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Gluten-Free Cookies Enriched with Blueberry Pomace: Optimization of Baking Process

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Abstract**—**With the aim of improving nutritional profile and antioxidant capacity of gluten-free cookies, blueberry pomace, by-product of juice production, was processed into a new food ingredient by drying and grinding and used for a gluten-free cookie formulation. Since the quality of a baked product is highly influenced by the baking conditions, the objective of this work was to optimize the baking time and thickness of dough pieces, by applying Response Surface Methodology (RSM) in order to obtain the best technological quality of the cookies. The experiments were carried out according to a Central Composite Design (CCD) by selecting the dough thickness and baking time as independent variables, while hardness, color parameters (L*, a* and b* values), water activity, diameter and short/long ratio were response variables. According to the results of RSM analysis, the baking time of 13.74min and dough thickness of 4.08mm was found to be the optimal for the baking temperature of 170°C. As similar optimal parameters were obtained by previously conducted experiment based on sensory analysis, response surface methodology (RSM) can be considered as a suitable approach to optimize the baking process.

Keywords**—**Baking process, blueberry pomace, gluten-free cookies, Response Surface Methodology.

I. Introduction

BLUEBERRIES are a rich source of anthocyanins and other antioxidant compounds, which may have health-promoting effects [1]. Due to a limited shelf life of fresh blueberries, they are commonly processed into juice, where a large quantity of pomace is generated. The pomace consists of skins, pulp residue, and seeds and is usually treated as a waste product [2]. However, the pomace can be processed into a new food ingredient by simply drying and grinding to reduce the coarse texture.

Celiac disease represents life-long intolerance to the gliadin fraction of wheat and the prolamins or rye (secalins), barley (hordeins) and possibly oats (avenin). Gluten is a protein which possesses structure-forming ability that affects elastic properties of dough and contributes to the overall appearance and crumb structure of many baked products.

Production of high-quality gluten-free products represents a significant technological challenge as the replacement of gluten in gluten-free formulation represents a very demanding task resulting in often low quality, poor mouth feel and low flavor products [3].

Consumers adhered to gluten free diets more and more require gluten-free foods that resemble the traditional ones. As consequence, in recent years, there has been an extensive research for the development of gluten-free sweet bakery products aimed at improving the structure, mouth feel, acceptability, shelf-life and nutritional quality of the finished products [4].

With an aim of improving nutritional and antioxidant capacity of gluten-free cookies, dried and ground blueberry pomace, by-product of juice production was used to substitute a part of the gluten-free mixture to obtain a new gluten-free formulation. As expected, by substituting a part of gluten-free mixture, dough properties were significantly changed and a product with different properties was obtained.

It is known that the quality of cookies is highly influenced by its composition and by a number of different parameters at the production line [5].

The most frequently used technique for the optimization of processing conditions, product development and understanding of a system performance is RSM [6].

Baking conditions - duration and temperature at which dough is thermally treated is known to highly influence the overall quality of a bakery product inducing the heat transfer and consequently the complex physicochemical changes that affects the formation of texture, aroma and color of a final product. [7].

Referring to all above mentioned, the main objective of this work was to optimize the baking process of new blueberry pomace gluten-free cookies, by applying RSM in order to achieve the best technological quality.

II. Material and Methods

A. Materials

Fresh blueberry pomace was obtained as a by-product from the juice production line at "Zdravo Organic", Selenča, Serbia. Pomace was dried in a dry heat sterilizer (Instrumentaria, Zagreb) at 40°C, until the water activity value of 0.3 was reached and then ground in a laboratory mill (KnifetecTM 1095 mill, Foss, Hoganas, Sweden). The fraction passing through the 0.80mm sieve was used.

Gluten-free mixture consisting of: corn starch, corn flour, potato starch, potato flour, rice flour, guar gum, baking powder, and salt were obtained from "Nutri allergy center", Zemun, Serbia.

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Vegetable fat, powdered eggs, sugar and glucose syrup were commercially available.

B. Cookies Preparation

Gluten free cookies in which 30% (w/w) of gluten free mixture was substituted with dried blueberry pomace were prepared according to the recipe given in Table I. All ingredients were weighed together and mixed for 10 min in Farinograph mixing bowl (Brabender, Germany) tempered at 30°C. The obtained dough was kept at 8°C for 24h. Thirty minutes before the processing, dough was tempered at the room temperature (20°C). Pilot scale dough sheeter (Mignon, Italy) was used to sheet the dough to the desired thickness. The dough was cut into round shapes of 50mm diameter, placed on a baking tray and baked in a laboratory oven (MIWE Gusto® CS, Germany). Baking temperature was set at 170°C. The obtained gluten-free cookies were first left to cool down at room temperature for 2h and then they were packed and stored for 24h in sealed polypropylene bags before the analysis.

TABLE I
FORMULATION OF COOKIES

Ingredient	Gluten free mixture base (%)
Gluten free mixture	70
Blueberry pomace	30
Sugar	35
Glucose syrup	16
Vegetable fat	18
Powdered egg	2
Water	36

C. Determination of Baking Quality of Cookies

AACC baking quality method [8] was used for determination of width (W), thickness (T), W/T ratio (cookie spread factor) and short/long ratio (S/L). Six cookies from each batch were measured giving a total of 12 measurements per treatment. In order to describe the deviation from the ideally round shape, short and long diameter were measured and their ratio was calculated. These parameters were measured using digital caliper (Carl Roth, Germany).

D. Color Evaluation of Cookies

Color measurements of cookies' top surfaces were carried out 24h after baking. These measurements were performed on 12 cookies of each treatment using a Minolta Chroma Meter CR-400 (Sensing Inc., Japan) colorimeter. The obtained results were expressed in terms of L* (lightness), a* (redness/greenness) and b* (yellowness/blueness) values.

E. Textural Characteristics of Cookies

Textural characteristics of cookies were determined through a three point bending test performed on a Texture analyzer TA.XT plus (Exponent Stable Micro System). Textural properties were determined 24h after baking and the obtained results were expressed as the hardness value.

F. Water Activity (a_w) and Moisture Determination

Prior to a_w and moisture determination, cookies were ground to 0.8mm particle size using laboratory mill (KnifetecTM 1095 mill, Foss, Hoganas, Sweden).

Water activity was determined using Testo 650 measuring instrument with a pressure-tight precision humidity probe (Testo AG, USA). Each result presents the average value of 3 measurements.

Moisture content of cookies was determined according to AOAC method [9].

G. Baking Weight Loss

Baking weight loss (BWL) was determined by measuring the weight of cookies before and after baking. It was calculated by using the equation:

$$BWL\ (\%) = (m_0 - m_t)/m_0 * 100$$

where m_0 was initial cookie weight (g); m_t was the weight (g) after baking time t (min); Cookie weights (m_0 and m_t) were determined as average values of 8 independent measurements.

H. Experimental Design and Statistical Analyses

RSM was applied in order to optimize the baking conditions of gluten-free cookies. The experiments were carried out according to CCD by selecting dough thickness and baking time as independent variables, while hardness, color parameters (L*, a* and b* values), water activity, diameter and short/long ratio were response variables. The effects of independent variables on the cookies' quality were studied using CCD, which involved 11 treatment combinations with three replications of the central point, generated by statistical software (Design-Expert 7.01, trial version, StatEase, Inc., USA) (Table II). The optimal values of examined factors were determined using desirability function approach.

Two separate batches of the cookies were prepared for each treatment. Analysis of variance and Duncan's multiple range tests were used to test the statistical significance. Statistical data analysis software system STATISTICA (StatSoft, Inc. (2008) data analysis software system, version 9.0. www.statsoft.com) was used for analysis. P values < 0.05 were regarded as significant.

TABLE II
CENTRAL COMPOSITE DESIGN FOR BAKING TIME AND DOUGH THICKNESS

Treatment	Baking time (min)	Dough thickness (mm)
1	13	4.5
2	13	2.38
3	13	4.5
4	11	6.0
5	15.83	4.5
6	15	3
7	13	6.62
8	13	4.5
9	11	3
10	10.17	4.5
11	15	6

III. RESULTS AND DISCUSSION

Baking is a complex process which results in a series of physical, chemical and biochemical changes in the product [10]. Physically, it is a process involving simultaneous heat and mass transfer phenomena, and both baking time and temperature are industrially important process considerations affecting the quality [10], [11]. Dimensions and moisture content changes of cookies are significant, and large variability in these parameters may cause breakdown (cracking, checking, etc) problems [12]. Typical baking temperatures (depending on the type of oven) for fiber enriched cookies are typically in the range 160-180ºC (depending on the type of oven) with a baking time between 7 and 16 minutes [13]. Referring to the various literature data, dough thickness of cookies was reported to vary between 3 and 7mm depending on the type and composition of cookies, as well as on baking conditions.

In this study, the temperature of 170°C was chosen on the basis of previous experience in baking gluten-free cookies using the experimental oven. Baking time and dough thickness were marked as experimental factors in CCD in the ranges (-1 level / + 1 level) 11-15min and 3-6mm, respectively. These ranges were chosen on the basis of literature data and preliminary experiments performed on this type of cookies.

The results of cookies' parameters are summarized in Tables III and IV. The statistical significance of the terms in the regression equation was determined by analysis of variance (ANOVA) for each response. The adequacy of the model was evaluated by coefficient of determination (R^2) and model F and p-values. Higher F value and lower p-value indicate that corresponding term is more significant. The results of ANOVA based on RSM (Tables V and VI) indicated significant influence of baking time and dough thickness on baking loss, hardness, a_w value, moisture content and L* value of cookies. Baking time was shown to be insignificant factor ($p>0.05$) regarding cookies' width and color parameters a* and b*. The influence of dough thickness on S/L ratio was shown to be insignificant ($p>0.05$). Relatively high values of R^2 obtained for all responses indicated good fit of experimental data to corresponding model equations. Model p-values which were lower than 0.05 (Tables V and VI) implied that models for all selected responses were significant.

TABLE III
BAKING QUALITY AND COOKIES' HARDNESS OF GLUTEN FREE COOKIES ENRICHED WITH BLUEBERRY POMACE

	Ratio S/L	Width (mm)	Baking loss (%)	Hardness (g)
1	0.966 ± 0.01[a,b]	51.29 ± 0.14[a]	14.36 ± 0.22[a]	3265.52 ± 140.82[a,b]
2	0.970 ± 0.01[b,c,d]	50.04 ± 0.15[b]	20.68 ± 0.16[d]	1814.08 ± 568.82[d]
3	0.968 ± 0.01[a,b,c]	51.35 ± 0.05[a]	14.41 ± 0.19[a]	3271.52 ± 128.70[a,b]
4	0.984 ± 0.01[d]	51.49 ± 0.13[a]	9.88 ± 0.52[b]	3054.96 ± 85.88[a,b]
5	0.937 ± 0.01[e]	51.29 ± 0.08[a]	15.88 ± 0.03[f]	4824.12 ± 232.30[e]
6	0.954 ± 0.00[a,f]	50.19 ± 0.09[b]	20.89 ± 0.25[d]	2772.64 ± 520.36[a]
7	0.953 ± 0.01[a,f]	51.26 ± 0.09[a]	10.51 ± 0.47[c]	3655.30 ± 584.86[b]
8	0.970 ± 0.01[b,c,d]	51.30 ± 0.10[a]	14.31 ± 0.11[a]	3272.19 ± 129.24[a,b]
9	0.950 ± 0.01[e,f]	50.24 ± 0.20[b]	16.65 ± 0.24[g]	3016.55 ± 123.05[a,b]
10	0.983 ± 0.00[c,d]	51.31 ± 0.06[a]	10.26 ± 0.36[b,c]	894.37 ± 104.20[c]
11	0.935 ± 0.01[e]	51.50 ± 0.33[a]	13.16 ± 0.25[e]	5497.78 ± 564.90[f]

Different letters in the same column indicate significant differences ($p < 0.05$) between the mean values according to the Duncan's range test

TABLE IV
GLUTEN FREE COOKIES ENRICHED WITH BLUEBERRY POMACE: COLOR PARAMETERS (L*, A* AND B*) OF COOKIES' TOP SURFACES, WATER ACTIVITY AND MOISTURE CONTENT

	L*	a*	b*	Moisture (%)	a_w
1	33.58 ± 1.02[a]	17.41 ± 0.32[a]	2.18 ± 0.07[a]	6.68 ± 0.01[a]	0.427 ± 0.00[a]
2	31.67 ± 0.81[b]	18.14 ± 0.34[c]	1.64 ± 0.11[b]	4.38 ± 0.01[c]	0.350 ± 0.00[b]
3	33.57 ± 0.99[a]	17.41 ± 0.36[a]	2.16 ± 0.07[a]	6.67 ± 0.02[a]	0.425 ± 0.00[a]
4	32.58 ± 0.68[d]	17.04 ± 0.38[a]	3.29 ± 0.13[e]	10.3 ± 0.02[i]	0.622 ± 0.00[h]
5	33.58 ± 1.02[a]	17.48 ± 0.39[a]	2.16 ± 0.06[a]	5.76 ± 0.02[e]	0.364 ± 0.00[c]
6	31.47 ± 1.10[b]	17.01 ± 0.71[a]	1.99 ± 0.15[a]	4.09 ± 0.01[b]	0.350 ± 0.00[b]
7	33.67 ± 0.75[a]	15.75 ± 0.44[b]	3.67 ± 0.22[c]	10.2 ± 0.03[h]	0.611 ± 0.00[g]
8	33.58 ± 1.00[a]	17.38 ± 0.35[a]	2.17 ± 0.09[a]	6.68 ± 0.03[a]	0.427 ± 0.00[a]
9	31.40 ± 0.68[b]	18.53 ± 0.51[c]	1.86 ± 0.12[b]	5.54 ± 0.02[d]	0.392 ± 0.00[d]
10	30.45 ± 0.46[c]	17.42 ± 0.38[a]	2.47 ± 0.09[d]	10.0 ± 0.04[g]	0.605 ± 0.00[f]
11	33.63 ± 0.94[a]	15.60 ± 0.58[b]	3.70 ± 0.27[c]	8.37 ± 0.01[f]	0.543 ± 0.00[e]

Different letters in the same column indicate significant differences ($p < 0.05$) between the mean values according to the Duncan's range test

TABLE V
THE INFLUENCE OF BAKING TIME AND DOUGH THICKNESS ON THE MODELED RESPONSES (F AND P-VALUES): SHORT/LONG RATIO, WIDTH, BAKING LOSS, HARDNESS,

	S/L	W (mm)	BL (%)	H (g)
Source	F-value p-value	F-value p-value	F-value p-value	F-value p-value
Baking time (min)	20.32 0.0028	0.024 >0.05	110.61 0.0001	13.40 0.0064
Dough thickness (mm)	0.11 >0.05	96.35 0.0002	386.00 <0.0001	6.42 0.0351
Model	9.96 0.0064	25.78 0.0014	104.44 <0.0001	9.91 0.0068
Model fit R^2	0.8102	0.9627	0.9905	0.7124

S/L – short long ratio; W (mm) – width; BL (%) – baking loss; H (g) – hardness

TABLE VI
THE INFLUENCE OF BAKING TIME AND DOUGH THICKNESS ON THE MODELED RESPONSES (F AND P-VALUES): MOISTURE, A_W AND COLOR PARAMETERS

	M (%)	a_w	L*	a*	b*
Source	F-value p-value	F-value p-value	F-value p-value	F-value p-value	F-value p-value
Baking time (min)	31.14 0.0005	16.40 0.0037	13.72 0.0139	5.02 >0.05	0.031 >0.05
Dough thickness (mm)	104.27 <0.0001	48.50 0.0001	17.04 0.0091	23.76 0.0012	98.14 0.0002
Model	67.71 <0.0001	32.45 0.0001	9.15 0.0148	14.39 0.0022	21.95 0.0021
Model fit R^2	0.9442	0.8903	0.9015	0.7824	0.9564

M (%) – moisture

Since the final goal of RSM was to optimize the baking conditions (time and dough thickness), the concept of desirability function was chosen. The optimization was conducted by specifying the following criteria: minimal a_w value and moisture content and maximal S/L ratio. Low values of water activity and moisture in a final product are desirable in order to prevent the growth of yeasts and moulds, while high S/L ratio values indicate more oval shape of cookies and can contribute to their easier packing and better consumers' acceptability.

The overall desirability function of the gluten-free cookies' baking process was shown in Fig. 1. The highest desirability of 0.665 was achieved by setting up experimental conditions as follows: 4.08mm for dough thickness and 13.7min for baking time.

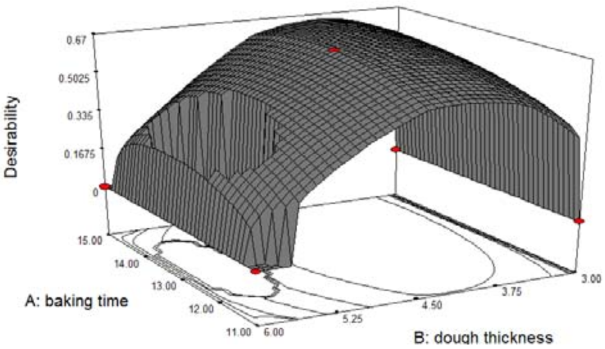

Fig. 1 Overall desirability function of the gluten free cookies' baking process

As similar optimal parameters (baking time of 14min and dough thickness of 4.5mm) were obtained by previously conducted experiment based on sensory analysis, RSM can be considered as a suitable approach to optimize the baking process [14].

IV. Conclusions

According to the results, it can be concluded that RSM presents an adequate modeling tool for the optimization of baking process of gluten-free cookies enriched with blueberry pomace. Using RSM approach, mathematical representation of the baking process and the assessment of the main contribution factors can also be done.

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