Research Article

Convective and Microwave Drying of Mushrooms (*A.bisporus* and *P.ostreatus*)

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ABSTRACT

Dried edible mushrooms are able to be consumed in soup and sauce recipes. Utilization of *A. bisporus* and *P. ostreatus* in food formulations could bring added value to these products. In this study, *A. bisporus* and *P. ostreatus* samples were dried at 60, 70 and 80°C in conventional oven and at 180, 360 and 600 W in a microwave oven until no weight changes were observed. Among 15 thin layer drying equations, Sigmoid model gave the best results after fitting the experimental moisture ratios. The effective moisture diffusivities of *A. bisporus* and *P. ostreatus* were in the range of 2.19068×10^{8} - 8.57569×10^{-8} m^2/s for convective, 1.92368×10^{-7} - 7.37349×10^{-7} m^2/s for microwave drying; 2.19068×10^{-8} - 1.20754×10^{-7} m^2/s for convective, 1.60293×10^{-7} -6.09115×10^{-7} m^2/s for microwave drying respectively. The activation energies were calculated as 66.86 kJ/mol and 12.64 W/kg for *A. bisporus* and 83.25 kJ/mol and 12.34 W/kg for *P. ostreatus.*

Keywords: *P. ostreatus, A. bisporus,* mushroom, Drying, Mathematical modeling

INTRODUCTION

Edible mushrooms have specific flavors, textures and high nutritional value, hence they have been becoming favourite food materials all over the world[1,2,3] and using in soup and sauce formulations.[4] On the other hand, mushrooms are not only valuable food sources, but also having medicinal properties[5,6] due to containing various bioactive molecules like antioxidants,[7,8] steroids, phenolics and terpenes.[3-9] Studies demonstrated that 150 types of mushroom had the antioxidant potential.[10]

Drying is one of the oldest preservation methods of foods. Conventional drying is the most common technique and microwaves supply rapid moisture removal. Heat and mass transfer occur at the same time in this processes,[11] thus some complexities could arise. In order to solve difficulties and understand the mechanism of dehydration, mathematical models could be helpful. Mathematical models are classified into three categories as empirical, semi-empirical and theoretical.[12]

The aim of this study was (i) to determine conventional and microwave drying kinetics of *A. bisporus* and *P. ostreatus,* (ii) to fit experimental drying data into 15 different mathematical models, (iii) to estimate effective moisture diffusivity of mushrooms, (iv) to calculate activation energies of samples.

MATERIALS AND METHODS

MATERIAL

A. bisporus and *P. ostreatus* were produced by using composts in Mushroom House of Osmaniye Korkut Ata University, Turkey. The mushrooms were cut into small pieces with a sharp knife manually, put onto glass petri dishes (120×17 mm) and dried immediately after cutting. All experiments were performed in triplicate and continued until no changes were observed in weight

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of samples. Initial moisture content of *A. bisporus* was 91.55±0.03% and *P.ostreatus* was 91.80±0.35% according to AOAC, 1990.[13]

Drying

A laboratory type natural convection oven (JSR, JSON-250) was used for convective drying. Studied temperatures were 60, 70 and 80°C and before experiments, the dryer was run idle for 5-6 min to reach target temperature. The weight of samples was determined in every 5 minutes manually by using a digital balance (Radwag, AS/X, Poland). The weighing procedure was not exceeded 10 s.

A microwave oven (Arçelik, MD 574, Turkey) having 6 different power level was also installed. Studied power levels and weighing times were 180, 360 and 600 W and 60, 40 and 30 s respectively. Samples on petri dishes were placed on a rotating plate (D=245 mm) in oven and the sample masses were defined as taking the petri out of system, weighing sample and then putting back into the oven. The measurement took about 10 s like in conventional drying.

Mathematical modeling

15 thin layer drying models called as; Lewis,[14] Page,[15] Modified Page,[16] Henderson and Pabis,[17] Logarithmic,[18] Two-term,[19] Midilli *et al.*[20] Wang and Singh,[21] Weibull,[22] Parabolic,[20] Cubic,[23] Thompson[24] Sigmoid[25], Rational[26] and Vega Lemus[27] were applied the moisture ratio data of samples. Moisture ratios MR were defined by the formula of M/M_0. M represents moisture (g) at any time and M_0 is the initial moisture (g) of sample. The highest determination coefficient R^2 and the lowest Root mean square error RMSE and chi square χ^2 levels[28] were used for selecting the best model which described the drying phenomenon. All statistical analysis was done with the aid of Origin lab Pro 2016 software.

To calculate effective moisture diffusivities (D_{eff}), Fick's second law for cylinder geometry was accepted.[11] On the other hand, Arrhenius type equation was valid for the activation energy (E_a) of convective drying, however in microwave; this equation was modified by Dadali and Özbek, 2008.[29]

RESULTS AND DISCUSSION

Drying kinetics

All mushroom samples were dehydrated until no weight changes were observed. Drying times were 12 h, 8 h and 6.5 h at 60, 70 and 80°C and 47 min, 23 min and 12 min at 180, 360 and 600 W for each type of mushroom respectively. When temperature/power increased, the drying time reduced. Same results were expressed by Doymaz, 2011[12] in pomegranate arils, Vega-Galvez *et al.*, 2009[26] in red pepper and Tulek, 2011[28] in oyster mushrooms as well.

Mathematical modeling

Thin layer drying models (semi-empirical) have been using for years to define dehydration behaviors of food materials, so in this research fifteen of them were fitted to experimental data and Sigmoid model gave the highest R^2 and the lowest RMSE and χ^2 values in all trials. The results of this model were given in Table 1. "k" represented drying constant (1/min) and "a", "b" and "c" were the constants. "d" term was not depicted in Table 1 because of closing to zero. Sigmoid model is not a common equation in available literature, but it identifies dehydration procedure very well compared to others. Süfer *et al.*, 2017[11] and Figiel, 2009[25] also claimed the

Results of sigmoid model

Sample	R^2	χ^2	RMSE	k (1/min)	a	b	c
A. bisporus - 60°C	0.99962	0.00000	0.00143	-0.06191	0.28717	0.75677	28.59153
A. bisporus - 70°C	0.99985	0.00000	0.00176	-0.03125	0.96911	0.27965	34.29353
A. bisporus - 80°C	0.99965	0.00003	0.00451	-0.02997	1.67795	-0.16933	27.33148
P. ostreatus - 60°C	0.99906	0.00001	0.00222	-0.04860	0.33948	0.73236	26.95817
P. ostreatus - 70°C	0.99992	0.00000	0.00114	-0.02092	1.21862	0.23625	24.80393
P. ostreatus - 80°C	0.99943	0.00004	0.00501	-0.02384	2.18050	-0.31211	15.21244
A. bisporus - 180 W	0.99934	0.00001	0.00297	-0.00210	0.94738	0.37656	315.43834
A. bisporus - 360 W	0.99939	0.00002	0.00363	-0.00421	1.00964	0.20757	312.97939
A. bisporus - 600 W	0.99925	0.00003	0.00433	-0.00721	0.99199	0.28247	136.64819
P. ostreatus - 180 W	0.99743	0.00004	0.00506	-0.00238	0.76058	0.38207	584.79122
P. ostreatus - 360 W	0.99922	0.00002	0.00410	-0.00684	0.65852	0.44874	250.41665
P. ostreatus - 600 W	0.99735	0.00008	0.00706	-0.00564	1.07520	0.20644	186.03805

certainty of this mathematical expression. Other suitable models which described drying phenomena of mushrooms were Cubic and Parabolic models (data not shown).

The effective moisture diffusivities for *A. bisporus* (E_a=66.86 kJ/mol and 12.64 W/kg) were 2.19068 × 10^{-8}/1.92368 × 10^{-7}, 5.02252 × 10^{-8}/4.16763 × 10^{-7} and 8.57569 × 10^{-8}/7.37349 × 10^{-7} m^2/s; for *P. ostreatus* (E_a=83.25 kJ/mol and 12.34 W/kg) were 2.19068 × 10^{-8}/1.60293 × 10^{-7}, 4.16763 × 10^{-8}/3.67530 × 10^{-7} and 1.20754 × 10^{-7}/6.09115 × 10^{-7} m^2/s at 60°C/180 W, 70°C/360 W and 80°C/600 W respectively. In higher temperatures/powers, increased moisture diffusivities were seen and diffusivities were comparably lower in conventional drying. Zogzas *et al.*[30] indicated the E_a values of foods were in range of 12.7-110 kJ/mol, hence levels for conventional drying were between in this gap. For microwave drying, there were no available data for comparison.

CONCLUSION

In this research, various drying methods and modeling of dehydration kinetics in *A.bisporus* and *P.ostreatus* were studied. Sigmoid model showed the best statistical outcomes in all samples and the moisture diffusivities of *A.bisporus* were always greater than the other. However, *P.ostreatus* had the highest E_a in conventional drying.

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CONFLICT OF INTEREST

None

ABBREVIATION USED

M: Moisture content at any time (g water); Mo: Initial moisture content (g water); MR: Moisture ratio; R^2: determination coefficient; RMSE: Root mean square error; X^2: Chi square; D eff: Effective diffusivity (m^2/s); Ea: Activation energy (kJ/mol and W/kg).

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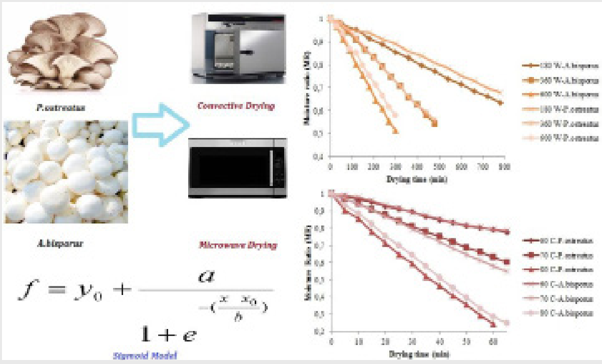
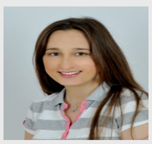
PICTORIAL ABSTRACT



SUMMARY

- Drying kinetics of *A.bisporus* and *P.ostreatus* in conventional and microwave oven were investigated.
- Drying temperatures of mushroom samples were 60, 70 and 80°C and power levels were 180, 360 and 600 W.
- Sigmoid model was the best for describing drying phenomena of all types of sample.
- Activation energy of *A.bisporus* was less than the other in conventional drying, however, *P.ostreatus* has the lowest value in microwave drying.

ABOUT AUTHORS



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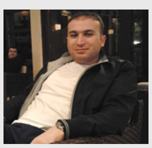

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