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Drying kinetics and optimization of microwave- assisted drying of quince pomace

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Abstract

In this study, microwave drying conditions of quince pomace optimized with respect to quality attributes (moisture content, color change and consumer acceptance). Response surface methodology (RSM) technique was used to develop models to respond to the microwave power (100, 2000, 300 W), and microwave time (5, 10, 15 min). The models obtained from the responses were adequate and acceptable because the coefficient of determination R^2 of the models was relatively high. Microwave power of 200W and microwave time of 8 minutes were concluded as the optimum conditions prior to air-drying at 50°C. To describe the drying process, the experimental data for moisture loss was converted to moisture ratios. The effective moisture diffusivity increased with increase in microwave power and its values varied from $1.83\text{-}4.87\times10^{-9}$ m^2/s. Using an exponential expression based on Arrhenius equation the activation energy and was found to be 16.41 W/mm.

Key words: Quince pomace; Microwave drying; optimization; Effective moisture diffusivity; Activation energy

Introduction

By-products of fruits and vegetables are given importance for human health because they contain high levels of dietary fiber and bioactive components (Hernandez-Ortega *et al.*, 2013). In the quince juice processing, quince pomace is a by-product that contains plenty of poly phenol, vitamin C, mineral and dietary fiber. Quince pomace has high moisture content (78 ± 1.37 % (w.b.)), making it susceptible to microbial decomposition. Most commonly preservation method is drying, mainly because of water removal and consequently a reduction in enzymatic deterioration. Hot air drying is the most common technique for fruits dehydration. Nevertheless, this thermal process is a very energy-consuming operation and results in too much degradation of product quality. Therefore, to reduce long drying times and improve the poor product quality of conventional hot air-drying, it is often recommended to combine this method with an advanced method of drying (Amiri Chayjan *et al.*, 2015; Noshad *et al.*, 2011a).

Microwave offers advantages that have been employed prior to or with conventional drying in food processing technologies. Several researchers have provided strong evidence that microwave-assisted drying is ideal for fruits and vegetables, which speed up drying process, increase mass transfer, and produce good quality products (Abano and Amoah, 2015; Tian *et al.*, 2015).

For the efficient operation of processing systems and unit processes yielding a highly acceptable product in food engineering, the optimization has been used. RSM has been reported to be used to determine the independent variables have a combined effect on the desired response. RSM is a collection of statistical and mathematical system that has been successfully used for developing, improving and optimizing such processes. This experimental strategy has been widely used in the development of food processes (Noshad et al., 2011b).

Therefore, the aims of this study were: 1) Optimization of the microwave- assisted drying of quince pomace, 2) Mathematical modeling for drying of quince pomace, and 3)

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Computing effective moisture diffusivity and activation energy of the quinces pomace.

Material and method

Fresh quinces were supplied from a local market in Ahvaz, Iran. The quince pomace consisted of the peel, pulp and remaining after juicing. It was kept in air tight plastic bottles and stored at a temperature of 4°C until the drying process. The moisture content was determined by heating in a drying oven (HERAEUS, Germany) at 105 ºC for 24h (Noshad et al., 2011b).

Microwave drying, experimental design

Response Surface Methodology (RSM) was used to find the best microwave drying conditions. The independent factors were power (100, 200, and 300 Watts), and time (5, 10, and 15 min). The responses were moisture content (Y_1), color change (ΔE) (Y_2) and acceptance (Y_3) of quince pomace. Actual and coded values of variation levels are shown in Table 1. The moisture losses of samples were recorded at 30s intervals during the drying process by a digital balance (AND DG 200) and an accuracy of ± 0.001 g. Drying process was carried out to reach moisture content of 40% on a wet basis.

After the microwave pretreatment, the slices were removed, weighed, and immediately subjected to a hot air cabinet dryer (Binder, Germany) set at the temperature of 50°C .The drying procedure was continued till the moisture content of the sample was reduced to about 5% (wet basis, wb), when the moisture content would not change any more(Wang *et al.*, 2007b). Each run was performed in triplicate.

Table1. Independent variables in this process

Factor	Name	Unit	Min	Max
X_1	Microwave power	Watt	100	300
X_2	Microwave time	min	5	15

Moisture content

The moisture content was determined by heating in a drying oven at 105 ºC for 24h (Noshad *et al.*, 2011b).

Color analysis

Since the computer vision system perceived color as RGB signals, which is device-dependent (Fernandez et al., 2005), the images taken were converted into L*a*b* units to ensure color reproducibility. Conversion from RGB to L*a*b* Transformation RGB into L*a*b space was performed using Color Space Converter plug-in of ImageJ software Ver.1.4g. Magic wand tool which is based on the Laplacian-of-Gaussian filter, used for selection of the true image of quince from the background in converted images. Statistical parameters of L*, a* and b* values were extracted from converted image. Color changes (ΔE) during drying process evaluated using equation (1):

$$\Delta E = \left[(L*_2 - L*_1)^2 + (a*_2 - a*_1)^2 + (b*_2 - b*_1)^2\right]^{\frac{1}{2}} \quad (1)$$

Sensory evaluation of quince pomace powder (acceptance)

A panel consisting of 10 trained panelists evaluated the quince pomace powder for different sensory attributes such as color, texture, taste and overall quality.

Determination of ascorbic acid (vitamin c)

The 2, 6-dichloroindophenol titrimetric method (AOAC Int. 967.21, 45.1.14, 1995) was used to determine the vitamin C content of quince pomace and powder. This method is based on the extraction of ascorbic acid, oxalic acid or met phosphoric acid, along with acetic acid titration with 2, 6-dichloroindophenol mentioned compounds to be bright pink color.5 mL of the clear sample obtained was diluted to 50 mL with met phosphoric acid–acetic acid solution and 7 mL was titrated against standard indophenols solution. Extractions and titrations were performed in triplicate (Gabriel et al., 2015).

Crude fiber content

The crude fiber content of quince pomace powder was measured using the AOAC (962.09, 1971) method. The sample was digested with 1.25% H_2SO_4 and 1.25% NaOH solutions under specific conditions. The residue was dried and then ignited. Crude fiber was measured by calculation of the loss on ignition of the residue (Mohanty et al., 2015). Crude fiber content test was performed in triplicate.

Calculation of effective diffusivities

The Fick's diffusion equation used to describe the drying characteristics of biological products in falling rate period. Crank (1979) developed this equation to use for various regularly shaped bodies such as rectangular, spherical and cylindrical products (Crank, 1979). By assuming uniform initial moisture distribution in products can be used the Eq. (2) for particles with slab geometry (Shen et al., 2011; Wang *et al*., 2007a):

$$MR=\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}\, t}{4L_0^2}\right) \quad (2)$$

Where D_{eff} is the effective diffusivity (m^2/s); L_0 is the half thickness of slab (m). For the long drying period, Eq. (2) can be further simplified to only the first term of series (Ozbek and Dadali, 2007). Thus, Eq. (3) is written in a logarithmic form as follows:

$$\text{Ln } MR=\ln\frac{8}{\pi^2}-\frac{\pi^2 D_{eff}\, t}{4L_0^2} \quad (3)$$

Diffusivities are typically determined by plotting experimental drying data in terms of ln MR versus drying time t in Eq. (4), because the plot gives a straight line with a slope as follows:

$$\text{Slope}=\frac{\pi^2 D_{eff}}{4L_0^2} \quad (4)$$

Calculation of activation energy

According to Abano (2016), for the standard microwave oven drying procedure, the internal temperature of the sample was not an assessable variable (Abano, 2016). Therefore, the use of Arrhenius-type equation was considered for illustrating the relationship between the diffusivity coefficient and the ratio of the microwave power output to sample thickness instead of temperature for the calculation of the activation energy. The activation energy is found as modified from the revised Arrhenius (Zarein et al., 2015):

$$D_{eff}=D_0\exp\left(-\frac{E_a q}{P}\right) \quad (5)$$

Where D_0 is the pre-exponential factor of the Arrhenius equation (m^2/s), Ea is the activation energy (w/mm), P is the microwave power (W), and q is the sample thickness (mm).

Statistical analysis:

Statistical significance of the terms in the regression equations was examined. The significant terms in the model were found by analysis of variance (ANOVA) for each response. The adequacy of the model was evaluated based on the R^2 and adjusted-R^2. Numerical and graphical optimization technique of the Design- Expert software was used for simultaneous optimization of the multiple responses. The desired goals for each variable and response were chosen. All the independent's variables were kept within range while the responses were either maximized or minimized (Eren and Kaymak-Ertekin, 2007; Noshad et al., 2011b).

Result and discussion

The effects of three microwave powers on the drying curve of quince pomace are shown in figure (1). It is obvious from Figs. 1 that increasing the microwave power cause an increase in drying rate so that, the time required to dry quince pomace samples from an initial moisture content of 78 ± 1.37 % (w.b) to the moisture content of 40 + 1.1% (w.b) was approximately 38, 18 and 11 min at 100, 200 and 300 W, respectively. Several researchers reported that considerable increase in microwave power causes an important increase in the drying rate in drying of various vegetables such as green bean slice (Doymaz *et al*., 2015), apple slice (Zarein *et al*., 2015) and kiwifruit (Tian *et al*., 2015). This could be due to the fact that at higher microwave power levels more heat is generated within the sample which thus results in creating a large vapor pressure difference between the center and the surface of the product (Wang *et al*., 2007a).

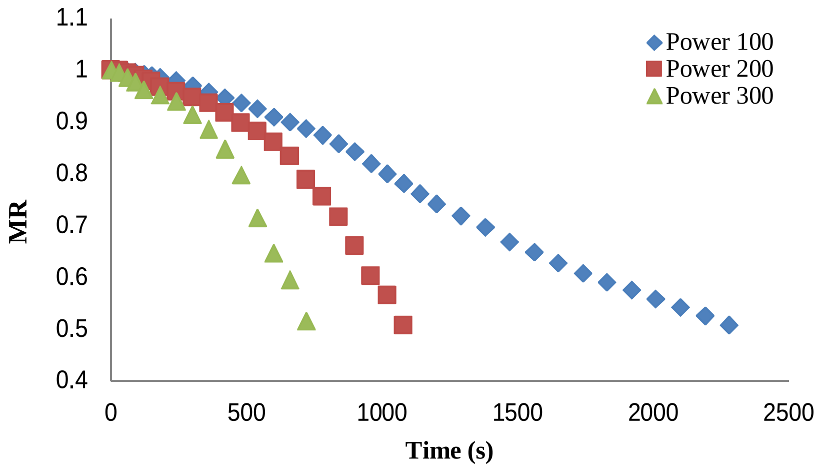

Fig1. Drying curves of quince pomace at different microwave power

Moisture content

The magnitude of P values in table (2) indicates the linear effects of all variables show a negative effect on moisture content. As expected, Fig. 2 shows that increase in microwave power and microwave time decrease the moisture content. Similar results have been reported by different researchers (Evin, 2011; Ozbek and Dadali, 2007). While, the quadratic terms of microwave power and time have a positive effect on moisture content, the interactions of 'microwave power and time' has not any significant effect on moisture content. A quadratic model (R^2= 96) described the effect of tested factors (microwave power and microwave time) on moisture content. The model and their coefficients showed in Eq. (6):

Moisture content= 57.62 -0.193 ×Power - 4.212 ×Time+3.24E- 04 ×Power^2 +0.156 × Time^2 (6)

Color change (ΔE)

The color change in the dried quince pomace was characterized in terms of ΔE, which varied from 11.45 to 37.72. The magnitude of p values in table (2) only indicates t the linear effects positive contribution of microwave power and time on color change. As shown in Fig.3 with the increase in microwave power and time, the color change value of quince pomace decreases. Compared to other treatment combination, microwave drying at lowest power in combination with time at lowest temperature is reduced color change. This trend may be due to the fundamental decrease in Millard reaction occurred at high air microwave power level and time (Omolola *et al*., 2015). The linear model (R^2=0.89) describe the effect of factors on color change value (Eq.7). The ANOVA results for color change value are shown in table 2.

Delta E = -1.19 + 0.09×Power+0.73× Time (7)

Sensory evaluation and consumer acceptance

Sensory evaluation and consumer acceptance is one of the most important quality factors. As shown in table 2, the linear and quadric effects of microwave power and linear effect of microwave time were statistically significant ($p \leq 0.05$) effect on acceptance. As shown in Fig 4 with the increase in microwave power and microwave time, the acceptance of quince pomace powder decreases as a result of the formation of undesirable compounds from the Maillard non-enzymatic reaction which reduces the acceptance of the product in terms of color, taste and odor (Hashemi Shahraki et al., 2012). The quadric model (R^2 = 93.8) describe the effect of factors on the acceptance (Eq. 8).

The ANOVA results for the acceptance are shown in table 2.

$$\text{Consumer acceptance}=5.17+3.9E\text{-}003\times \text{Power} -0.0916\times\text{Time}-3.976E\text{-}005\times\text{Power}^2 \quad (8)$$

Fig 2.Response surface plot for the effects of microwave power and drying time on moisture content

Table 2. ANOVAs evaluation of linear, quadratic and interaction terms for each response variable and coefficient of prediction models:

Source	Moisture content			Color change			consumer acceptance		
	DF	Sum of squares	p-value	DF	Sum of squares	p-value	DF	Sum of squares	p-value
Model	4	535,58	0.001	2	564.4	0.001	3	10.41	0.001
X_1	1	243.21	0.001	1	483.75	0.001	1	8.64	0.001
X_2	1	178	0.001	1	80.64	0.0052	1	1.26	0.001
$X_1 X_2$									
X^2_1	1	29.06	0.0075				1	0.51	0.029
X^2_2	1	42.08	0.0027						
Lack of fit	4	14.38	0.1251	6	26.17	0.47	5	0.31	0.665
R^2	0.966			0.898			0.938		
Adj-R^2	0.95			0.87			0.917		

p-value < 0.05 is significant at ≤ 0.05. ,Lack of fit is not significant at p-value > 0.05.

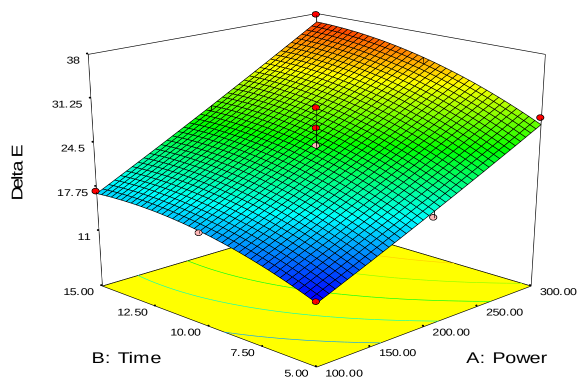

Fig3. Response surface plot for the effects of microwave power and drying time on color change

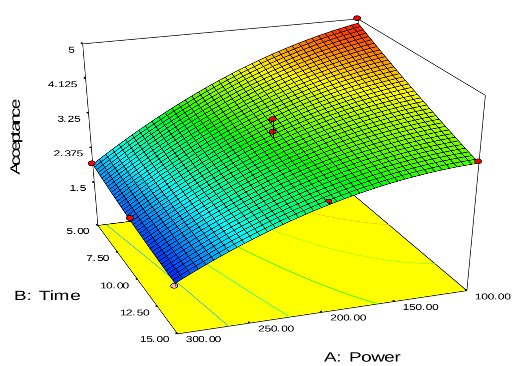

Fig4. Response surface plot for the effects of microwave power and drying time on consumer acceptance

Optimization

The optimum condition for microwave

drying of quince pomace was determined to obtain maximum acceptance and minimum moisture content and color change. Second order polynomial models obtained in this study were utilized for each response in order to determine the specified optimum conditions. These regression models are valid only in the selected experimental domain. So, optimization criteria were selected based on different parameters including economic and product quality related attributes (Eren and Kaymak-Ertekin, 2007; Noshad *et al.*, 2015).

By applying desirability function method, a solution was obtained for the optimum covering the criteria as 8 min for microwave time and 200 W for microwave power.

Analysis of quince pomace powder was carried out at optimal conditions to measure the amount of vitamin C and crud fiber. The vitamin C and crude fiber content of quince pomace powder were 4.27±0.14 and 12.27 ±0.21, respectively while vitamin C content of fresh quince pomace was 19.95±1.03.

Effective diffusivities and activation energy

The calculated values of D_{eff} for different microwave power are presented in Table 3. The effective diffusivity values of dried samples at 100-300 W were altered in the range of 1.83-4.87×10^{-9} m^2/s. It is obvious from table 3 that increasing the microwave power caused an increase in D_{eff}. Increased heat energy as a result of an increase in microwave power is reported to enhance the activity of the water molecules leading to higher moisture diffusivity these values are within the general range 10^{-8}-10^{-12} m^2/s for drying of food materials (Darvishi *et al.*, 2013; Sadi and Meziane, 2015).

Table 3.Values of effective diffusivities obtained for quince pomace at different condition drying

Microwave Power	Effective diffusivity (m^2/mm)
100	1.83×10^{-9}
200	3.25×10^{-9}
300	4.87×10^{-9}

The energy needed to initiate internal moisture diffusion is the active energy. It is an indication of the temperature sensitivity of $D_{eff.}$ The activation energy obtained for drying process was 16.41 W/mm. The activation energy values obtained in this study were lower than the 46.91W/mm reported for microwave-vacuum-drying of tomato slices (Abano *et al.*, 2012) but generally higher than the 5.54W/mm for okra (Dadali *et al.*, 2007).

Conclusion

Regression models were developed to effectively predict the quality parameters at any given microwave power and drying time using RSM. The moisture content of quince pomace powder was observed to decrease significantly as a result of both processes. Color change values increased significantly due to browning and Millard reactions which take place during drying of samples. Acceptance of samples decreased as a result of the formation of undesirable compounds from the Maillard non-enzymatic reaction which reduces the acceptance of the product in terms of color, taste and odor. The drying conditions of 200 W microwave power and 8 min drying time were found optimum for product quality**.** The effective moisture diffusivity values varied from 1.83-4.87×10^{-9} m^2/s and increased with increase in microwave power. The activation energy was calculated using an exponential expression based on Arrhenius equation and was found to be 16.41 W/mm.

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ارزیابی کینتیک خشک شدن و بهینه یابی شرایط خشک کردن مایکروویو- هوای داغ پسماند میوه به

عادیه انور[1]- بهزاد ناصحی[2*]- محمد نوشاد[3]- حسن برزگر[3]

تاریخ دریافت:1395/08/04
تاریخ پذیرش:1395/10/16

چکیده

در این پژوهش روش سطح پاسخ برای بهینه یابی شرایط خشک کردن پسماند میوه به توسط امواج مایکروویو مورد استفاده قرار گرفت. اثر تـوان مایکروویو (300-100 وات) و زمان خشک کردن (15-5 دقیقه) به عنوان متغییرهای مستقل بر میزان رطوبت، تغییرات رنـگ و پـذیرش کلـی پـودر پسماند میوه به، به عنوان متغییر وابسته (پاسخ) مورد ارزیابی قرار گرفت. مدل های رگرسیونی به دست آمده برای تمام پاسخ ها در سطح 95% اطمینان معنی دار بود. شرایط بهینه به دست آمده برای کمینه میزان رطوبت و تغییرات رنگ و بیشینه پذیرش کلی عبارت بود از: توان 200 وات و زمان 8 دقیقه. ضریب نفوذ موثر پودر پسماند به در خشک کن مایکروویو بین $1/83 - 4/87 \times 10^{-9}$ ($\frac{m^2}{s}$) ، به دست آمد مقدار انرژی فعال سازی با استفاده از معادله آرنیوس برمبنای رابطه بین توان مایکروویو و ضریب نفوذ موثر محاسبه شد که $16/41\ \frac{W}{mm}$، بود.

واژه های کلیدی: پسماند به، مایکروویو، بهینه یابی، نفوذپذیری موثر رطوبت، انرژی فعال سازی

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