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 - 8.57569×10⁻¹² m²/s for convective, 1.92368×10⁻⁷ - 7.37349×10⁻¹⁷ m²/s for microwave drying; 2.19068×10⁻⁷ - 1.20754×10⁻⁷ m²/s for convective, 1.60293×10⁻⁷ - 6.09115×10⁻⁷ m²/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 world¹²,³ and using in soup and sauce formulations.⁴ On the other hand, mushrooms are not only valuable food sources, but also having medicinal properties⁵,⁶ 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.

MATERIAL 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.
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 (Arcelik, 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,29 Midilli *et al.*,20 Wang and Singh,21 Weibull,22 Parabolic,29 Cubic,23 Thompson24 Sigmoid25, Rational26 and Vega Lemus27 were applied the moisture ratio data of samples. Moisture ratios MR were defined by the formula of M/M₀. M represents moisture (g) at any time and M₀ is the initial moisture (g) of sample. The highest determination coefficient R² and the lowest Root mean square error RMSE and chi square χ² values28 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 (Dₑ), Fick’s second law for cylinder geometry was accepted.11 On the other hand, Arrhenius type equation was valid for the activation energy (Eₐ) 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 in pomegranate arils, Vega-Galvez *et al.*, 2009 in red pepper and Tulek, 2011 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 R² and the lowest RMSE and χ² 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 and Figiel, 2009 also claimed the

<table>
<thead>
<tr>
<th>Sample</th>
<th>R²</th>
<th>χ²</th>
<th>RMSE</th>
<th>k (1/min)</th>
<th>a</th>
<th>b</th>
<th>c</th>
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<tbody>
<tr>
<td><em>A. bisporus</em> - 60°C</td>
<td>0.9962</td>
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<td>0.00000</td>
<td>0.00176</td>
<td>-0.03125</td>
<td>0.96911</td>
<td>0.27965</td>
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<tr>
<td><em>A. bisporus</em> - 80°C</td>
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<td>0.00003</td>
<td>0.00451</td>
<td>-0.02997</td>
<td>1.67795</td>
<td>-0.16933</td>
<td>27.33148</td>
</tr>
<tr>
<td><em>P. ostreatus</em> - 60°C</td>
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<td>0.00001</td>
<td>0.00222</td>
<td>-0.04860</td>
<td>0.33948</td>
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<td><em>P. ostreatus</em> - 70°C</td>
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<td>1.21862</td>
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<td><em>P. ostreatus</em> - 80°C</td>
<td>0.9943</td>
<td>0.00004</td>
<td>0.00501</td>
<td>-0.02384</td>
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<td>15.21244</td>
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<tr>
<td><em>A. bisporus</em> - 180 W</td>
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<td>0.00001</td>
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<td>-0.00210</td>
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<td>0.37656</td>
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<td><em>A. bisporus</em> - 360 W</td>
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<td>-0.00421</td>
<td>1.00964</td>
<td>0.20757</td>
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<tr>
<td><em>A. bisporus</em> - 600 W</td>
<td>0.9925</td>
<td>0.00003</td>
<td>0.00433</td>
<td>-0.00721</td>
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<td>0.28247</td>
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<tr>
<td><em>P. ostreatus</em> - 180 W</td>
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<td><em>P. ostreatus</em> - 360 W</td>
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<td>0.00008</td>
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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 \((E_a=66.86 \text{ kJ/mol and } 12.64 \text{ W/kg})\) were 2.19068 \(\times 10^7\)/1.92368 \(\times 10^7\), 5.02252 \(\times 10^8\)/4.16763 \(\times 10^7\) and 8.57569 \(\times 10^7\)/7.37349 \(\times 10^7\) \(m^2/s\); for \( P. \) ostreatus \((E_a=83.25 \text{ kJ/mol and } 12.34 \text{ W/kg})\) were 2.19068 \(\times 10^7\)/1.60293 \(\times 10^7\), 4.16763 \(\times 10^8\)/3.67530 \(\times 10^7\) and 1.20754 \(\times 10^7\)/6.09115 \(\times 10^7\) \(m^2/s\) 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.

ACKNOWLEDGEMENT

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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\(^2/s\)); \( E_a \): Activation energy (kJ/mol and W/kg).

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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.

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