Process Optimisation of Vacuum Drying of Onion Slices

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Abstract

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Dehydration of untreated and pre-treated onion slices under vacuum was optimised using the response surface methodology. The effects of the drying temperature (50–70°C), slice thickness (1–5 mm), and treatment (5% NaCl and 0.2% $K_2S_2O_5$) were observed on the responses, viz. final moisture content, colour change, flavour content, and rehydration ratio of the dehydrated onion slices. Full factorial design was employed for the analysis. Optimisation of the vacuum drying process was achieved based on the criteria of maximum flavour retention, 3–3.5% db moisture content, acceptable colour, and rehydration ratio using numerical technique. The optimum condition for the treated sample was found at 58.66°C drying temperature and 4.95 mm slice thickness. Optimum values of the response parameters, namely the moisture content, colour, flavour content, and rehydration ratio were obtained as 3.5% d.b., 30.33 OI/g dried sample; 4.35 µmol/g dried sample and 4.82, respectively.

Keywords: dehydratation; optimum value; *Allium*; response surface methodology

Onion, one of the main 'bulbs' of Allium family, is the most commonly used spice in the cuisine and culinary preperations in tropical countries. Almost 175 countries grow onion, and among them China ranks the first with 20.55 million tones production achieved in 2007. Onion helps to prevent several diseases such as cancer, tumour (Block 1985, 1994; Block *et al.* 1997; Stavric 1997; Kamel & Saleh 2000; Miron *et al.* 2003), cataract, cardiovascular disease (Ernst *et al.* 2002), asthma (Dorsch & Wanger 1992), ulcer, etc (Elsom *et al.* 2000; Cañizares *et al.* 2004). It is also used as antimicrobial (Whitmore & Naidu 2000) and anti-aggigating agents (Mochizuki & Nakazawa 1995) and antioxidant (Nuutila *et al.* 2003).

Onion is mainly known for its characteristic flavour which adds a delicious taste to almost all the food preperations. Since ancient times, onion has been mainly used for its cuisine and culinary properties. Therefore, the main challenge has been to preserve the pungent taste, flavour, and colour of onion along with the desired moisture content as it is responsible for most of the deteriorative microbial reactions, for safe storage life and rehydration ratio during dehydration process.

Vacuum drying is a potential dehydration technique mainly used for heat sensitive food products due to drying at lower pressure and temperature under low oxygen environment. Better product quality such as taste, flavour, or rehydration ratio can be achieved by high degree vacuum treatment (Drouzas & Schubert 1996). The lower pressure allows the drying temperature to be reduced and results in higher quality than the classical convective air drying process at atmospheric pressure (Kompany *et al.* 1993; Jaya & Das 2003).

The objective of this study was therefore to optimise the process parameters in vacuum drying of onion slices. The imporatant parameters that we need to consider during vacuum drying are the vacuum level, temperature to which the product is subjected, product dimensions etc. as independent parameters. The effects of these independent parameters can be seen on the qualitative parameters of the dried product such as final moisture content, colour and flavour of the product, nutritional loss, and rehydration ratio. The common pressure level used for dehydration of food products ranges from 6 kPa to 25 kPa (Arevalo-Pinedo & Murr 2007). In the present case, the vacuum level inside the chamber was fixed at the maximum vacuum attainable inside the chamber as it was within the limits and with lowering the vacuum level, drying will be faster. Optimisation is therefore to be done on the rest of the parameters involved. To achieve the most preferred operational combinations for vacuum drying of onion, optimisation was done using the response surface methodology (RSM) as this method provides the best possible combination for the entire experimental range (Madamba 2002). RSM has been a popular choice of various researchers of engineering, chemical, industrial, and biological fields for analysing the effects of the process variables on the response and to optimise the process parameters. RSM has been applied for optimisation of the extraction of phenolic compounds from wheat (Liyana-Pathirana & Shahidi 2005); optimisation of processing parameters of horse mackerel in a heat pump drier (Shi *et al.* 2008); optimisation of the process conditions of twin screw extruder for barley-grape pomace blends (Altan *et al.* 2008); vacuum drying process of celery (Madamba & Liboon 2001); and for hot air drying of olive leaves (Erbay & Icier 2009).

MATERIAL AND METHODS

Sample preperation. Onions (Nasik red) were bought from a local market at Kharagpur (India) and stored at room temperature for one day prior to the experiments. They were thoroughly cleaned to remove any dirt or dust particles attached to the surface. Then they were peeled and cut into slices of the required thickness of 1 mm, 3 mm, and 5 mm with a slicer. After that, some slices were kept for drying under vacuum without any treatment. The other lot of onion slices was given a pretreatment by dipping into a solution of 5% sodium chloride (NaCl) and 0.2% potassium metabisulfite ($K_2S_2O_5$) (Raj *et al*. 2006; Sutar *et al*. 2007) for 15 min at normal ambient temperature. The ratio of sliced onion pieces to the pretreatment solution was 1:4. The slices were then taken out from the solution and the surface moisture was carefully removed with a tissue. Both the untreated and treated samples, each weighing 100 g, were dried under a constant 50 mm Hg absolute pressure level (710 mm Hg vacuum) at three different plate temperatures of 50, 60, and 70°C using a laboratory scale vacuum dryer.

Experimental design and statistical analysis. The design of the experiments was done by full factorial design and using statistical software Design Expert 7.0.0. RSM was employed using general factorial design for two numeric factors and one categoric factor. The drying temperature, onion slice thickness, and initial condition of the sample were regarded as independent variables. The numeric factors, namely the temperature and thickness, were chosen to have three levels each whereas the categoric factor encompassed the treated and untreated samples. Nine experiments covering the three temperatures and three thicknesses were conducted with both the untreated and treated samples separately making a total of eighteen experiments. Table 1 depicts the actual and coded levels of the independent variables. Both the untreated and treated onion slices of a particular thickness were placed in separate stainless steel trays in single layers. Drying continued until constant weight of the sample was obtained in three consecutive readings.

The responses commonly used for quality evaluation of dried onion are the final moisture content, colour change (non enzymatic browning), flavour content, and rehydration ratio. It has been assumed that the responses (Y_k) are the functions of the three independent variables as mentioned

Table 1. Experimental design for vacuum drying of onion slice

Parameters	Initial thickness of onion slice X_1 (mm)			Vacuum chamber plate temperature X_2 (°C)		
Real value	1	3	5	50	60	70
Coded value	–1	0	+1	–1	0	+1

in Equation 1; k (1, 2, 3, 4) denoting the specific response.

$$Y_k = f_k\,(T, l, c) \qquad (1)$$

where:
T – drying temperature (°C)
l – slice thickness (mm)
c – condition applied to the sample, i.e. treated or untreated

The initial moisture content of the fresh onion sample and the moisture content of the vacuum dried onion slices on dry basis (db) were determined according to the vacuum oven method of Ranganna (2005). The colour of dried onion changes due to non-enzymatic browning that occurs during drying. The extent of browning in the dried onion samples was determined in terms of optical index (OI) by the official method of Adoga (2005). The pyruvate content or thiolsulphinate concentration (TC) is considered as an indicator of flavour intensity or pungency of onion. Thiolsulphinate was extracted by hexane and the absorbance of the extract was observed at 254 nm by UV-VIS spectrophotometer. Rehydration ratio (weight of the sample before rehydration/weight of the sample after rehydration) was determined by using the standard procedure as suggested by Ranganna (2005).

For all combinations of the operational parameters studied, the final moisture content was within the acceptable range of dehydrated onion (< 6–7%) reported in the literature (Sarsavadia 1999) and was observed within the range of 2.03–3.73% d.b. The colour values in terms of the optical index (OI < 90) and rehydration ratio (RR > 2.5) were well within the permissible levels as recommended by Adoga (2005) and Ranganna (2005), respectively. Flavour content i.e. TC was within the range reported in the literature (3.61 µmol/g to 4.97 µmol/g dried sample based on 20.2% to 10.4% grade of comminution Resemann *et al.* 2004). The generalised second order polynomial equation was fitted to the experimental data to approximate the function Y_k as follows:

$$Y_k = b_{k0} + \sum_{i=1}^{3} b_{ki} x_i + \sum_{i=1}^{3} b_{kii} x_i^2 + \sum_{i \neq j=1}^{3} b_{kij} x_i x_j \qquad (2)$$

where:
Y_k – response (Y_1 – moisture content; Y_2 – colour; Y_3 – flavour; Y_4 – rehydration ratio)
b_0, b_i, b_{ii}, b_{ij} – constants, linear, quadratic, and cross product regression coefficients, respectively
x_i' – coded values of the independent variables

Final moisture content. The final moisture content of the vacuum dried onion slices was determined on dry basis according to the vacuum oven method of Ranganna (2005).

Colour in terms of non enzymatic browning (NEB). The extent of NEB in dried onion slices was determined in terms of the optical index (OI) by extraction of the brown pigments of the dried onion (1 g) using 10% NaCl solution and subsequent measurement of the transmittance of the clear filtrate at 420 nm with a spectrophotometer (ADOGA 2005). The measurement was done in triplicate and the optical index was calculated based on 1% solution and 5.0 cm cell path used as follows:

$$\text{OI} = \log\left(\frac{100}{T}\right) \times \frac{5 \times 1000}{b \times w} \qquad (3)$$

where:
T – percentage transmittance
b – cell path used (cm)
w – weight of sample (g)

Flavour in terms of thiosulphinate content (TC). The amount of thiosulphinate in the dried onions was determined by the method developed by Freeman and McBreen (1973) and later modified by Samaniego-Esguerra *et al.* (1991). This method was further used by Kaymak-Ertekin *et al.* (2005) to measure thiosulphinate content in convective hot air dried onion slices. The amount of thiosulphinate in the dried onions was determined by extraction of TC with hexane. The absorbance of the extract was observed at 254 nm by UV-VIS spectrophotometer. The thiosulphinate content of the hexane solution was calculated using the equation:

$$C = A/(\varepsilon \times b) \qquad (4)$$

where:
A – absorbance
b – path length (cm)
C – concentration of the solution (µmol/g)
ε – molar absorptivity of thiosulphinate solution [g/(µmol·cm)]

The molar absorptivity of thiosulphinate solution at 254 nm was found to be ε = 0.014 [g/(µmol·cm)].

Rehydration ratio. Rehydration ratio was determined by the method used for rehydration test of fruits and vegetables (Ranganna 2005). The sample weight before and after rehydration was calculated and rehydration ratio was determined as follows:

$$\text{Rehydration ratio} = \frac{\text{Sample weight after rehydration}}{\text{Sample weight before rehydration}} \quad (5)$$

RESULTS AND DISCUSSION

The experimental values of responses are shown in Table 2. Statistical analysis was performed to determine the significance of the independent parameters, viz. the drying temperature, thickness, and treatment on the responses, viz. the moisture content, colour, flavour, and rehydration ratio. Mathematical models were evaluated for each response using multiple regression analysis and regression coefficients were calculated in order to estimate the behaviour of the responses as a function of independent variables.

ANOVA on each response variable was performed on the experimental data for determining the significant terms and was judged by F-statistic calculated from the data. Their significance at 95% confidence interval as well as the proportion of variability ($R^2 > 0.94$) was explained for the response surface models for the moisture content, colour, flavour and rehydration ratio. Model adequacies were checked by R^2, adj-R^2, Pred-R^2, and CV. The extent of dispersion in the data was explained by the coefficient of variation (CV). CV was found to be well within the acceptable range (< 5). It indicated that the drying temperature, slice thickness, and condition of the sample significantly affected the colour, flavour content and rehydration ratio of the dried onion slices in vacuum drying process. The quadratic model for the final moisture content, colour in terms of optical index (OI/g dried sample), and flavour in terms of TC (µmol/g dried sample) fitted adequately posing no significant lack of fit. However, the rehydration ratio was better explained by linear combination of temperature and slice thickness. Table 3 represents the statistical parameters stated above for each response.

Regression coefficients obtained for the quadratic (moisture content, colour, and flavour) and linear

Table 2. Experimental combination for vacuum drying of onion slices for factorial design

Run No.	Temperature (°C)	Thickness (mm)	Condition	Moisture content (% db)	Colour (OI/g)	Flavour (TC, µmol/g)	Rehydration ratio
1		1		3.53	18.41	3.19	6.30
2	50	3		3.65	25.39	3.31	5.40
3		5		3.73	28.91	3.92	4.99
4		1		3.38	24.35	3.07	6.12
5	60	3	untreated	3.47	29.46	3.29	5.67
6		5		3.47	32.46	3.87	5.07
7		1		2.51	28.73	2.96	6.54
8	70	3		2.55	34.76	3.21	5.75
9		5		2.53	38.68	3.71	5.20
10		1		3.43	16.73	3.97	5.89
11	50	3		3.50	22.90	4.21	5.24
12		5		3.50	26.72	4.43	4.74
13		1		3.38	21.81	3.83	6.12
14	60	3	treated	3.44	26.73	3.93	5.07
15		5		3.43	30.47	4.32	4.91
16		1		2.03	25.31	3.71	6.20
17	70	3		2.11	32.32	3.79	5.73
18		5		2.44	36.51	4.21	5.08

Table 3. Anova for the model selected and the responses

Source	df	Moisture content		df	Colour		df	Flavour		df	Rehydration ratio	
		sum of squares	*P*-value		sum of squares	*P*-value		sum of squares	*P*-value		sum of squares	*P*-value
Model	8	5.39	< 0.0001	8	589.93	< 0.0001	8	3.40	< 0.0001	3	4.83	< 0.0001
x_1	1	4.28	< 0.0001	1	273.07	< 0.0001	1	0.17	< 0.0001	1	0.31	0.0012
x_2	1	0.058	0.0575	1	284.32	< 0.0001	1	1.16	< 0.0001	1	4.28	< 0.0001
x_3	1	0.14	0.0089	1	26.02	< 0.0001	1	1.91	< 0.0001	1	0.23	0.0036
x_1x_2	1	2.35E-03	0.6729	1	0.054	0.7213	1	4.10E-04	0.7306			
x_1x_3	1	0.024	0.1991	1	0.23	0.4682	1	0.012	0.0891			
x_2x_3	1	3.99E-03	0.5830	1	0.14	0.5688	1	0.060	0.0020			
x_1^2	1	0.88	< 0.0001	1	0.65	0.2352	1	3.58E-05	0.9188			
x_2^2	1	2.00E-04	0.9013	1	5.45	0.0050	1	0.082	0.0007			
Residual	9	0.11		9	3.61		9	0.029		14	0.27	
Total	17	5.50		17	593.54		17	3.43		17	5.10	
R^2		0.9798			0.9939			0.9915			0.9470	
Adj-R^2		0.9619			0.9885			0.9839			0.9357	
Pred-R^2		0.9070			0.9726			0.9667			0.9211	
Adequate precision		19.21			48.41			37.53			26.67	
PRESS		0.51			16.27			0.11			0.40	
CV		3.56			2.28			1.53			2.50	

x_1 = temperature, x_2 = thickness, x_3 = initial condition of sample i.e. untreated or treated

(rehydration ratio) models of the four responses are presented in Table 4. The contour plots for visualising the changing nature of the moisture content, colour, flavour content, and rehydration ratio with the independent variables, viz. the drying temperature, slice thickness, and sample condition, were generated. The effects of two numeric factors on any response were analysed for the two fixed categoric factors. The response surfaces generated for the untreated samples are presented in Figures 1–4. The effects of the variables on the responses were discussed by the evaluation of these plots. It can be observed from the table that there were minute changes in the coefficient values for the intercept and linear terms of the responses for the untreated and treated samples, whereas quadratic terms were similar for the untreated and treated samples. Therefore, the response surfaces

Table 4. Regression coefficients of the second order polynomials relating the responses with variables

Coefficient	Moisture content		Colour		Flavour		Rehydration ratio	
	quadratic	linear	quadratic	linear	quadratic	linear	quadratic	linear
β_0	–9.9698	9.6656	5.5497	4.4826	3.7495	4.9898	5.5973	5.3690
β_1	0.5044	0.4956	–0.0049	–0.0325	–0.0136	–0.0198	0.0162	0.0162
β_2	–0.0150	0.0033	3.8838	3.9919	–0.0447	–0.1156	–0.2988	–0.2988
β_{11}	–0.0047	–0.0047	0.0040	0.0040	2.9E-05	2.9E-05	–	–
β_{22}	–0.0018	–0.0018	–0.2919	–0.2919	0.0357	0.0357	–	–
β_{12}	0.0008	0.0009	0.0041	0.0041	0.0004	0.0004	–	–

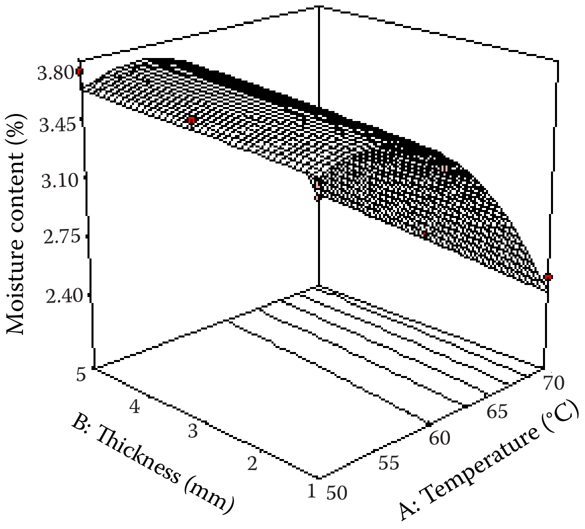

Figure 1. Contour plots of moisture content for untreated dried onion slices

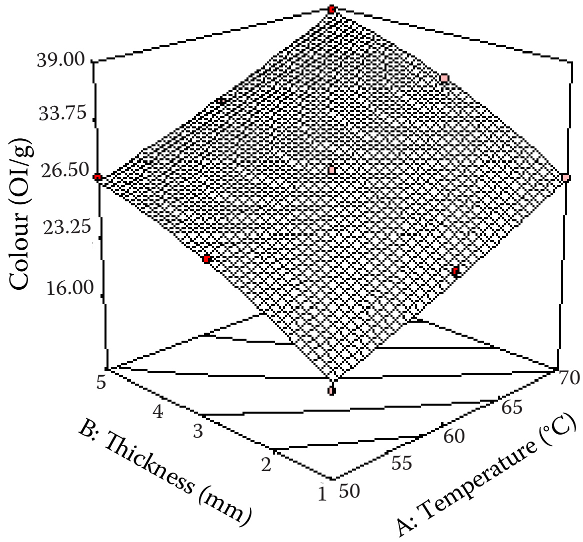

Figure 2. Contour plots of colour change for untreated treated dried onion slices

generated for the untreated slices are presented here and similar plots can be generated for the treated slices also.

Final moisture content

The final moisture content (FMC) decreased with increasing temperature with both the untreated and treated slices. The effect of thickness on the final moisture content was more pronounced at higher temperature. FMC decreased slightly in the case of thinner slices. Since the moisture content of vacuum dried onion slices was well within the moisture content range of safe moisture level, further reduction was not required.

Colour development

Colour development in onion increased due to non enzymatic browning (NEB) which occurred faster at high temperature. Greater thickness, on the other hand, increased the drying time thereby exposing the slices to heated environment for a longer time compared to thin slices. Therefore, the increase in temperature and thickness resulted in a higher colour value as depicted in Figure 2. However, the treated slices showed less colour development due to sulfite treatment. Thus, the colour value can be minimised by involving the sulfite treatment and adopting a lower drying temperature as well as slice thickness.

Flavour content

Thiosulphinate is volatile in nature and degrades at high temperature. Therefore, the increase in temperature resulted in a slight decrease in flavour content in onion but the increase in thickness facilitated significantly higher flavour content (Figure 3) because with a higher thickness the area exposed to the heated environment per unit mass of onion was smaller and the proportion of flavour coming in direct contact with the heated plate was substantially reduced. NEB developed off flavour and deteriorated the characteristic flavour of onion. As a result, the treated samples showed a higher flavour content than the untreated samples. It is evident that the flavour content can be maximised by involving the sulfite treatment and adopting a lower drying temperature and a greater slice thickness.

Rehydration ratio (RR)

Rehydration efficiency was better at a higher temperature and a smaller thickness (Figure 4). Because of faster drying at higher temperature, less damage occurred to the pore structure while for greater thickness, due to the prolonged heating the extent of shrinkage was greater which lowered the rehydration efficiency. For the treated samples, the amount of the collapsed cells was larger and hence the rehydration attained was lower. Thus, the RR can be maximised by drying

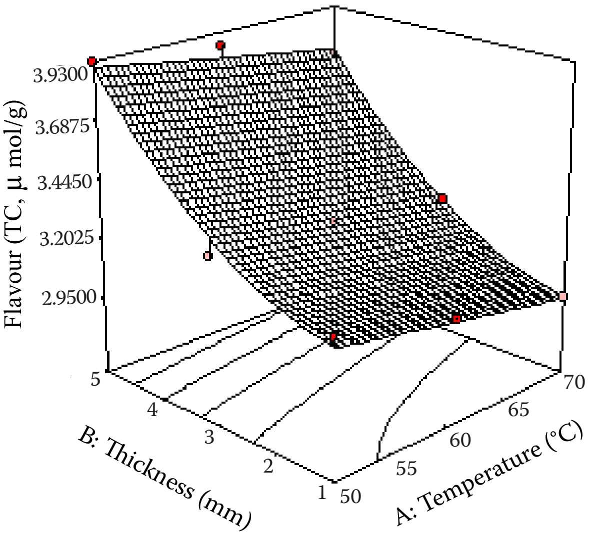

Figure 3. Contour plots of flavour content for untreated treated dried onion slices

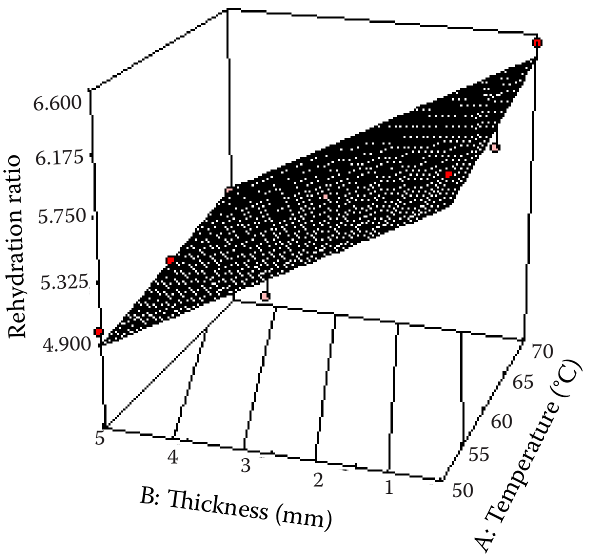

Figure 4. Contour plots of rehydration ratio for untreated treated dried onion slices

the untreated samples at higher temperature and lower slice thickness.

Optimisation

The predictive models of responses, i.e. colour, flavour, and rehydration ratio, were further used for attaining the optimum process conditions for drying onion slices under vacuum. The optimum drying conditions pertaining to the final moisture content (3.0–3.5% db), acceptable colour value (16.73–38.68 OI/g sample), rehydration ratio (4.74–6.54), and maximum flavour content value (≈ 4.35 TC, µmol/g sample) were determined. These regression models were valid only for the selected experimental domain. The final moisture content, colour (as per ADOGA, 2005 standards), and rehydration ratio (> 2.5, Madamba 1997) were well within the acceptable limits. Therefore, the main objective of optimisation was to achieve maximum flavour content. By applying the desirability function method (Eren & Kaymak-Ertekin 2007), twelve solutions were obtained for the optimum covering criteria with a desirability value of 0.935. The optimum condition emerging from the study pertaining to solution one was 58.66°C drying temperature and 4.95 mm slice thickness with the treated sample sets. The response values at the optimum condition were found to be 3.5% db for the moisture content, 30.33 (OI/g dried sample) for colour, 4.35 (µmol/g dried sample) for flavour, and 4.82 for the rehydration ratio.

CONCLUSIONS

The process parameters for vacuum drying of onion slices were optimised using full factorial design so that it could be further upgraded for commercial application. The qualitative traits specifically colour, flavour, and rehydration ratio of vacuum dried onion were found very good. Second order polynomial relation fitted well to the correlation of the independent variables, the drying temperature, slice thickness, and treatment, with the responses such as the final moisture content variation, colour development, and flavour content of dried onion slices. The process optimisation was done using the response surface methodology, and efficient flavour and colour retention together with an acceptable moisture content and a high value of rehydration ratio were achieved. The maximum weightage was given to the flavour retention followed by the colour of the dried product because, based on those two parameters, only dehydrated onions are characterised. The optimised condition was evinced to be 58.66°C drying temperature and 4.95 ≈ 5 mm slice thickness with the treated samples. The corresponding colour value was OI 30.33 per g dried sample which is very low compared to the conventional drying methods and within the range recommended by ADOGA (2005), which is 90 in the case of dehydrated onion. Low OI value signifies less non enzymatic browning in the samples, therefore, the vacuum dried onion is highly acceptable in the terms of quality. Flavour content

(4.35 μmol/g dried sample) as well as rehydration ratio (4.82) was also high for vacuum dried onion, which justifies the utility of the present study.

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