Acta Sci. Pol., Technol. Aliment. 12(3) 2013, 253-262
pISSN 1644-0730 eISSN 1889-9594 www.food.actapol.net/

OPTIMIZATION OF PROCESS PARAMETERS FOR MICROWAVE-VACUUM PUFFING OF BLACK RADISH SLICES USING THE RESPONSE SURFACE METHOD

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ABSTRACT

Background. Due to the health-promoting value of black radish, authors decided to investigate the feasibility of forming – from its roots – chips, using the process of microwave-vacuum puffing. In order to produce desirable quality of chips, there is a need to determine the most advantageous values of process parameters. The main goal of the paper is to investigate the possibility of determining the best processing conditions for microwave-vacuum formation of black radish chips that can maximize the chips expansion ratio while maintaining consumer acceptability of sensory quality of chips.
Material and methods. The raw material for analyses comprised fresh roots of black radish (*raphanus sativus linné varietas niger*). A three-level, one-factor central composite experimental design (DOE) was applied. The response surface method (RSM) was used as a part of the Statistica software and the R computer program for optimization. Response surfaces were built using the second degree polynomial that includes principal effects of processing parameters values and their interactions.
Results. A regression model was derived, based on results of natural experiments, that give a satisfactory prediction level (R^2 = 0.96) of the expansion ratio of black radish chips as a function of processing conditions. Then, the best values of process parameters were found using the RSM. The best processing parameters values were determined to be 0.39 kg·kg^{-1} wb (wet basis) moisture content of pre-dehydrated radish slices, 14.5 kPa vacuum absolute pressure and 80 s of microwave heating time during puffing (for the 650 W power output of the microwave generator).
Conclusion. Optimized process of puffing of black radish slices using the RSM provided a satisfactory high value of the sensory quality index of chips. In this paper we do not analyze the physical structure of chips. In the future more research needs to be done in this area.

Key words: black radish, microwave-vacuum drying, puffing, response surface method, sensory quality

INTRODUCTION

By selecting appropriate drying methods and their parameters we may modify desirable attributes of biological products. Such an opportunity is offered by multi-stage drying using microwave-vacuum drying (MVD) and hot air drying [Varnalis et al. 2001, Stępień 2008, Figiel 2010]. MVD provides an enhanced quality and preservation of nutritive value of food in comparison to air drying at atmospheric pressure [Setiady

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et al. 2007, Therdthai and Zhou 2009, Bai-Ngew et al. 2011].

Preceding MVD of sliced vegetables with hot air drying under atmospheric pressure (to form a partially dried layer at the surface) results in a situation when during MVD within the product the pressure of vapour increases, leading to an increased volume, i.e. a puffing occurs [Varnalis et al. 2001]. The phenomenon of puffing results in the formation of a porous crispy texture of the material [Zhang et al. 2007]. In order to produce desirable quality of dried bio-materials, found acceptable by consumers, we need to determine the most advantageous combination of process parameters [Chayjan et al. 2012, Nath et al. 2007, Varnalis et al. 2004]. Since different biological materials have different physical and biochemical structures, the best combination of process parameters for puffing formation is specific for each individual raw material. Using the response surface method (RSM) Varnalis et al. [2004] identified the most advantageous combination of processing parameters for puffing formation from potato cubes, while Zhang et al. [2007] and Han et al. [2010] did analogously for freshwater fish and apple chips, respectively.

Extract from roots of black radish is used in treatment of e.g. the liver, stomach and the duodenum [Ediage et al. 2011]. The raw vegetable is used for culinary purposes to a limited degree. Due to the health-promoting value of this vegetable, authors decided to investigate the feasibility of forming – from slices cut from its roots – chips with quality attributes acceptable for consumers [Pawlak and Ryniecki 2012]. The aim of this study was to confirm the experimental assumption on the applicability of the RSM in the determination of the best combination of process parameters values (Fig. 1) for microwave-vacuum formation of black radish chips that maximize the chips expansion ratio, while maintaining consumer acceptability of sensory quality of chips.

MATERIAL AND METHODS

Formation of chips from black radish slices. The raw material for analyses comprised fresh roots of black radish with a moisture content of 0.891 ±0.47 (SD) kg·kg^{-1} wb (wet basis), purchased on the local market and stored at 5°C. Immediately before the 1st stage of drying the raw material was cut into slices of 5 mm in thickness and next slices of 32 mm in diameter were cut. In the first stage of drying slices were dried in a thin layer with hot air at a temperature of 60°C and a velocity of 1.1 m·s^{-1} (at atmospheric pressure and without the use of microwave energy). The aim of this stage was to close external layers of sliced radish. Slices were dried to moisture content justified by the optimization method.

Several radish slices of 15.0 ±0.72 g dried to the specified moisture content in the first stage, were dried in the second stage using the microwave-vacuum method in order to form chips. The diagram of the dryer manufactured by Promis-Tech Wrocław, Poland, is presented in Figure 2. The dried material was placed inside the vacuum drying drum. Inside the drum air pressure may be reduced to approx. 4 kPa. The drying drum is placed inside the microwave chamber between antennas connected with a microwave generator

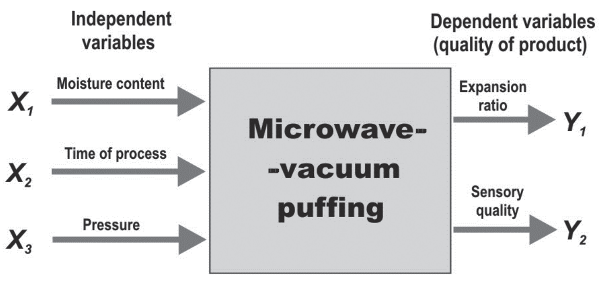

Fig. 1. Process parameters (independent variables) of microwave-vacuum puffing to be optimized and dependent variables (quality attributes of black radish chips)

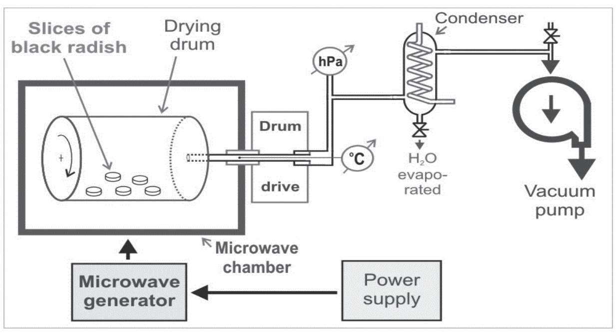

Fig. 2. Schematic diagram of microwave-vacuum dryer

with a frequency of 2.45 GHz. The power of the generator may be adjusted within the range of 0-650 W. In the axis of the drum in its back section a rotating shaft is assembled in the form of a thick-walled pipe discharging air from the drum. The section of the shaft located outside the impact zone of microwaves was connected with the drum drive, producing drum rotations within the range of 11 to 19 rpm. This part of the shaft rotates tightly inside an immobile connector, which was attached to a vacuum pump through a water vapour condenser. The task of the condenser is to dry air sucked in by an oil vacuum pump. Measurements of pressure and temperature of the air leaving the drying drum may be taken at this dryer. Then, after the second stage of drying with the aim of forming chips, moisture content of chips was reduced to the final value of 0.1 $kg \cdot kg^{-1}$ wb using the same drying method as in the first stage of drying.

Radish moisture content. The radish moisture content determined with the assistance of a Sartorius MA 30 electronic moisture analyser (Germany) was treated as the reference (based on a precision weighing balance at drying of 5 g sample at 100°C to constant mass). This moisture analyser was verified using the oven method [ISO 1982]. The measuring accuracy of the analyser is 0.0005 $kg \cdot kg^{-1}$ wb.

Expansion ratio. The value of the expansion ratio for black radish slices was determined as a ratio of volume of several slices after the third stage of final hot air drying to their volume before puffing in the second stage of drying (the microwave-vacuum method). The volume of slices was determined according to the method described by Mazza [1983]. Several black radish slices were placed in a sample dish of 25 ml. Next a toluene, by nature not penetrating into particles, was transferred to the dish from a burette of 25 ml. The volume of toluene remaining in the burette was equal to the volume of radish slices. Determinations were made in three replications.

Sensory analysis. Sensory quality is connected with consumer acceptance and trust in the product and it is defined by interactions between food and consumers [Ares et al. 2009]. Organoleptic attributes of black radish chips were evaluated by the method using scales [PN-ISO 1998]. A 5-point scale was used, which consists of five quality levels for the evaluation of each quality attributes. Four quality attributes were used: colour, aroma, taste and tenderness, which needed to be assessed in the same 5-point scale. Individual attributes (indicators) of sensory quality were ascribed by experts, considering the weight of a given attribute for the overall score of black radish chips, in the form of the following weight coefficients (weights): 0.20 (colour), 0.10 (aroma), 0.40 (taste) and 0.30 (tenderness). The method combined all the attributes evaluated separately into one figure referred to as a sensory quality index, which comprehensively expresses the overall quality of the tested product. Prior to the onset of the final appraisal, the designed system of the point scale must be verified by preliminary evaluations of puffing processes conducted several times.

Statistical analysis. The Statistica, v. 10 software [2011] and the R, v. 2.10.0 [2009] were used. A three-level, one-factor central composite experimental design was applied. Sixteen combinations of independent variables were selected randomly. Response surfaces were built using the following polynomial (that includes principal effects of processing parameters values, their interactions and square terms):

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_{11}X_1^2 + a_{22}X_2^2 + a_{33}X_3^2 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 \quad (1)$$

The multivariate regression analysis was performed using the same statistical programs (Statistica and the R).

RESULTS AND DISCUSSION

Effect of moisture content on the expansion ratio. The amount of heat, released in biological materials in the microwave field, depends to a considerable degree on their water content, since it is mainly water particles, being polar dielectrics, vibrating in coordination with the electromagnetic wave, rubbing against one another causing the emission of heat [Sanga et al. 2000, Sutar and Prasad 2007]. In the generation of the puffing effect a large amount of heat is required for the phase transition of water liquid into vapour in the entire volume of the product. The produced vapour increases internal pressure and the driving force of water molecule movement from the inside to the surface [Krulis et al. 2005]. On the other hand, for the puffing effect to occur in sliced vegetables it is necessary to form a dried surface layer so that it may retain vapour in the product [Varnalis et al. 2001, 2004]. In view of the above, the drier the sliced vegetables are, the more tightly closed the surface layer is for vapour. Thus, for a given material structure there exists the most advantageous range of moisture content, and it was the aim of the investigations preceding optimization of process parameters for MVD to find this range of moisture content. For this reason the effect of water content in black radish on puffing was analysed first.

The other constant values of the process parameters were preliminarily adopted on the basis of the state of knowledge from the review of literature on the subject and practical knowledge concerning MVD of other vegetables, mainly carrot: pressure in the drying drum 5 kPa, microwave generator power 650 W (maximum possible) and time of MVD 90 s. Results of a series of experiments for the above mentioned process parameters and different values of moisture content in samples are presented in Figure 3.

Samples of black radish slices with a moisture content of 0.275 ±0.0035 $kg \cdot kg^{-1}$ wb and 0.35 ±0.0047 $kg \cdot kg^{-1}$ wb in MVD reached the highest values of the expansion ratio (1.82 ±0.37 and 1.83 ±0.44 respectively). In samples with a lower moisture content, e.g. 0.125 ±0.0041 $kg \cdot kg^{-1}$ wb, the expansion ratio was much lower (1.23 ±0.02). Similarly as other authors [Giri and Prasad 2007], we are of an opinion that in those samples drying shrinkage and internal resistance to mass transfer were too big. At the same time an insufficient amount of water vapour prevented the generation of a sufficiently high pressure required for the disruption of the material structure and puffing of slices as stated e.g. Zhang et al. [2007]. In turn, in radish slices with a higher moisture content (0.425 ±0.101 $kg \cdot kg^{-1}$ wb and 0.50 ±0.0094 $kg \cdot kg^{-1}$ wb) the amount of water vapour was supposedly sufficient, but the surface layer was not sufficiently tight to retain vapour and generate sample puffing pressure. Moisture content of the material, for which the puffing index was highest (0.35 $kg \cdot kg^{-1}$ wb), was used in further studies on the effect of MVD time on the puffing result.

Effect of microwave heating time on the expansion ratio. Power output of the MVS should be sufficiently high to provide an adequately high difference in water vapour pressures between the inside and the surface of products, i.e. a sufficiently high driving force for the heat and mass transfer [Wang and Xi 2005, Giri and Prasad 2007, Therdthai and Zhou 2009, Bai-Ngew et al. 2011]. Zhang et al. [2007], searching for the most advantageous combination of process parameters for MVD, determined the most advantageous heating time for the maximum power output of their MVS. A similar procedure was adopted by the authors of this study. For the constant microwave power output of 650 W (the ultimate of the MVS) drying time in the range from 30 to 180 s was selected for investigations. The other constant values of the process parameters were preliminarily adopted as follows: material moisture content of 0.35 $kg \cdot kg^{-1}$ wb (a result of an earlier analysis), while pressure in the drying drum was 5 kPa. Results of the series of experiments for the above mentioned process parameters and different drying times are presented in Figure 4.

Samples of black radish slices heated using microwaves for 80 s in the process of MVD had the highest value of the expansion ratio (1.84 ±0.14). When drying

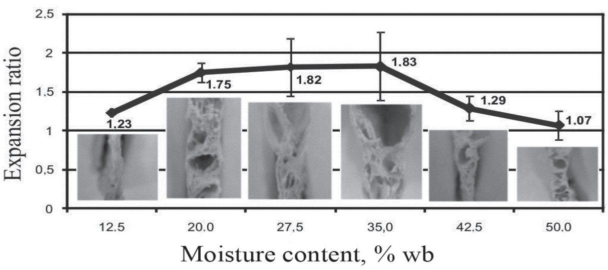

Fig. 3. Effect of material moisture content, initial for microwave-vacuum drying, on puffing effect in slices cut from root tissue of black radish

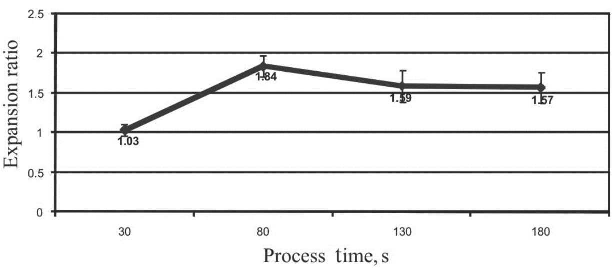

Fig. 4. Effect of microwave-vacuum drying time (for power output of the microwave-vacuum system, MVS, of 650 W) on puffing effect of slices cut from root tissue of black radish

time was reduced to 30 s the expansion ratio decreased to 1.03 ±0.07, which may be explained by a lack of generation of sufficiently high vapour pressure in radish slices [Nath et al. 2007]. In turn, when drying time was extended to 130 s and to 180 s a decrease was observed in the expansion ratio at simultaneous adverse changes in quality of dried vegetables, disqualifying it as a product for human consumption. Unfavourable changes in colour and local burns occurred on slices surfaces. This was an effect of excessive water loss on sharp margins of slices and an excessive increase in temperature in those places [Nath et al. 2007, Zhang et al. 2007]. Drying time of 80 s, for which the value of expansion ratio was highest, was applied in the next stage of the study on the effect of pressure in the drying drum on the puffing effect.

Effect of pressure inside the drying drum on the expansion ratio. The most advantageous pressure in the drying drum of the microwave-vacuum dryer indicated by different authors varied for different materials. Zhang et al. [2007] stated that for drying of pieces of cut spotted bighead carp the absolute pressure is 5 kPa, while Bondaruk et al. [2007] reported that for drying of potato cubes it is 24 kPa. The authors decided to verify both above mentioned values. Moreover, two higher pressure values were included: an intermediate pressure between absolute pressure of 24 kPa and atmospheric pressure, i.e. pressure of 62 kPa, as well as barometric pressure.

The other constant values of process parameters were preliminarily adopted as a result of the earlier analysis: moisture content of the material 0.35 kg·kg^{-1} wb and drying time 80 s (at a power output of the MVS of 650 W). Results of the series of experiments for the above mentioned process parameters and different values of absolute pressure in the drying drum are presented in Figure 5.

Figure 5 clearly indicates that the expansion ratio is approximately proportional to partial vacuum in the drying drum, which may result from a similar trend of changes occurring between boiling point of water and the vacuum degree in the applied range of pressures. However, the difference between values of the expansion ratio for absolute pressures of 5 and 24 kPa is slight (only 0.02) and falls within the range of error for the measurement method. At the atmospheric pressure the puffing effect is also evident (the expansion

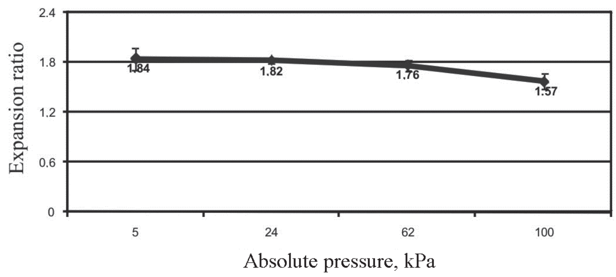

Fig. 5. Effect of absolute pressure in the drying drum on puffing effect of slices cut from root tissue of black radish

ratio of 1.57 ±0.09). Many authors stressed that the greatest importance of partial vacuum is manifested in the quality of dried products. Vacuum reduces changes in colour and taste [Hu et al. 2006, Zhang et al. 2006, Setiady et al. 2007], has a positive effect on the formation of pores in the material structure [Giri and Prasad 2007] and to a considerable degree prevents the formation of burnt spots on the surface of dried products [Therdthai and Zhou 2009, Bai-Ngew et al. 2011].

Optimization of processing parameters. RSM was used to find the best combination of the process parameters (X_1, X_2, X_3) that can maximize expansion ratio (Y_1) during microwave-vacuum puffing, with the bound set on the sensory quality of black radish chips (Y_2). Preliminary experiments established separate effects of factors (input variables) on the attribute (response Y_1). Based on these experiments, the three levels of each of three independent variables were set for searching of maximum of Y_1. The coding of input variables is presented in Table 1. The central points of factors X_1 and X_2 were set to be equal to the values of

Table 1. Coding of levels of factors used in designing natural experiments for optimization of the puffing process of black radish slices

Independent variables	Codes		
	–1	0	1
X_1 – moisture content, kg·kg^{-1} wb (wet basis)	0.312	0.35	0.388
X_2 – puffing time, s	55	80	105
X_3 – vacuum absolute pressure, kPa	5	14.5	24

0.35 kg·kg^{-1} wb, and 80 s, i.e. the values, for which the attribute Y_1 had the highest values in preliminary experiments. The lower and the upper bounds for the X_1 and X_2 were set, similarly to the optimization procedure by Ryniecki and Nellist [1991], by halving the step sizes used in preliminary experiments. The investigated range for factor X_3 was set to be between 5 kPa (the ultimate pressure of the vacuum pump) and 24 kPa, with the central point half-distance between the lower and upper bounds.

Sixteen combinations of coded values of three independent variables (including two center points), used to obtain experimental data for optimization, were selected randomly. Combinations of factors and the results of sixteen natural experiments are summarised in Table 2. Data obtained from the experiments concerning X_1, X_2, X_3 and Y_1 were analysed using the multivariate regression and they were fitted to equation (1). Recorded values are presented in Table 3.

On the basis of Table 3 it may be stated that equation (1) for the response variable Y_1 takes the form:

$$Y = 1.78 + 0.06X_1 + 0.23X_2 - 0.02X_3 + 0.11X_1^2 - 0.53X_2^2 + 0.08X_3^2 - 0.04X_1X_2 + 0.01X_1X_3 + 0.01X_2X_3 \quad (2)$$

Table 2. Combinations of input parameters (X_1, X_2, X_3) and output responses (Y_1, Y_2) of microwave-vacuum puffing of black radish slices

No	X_1	X_2	X_3	Y_1	Y_2
1	0	–1	0	1.14	3.31
2	1	1	1	1.74	3.16
3	0	0	–1	1.86	3.39
4	–1	–1	1	1.07	2.91
5	–1	1	–1	1.70	3.19
6	1	0	0	1.91	3.55
7	1	–1	–1	1.31	3.55
8	–1	0	0	1.82	3.10
9	–1	1	1	1.68	3.01
10	1	–1	1	1.29	3.23
11	0	0	1	1.81	3.21
12	0	0	0	1.84	3.34
13	0	1	0	1.31	3.31
14	–1	–1	–1	1.13	3.08
15	0	0	0	1.84	3.34
16	1	1	–1	1.76	3.66

Table 3. Multivariate regression analysis showing the lack of fit for the response variable Y_1 to the second-order model described by equation (1)

	Regression coefficient (estimate)	Standard error	*t* value	*Pr*(>|*t*|)
(Intercept)	1.78	0.048	36.778	<0.0001***
X_1	0.06	0.032	1.886	0.1082
X_2	0.23	0.032	6.957	0.0004***
X_3	–0.02	0.032	–0.526	0.6179
X_1^2	0.11	0.063	1.809	0.1203
X_2^2	–0.53	0.063	–8.352	0.0002***
X_3^2	0.08	0.063	1.333	0.2309
X_1X_2	–0.04	0.036	–0.968	0.3704
X_1X_3	0.01	0.036	0.138	0.8945
X_2X_3	0.01	0.036	0.138	0.8945

Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

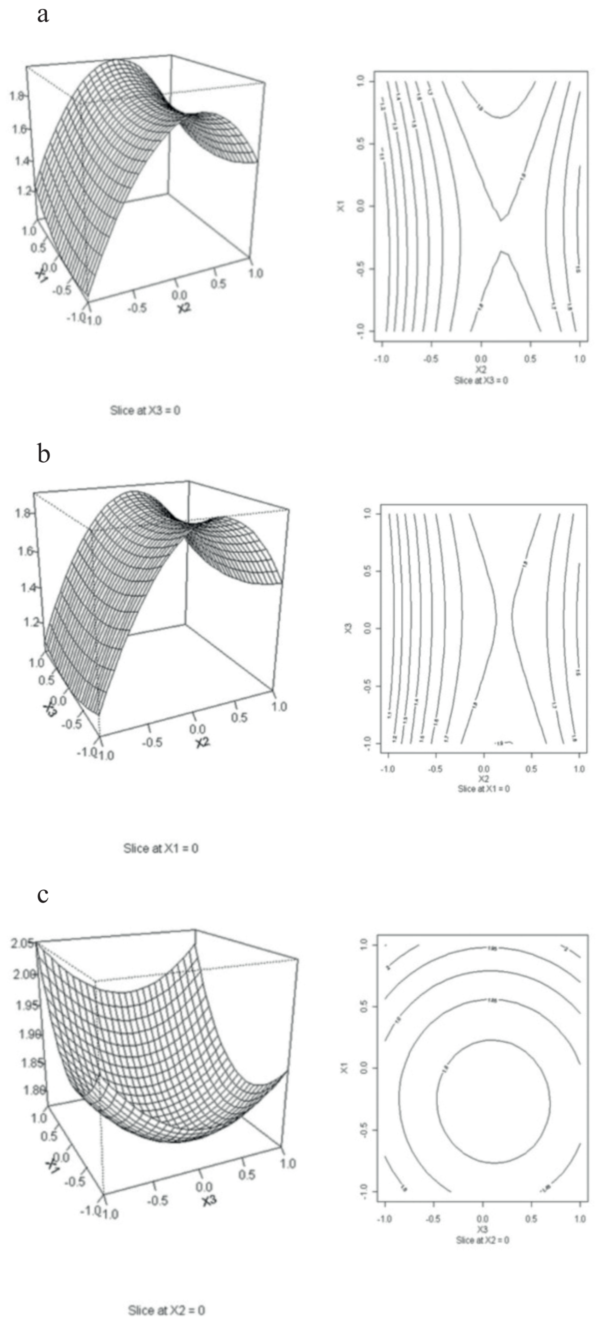

Fig. 6. Response surface plots showing the dependency of the response variable Y_1 on input variables X_1, X_2, and X_3

A high coefficient of determination R^2 (=0.96) indicates that the variables adequately fit the regression equation, which means that the empirical model well described the variation of the puffing. A stationary point (a saddle point) was established for $X_1 = -0.236$ (=0.3412 kg·kg^{-1} wb), $X_2 = 0.222$ (=85.55 s) and $X_3 = 0.102$ (=15.47 kPa). Figure 6 presents plots for the dependence between the response variable (expansion ratio Y_1) and moisture content of the material (X_1), puffing time (X_2) and pressure (X_3).

The greatest effect on changes in the expansion ratio is observed for puffing time, X_2, for which the regression coefficient is 0.23 (Table 3). Response surfaces presented in Figures 6 a (where X_1 and X_2 are independent variables) and 6 b (where X_2 and X_3 are independent variables) indicate that the most advantageous puffing time (X_2) of black radish slices, both for changes in material moisture content (X_1) within the range of 0.313-0.388 kg·kg^{-1} wb and changes in absolute pressure (X_3) of 5-24 kPa, is approx. 80 s (code 0.0), at the maximum power output of the MVS of 0.65 kW. In turn, response surfaces presented in Figures 6 a and 6 c indicate that the highest values of material moisture content (within the optimized range of changes) generate the highest values of the expansion ratio. Taking into consideration this fact, as well as the results of experiments for a wider range of changes in material moisture content presented in Figure 3, it may be stated that the most advantageous moisture content of the material is approx. 0.39 kg·kg^{-1} wb. As it could have been expected, the smallest effect on the expansion ratio was observed for absolute pressure in the analysed range of changes, as the regression coefficient was only –0.02 (Table 3).

The highest value of the expansion ratio ($Y_1 = 1.91 \pm 0.03$) recorded in natural experiment for the following combination of input parameters for the puffing process, i.e. moisture content of black radish slices $X_1 = 0.388$ kg·kg^{-1} wb, puffing time $X_2 = 80$ s, and absolute pressure $X_3 = 14.5$ kPa (Table 2). The sensory quality index (dependent variable Y_2) for this combination X_1, X_2 and X_3 reached one of the highest values (3.55 ±0.58) among the 16 analysed natural experiments (Table 2). In accordance with the adopted methodology of determination the sensory quality index, chips made from black radish to be found acceptable by consumers should have $Y_2 > 3.0$. It means that the above mentioned combination of X_1, X_2 and X_3 is the best combination of input parameters for the process of microwave-vacuum puffing of black radish slices that can maximize the expansion ratio (Y_1) with the

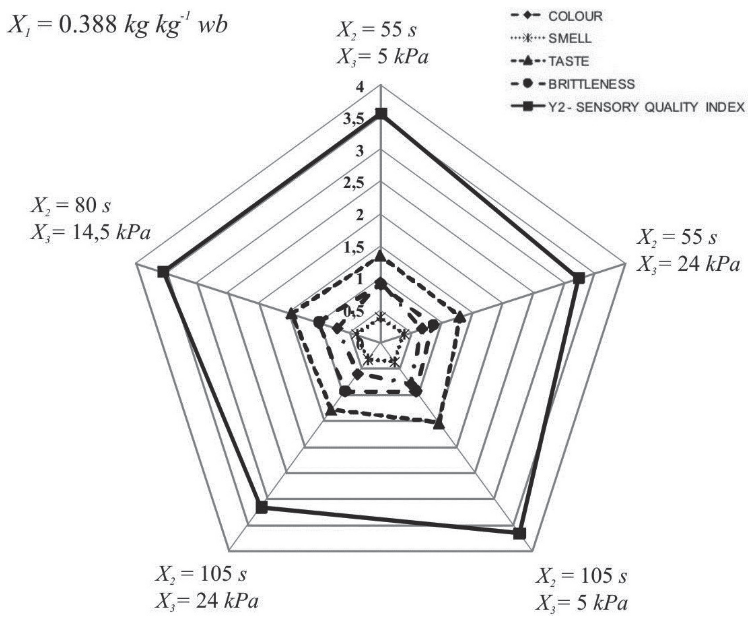

Fig. 7. Sensory quality index determined using the scales method of five points (the evaluation was conducted by a panel of six experts with exceptional knowledge and experience in the technology and evaluation of the final product; SD of sensory quality index varied from 0.352 to 0.933)

bound set on the sensory quality (Y_2). Furthermore, for this combination of X_1, X_2 and X_3 brittleness of black radish chips has the highest value (Fig. 7).

CONCLUSIONS

The tests for separate factors showed that there are hills of high values for the main output variable (expansion ratio) for such processing parameters as energy emitted from the microwave generator during microwave-vacuum puffing and also moisture content of the pre-dehydrated radish slices.

Using RSM an equation was derived that gives a satisfactory prediction ($R^2 = 0.96$) for the expansion ratio of black radish chips produced by microwave-vacuum puffing – as a function of processing parameters such as moisture content of the pre-dehydrated material, time of the puffing process, and the vacuum absolute pressure inside a drying drum.

The greatest effect on changes in the expansion ratio, among the optimized process parameters of microwave-vacuum puffing of black radish (moisture content of the pre-dehydrated material in the range 0.313-0.388 $kg \cdot kg^{-1}$ wb, puffing time of 55-105 s, and the vacuum absolute pressure of 5-24 kPa), is found in case of puffing time, for which the regression coefficient is 0.23 (for the others it is lower or equal to 0.06).

The application of RSM, preceded by the conducted series of preliminary experiments, made it possible to determine the following best combination of process parameters for microwave-vacuum puffing producing chips from slices of 5 mm in thickness, cut from black radish roots and pre-dried with hot air at 60°C: moisture content of slices before the onset of the puffing process of 0.39 $kg \cdot kg^{-1}$ wb, absolute pressure in the drying drum of 14.5 kPa, and 80 s of microwave heating time during puffing (for the 650 W power output of the microwave generator). This combination of process parameters can maximize the expansion ratio, at the same time providing a satisfactory high value of the sensory quality index.

In this paper we do not analyse the physical structure of chips. In the future more study needs to be done in this area.

ACKNOWLEDGMENTS

Authors are grateful for the financial support provided by the Poznań University of Life Sciences, Poland within the framework of funds no. 508-52-11.

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OPTYMALIZACJA PARAMETRÓW PROCESU MIKROFALOWO-PODCIŚNIENIOWEGO KSZTAŁTOWANIA ‘PUFFINGU’ Z RZODKWI CZARNEJ METODĄ POWIERZCHNI REAKCJI

STRESZCZENIE

Wprowadzenie. Rzodkiew czarną wyróżniają walory prozdrowotne i dlatego autorzy podjęli badania nad tworzeniem z jej korzenia chipsów, z wykorzystaniem procesu mikrofalowo-podciśnieniowego kształtowania ‘puffingu’. Konieczność uzyskania pożądanej jakości chipsów wymusza potrzebę wyznaczenia najkorzystniejszych wartości parametrów wymienionego procesu. Głównym celem pracy jest zbadanie możliwości zastosowania metody powierzchni reakcji do wyznaczenia najkorzystniejszych warunków przebiegu procesu mikrofalowo-podciśnieniowego kształtowania chipsów z rzodkwi czarnej z punktu widzenia maksymalizacji wskaźnika powiększenia objętości produktu przy satysfakcjonującej konsumentów wartości wskaźnika jakości sensorycznej.
Materiał i metody. Surowcem do badań były świeże korzenie rzodkwi czarnej (*Raphanus sativus linné varietas niger*). Do doświadczeń naturalnych (DOE) zastosowano plan centralny kompozycyjny dla doświadczenia jednoczynnikowego z trzema poziomami. Optymalizację przeprowadzono z wykorzystaniem metody powierzchni reakcji (RSM), w ramach programów komputerowych ‘Statistica’ i ‘R’. Powierzchnie odpowiedzi zbudowano z użyciem wielomianu drugiego stopnia, który uwzględnia wpływ wartości parametrów procesu oraz interakcji między nimi.
Wyniki. Na podstawie wyników doświadczeń naturalnych wyznaczono empiryczny model regresji mający wysoki współczynnik determinacji R^2 (0,96), co wskazuje, że model dobrze opisuje zależność wartości wskaźnika nadymania rzodkwi czarnej od wartości parametrów procesu. Następnie zastosowano RSM, co umożliwiło wyznaczenie najlepszej kombinacji wartości parametrów procesu: wilgotność plasterków rzodkwi czarnej przed rozpoczęciem procesu kształtowania ‘puffingu’ równa 39%, ciśnienie absolutne procesu równe 14,5 kPa i czas ogrzewania mikrofalowego równy 80 s (przy mocy generatora mikrofal równej 650 W).
Konkluzja. Proces kształtowania ‘puffingu’, którego parametry zoptymalizowano z użyciem RSM, umożliwił wytworzenie chipsów o satysfakcjonująco dużej wartości wskaźnika jakości sensorycznej. W pracy nie analizowano struktury fizycznej chipsów. Powinno to być przedmiotem badań w przyszłości.

Słowa kluczowe: rzodkiew czarna, suszenie mikrofalowo-podciśnieniowe, kształtowanie ‘puffingu’, metoda powierzchni reakcji, jakość sensoryczna

Received – Przyjęto: 1.12.2012

Accepted for print – Zaakceptowano do druku: 17.05.2013

For citation – Do cytowania

Pawlak T., Ryniecki A., Siatkowski I., 2013. Optimization of process parameters for microwave-vacuum puffing of black radish slices using the response surface method. Acta Sci. Pol., Technol. Aliment. 12(3), 253-262.