying is one of the effective methods in the preservation of edible mushrooms that provides the physico-chemical and microbiological stability to the product but variation in quality retention has been reported due to different methods of drying (Sehrawat et al., 2018). Main restraining factor with respect to the drying technique is the hardship faced in upholding the colour properties of the produce. Amalgamation of chemical technique as pre-treatment preceding to drying of mushrooms will aid in resolving the problem. Mushrooms preserved by drying process have a characteristic flavour and has been commonly used in different food formulations like instant soups, and salads (Guineand Barroca, 2011). Keeping these in mind, the present study was undertaken to determine the effect of different pre-treatment and drying technique on physical, chemical and nutritional attributes of oyster mushroom in a developed multi-mode dryer and to understand the drying behaviour at different temperatures.

Materials and methods

Sample preparation

Oyster mushrooms were obtained from Regional Research Station on Mushroom, Maharana Pratap Horticulture University, Murthal, Haryana, India. The samples were washed with water to remove the extraneous matter and sorted manually to maintain uniformity. Oyster mushrooms used for the present study was of medium size with average length of 4 cm and width of 3 cm at broader end. The damaged, oversized, undersized and immature mushrooms were removed. For each treatment 100 g of sample was taken.

Pre-treatment optimization

The effect of different pre-treatments on the enzymatic activity of oyster mushrooms was studied initially to fix the pre-treatment technique that has to be carried out before drying. The pre-treatments involved in this study were determined on the basis of previous studies and preliminary experiments conducted. The pre-treatments involved in the study were: blanching at 70 ^{o}C for 5 min (treatment 1), blanching at 80 ^{o}C for 2 min (treatment 2), blanching at 90 ^{o}C for 1 min (treatment 3), citric acid (CA) 0.5% (treatment 4), potassium metabisulphite (KMS) 0.25% (treatment 4) (Table 1). The blanching process involved keeping the beaker filled with 500 mL water in water bath and once the required temperature was achieved then 100 g of oyster mushroom samples were put in the beaker for the respective time. After treatment water was drained and samples were washed immediately with cold water to stop further enzymatic activity.

Initially, the effect of these five pre-treatments on the enzyme activity of oyster mushrooms was studied. The second stage of pre-treatment optimization involved the study on the effect of pre-treatment combinations on the enzymatic activity. The pre-treatment combinations involved in this study were: CA (0.5%) + blanching at 70 ^{o}C for 10 min (treatment 6), CA (0.5%) + blanching at 70 ^{o}C for 5 min (treatment 7), CA (0.5%) + blanching at 80 ^{o}C (treatment 8) for 5 min, CA (0.5%) + blanching at 80 ^{o}C for 2 min (treatment 9), CA (0.5%) + blanching at 90 ^{o}C for 2 min (treatment 10). The design for pre-treatment experiment is given in Table 1. For combination mode process was similar to that of blanching with exception that instead of only water now the solution of CA was used. The evaluation of the effect of these techniques on the enzyme activity of oyster mushrooms was done on the basis of polyphenol oxidase (PPO) activity and vitamin C analysis. The best among these treatments were considered as the final pre-treatment prior to the drying technique.

Table 1. Experimental design and treatments used in the present study

	Initial Pre-treatment study
1	Blanching at 70 ^{o}C for 5 min
2	Blanching at 80 ^{o}C for 2 min
3	Blanching at 90 ^{o}C for 1 min
4	Citric acid (CA) 0.5%*
5	Potassium metabisulphite (KMS) 0.2 %
	Pre-treatment Combination
	CA (0.5%)
6	Blanching at 70 ^{o}C for 10 min
7	Blanching at 70 ^{o}C for 5 min
8	Blanching at 80 ^{o}C for 5 min
9	Blanching at 80 ^{o}C for 2 min*
10	Blanching at 90 ^{o}C for 2 min
	Optimised pre-treatment {CA (0.5%) + Blanching at 80 ^{o}C for 2 min}*
	followed by drying techniques
	Hot air drying (60-80 ^{o}C)
	Vacuum drying (60-80 ^{o}C)
	Sun drying

1, 2, 3,….., 10 represents different treatments and *represents optimised conditions; CA – Citric acid

Analysis of PPO activity

PPO activity in oyster mushrooms was assayed according to Queiroz et al. (2011) method. To prepare the crude enzyme extract for the experiment, oyster mushrooms after subjecting to selected pre-treatments were cut into thin slices and homogenized in a blender. After homogenisation, the resultant mixture was centrifuged in a centrifuge at 1000 *g* for 20 min at 4^{o}C. The supernatant thus collected constituted crude PPO extract from the oyster mushrooms. The assay was performed by adding 1 mL of catechol (0.175 M) and 2 mL of citric phosphate buffer (pH 6.5) to 0.5 mL of crude enzyme extract. PPO activity was determined using a spectrophotometer at 420 nm and calculated based on the slope of linear portion of the curve plotted with ΔA_{420} against time (up to 5 min, respectively). One unit of enzyme activity was explained as 0.001 ΔA_{420} min^{-1} mL^{-1} of extract. This is the amount of enzyme which resulted in a change of 0.001 in absorbance unit per min. Percentage PPO inhibition was also calculated. Three replications were conducted, and average value was noted.

Drying

Drying (vacuum and hot air) of oyster mushroom was carried out in a recently developed multi-mode novel drying unit (NiftEMA-DU) at National Institute of Food Technology Entrepreneurship and Management, Kundli, India (Chandra et al., 2021; Sehrawat et al., 2019). NiftEMA-DU facilitates different types of drying i.e., hot air, vacuum, superheated steam etc. in the same dryer geometry so the specific effect of hot air and vacuum on the product quality can be easily studied. Along with that, a comparison with sun drying was also conducted in order to find out the optimum technique for the same. The change in the drying behaviour, drying time and final quality of the dried product with respect to different drying temperatures were also studied. Vacuum (10 kPa) and hot air drying of 100 g of oyster mushrooms was done at 50 ^{o}C, 60 ^{o}C and 70 ^{o}C. The dried oyster mushroom samples were packaged in polythene bags and stored in desiccator. Sun drying of oyster mushroom samples was done at open air by spreading the samples uniformly on a tray.

Determination of quality after drying

Moisture content of the oyster mushroom samples was determined based on the method as given in details by Pareek and Kaushik (2012). Colour of oyster mushroom samples was determined by Hunter Lab colorimeter. The sample was placed under the eye and the *L**, *a**, and *b** values were monitored for each sample and average of six readings were reported. The colour changes were calculated by Equation 1.

$$\triangle L = \frac{L-L_i}{L_i}, \quad \triangle a = \frac{a-a_i}{a_i} \quad and \quad \triangle b = \frac{b-b_i}{b_i} \qquad \text{Eq. 1}$$

Where, *L*, *a*, and *b* represent the lightness, redness and yellowness of the dried oyster mushroom samples, respectively. L_i, a_i and b_i are the lightness, redness and yellowness of the fresh oyster mushroom samples, respectively.

The colour value of the samples is expressed in terms of ΔE, which is calculated based on change in lightness (ΔL), redness (Δa) and yellowness (Δb) as Equation 2.

$$\Delta E = \sqrt{(\triangle L)^2 + (\triangle a)^2 + (\triangle b)^2} \quad \text{Eq. 2}$$

Browning index (BI) of the dried samples were calculated as Equation 3.

$$BI = \frac{100(x-0.31)}{0.17} \quad \text{Eq. 3}$$

Where x is:

$$x = \frac{a+1.75L}{5.645L+a-3.012b} \quad \text{Eq. 4}$$

Rehydration ratio (RR), which indicates the rehydration characteristics, was determined by immersing 5 g of the sample in distilled water at 90 ^{o}C for 10 min. RR was illustrated as the ratio of the mass of rehydrated sample to the dry mass of the sample.

Ascorbic acid (AA) content of oyster mushroom was determined according to Louaileche et al. (2015) method. AA content was measured at 515 nm using UV visible spectrophotometer. The AA content was calculated on the basis of the standard curve of AA (R^2=0.98) and the results were finally expressed in mg g^{-1} of dry matter.

To prepare the methanolic extracts of the dried sample, 1 g of dried sample was mixed with 10 mL of methanol and homogenised in a tissue homogeniser at 5000 *g* for 5 min. The resultant mixture was centrifuged at 10,000 *g* for 10 min at room temperature and the supernatant was collected and extraction was repeated with the residue and with 10 mL of methanol. Sum of first and second supernatant was used for further analysis. The phenolic activity of oyster mushrooms was determined using Folin Ciocalteu assay. Assay was performed as reported by Palacios et al. (2011). Total phenolic content (TPC) of dried sample was calculated on the basis of standard curve of gallic acid (R^2=0.99) and the results were finally expressed as mg of gallic acid equivalent g^{-1} of dry matter.

The flavonoid content in dried oyster mushrooms was evaluated by aluminium chloride colorimetric assay using UV spectrophotometer. The experiment was performed by adding 1.5 mL of methanol, 0.1 mL of 10% aluminium chloride and 0.1 mL of 1 M potassium acetate solution to 1 mL of methanolic extract of dried sample. The mixture was incubated for 40 min at room temperature and the absorbance was measured at 415 nm with deionised water as blank. Total flavonoid content (TFC) was calculated on the basis of the calibration curve of quercetin (R^2=0.99) and results were finally expressed as mg of quercetin equivalent g^{-1} of dry matter. The 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity (RSA) was measured in the methanolic extracts as proposed by Vasco et al. (2008) with slight modifications. The antioxidant potential based on ferric reducing antioxidant power (FRAP) assay was determined according to the method of Maurya et al. (2018). Antioxidant potential was calculated on the basis of the calibration curve of Trolox (R^2=0.99) and results were finally expressed as mg of Trolox equivalent g^{-1} of dry matter.

All experiments were done in triplicate and average values were used. Standard deviation was calculated using simple one-way ANOVA.

Modelling of drying data

Drying kinetics is correlated with various transport properties like moisture and thermal diffusivity and mass and heat transfer coefficients. The moisture ratio of the oyster mushroom samples was calculated by the Equation 5.

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad \text{Eq. 5}$$

Where, MR = moisture ratio; M_t = moisture content (kg water/kg dry matter) at time t; M_e = equilibrium moisture content (kg water/kg dry matter); M_o = initial moisture content (kg water/kg dry matter) at time = 0

To understand the drying process of oyster mushrooms, four different drying models were used in the study and these were selected based on the preliminary screening where more than 20 models were tried and the best four are shown here. Four models used to describe the drying curve equation of oyster mushrooms are Lewis [MR = exp(-kt)]; Henderson and Pabis [MR = aexp(−kt)]; Page [MR = exp(−kt^n)]) and Modified Page {MR = exp[−$(kt)^n$]}.

Where, k = drying rate constant (min^{-1}); a and n are the parameters of different model; and t = drying time in min.

All the explained models were tested for their validity to oyster mushroom, vacuum drying and hot air drying. The coefficient of determination (R^2), root mean square error (RMSE) and reduced Chi square ($\chi 2$) were used as the primary a criterion to select the best equation expressing the drying techniques involved in the study. RMSE gives the deviation between the predicted and experimental values and is

expressed as in equation 6. The goodness of fit of the tested mathematical models to the experimental data was evaluated from the coefficient of determination (R^2). The higher the R^2 value, the better is the goodness of fit (Sehrawat and Nema, 2018).

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{n}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]} \quad \text{Eq. 6}$$

$$Chi\ square(\chi 2) = \frac{\left[\frac{1}{N}\sum_{i=1}^{n}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]}{N-z} \quad \text{Eq. 7}$$

Where, $MR_{exp,I}$ is the I^{th} experimentally observed moisture ratio, $MR_{pre,I}$ is the I^{th} predicted moisture ratio, N is the number of observations and z is the number constants.

Results

Effect of Pre-treatment on PPO activity

Pre-treatment optimization was a part of a preliminary research work to understand the effect of different blanching and chemical treatments on polyphenol oxidase enzyme activity in mushrooms. Experiments were done in two different steps which involved the individual and combined effect of different blanching and chemical treatments. Enzymatic activity of PPO enzyme was reduced by the application of these treatments (Fig. 1). Highest % PPO inhibition among 1-5 treatment was found with CA (54.13 ± 0.78%) followed by KMS (48.1 ± 1.88%). Among the heat treatments formulations, blanching at 90 °C (39.6 ± 0.52%) was superior to other two blanching treatments i.e., 80 °C (37.9 ± 0.73%) and 70 °C (28.78 ± 1.56%) in controlling the enzymatic activity. Since the use of KMS is restricted in food so, in further experiments (treatment 6-10) CA was used in combination with blanching.

Results of the individual treatments were in the range of 0.04-0.069, 0.001 ΔA_{420} min^{-1} mL^{-1} whereas those of combination treatments were in the range of 0.01-0.04, 0.001 ΔA_{420} min^{-1} mL^{-1}. The combination of CA and blanching treatment at 70, 80 and 90 °C was found to be more effective than individual chemical and blanching treatments on oyster mushrooms. The effectiveness of treatment 6, 7, 8, 9, 10 in % PPO inhibition of oyster inhibition was 21.03 ± 0.3%, 25.48 ± 1.31%, 59.65 ± 0.5%, 76.54 ± 0.81%, 61.78 ± 1.01%, respectively. CA treatment with blanching at 80 °C for 2 min (76.54 ± 0.81%) exhibited almost constant absorbance values for a certain period which signifies that this combination (treatment 9) is the most effective treatment in case of oyster mushrooms. For further studies CA treatment with blanching at 80 °C for 2 min i.e., treatment 9 was given before drying.

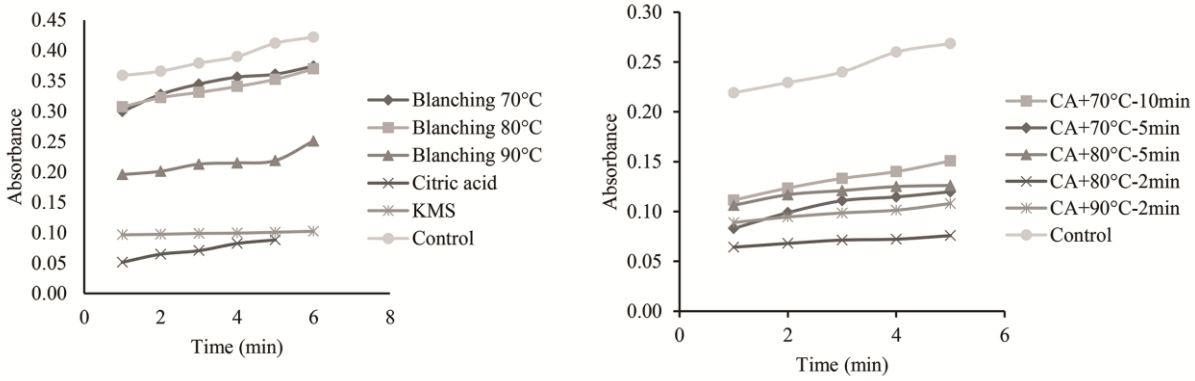


Fig. 1. Polyphenol oxidase (PPO) activity of mushrooms subjected to different pre-treatments

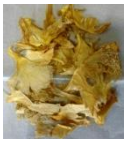
Effect of drying parameters on quality of dried product

Colour

Comparison between different drying techniques and temperatures effect on the colour and Browning Index (BI) of dried oyster mushroom samples is given in Table 2. The degree of colour change of dried oyster mushrooms samples ranged from 1.9 to 5.4. Vacuum dried samples at 50 °C showed the highest colour retention. High temperature was not suitable for drying of mushrooms as drying at 70 °C (both hot air and vacuum dried samples) exhibited higher colour change values irrespective of the drying technique involved. Exceptionally high ΔE value was observed in case of hot air-dried samples at 50 °C in comparison with the vacuum dried samples at same temperature. This decrease in the colour value can be due to the higher drying time at 50 °C.

BI is a technological indicator that epitomizes the brown colour development in the product and is important to have lower BI in food samples. The low BI value exhibited by vacuum dried samples explains the effectiveness of vacuum drying of oyster mushroom in retaining the colour. In sun dried samples, the change in colour (5.391 ± 0.08) and BI (60.02 ± 0.16) was highest. Among different samples from the colour value, better colour retention was obtained by vacuum drying at 50 °C and 60 °C and using hot air drying at 60 °C.

Table 2. Comparison of colour values, rehydration ratio and drying time of dried mushroom samples

	Hot air drying			Vacuum drying			Sun drying
	50°C	60°C	70°C	50°C	60°C	70°C	
							
*L**	61.07±0.87^{e}	66.5±0.76^{c}	59.6±0.50^{f}	70.73±0.17^{a}	68.57±0.17^{b}	63.29±0.4^{d}	51.53±0.45^{g}
*a**	3.80±0.08^{b}	2.83±0.075^{e}	3.83±0.025^{b}	-0.86±0.08^{f}	3.08±0.25^{d}	3.56±0.11^{c}	5.85±0.07^{a}
*b**	25.64±0.46^{a}	20.87±0.49^{cd}	23.60±0.36^{b}	18.93±0.24^{f}	19.46±0.63^{ef}	21.57±0.17^{c}	21.14±1.67^{c}
ΔE	3.2±0.09^{b}	2.12±0.08^{e}	3.23±0.03^{b}	1.95±0.08^{e}	2.37±0.27^{d}	2.91±0.12^{c}	5.391±0.08^{a}
BI	56.8±0.24^{a}	38.4±0.18^{d}	52.35±0.33^{b}	29.43±0.44^{e}	36.021±1.53^{d}	45.32±0.49^{c}	60.02±0.16^{a}
RR	3.76±0.01^{c}	3.6±0.025^{d}	3.25±0.029^{f}	4.20±0.07^{a}	4.05±0.04^{b}	3.35±0.03^{e}	2.85±0.026^{g}
Time (min)	90±0.0	70±0.0	35±0.0	150±0.0	120±0.0	90±0.0	360± 0.0

Values are represented as mean ± SD. Different superscript letters within the same row indicates that the values are significantly different ($p<0.05$); BI – Browning Index; RR – Rehydration Ratio

Rehydration ratio

The RR of the dried mushroom samples ranged between 2.8 to 4.2. Rehydration values of hot air-dried samples ranged between 3.2-3.8 and that of vacuum dried samples were 3.3-4.2. At every temperature, vacuum dried samples exhibited better rehydration values when compared with hot air-dried samples. Vacuum dried samples at 50°C (4.20 ± 0.07) had higher RR. Higher temperatures (70°C) resulted in poor RR of dried oyster mushrooms (Table 2). In sun dried samples RR was 2.85 ± 0.026.

Ascorbic acid content

Comparison between AA content of oyster mushrooms dried under different drying techniques is depicted in Table 3. The results exhibited a significant difference in AA % retention by different drying technique and temperature. Percentage retention of AA in sun dried samples was 33% only. In terms of retention of AA, hot air drying (34% to 41%) was unfitting for oyster mushroom drying and was inferior to vacuum drying (62% to 73%) technique.

Total phenolic content

The TPC in dried mushrooms is depicted in Table 3. The sun-dried samples showed the least retention of phenolics (28%). Vacuum dried samples (2.58 ± 0.020 to 3.31 ± 0.026) were superior to hot air-dried samples (2.53 ± 0.010 to 2.77 ± 0.017) at varying temperatures of drying. In hot air-drying technique, the highest retention of TPC was observed at 60 °C (2.77 ± 0.017) which is contrary to the trend followed in vacuum drying was at 50 °C (3.31 ± 0.026). There was a remarkable decrease in the TPC of hot air-dried samples at 50 °C (2.67 ± 0.010). This implies the fact that TPC of the oyster mushroom samples is highly sensitive to temperature, time and different method of drying as well.

Table 3. Bioactive component of the fresh and the dried mushroom samples

Drying technique	Temperature (°C)	Phenolic content (mg GAE/g dm)	Flavonoid content (mg QE g dm)	Ascorbic Acid (mg AA/g dm)	DPPH activity (% RSA)	FRAP value (mg TE/g dm)
Fresh sample		4.34±0.201	1.96±0.062	20.69±0.505	30.43±0.554	5.54±0.097
Hot air drying	50	2.67±0.010^{d}	0.56±0.004^{f}	7.42±0.005^{e}	14.21±0.770^{e}	1.91±0.043^{g}
	60	2.77±0.017^{c}	0.76±0.029^{d}	8.49±0.047^{d}	17.20±0.460^{c}	2.75±0.014^{d}
	70	2.53±0.010^{f}	0.58±0.003^{e}	7.10±0.024^{f}	15.40±0.470^{d}	2.44±0.008^{e}

Drying technique	Temperature (°C)	Phenolic content (mg GAE/g dm)	Flavonoid content (mg QE g dm)	Ascorbic Acid (mg AA/g dm)	DPPH activity (% RSA)	FRAP value (mg TE/g dm)
Vacuum drying	50	3.31±0.026[a]	1.57±0.019[a]	15.15±0.080[a]	23.50±0.410[a]	4.44±0.210[a]
	60	2.91±0.013[b]	1.21±0.002[b]	14.65±0.090[b]	20.43±0.190[b]	3.79±0.093[b]
	70	2.58±0.020[e]	0.95±0.008[c]	12.84±0.330[c]	17.39±0.530[c]	3.17±0.022[c]
Sun drying		2.093±0.05[g]	0.519±0.003[g]	6.927±0.01[g]	10.26±0.510[f]	2.19±0.007[f]

GAE – Gallic Acid Equivalent; QE-Quercetin Equivalent; AA- Ascorbic Acid; RSA- Radical Scavenging Activity; TE=Trolox Equivalent; Values are represented as mean ± SD. Different superscript letters within the same column indicates that the values are significantly different ($p<0.05$)

Total flavonoid content

High temperature exhibited lowest retention of flavonoids with only variation in case of hot air drying at 50 °C with TFC around 0.56 ± 0.004 mg QE g^{-1} dm. Sun drying of oyster mushrooms resulted in samples with very low flavonoid content (26%). As observed in case of other parameters, vacuum drying at 50 °C (80%) of oyster mushroom furnished better retention of TFC and in hot air drying at 60 °C (39%) at different temperatures studied. There was a significant variation between the hot air-dried samples (29% to 39%) and vacuum dried samples (48% to 80%), which projects the fact that vacuum drying is most suitable for the drying of oyster mushrooms.

Total antioxidant activity

2,2-Diphenyl-1-picrylhydrazyl radical-scavenging activity

RSA of dried samples were in the range of 10-24% with sun dried samples exhibits the least scavenging activity. The scavenging activity of fresh sample was about 30.43% and that of vacuum dried sample at 50 °C which showed the highest scavenging activity among dried samples which was 23.50%. The decrease of scavenging activity among the dried samples was also less. RSA of dried samples showed a similar pattern with the results of TPC and TFC.

Ferric reducing antioxidant power assay

Among all the techniques involved, the FRAP of vacuum dried samples at 50 °C (4.44 ± 0.210) was found to be higher whereas, the lowest FRAP value was recorded in sun dried samples (2.19 ± 0.007). In samples dried using hot air-drying maximum retention was obtained at 60 °C (2.75 ± 0.014) as compared to 70 °C (2.44 ± 0.008) and 50 °C (1.91±0.043) indicating that apart from temperature even the drying time plays a role in influencing quality of oyster mushroom.

Discussions

Effect of Pre-treatment on PPO activity

PPO enzyme is responsible for brown colour development in oyster mushroom which is known as enzymatic browning. This brown colour development is not desirable since it leads to colour degradation in oyster mushroom samples. So, a suitable pre-treatment can help in reducing the enzymatic browning. Among the individual pre-treatment i.e., chemical, and blanching (thermal treatment), the chemical treatment was found to be more effective. As dispersing of mushroom samples in chemical solution leads to lower down the pH which resulted in higher % PPO inhibition. Jafri et al. (2013) also stated that the efficiency of acids in controlling the enzyme activity is by their capacity to lower the pH of the system.

Double inhibitory effect of chemical and blanching on PPO activity was also reported by Jafri et al. (2013) which is in accordance with the current results. The combination of CA and blanching treatment at 70, 80 and 90 °C was found to be more effective than individual chemical and blanching treatments on oyster mushrooms. This was due to the synergistic effect of high temperature and low pH combination in inhibiting the PPO activity.

Effect of drying parameters on quality of dried product

Colour

Customer acceptance can be unswervingly corelated with the colour of the produce which makes the same parameter responsible for the initial acquiescence. The results showed that vacuum drying at low temperature stands superior to other treatments in maintaining the colour of oyster mushroom samples. The superiority of colour for the vacuum dried samples while comparing with the hot air-dried samples can be due to their less drying time and near absence of oxygen. Time taken for hot air drying of oyster mushrooms was twice that of vacuum drying which affected overall quality of the final samples in terms of colour. Similar effect was also noticed by Argyropoulos et al. (2011) for hot air-dried *Boletus edulis* mushrooms and by Kotwaliwale et al. (2007) for hot-air dried oyster mushrooms.

Low BI directly implies the better quality of dried product. Similar trend of ΔE values was obtained in BI also. In sun dried samples, the change in colour and BI was highest which could be ascertained to the fact of very slow rate of drying. This correlation is due to the difference in L^*, a^* and b^* values obtained which directly affected the BI. The temperature dependency of the colour values of the dried oyster mushroom samples explains the fact that high temperature drying is not appropriate for the oyster mushrooms which results in high colour degradation. The low BI value exhibited by vacuum dried samples explains the effectiveness of vacuum drying of oyster mushroom.

Rehydration ratio

The rehydration characteristics of dried mushroom samples were affected by drying temperature and the technique. Rehydration properties of mushrooms were higher at lower temperatures and vacuum assisted drying as revealed by the higher value of RR. Maurya et al. (2018) obtained a similar result on evaluating the rehydration characteristics of dried red bell pepper. Benseddik et al. (2019) also reported a similar observation on the effect of drying technique on rehydration characteristics of pumpkin. The results of the study clearly indicate that higher temperatures are not suitable in case of effective drying of mushrooms. As high temperature negatively affected the rehydration value of mushrooms in both the drying techniques. In sun dried samples, the rate of moisture absorption was very less resulting in poor RR.

Ascorbic acid content

AA is sensitive to temperature as high temperature leads to degradation of AA (Tewari et al., 2017). Temperature dependency of AA content within the same drying technique varied as with higher temperature shows less retention of AA (Singhal et al., 2020). Similarly, in our study in both the drying techniques, samples dried at higher temperatures showed less AA retention. High degradation percentage of AA in sun dried samples (33%) may be due to the uncontrolled and non-uniform drying of samples under sunlight. In terms of retention of AA, hot air drying is inappropriate for mushroom drying and is inferior to vacuum drying technique due to the temperature dependency of the content.

Total phenolic and total flavonoid content

The content of phenolic compounds is an important indicator and is well correlated with the antioxidant activity of the product. TPC of the dried samples exhibits a similar trend that of AA with low temperature resulting to higher retention (Miranda et al., 2010). But the variation between drying methods at a particular temperature is not similar to the AA results. The sun-dried samples showed the least retention of phenolic content. Mishra et al. (2016) also reported a lower retention of TPC in sun dried oyster mushrooms. The detrimental effect of high temperature drying was also evident in case of other discussed parameters and the effect is similar in case of TPC also. Vacuum dried samples were superior to hot air-dried samples at every temperature of drying. In hot air-drying technique, the highest retention of phenolic content was observed at 60°C which is contrary to the trend followed in vacuum drying. Similar observation was reported by Valiente et al. (2016) during convective drying of *Pleurotus ostreatus*. Similar to TPC results, the temperature and drying technique correlation of TFC of dried mushrooms is inevitable. Superiority of vacuum dried samples over air dried samples is emphasised again by the findings of flavonoid content retention. Convective drying of oyster mushrooms also exhibited a similar result in research work conducted by Valiente et al. (2016).

Total antioxidant activity

2,2-Diphenyl-1-picrylhydrazyl radical-scavenging activity

Analogues to the TPC results, RSA was also negatively affected with increase in temperature. Compared to other parameters under study, RSA of dried oyster mushroom samples showed less degradation as compared to fresh sample. But the maximum degradation was above half of the scavenging activity of fresh sample. RSA also exhibits a temperature dependency with high temperatures not favourable in retaining the scavenging activity. There is a significant difference between RSA of vacuum dried and hot air-dried samples. Strong DPPH RSA can be correlated with high levels of TPC and TFC of vacuum dried samples.

Ferric reducing antioxidant power assay

Drying of oyster mushrooms is resulted in half per cent decrease in the reducing power. Hot air-dried samples at 70 and 50 °C showed a significant difference in FRAP value illustrating that the drying time has strong influence on the chemical parameters of dried product. FRAP values of dried oyster mushroom samples exhibits a similar trend as of DPPH RSA which

explains the fact that all the parameters have a significant role in total antioxidant activity of a sample. In all the chemical properties studied the trend in retention of components was in increasing order with decrease in temperature in the samples dried using vacuum drying indicating the negative effect of increase in temperature.

Drying kinetics

Effect of moisture content and drying temperature on drying rate

The drying time of oyster mushroom under vacuum was lower when compared with other drying techniques employed in the study. Since radiation effect being more prominent in vacuum drying of oyster mushroom slices due to frequent use of heater to maintain temperature, would have led to higher drying rates as compared to hot air drying. Higher drying rates resulted in lower drying time for vacuum dried slices. Intermittent effect of sun rays and non-uniform drying led to longer drying time in case of sun-dried oyster mushroom samples.

Initially, the drying rate of oyster mushroom samples were very high and then as moisture content of the sample advanced towards equilibrium moisture content, the drying rate was reduced. Similar results were reported by Artnaseaw et al. (2010) during the drying of shitake mushrooms. At initial conditions of drying, there is a significant difference between the air temperature and sample so, more energy is absorbed by the water at the product surface which in turn enhanced the heat transfer rates of drying. Since evaporation of free moisture from surface of oyster mushroom samples is faster whereas at the end of drying process surface moisture dries out removal of moisture occurs from inside the samples which is bound moisture and difficult to remove, thereby reduces the drying rates. The experimental results indicate that there is no constant rate period of drying, only falling rate periods were observed in drying kinetics of hot air-dried oyster mushroom samples. Since, various factor influences the rates i.e., drying technique, product dimensions and moisture diffusivity. A similar observation was reported during the thin layer drying of shitake mushrooms by Rhim and Lee (2011) where absence of constant drying rate period was found and stated that diffusion of moisture is the dominant factor. Similarly, only falling rate periods were also observed in other food commodities i.e., mango (Sehrawat et al., 2018), onion (Sehrawat and Nema, 2018), mushroom (Bhattacharya et al., 2015), and in carrot, green pea, pumpkin (Krokida et al., 2003). The effect of increasing drying rate with drying temperature was found in dried oyster mushroom samples, i.e., drying rate increased with the increase in drying temperature due to high heat transfer which in turn reduced drying time.

Evaluation of models

Among the four models, after evaluating the R^2, RMSE and χ^2 values, Page model was found to be appropriate to represent the drying behaviour of oyster mushroom, followed by modified page model. The applied model provides a good agreement between the experimental and predicted moisture ratios emphasizing a perfect fit. Results of the modelling study showed the agreement of the Page model with the drying data of drying of oyster mushrooms (Fig. 2). Page model was also suggested by Salehi et al. (2017) as the best model for representing the infrared - vacuum drying characteristics of button mushrooms. Giri and Prasad (2007) also reported about the best fit of air-drying behaviour of button mushrooms in Page model for drying. Among different constant parameters rate constant (k) is an important factor and was found to be hastened up with increase in drying temperature in the models studied which include k in the empirical equation. It was found to be highest in case of vacuum dried oyster mushroom samples (0.003190 to 0.18046) in comparison to hot air-dried oyster mushroom samples (0.02200 to 0.09489) as predicted by different models. It was observed that in case of vacuum dried and hot air-dried oyster mushroom samples and k was lowest in case of Handerson and Pabis model and highest in case of Page model (Table 4).

Variation of the coefficient a and n with temperature was not systematic in case of vacuum dried oyster mushroom samples whereas was systematic in case of hot air-dried samples as found to be increase with increase in temperature. Also differences in n value are not different at 60 ^{o}C and 70 ^{o}C. Variation in k was systematic with temperature whereas other model coefficients were not systematic in dried *Agaricus bisporus* and *Pleurotus florida* mushroom (Arora et al., 2003), tomato slices (Purkayastha et al., 2013) and mango cubes (Sehrawat et al., 2018).

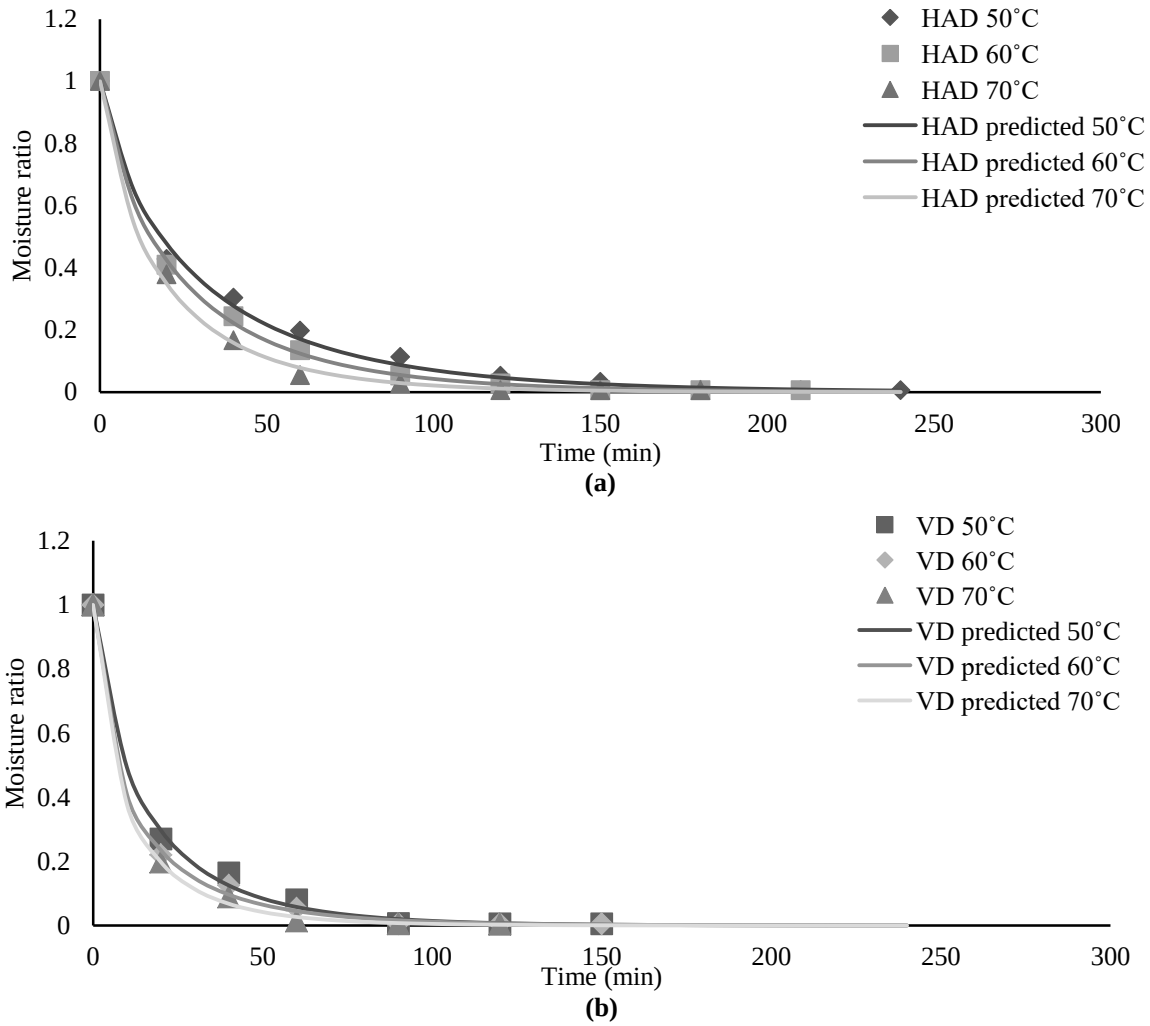


Fig. 2. Moisture ratio curves of predicted and experimental values of mushrooms using (a) hot air drying technique and (b) vacuum drying technique

Table 4. Empirical constants and statistical results of different models for hot air and vacuum drying of mushroom

Drying Method	Model	Temp (°C)	Constants and coefficients			R^2	χ^2	RSME
			k	a	n			
Hot air Drying	Lewis Model	50	0.02410			0.98403	0.002915	0.05227
		60	0.02890			0.98902	0.002773	0.05041
		70	0.03530			0.99153	0.003021	0.05182
	Handerson & Pabis Model	50	0.02200	1.43089		0.97910	0.037256	0.18689
		60	0.02510	1.74927		0.98032	0.11606	0.31985
		70	0.02820	2.44562		0.97559	0.462528	0.64120
	Page Model	50	0.06885		0.79270	0.99784	0.000326	0.01688
		60	0.07586		0.80960	0.99952	8.48E-05	0.00841
		70	0.09489		0.80380	0.99911	0.00024	0.01321
	Modified Page Model	50	0.03419		0.79270	0.99754	0.00035	0.01743
		60	0.04137		0.80960	0.99952	9.50E-05	0.0088
		70	0.05341		0.80380	0.99911	0.00026	0.01401

Drying Method	Model	Temp (°C)	Constants and coefficients			R^2	χ^2	RSME
			k	a	n			
Vacuum Drying	Lewis Model	50	0.04130			0.98569	0.004873	0.06463
		60	0.04240			0.97839	0.007910	0.08234
		70	0.05330			0.98935	0.004565	0.06168
	Handerson & Pabis Model	50	0.03390	0.45850		0.97278	0.059492	0.02061
		60	0.03190	0.32851		0.95261	0.090886	0.25479
		70	0.04050	0.33444		0.97049	0.111510	0.27270
	Page Model	50	0.11843		0.77650	0.99818	0.000606	0.02081
		60	0.18139		0.69300	0.99922	0.000250	0.01336
		70	0.18046		0.73210	0.99961	0.000153	0.01011
	Modified Page Model	50	0.06409		0.77650	0.99812	0.000757	0.02247
		60	0.08515		0.69300	0.99923	0.000312	0.01443
		70	0.09645		0.73210	0.99961	0.000205	0.01108

Conclusion

Among the chemical and blanching treatments, combination of CA treatment with blanching at 80 °C for 2 min exhibited almost constant absorbance values for a certain period of time which signifies that combination is the most effective treatment in oyster mushrooms. Vacuum drying of the oyster mushroom samples was effective in maintaining all the quality parameters of oyster mushroom samples up to a desired level. High temperature is not appropriate for the drying of oyster mushrooms. Drying technique and temperature have a profound effect on the drying period and drying kinetics of oyster mushrooms. Drying temperature has a positive correlation with drying time required and this was evident in all the methods of drying. With the increase in temperature, the time required for drying was decreased. Among techniques employed in the study, vacuum drying of oyster mushrooms took short time to attain the desired level of drying. Page model was found to be the appropriate fit for describing the drying behaviour of vacuum and hot air-dried samples.

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Conflict of interest

The authors declare no conflict of authors.

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