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Influence of Drying Process Variables on Fresh and Osmotically Pre-Treated Mushrooms

Influência das Variáveis do Processo de Secagem em Cogumelos Frescos e Desidratados Osmoticamente

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SUMMARY

The aim of this work was to study the drying of fresh and osmotically dehydrated mushrooms and evaluate their qualities. The osmotic treatment was carried out at 20 °C with a 10% w.w^{-1} salt solution, 80 rpm agitation and 60 min immersion time. The mushrooms were dried in a vertical bed dryer with forced air-flow. An experimental design was applied to evaluate the influence of the temperature and air velocity on the drying constant, obtained according to an exponential model and on the colour difference between the dried and fresh samples. Using Response Surface Methodology, a condition was chosen to obtain the largest drying constants and smallest colour differences. The optimum conditions for the drying process were 70 °C and 2.0 m/s, and 80 °C and 2.5 m/s for fresh and osmotically dehydrated mushrooms, respectively. The dried mushrooms presented β-glucan content values of 6.14 ± 0.55 and 6.77 ± 0.47 g.100 g^{-1} d.b under the optimised drying conditions. Osmotically dehydrated samples showed a slower re-hydration rate and smaller water activity than samples without pre-treatment.

RESUMO

O objetivo deste trabalho foi estudar o processo de secagem de cogumelos frescos e desidratados osmoticamente e avaliar suas qualidades. O tratamento osmótico foi conduzido a 20 °C com solução salina 10% p.p^{-1}, 80 rpm de agitação e 60 min de tempo de imersão. Os cogumelos foram secos em um secador vertical de leito fixo com escoamento de ar forçado. Um planejamento experimental foi aplicado para avaliar a influência das variáveis temperatura e velocidade do ar na constante de secagem, obtido de acordo com o modelo exponencial, e na diferença total de cor entre as amostras frescas e secas. Através de Metodologia de Superfície de Resposta, foi escolhida uma condição de processo de modo a obter maiores valores de constante de secagem e menores valores de diferença total de cor. As condições otimizadas do processo foram 70 °C e 2,0 m/s, e 80 °C e 2,5 m/s para as amostras sem e com pré-tratamento osmótico, respectivamente. Nas condições otimizadas, os cogumelos secos apresentaram valores de conteúdo de β-glucana de 6,14 ± 0,55 e 6,77 ± 0,47 g.100 g^{-1} (base seca). As amostras desidratadas osmoticamente apresentaram uma menor taxa de reidratação e menor valor de atividade de água do que as amostras sem pré-tratamento.

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1. INTRODUCTION

Mushrooms have long been used as food in soups and sauces due to their soft texture and unique, enhanced flavour. In addition, mushrooms have recently become attractive as a functional food.

Agaricus blazei is a Brazilian mushroom popularly known as the sun mushroom, and is frequently consumed as a food due to its unique flavour; or as a tea for its medicinal effect. This mushroom is used to combat physical and emotional stress, osteoporosis and ulcers; for quality of life improvement in diabetic people, cholesterol reduction, and the treatment of circulatory and digestive problems. In addition, it has shown anti-tumour activity (MIZUNO et al., 1990), immunomodulation effect (MIZUNO et al., 1998), and antimutagenic and anticlastogenic properties (DELMANTO et al., 2001). Mizuno et al. (1990) isolated the active compounds found in the *Agaricus blazei* mushroom and found polysaccharides showing anti-tumour activity, the major fraction of which was a glucan–protein complex with a β-(1→6)-D-glucan linkage.

Mushrooms are highly perishable due to their high moisture content. Therefore, fresh mushrooms have been processed to improve their shelf life. Amongst the various methods employed for preservation, drying is a process in which the water activity of the food is reduced by removal of the water by vaporization or sublimation, minimizing enzymatic and microbiological reactions. Drying is a simultaneous heat and mass transfer process, accompanied by a phase change. The drying rate depends on factors that influence the transfer mechanisms, such as the vapour pressure of the material and of the drying air, the temperature and air velocity, water diffusion in the material, the thickness and surface exposed for drying (BARBANTI et al., 1994; VAN ARSDEL, 1973).

This process causes serious damage to the food, such as loss of vitamins, mineral salts and texture. Osmotic dehydration is usually employed as a pre-treatment for drying to retain the nutritional and sensory quality of the food. This process is used for the partial removal of water from the food by immersion in a hypertonic solution. Diffusion of the water is accompanied by a simultaneous counter diffusion of osmotic solution solutes into the tissue. Other food solutes present (such as sugars, minerals and nutrients) are lost in the hypertonic solution (RAOULT-WACK, 1994). The osmotic dehydration of mushrooms (*Agaricus bisporus*) has been studied as a pre-treatment for microwave drying by Torringa et al. (2001) and for air-convective drying by Shukla and Singh (2007).

Response surface methodology has been employed in industrial investigations and other processes due to its practical utility in their optimisation. This methodology presupposes the use of experimental design techniques to investigate and learn about the functional form of the process that involves one or more dependent variables influenced by various factors or independent variables (CORZO and GOMEZ, 2004).

The aim of the present work was to evaluate the influence of some variables on the drying of fresh and osmotically dehydrated mushrooms. The specific objectives were: 1) to model the influence of the temperature and air velocity on the drying constant and colour loss using a screening design methodology; 2) to optimise mushroom drying to obtain the maximum drying constant and minimum total colour difference between the dried and fresh samples using response surface methodology; 3) to characterize the dried products under the optimised conditions.

2. MATERIAL AND METHODS

2.1 Material

Fresh mushrooms (*Agaricus blazei*), with an average initial moisture content of 89% w.w^{-1}, were supplied by the Group Agaricus of Piedade Industry, located in the city of Pilar do Sul, Brazil. The samples were visually sorted by colour (light yellow) and size (average diameter of 3 cm and length of 5 cm) and longitudinally cut into slices 0.5 mm thick using a cutter designed for this purpose.

The main characteristics of the mushrooms are summarized in Table 1. The results were very close to those obtained by Mizuno et al. (1990), with the exception of the protein and carbohydrate contents. The pH and water activity values of the fresh mushrooms were 6.24 ± 0.01 and 0.995 ± 0.001, respectively.

The osmotic solution was prepared with distilled water and commercial sodium chloride.

TABLE 1. Composition of *Agaricus blazei* mushrooms.

Content	Mean ± standard deviation	Mizuno et al. (1990) (%)
Moisture (wt, %)	88.75 ± 0.12	85-87
Carbohydrate (db, %)	51.47 ± 1.07	38-45
Fibres (db, %)	6.76 ± 0.44	6-8
Fat (db, %)	4.09 ± 0.18	3-4
Ash (db, %)	7.29 ± 0.09	5-7
Proteins (db, %)	30.40 ± 0.09	40-45

2.2 Physical-chemical analysis

The chemical composition (moisture, protein, fat, ash and fibre content) of the fresh mushroom was determined according to A.O.A.C. (1995). The carbohydrate content was calculated by difference. Water activity was measured with a Decagon CX-2T hygrometer (Aqualab – Decagon Devices Inc., Pullman, WA, USA) and pH was determined with a potentiometer (Mettler Toledo, model 320, Columbus, USA). All determinations were made in triplicate.

2.3 Colour measurement

The colour of the fresh and dried samples (with and without osmotic pre-treatment) was measured using the CIELAB colour scale. The parameters L* (lightness), a* (green–red coordinate) and b* (blue–yellow coordinate) were obtained by using the Color Quest II colorimeter (Hunter, Virginia, USA). The previously calibrated equipment was operated with the D65 illuminant and 10° standard observer. All the parameters were measured in triplicate.

The colour of the dried samples was analysed in terms of ΔL*, Δa*, Δb* and ΔE*. The values for ΔL*, Δa* and Δb* indicate how much a standard sample differs from another with respect to L*, a* and b*, according to Equations 1, 2 and 3:

$$\Delta L^* = L^* - L^*_0 \tag{1}$$

$$\Delta a^* = a^* - a^*_0 \tag{2}$$

$$\Delta b^* = b^* - b^*_0 \tag{3}$$

where the subscript 0 represents the fresh sample.

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The total colour difference (ΔE^*) is a single value which takes into account the differences between the L*, a* and b* values of the sample (dried mushroom) and standard (fresh mushroom) and is calculated according to the following equation:

$$\Delta E^* = \sqrt{\left(L^* - L^*_0\right)^2 + \left(a^* - a^*_0\right)^2 + \left(b^* - b^*_0\right)^2} \tag{4}$$

2.4 Osmotic pre-treatment

The samples were osmotically dehydrated in a NaCl solution (concentration of 10% w.w^{-1}) at a temperature of 20 °C, 60 min process time and 80 rpm agitation. The slices were placed in 250 mL beakers containing the osmotic solution, where the sample:solution ratio was 1:10, to avoid dilution of the solution. The process conditions were based on the results obtained by Torringa et al. (2001), where maximum water loss and minimum solids gain were observed.

The process was carried out in a shaker (Tecnal, model TE-421).

After removal from the solution, the dehydrated slices were drained and the excess solution on the surface removed using adsorbent paper.

2.5 Air-drying

A convective tray dryer was used in the experiments with fresh and osmotically dehydrated mushrooms slices. The tests were carried out at various air temperatures (40-80 °C) and air velocities (1.0-2.5 m/s). The dryer system consisted of a vertical airflow through the trays and was arranged as a closed circuit. For the air heating, three electric resistances were used (two of 1600 W and one of 800 W), which could be worked independently, and manually set into operation by a digital thermostat. A thermohygrometer (TESTO, model 635) was used to measure the dry bulb temperature and the drying air humidity. A digital anemometer (AIRFLOW Co., model LCS 6000) was used to measure drying air velocity.

The sample was weighed using a semi-analytical balance with a resolution of 0.001 g. Weighing intervals of 15 min were used during the first hour of processing, 30 min for the next 2 h, and then 1 h until the sample weight became constant. The equilibrium moisture content was calculated according to Kurozawa et al. (2005).

The sample moisture contents were gravimetrically determined using a vacuum oven at 25 in Hg (Suprilab, model EST920) at 70 °C for 24 h. The weight and moisture content data of the sample were used to calculate the drying constant (K) in Equation (5):

$$\frac{X_t - X_e}{X_0 - X_e} = \exp(-Kt) \tag{5}$$

where X_t, X_e and X_0 (g water/g dried mass) were the average moisture contents at time t (s), equilibrium and the initial condition, respectively; K is the drying constant (s^{-1}).

This model, first suggested by Lewis (1921), is similar to the Newton's law for cooling, which considers that the food moisture content is similar to the heat flow from a sample immersed in the cold fluid. This model assumes that all the resistances to moisture transfer are in the boundary layer, considering internal resistance to be insignificant. It has been used to model the thin-layer drying of various agricultural products, such as pistachio nuts (KASHANINEJAD et al., 2007), grapes (DOYMAZ, 2006) and kiwi (SIMAL et al., 2005), presenting a good fit.

2.6 Experimental design and statistical analysis

A 2^2 factorial experimental design was used to evaluate the influence of the independent variables temperature and air velocity in the drying of the mushrooms, and the levels are shown in Table 2. The levels ±1.41 were required when the linear model did not show a good fit.

TABLE 2. Levels of the independent variables in the experimental design.

Independent variables	−1.41	−1	0	+1	+1.41
Temperature (°C)	40	45	60	75	80
Air velocity (m/s)	1.0	1.2	1.75	2.3	2.5

It was assumed that a mathematical function φ, Equation 6, exists for the response variable Y (drying constant K, ΔL^*, Δa^*, Δb^* and ΔE^*) in terms of the independent variables (temperature and air velocity):

$$Y = \phi(T, v_{air}) = \beta_0 + \beta_1 T + \beta_2 v_{air} + \beta_{11} T^2 + \beta_{22} v^2_{air} + \beta_{12} T v_{air} \tag{6}$$

where β_0 corresponds to the mean value of the function φ, the subscripts 1, 2, 11 and 22 represent the main linear and square effects associated with each variable and the subscript 12 represents the interaction between the variables.

The software Statistica 5.0 was used to obtain the regression coefficients.

Response Surface Methodology (RSM) was used to optimise mushroom drying for the maximum drying constant and minimum total colour difference.

2.7 Quality of dried products

Using the optimised process conditions, the dried products were characterized in terms of β-glucan content, water activity and rehydration properties.

The β-glucan content was determined according to the methodology described by Park et al. (2003). In this method, the samples were treated with α-amylase, bacterial protease, fungal glucoamylase and sulphuric acid, resulting in the release of glucose. The β-glucan concentration (g.100 g^{-1}) was quantified using the following equation:

β-glucan (g.100 g^{-1}) = glucose (g.100 g^{-1}) x 0.9 $\qquad$ (7)

where the glucose content (g.100 g^{-1}) was determined by a spectrophotometric method.

The rehydration properties were evaluated gravimetrically by immersing the dried sample in water at 65 °C. At pre-determined intervals (1, 2, 3, 5, 8, 12 and 15 min), samples were removed from the water, drained, placed on absorbent paper to remove excess water and weighed. The sample moisture content was gravimetrically measured using a vacuum oven with 25 in Hg (Suprilab, model EST920) at 70 °C for 24 h.

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The Decagon Aqualab CX-2 (Pullman, WA) was used to measure the water activity of the dried mushrooms at 25 °C.

3. RESULTS AND DISCUSSION

3.1 Experimental design

The experimental data, obtained according to the experimental design, are shown in Tables 3 and 4.

The levels ±1.41 are used when a linear model does not show high determination coefficient values. When it shows a good fit, it is not necessary to add axial points to obtain a quadratic model.

Therefore, for the response of the drying constant, only the factorial and centre points were used (Table 3), since this response presented a good fit to the linear model, as shown in Table 9.

The statistical analysis (Table 5) at a 90% confidence level ($p \leq 0.1$) revealed that the drying constant K for fresh mushrooms was positively affected by the temperature and the air velocity. The temperature presented the greatest influence on the drying constant estimated. With respect to the osmotically pre-treated samples, the temperature, (L) and (Q), and air velocity (L) presented a significant effect for $p \leq 0.1$.

According to Table 6, which shows the effects for the response of ΔL^*, it can be seen that all the factors were signifi-

TABLE 3. Experimental data for fresh mushrooms under different conditions of temperature T and air velocity v_{air}.

		Independent variables		Dependent variables				
		T (°C)	v_{air} (m/s)	K × (10⁻⁴ s⁻¹)	ΔE*	ΔL*	Δa*	Δb*
Factorial	1	45	1.2	2.02	14.35	−13.81	1.90	3.45
	2	75	1.2	6.00	29.15	−27.82	5.01	7.15
	3	45	2.3	3.54	25.11	−24.56	4.26	1.99
	4	75	2.3	8.06	23.60	−19.03	4.71	13.13
Axial	5	40	1.75	2.17	10.65	−3.94	−0.01	9.89
	6	80	1.75	6.67	22.55	−20.67	8.10	3.96
	7	60	1.0	2.59	24.15	−22.77	5.20	6.14
	8	60	2.5	4.69	22.63	−22.14	4.49	−1.42
Center	9	60	1.75	4.99	12.98	−6.94	9.53	5.43
	10	60	1.75	4.18	8.98	−4.41	6.92	3.66
	11	60	1.75	4.26	9.83	−3.28	8.17	4.36

TABLE 4. Experimental data for osmotically pre-treated mushrooms under different conditions of temperature T and air velocity v_{air}.

		Independent variables		Dependent variables				
		T (°C)	v_{air} (m/s)	K (× 10⁻⁴ s⁻¹)	ΔE*	ΔL*	Δa*	Δb*
	1	45	1.2	2.99	26.03	−25.28	4.74	4.03
	2	75	1.2	7.05	34.20	−33.05	4.46	7.62
Factorial	3	45	2.3	3.43	28.82	−27.63	7.49	3.27
	4	75	2.3	7.05	31.19	−26.7	7.03	14.51
	5	40	1.75	2.78	23.90	−19.36	4.74	13.19
Axial	6	80	1.75	5.61	30.67	−29.5	8.33	1.03
	7	60	1.0	3.65	26.88	−25.78	6.86	3.23
	8	60	2.5	6.24	33.20	−32.72	4.99	−2.96
	9	60	1.75	6.85	34.26	−33.91	−1.44	4.63
Center	10	60	1.75	7.25	33.74	−33.59	−0.91	3.08
	11	60	1.75	7.15	35.12	−34.9	−2.61	2.20

TABLE 5. Estimated effects and p-values for the response of the drying constant K.

Factors	Fresh mushrooms			Osmotically dehydrated mushrooms		
	Estimated effect (x10⁻⁵)	Error (x10⁻⁵)	p-value	Estimated effect (x10⁻⁵)	Error (x10⁻⁵)	p-value
Overall mean	47.2	1.8	<0.00	70.8	5.0	<0.00
Temperature (L)	42.5	4.9	<0.00*	29.2	6.1	0.01*
Temperature (Q)	-	-	-	−26.1	7.2	0.02*
Air velocity (L)	17.9	4.9	0.03*	10.3	6.1	0.15
Air velocity (Q)	-	-	-	−18.6	7.2	0.05*
Temperature x air velocity	2.7	4.9	0.62	−2.2	8.6	0.81

*Indicates that the corresponding parameter had a significant effect (p < 0.10). (L) and (Q) indicate the linear and square factors.

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cant at p ≤ 0.10 for the fresh mushrooms, with the exception of air velocity (L). For the pre-treated sample, only temperature was significant. Table 7 shows the estimated effects for the response of Δa*. The linear and square factors for the parameter temperature and the square factor for air velocity were significant at p ≤ 0.1 for the mushrooms without pre-treatment. For the response of Δb*, no independent variables were significant.

Analysing Table 8, where the effects for the response of total difference in colour (ΔE*) are displayed, all the factors were significant at p ≤ 0.1, with the exception of the air velocity (L) for mushrooms without the pre-treatment and for the air velocity (L) and the interaction for the osmotically dehydrated sample.

Without considering non-significant terms, both experimental designs were tested for adequacy and fitness by the analysis of variance (ANOVA) as shown in Tables 9 and 10. These tables show that the lack of fit was lower with respect to the total, when the difference between the F_c values and the F_t values was bigger.

Therefore, the following correlations were proposed to explain the drying constant K, ΔL*, Δa* and the total difference in colour ΔE*, in the drying of fresh (F) and osmotically dehydrated (OD) mushrooms (Equations 8 to 14). According to Table 9, the fitted models were significant (p ≤ 0.10), possessing low residual values and satisfactory values for the determination coefficients. According to Table 10, only the model for ΔL* was not predictive,

presenting a significant lack of fit, and therefore the curve was not generated for this model.

$$K_F = \left(4.72 + 2.13\,T + 0.89\,v_{air}\right) \times 10^{-4} \tag{8}$$

$$K_{OD} = \left(7.08 + 1.46\,T - 1.30\,T^2 - 0.93\,v_{air}^{\ 2}\right) \times 10^{-4} \tag{9}$$

$$\Delta L\,{^*}_F = -4.88 - 4.02\,T - 4.70\,T^2 - 9.77\,v_{air}^{\ 2} + 4.88\,T \times v_{air} \tag{10}$$

$$\Delta a\,{^*}_F = 8.21 + 1.88\,T - 2.2\,T^2 - 1.8\,v_{air}^{\ 2} \tag{11}$$

$$\Delta a\,{^*}_{OD} = -1.65 + 4.03\,T^2 + 3.72\,v_{air}^{\ 2} \tag{12}$$

$$\Delta E\,{^*}_F = 10.60 + 3.76\,T + 3.77\,T^2 + 7.26\,v_{air}^{\ 2} - 4.18\,T \times v_{air} \tag{13}$$

$$\Delta E\,{^*}_{OD} = 34.37 + 2.51\,T - 3.02\,T^2 - 1.82\,v_{air}^{\ 2} \tag{14}$$

where T is the temperature (uncoded value) and v_{air} is the air velocity (uncoded value).

Figures 1 to 8 illustrate the influence of temperature, air velocity and osmotic pre-treatment on the drying constant K of the exponential model, the difference in lightness ΔL*, the difference

TABLE 6. Estimated effects and p-values for the response of ΔL*.

Factors	Fresh mushrooms			Osmotically dehydrated mushrooms		
	Estimated effect	Error	p-value	Estimated effect	Error	p-value
Overall mean	−4.86	2.11	0.07	−34.13	1.54	<0.01
Temperature (L)	−8.04	2.58	0.03	−5.30	1.89	0.04
Temperature (Q)	−9.42	3.08	0.03	9.07	2.26	0.01
Air velocity (L)	−0.27	2.58	0.92	−1.45	1.89	0.48
Air velocity (Q)	−19.64	3.08	<0.01	4.22	2.26	0.12
Temperature x air velocity	9.77	3.65	0.04	4.35	2.67	0.16

TABLE 7. Estimated effects and p-values for the response of Δa*.

Factors	Fresh mushrooms			Osmotically dehydrated mushrooms		
	Estimated effect	Error	p-value	Estimated effect	Error	p-value
Overall mean	8.21	0.93	<0.01	−1.65	0.96	0.15
Temperature (L)	3.76	1.14	0.02	1.08	1.18	0.40
Temperature (Q)	−4.42	1.35	0.02	8.06	1.41	<0.01
Air velocity (L)	0.27	1.14	0.82	0.67	1.18	0.59
Air velocity (Q)	−3.61	1.35	0.04	7.45	1.41	<0.01
Temperature x air velocity	−1.33	1.60	0.44	−0.09	1.67	0.96

TABLE 8. Estimated effects and p-values for the response of total difference in colour ΔE*.

Factors	Fresh mushrooms			Osmotically dehydrated mushrooms		
	Estimated effect	Error	p-value	Estimated effect	Error	p-value
Overall mean	10.60	1.55	<0.00	34.37	1.02	<0.00
Temperature (L)	7.53	1.90	0.01	5.04	1.25	0.01
Temperature (Q)	7.53	2.26	0.02	−6.40	1.50	0.01
Air velocity (L)	0.77	1.90	0.70	2.18	1.25	0.14
Air velocity (Q)	14.32	2.26	<0.00	−3.63	1.50	0.06
Temperature x air velocity	−8.16	2.68	0.03	−2.90	1.77	0.16

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TABLE 9. Analysis of variance for the drying constant K in the drying of fresh mushrooms.

Source	SS	DF	MS	F_c	F_t
Drying constant K					
Regression	212.67×10^{-9}	2	106.33×10^{-9}	54.12	4.32
Residual:	7.86×10^{-9}	4	1.96×10^{-9}		
Lack of fit	3.87×10^{-9}	2	1.94×10^{-9}		
Pure error	3.98×10^{-9}	2	1.99×10^{-9}		
Total	2.20×10^{-9}	6			$R^2 = 0.9644$
ΔL*					
Regression	784.16	4	196.04	17.35	3.18
Residual:	67.80	6	11.30		
Lack of fit	60.77	4	15.19		
Pure error	7.02	2	3.51		
Total	851.96	10			$R^2 = 0.9204$
Δa*					
Regression	63.77	3	21.26	10.08	3.07
Residual:	14.76	7	2.11		
Lack of fit	11.35267	5	2.27		
Pure error	3.408067	2	1.70		
Total	78.53016	10			$R^2 = 0.8120$
Total difference in colour ΔE*					
Regression	486.52	4	121.63	19.68	3.18
Residual:	37.09	6	6.18		
Lack of fit	28.20	4	7.05		
Pure error	8.88	2	4.44		
Total	523.60	10			$R^2 = 0.9292$

TABLE 10. Analysis of variance for the drying constant K in the drying of osmotically dehydrated mushroom.

Source	SS	DF	MS	F_c	F_t
Drying constant K					
Regression	384.90×10^{-9}	3	94.97×10^{-9}	11.33	3.07
Residual:	58.70×10^{-9}	7	8.38×10^{-9}		
Lack of fit	57.83×10^{-9}	5	1.16×10^{-9}		
Pure error	0.87×10^{-9}	2	0.43×10^{-9}		
Total	343.60×10^{-9}	10			$R^2 = 0.8292$
ΔL*					
Regression	150.04	2	75.02	7.17	3.11
Residual:	83.68	8	10.46		
Lack of fit	82.74	6	13.79		
Pure error	0.93	2	0.47		
Total	233.72	10			$R^2 = 0.6420$
Δa*					
Regression	130.79	2	65.40	30.48	3.11
Residual:	17.17	8	2.15		
Lack of fit	15.65	6	2.61		
Pure error	1.51	2	0.76		
Total	147.96	10			$R^2 = 0.8840$
Total difference in colour ΔE*					
Regression	94.32	2	47.16	7.25	3.11
Residual:	52.04	8	6.50		
Lack of fit	18.49	1	18.49		
Pure error	33.55	7	4.79		
Total	146.36	10			$R^2 = 0.7708$

SS: sum of squares; DF: degrees of freedom; MS: mean square; F_c: calculated F distribution value; F_t: tabulated F distribution value ($p \leq 0.10$).

in the green–red coordinate Δa* and the total difference in colour ΔE*, during the drying of mushrooms.

According to Figure 1a, the temperature and air velocity positively and linearly affected the drying constant of the fresh samples. The parameter K represents the water diffusion velocity in the material (EL-AOUAR et al., 2003). The increase in the drying constant with increasing air-drying temperature is coherent with the literature. This linear dependence of the mass transfer coefficient on the temperature and air velocity can be explained by an increase in heat transfer from the drying air to the sample, decreasing external resistance (PARK et al., 2002).

For osmotically dehydrated mushrooms (Figure 1b), little shrinkage of the samples was observed, indicating a preservation of the porous structure of the samples during the drying process. Due to this, the pre-treated samples presented smaller internal (solid matrix) resistance than the in nature mushrooms, possibly justifying the quadratic trends of the temperature and air velocity that smoothed out the effect of these parameters. In addition other effects like superficial hardening, which hinder the transfer of moisture from sample to air, influence the behaviour of the mass transfer coefficient during drying.

With respect to the mushrooms without the osmotic pre-treatment, the parameter K was lower than for the pre-treated mushrooms, except for the experiments at 75 °C/2.3 m/s (experiment 4) and 80 °C/1.75 m/s (experiment 6) (Figure 2). This

can be explained by the reduction in superficial hardening due to the osmotic dehydration treatment.

Figures 3 and 4 show the influence of the temperature and air velocity on the difference in lightness ΔL* and the difference in the green–red coordinate Δa*, between the fresh and dried samples. The ΔL* values were negative, indicating that the dried sample was darker than the fresh mushrooms. The positive values for Δa* meant that the dried samples were redder than the fresh sample, and the negative values meant that the dried sample was greener than the fresh sample. It is well known that the colour parameters L* and a* are correlated with darkening in fruit and vegetable tissues due to enzymatic and non-enzymatic browning. These phenomena can be seen in Figures 3, 5 and 7.

A quadratic trend for temperature can be seen in Figure 3, in which there is a decrease in browning up to 50 °C, probably due to inactivation of the polyphenoloxidase. Mushroom polyphenoloxidase (PPO) is a heat sensitive enzyme readily inactivated by temperatures exceeding 50 °C. In the presence of oxygen and PPO, natural phenolic compounds are oxidized to the corresponding o-quinones, which subsequently polymerise to brown pigments (WEEMAES et al., 1997). At elevated temperature, a slight increase in browning may be associated with the Maillard reaction, which is a non-enzymatic reaction involving carbonyl and amino compounds with the formation of brown pigments (melanoidins). This reaction is highly temperature dependent and its reaction rate generally

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increases from 2-3 times for each 10 °C rise in temperature (DAVIDEK and DAVIDEK, 2004).

Figure 4 shows the effect of osmotic pre-treatment on ΔL^*. Osmotically treated mushrooms presented more browning than the in nature mushrooms. This behaviour indicates that the osmotic dehydration was not efficient in preventing colour loss. Baroni
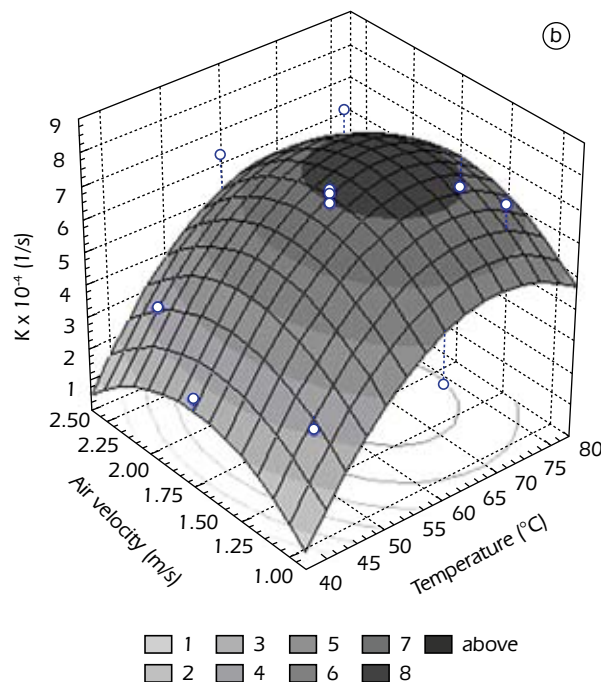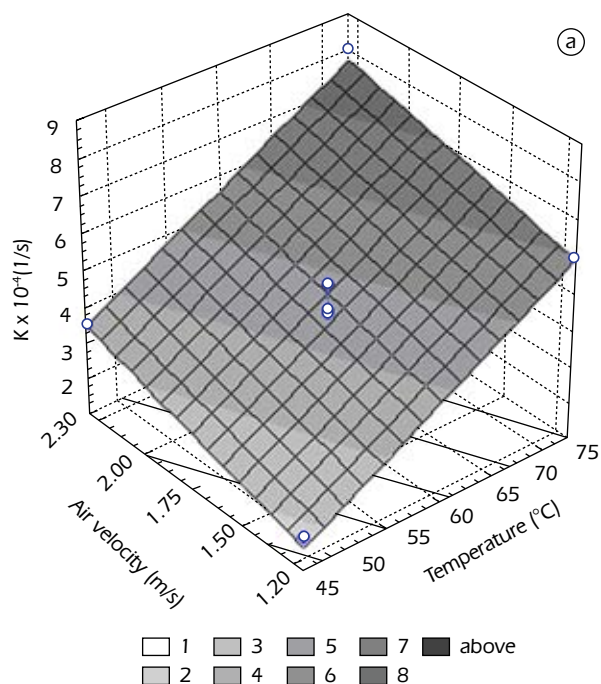
(2004) obtained similar results, studying the drying of osmotically dehydrated tomato using sodium chloride (10% w.w^{-1}). The author suggested that the salt impregnated samples presented a greater oxidation potential than the other samples. However, there is little information about the influence of sodium chloride on the colour parameters of foodstuffs.

In Figure 5a it is evident that the green–red coordinate of the dehydrated mushroom was strongly affected by the temperature and air velocity. Δa^* presented negative values under extreme conditions for the samples not osmotically pre-treated, indicating that the dried samples were greener than the fresh samples, and the Δa^* values increased up to 60 °C and 1.75 m/s. On the other hand, the osmotic dehydrated samples exhibited a loss in Δa^* with increase in these variables up to 60 °C and 1.75 m/s. Figure 6

FIGURE 2. Influence of osmotic dehydration (OD) on the drying constant K.

FIGURE 1. Influence of temperature and air velocity on the drying constant (K) for (a) fresh and (b) osmotically dehydrated mushrooms.
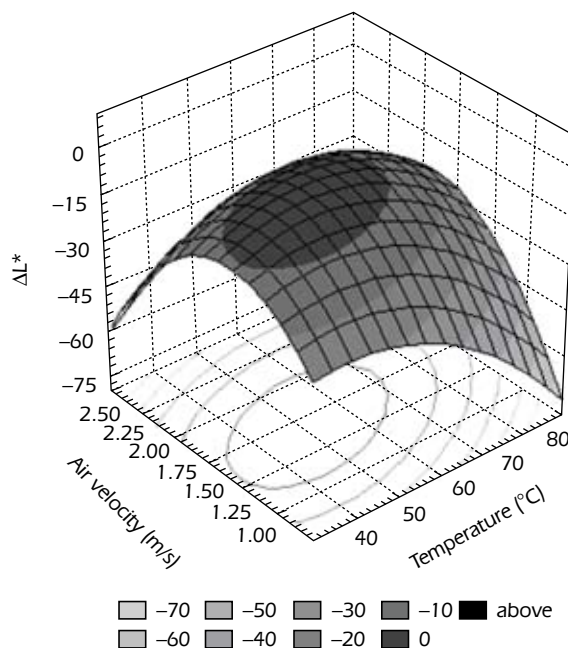
FIGURE 3. Influence of temperature and air velocity on ΔL^* for fresh mushrooms.

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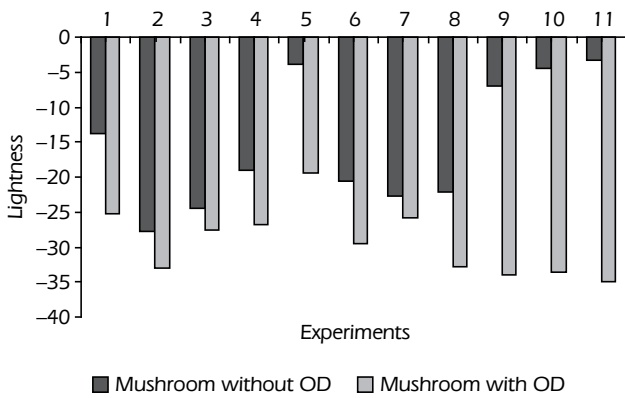
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FIGURE 4. Influence of osmotic dehydration (OD) on ΔL*.

shows the effect of the osmotic pre-treatment on the green–red coordinate. Osmotically treated mushrooms presented higher Δa* values than the in nature mushrooms, except for experiments at 75 °C/1.2 m/s (experiment 2) and at 60 °C/1.75 m/s (experiments 9, 10 and 11).

Figures 7 and 8 indicate the influence of the process variables and the osmotic pre-treatment on the total colour difference ΔE* between the fresh and dried samples. ΔE* is a single value which takes into account the differences between L*, a* and b* of the sample (dried mushroom) and standard (fresh mushroom), parameters previously discussed.

3.2 Optimisation

The application of response surface methodology to the drying process is important to ensure that the processing conditions used yield an acceptable quality product. Many authors have studied this technique to evaluate the influence of the variables on the drying rates and on final product quality (MADAMBA, 2002; SWAMI et al., 2007; LOPES et al., 2007).

Mushroom drying was optimised using Response Surface Methodology (RSM) for maximum drying constant K and minimum total colour difference ΔE*.

Figure 9 shows the superimposed curves of the drying constant and the total colour difference with and without osmotic pre-treatment. The drying constant curves are represented by area and total colour difference curves by lines. The optimum processing conditions are indicated by the white region.

In Figure 9a, the biggest ΔE* values are sited in the temperature region from 45-55 °C and air velocity region from 1.50-1.75 m/s. However, the maximum drying constant response was achieved at a higher temperature and air velocity, where the total colour difference of the mushroom was high. This is not of interest because it causes a quality loss in the dried product. Thus, the optimum region is located between the optimal regions of the responses studied: 70 °C and 2.0 m/s.

For osmotically dehydrated mushrooms (Figure 9b), the maximum drying constant and the minimum ΔE* were sited in different regions. Analogously, the optimum region was located between the optimal regions for the responses studied: 80 °C and 2.5 m/s.
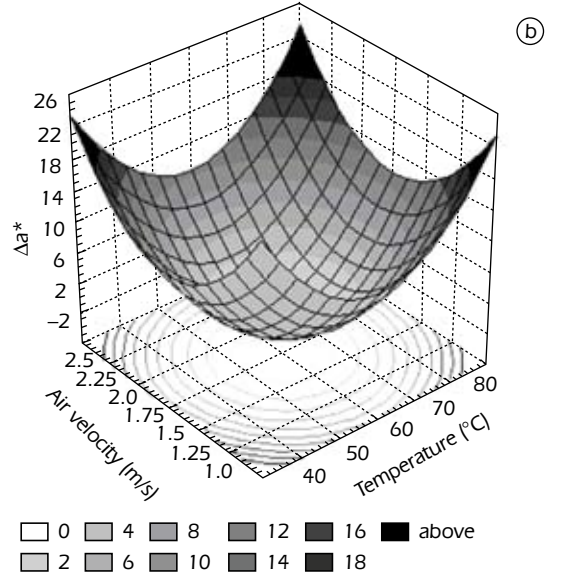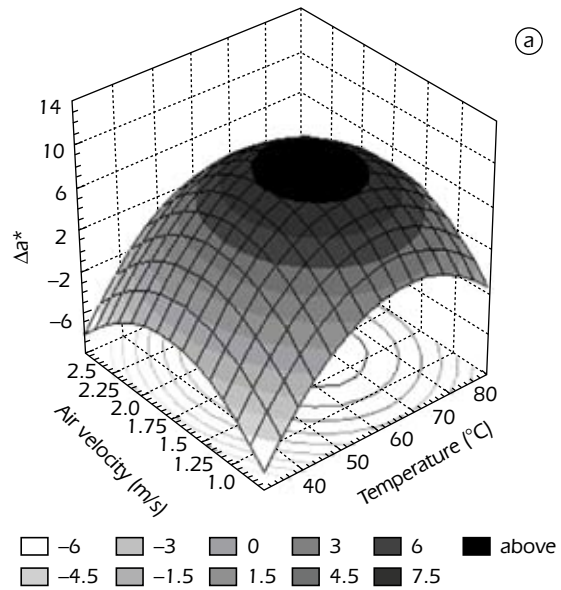

FIGURE 5. Influence of temperature and air velocity on Δa* for (a) fresh and (b) osmotically dehydrated mushroom.
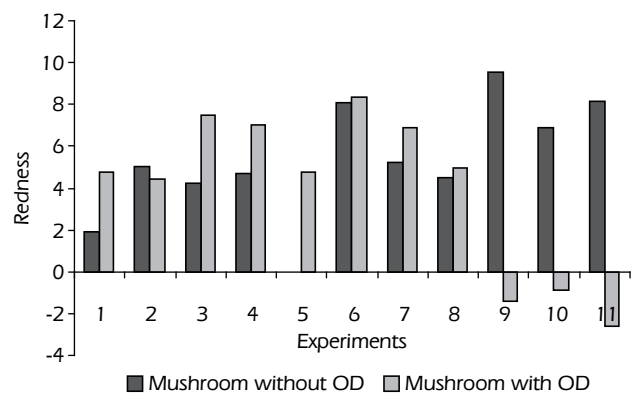

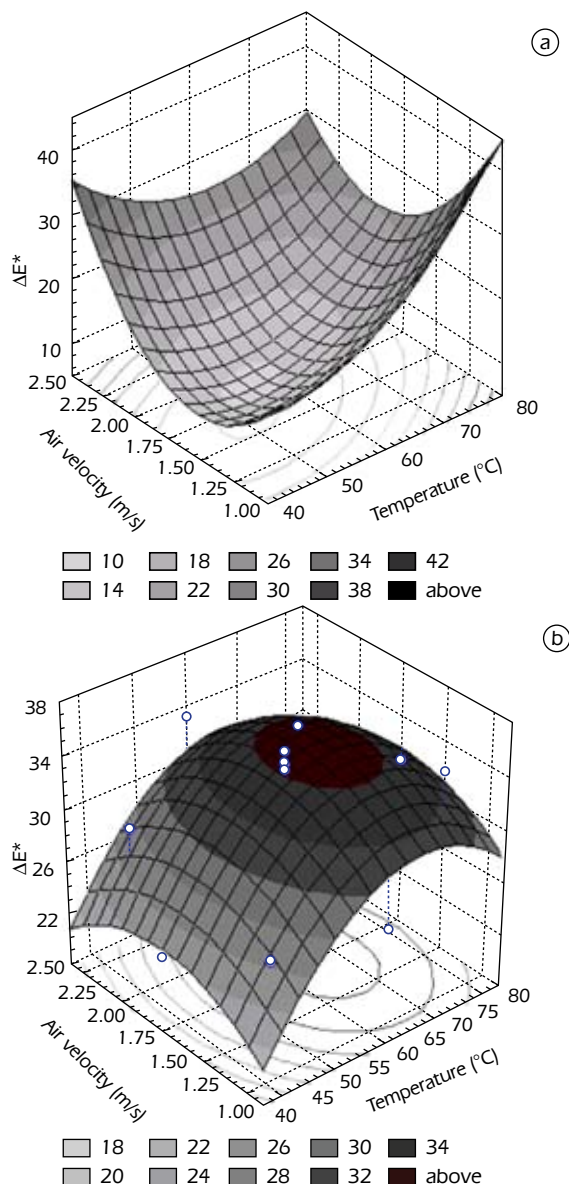**FIGURE 6.** Influence of osmotic dehydration (OD) on Δa*.

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FIGURE 7. Influence of temperature and air velocity on total colour difference (ΔE^*) for (a) fresh and (b) osmotically dehydrated mushrooms.
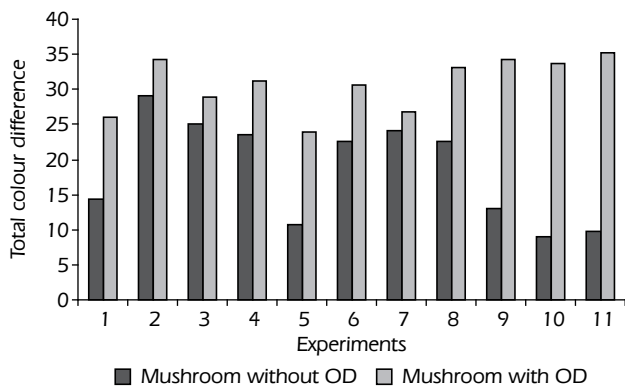

FIGURE 8. Influence of osmotic dehydration (OD) on ΔE^*.
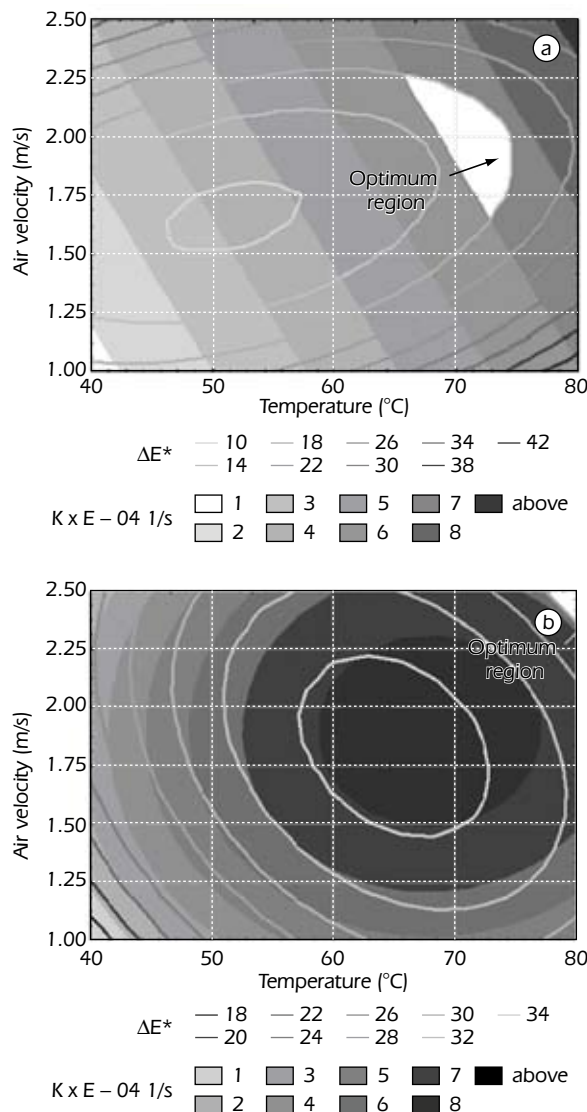

FIGURE 9. Superimposition of the drying constant and total difference colour curves for (a) fresh and (b) osmotically dehydrated mushrooms.

3.3 Quality

Products dried under the optimised conditions to moisture contents of 10% w.w^{-1} were evaluated in terms of β-glucan content, water activity (a_w) and rehydration properties. The results obtained are shown in Table 11 and Figure 6.

According to Table 11, osmotic dehydration had no effect on the β-glucan content. With respect to water activity, the osmotically dehydrated samples presented lower values than the samples without this pre-treatment. Sodium chloride is an electrolytic substance, which, when dissociated into ions, interacts with the water molecules and consequently decreases the water activity of the product.

Analysing Figure 10, the osmotically dehydrated mushrooms showed smaller amounts of absorbed water than the samples without pre-treatment. This behaviour was probably due to the incorporation of soluble solids during osmotic dehydration, which

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TABLE 11. β-glucan content and water activity (a_w) of fresh and dried mushrooms, with and without osmotic pre-treatment.

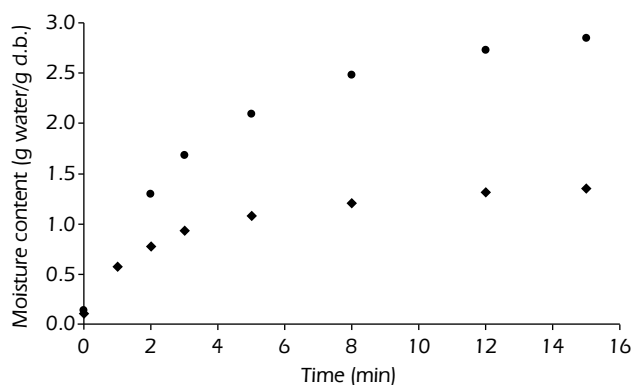| Samples	β-glucan (g.100 g^{-1} dried mass)	a_w
Fresh	7.48 ± 0.16	0.995 ± 0.001
Without osmotic pre-treatment	6.14 ± 0.55	0.438 ± 0.002
With osmotic pre-treatment	6.77 ± 0.47	0.415 ± 0.006

FIGURE 10. Rehydration curves of the dried mushrooms with (♦) and without (•) osmotic pre-treatment.

resulted in a decrease in the empty porosity. Similar behaviour was observed by Severini et al. (2005) for potatoes osmotically dehydrated in a glucose-sodium chloride solution, and by Rodriguez et al. (2003) for seaweeds osmotically pre-treated in a sucrose-sodium chloride solution.

4. CONCLUSIONS

The air-drying of the mushroom slices was greatly affected by the process variables of temperature and air velocity with respect to the drying constant and total colour difference. All the empirical models obtained using the screening design were considered predictive for the drying constant and colour parameters, with the exception of Δb* for the *in nature* sample, and Δb* and ΔL* for the pre-treated mushrooms. Osmotically dehydrated samples presented higher drying constants, due to superficial hardening and a reduction in shrinkage. However, osmotic dehydration was not efficient in preventing colour loss. *In nature* mushrooms presented less browning than osmotically dehydrated samples. The optimum conditions for the drying process were 70 °C and 2.0 m/s, and 80 °C and 2.5 m/s for fresh and osmotically dehydrated mushrooms, respectively. Under the optimised drying conditions, the dried mushrooms presented values for the β-glucan content of 6.14 ± 0.55 and 6.77 ± 0.47 g.100^{-1} g d.b. Osmotically dehydrated samples showed slower rehydration and lower water activity than samples without this pre-treatment. These results are important to obtain a product with acceptable quality. The colour, nutritional value and rehydration property of the dried products are of prime importance to the consumer as product quality criteria.

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