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The effect of extrusion variables on the colour of bean-based extrudates

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A mixture of bean (50%), einkorn wheat (40%), and buckwheat (10%) was extruded in a laboratory single screw extruder, using die with 3 mm diameter. The effect of extrusion conditions, including moisture content, barrel temperature, screw speed, and screw compression ratio on colour of the extrudates was investigated. Response surface methodology with combinations of moisture content (16, 19, 22, 25, 28%), barrel temperature (120, 140, 160, 180, 200ºC), screw speed (120, 140, 160, 180, 200 rpm), and screw compression ratio (1:1, 2:1, 3:1, 4:1, 5:1) was applied. Feed screw speed was fixed at 50 rpm. Feed zone temperature and metering zone temperature were kept constant at 100 and 140ºC, respectively. The total colour differences between the extruded and non-extruded samples (ΔE) were determined. The average ΔE values ranged from 11.92 to 21.15. Statistical analysis showed that the barrel temperature and moisture content had an effect on the total colour differences ($P<0.05$) whereas the screw speed and screw compression ratio had no effect on the colour.

Keywords: colour, extrusion, bean-based extrudates

INTRODUCTION

Extrusion is widely used as a high-temperature short-time process to produce commercially shelf stable extruded products. Many physical and chemical changes take place during the process, including the gelatinization of starch, denaturation of protein and even complete cooking. To fully understand changes during the process, evaluation of the effect of extrusion process variables on the extruded product is very important. There are many process and product-dependent variables associated with the extrusion process such as barrel temperature, screw speed, die diameter, and raw material composition [1-6].

Colour is an important component of the visual appearance of foods. It may also be related to the wholesomeness of foods. Along with flavour and texture, colour is often perceived as a valuable quality factor in the acceptability and marketability of food products. Colour is perceived three dimensionally, based on responses of three different receptors (red, green and blue) in the human eye [7], yet all three dimensions may not be of practical importance. The Judd–Hunter L, a, b and CIELAB L*, a*, b* are alternative colour scales used to measure the degree of lightness (L*), redness or greenness (±a*) and yellowness or blueness (±b*), with the CIELAB scale being most commonly used for the evaluation of colour in foods [8]. Conversion of a* and b* readings to hue and chroma values gives results more closely associated with human perception [9].

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The purpose of this study was to evaluate the effect of extrusion variables on the colour characteristics of bean-based extrudates.

MATERIALS AND METHODS

Raw materials and preparation

The raw materials einkorn wheat and buckwheat are provided and delivered by village of Lomets, municipality of Troyan, Bulgaria. The bean is variety "Bivolare" and it is grown in the Rhodope Mountains, Bulgaria.

Bean seeds, einkorn wheat, and buckwheat were ground using a hammer mill and passed through standard sieves to be obtained homogenized meals. The bean meal, einkorn wheat meal, and buckwheat meal were blended at a ratio of 50:40:10 (w/w/w). Samples of prepared composite meal were mixed with distilled water to be obtained various moisture contents (Table 1). The wet materials were placed and kept in sealed plastic bags for 12 h in a refrigerator at 5ºC. The samples were tempered for 2 h at room temperature prior to extrusion.

Extrusion process

The samples were extruded in a laboratory single screw extruder (Brabender 20 DN, Germany). The compression ratio of the screw was 1:1, 2:1, 3:1, 4:1, 5:1 according to the experimental design (Table 1). The extruder barrel (476.5 mm in length and 20 mm in diameter) contained three sections and independently controlled die assembly electric heaters. The screw speed was 120, 140, 160, 180, 200 rpm. Feed zone temperature and metering zone temperature were kept constant at 100 and 140ºC, respectively. The temperature of the extruder die was 120, 140, 160, 180, 200ºC. The feed screw speed was fixed at 50 rpm and the die diameter was 3 mm.

Table 1. Experimental design for the extrusion experiments

Run №	Coded levels				Actual levels			
	X_1	X_2	X_3	X_4	Moisture content (*W*, %)	Barrel temperature (*T*, ºC)	Screw speed (*N*, rpm)	Screw compression ratio (*K*)
1	-1	-1	-1	-1	19	140	140	2:1
2	1	-1	-1	-1	25	140	140	2:1
3	-1	1	-1	-1	19	180	140	2:1
4	1	1	-1	-1	25	180	140	2:1
5	-1	-1	1	-1	19	140	180	2:1
6	1	-1	1	-1	25	140	180	2:1
7	-1	1	1	-1	19	180	180	2:1
8	1	1	1	-1	25	180	180	2:1
9	-1	-1	-1	1	19	140	140	4:1
10	1	-1	-1	1	25	140	140	4:1
11	-1	1	-1	1	19	180	140	4:1
12	1	1	-1	1	25	180	140	4:1
13	-1	-1	1	1	19	140	180	4:1
14	1	-1	1	1	25	140	180	4:1
15	-1	1	1	1	19	180	180	4:1
16	1	1	1	1	25	180	180	4:1
17	-2	0	0	0	16	160	160	3:1
18	2	0	0	0	28	160	160	3:1
19	0	-2	0	0	22	120	160	3:1
20	0	2	0	0	22	200	160	3:1
21	0	0	-2	0	22	160	120	3:1
22	0	0	2	0	22	160	200	3:1
23	0	0	0	-2	22	160	160	1:1
24	0	0	0	2	22	160	160	5:1
25	0	0	0	0	22	160	160	3:1
26	0	0	0	0	22	160	160	3:1
27	0	0	0	0	22	160	160	3:1

Total colour difference (ΔE)

The extrudates were finely ground using a laboratory hammer mill. The colour parameters determined for the raw blends (non-extruded) and extruded samples included L^*, a^* and b^* values (CIE Lab system) using a colorimeter Colorgard 2000, BYK – Gardner Inc., USA. Total colour difference (ΔE) was calculated applying the equation

$$\Delta E = \sqrt{(L - L_o)^2 + (a - a_o)^2 + (b - b_o)^2} \qquad (1)$$

where L, a, and b are the values for the extruded samples; L_o, a_o, and b_o are the values for the raw mixture.

The colour parameters are the mean values of ten observations.

Experimental design and data analysis

A central composite rotatable design was used to investigate the effect of the moisture content (X_1), barrel temperature (X_2), screw speed (X_3), and screw compression ratio (X_4) on the total colour difference (response, y) in 27 runs of which 16 were for the factorial points, 8 were for axial points, and 3 were for centre points [10]. The outline of the experimental design is outlined in Table 1.

The levels of the independent variables were established according to literature information and preliminary trials.

A second order polynomial model for the dependent variable (total colour difference) was established to fit the experimental data:

$$y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} x_i x_j \qquad (2)$$

where b_0 = intercepts, b_i are linear, b_{ii} are quadratic, and b_{ij} are interaction regression coefficient terms.

SYSTAT statistical software (SPSS Inc., Chicago, USA, version 7.1) and Excel were used to analyze the data results.

RESULTS AND DISCUSSION

The total colour differences between the extruded and non-extruded samples expressed by

ΔE are given in Table 2. Higher ΔE means darker products. The total colour change in extruded samples ranged between 11.92 and 21.15 (Table 2). The extrudates were darker in colour compared to their raw blends. L^* values of the extruded samples (from 66.97 to 76.43) were lower than L_o value of the raw mixture (87.59). A similar finding has been reported by Leonel et al. [11], Bhattacharya et al. [12]. This may be due to the formation of brown pigments through non-enzymatic Maillard reactions between proteins and reducing sugars that occur during the product processing [13, 14].

Table 2. Total colour differences of bean-based extrudates

№	L^*	a^*	b^*	ΔE
1	71.33	5.78	15.11	16.92
2	66.97	5.99	14.96	21.15
3	73.53	6.15	15.45	14.98
4	71.45	6.20	14.67	16.79
5	71.52	6.41	15.96	17.06
6	69.15	6.45	14.79	19.08
7	73.67	6.47	16.09	15.11
8	71.73	6.74	16.24	17.01
9	67.80	6.98	16.19	20.76
10	68.24	5.78	13.45	19.67
11	76.43	3.99	15.47	11.92
12	71.53	4.51	15.65	16.69
13	71.49	4.99	16.05	16.88
14	69.58	4.78	15.53	18.56
15	72.34	4.60	16.73	16.24
16	69.69	4.52	15.31	18.38
17	71.49	4.83	16.84	17.09
18	68.08	4.39	15.23	19.93
19	67.46	6.29	16.11	20.95
20	75.73	3.57	16.22	12.81
21	72.15	4.09	16.67	16.34
22	69.85	4.12	16.21	18.41
23	69.78	4.71	16.71	18.66
24	68.82	3.94	18.18	19.97
25	70.82	4.06	16.89	17.67
26	71.10	3.83	16.48	17.27
27	70.51	4.01	16.95	17.98

Chroma a* (redness) values ranged from 3.57 to 6.98. There was little variability in this parameter during the extrusion, which indicates that the development of the red colouration is negligible. Similar results have been observed by Leonel et al. [11].

Responses of the b* colour parameter, which represents variation from blue to yellow, varied according to the treatment (from 13.45 to 18.18). The positive b* values indicate the yellowness of the sample. For all samples, the b* values were higher for the extrudates than for the raw mixture, which indicates more yellow products. The results correspond with established from Leonel et al. [11] and Paes and Maga [15].

Studies were conducted using the response surface method. The independent and dependent variables were fitted to the second order model equation and examined for the goodness of fit. The analysis of variance were performed to evaluate the lack of fit and the significance of the linear, quadratic and interaction effects of the independent variables on the dependent variables. The R-squared is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit [16]. When R^2 approaches unity, the better the empirical model fits the actual data. The smaller is R^2, the less relevant the dependent variables in the model have in explaining the behavior of variation [10]. It is suggested that for good fit model, R^2 should be at least 80%.

The results of the statistical analysis of variance (ANOVA) for the colour show that 3 effects have P-values less than 0.05 indicating that they are significantly different from zero at the 95.0% confidence level. The R-squared statistic is 0.83; the standard error of the estimate - 1.35, the mean absolute error - 0.71. The regression equation describing the effect of extrusion variables on the total colour difference of bean-based extrudates is given in Table 3.

Table 3. Regression equation coefficients for total colour differences of bean-based extrudates in terms of coded variables

Variables	Coefficients
Constant	55.7281
X_1	-0.3219*
X_2	-0.2334*
X_3	-0.1579
X_4	-0.6792
X_1X_1	0.0113
X_2X_2	-0.0008
X_3X_3	-0.0005
X_4X_4	0.3029
X_1X_2	0.0039
X_1X_3	-0.0021
X_1X_4	-0.0513
X_2X_3	0.0021*
X_2X_4	-0.0073
X_3X_4	0.0081

X_1 - moisture content (%), X_2 - barrel temperature (°C), X_3 - screw speed (rpm), X_4 - screw compression ratio.
*Significant at 95% CI.

The coefficients in the regression equation can be used to examine the significance of each term relative to each other when used with coded values. Statistical analysis showed that the barrel temperature and moisture content had an effect on the total colour differences (P<0.05) whereas the screw speed and screw compression ratio had no effect on the colour.

Each of the estimated effects and interactions are shown in the standardized diagram - the Pareto diagram (Fig.1). It consists of horizontal blocks with lengths proportional to the absolute values of the estimated effects, divided by their standard errors. The vertical line in the Pareto diagram represents the value of the Student criterion at 95 % confidence level and separates factors that are significant to those that are not. The Pareto diagram shows the predominance of the barrel temperature (factor B). Next in order of importance is the moisture content (factor A) and the less influential parameter is the interaction between the barrel temperature and screw speed (B × C). In total, there are three statistically significant effects.

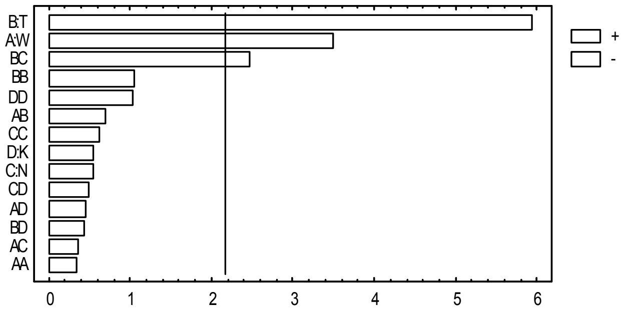

Fig.1. Estimated effects of regression model coefficients on the total colour difference

The residual quantity distribution for the regression model of the total colour change is uniformly distributed around zero and no values exceed two times the standard error (Fig.2).

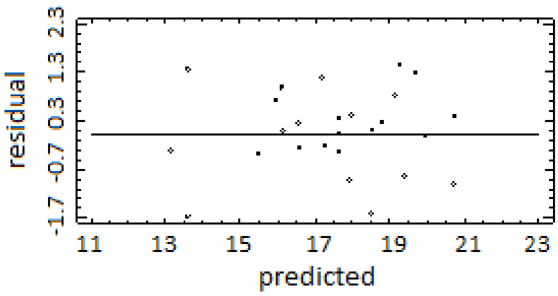

Fig.2. Residual distribution diagram

The effect of changes in moisture content and barrel temperature on the total colour differences of the samples is given in Fig.3. ΔE values increased with an increase in moisture content.

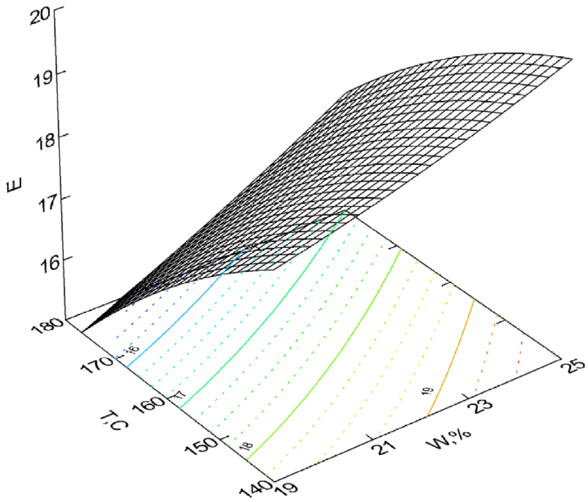

Fig.3. Effect of moisture content and barrel temperature on the total colour difference (ΔE) of bean-based extrudates

Our results show that the total colour difference of the extruded mixture increases by 17% (L^* value decreases from 71.49 to 68.08) when increasing the moisture content from 16 to 28% at barrel temperature 160ºC, screw speed 160 rpm, and screw compression ratio 3:1. Gujska and Khan [17] have extruded high starch fractions of navy, pinto, and garbanzo beans with different feed moisture contents. They have reported that increasing moisture content resulted in decreased L^* values of the extruded beans.

Although, the screw speed was not a significant parameter (Table 3), at low screw speeds a slight increase in colour change observed (Table 2) due to longer residence times which might increase the extent of chemical reactions. On the other hand, the increased screw speed increases the shear and temperature and could lead to more browning. The final effect being the result of the two opposite trends [13, 18].

CONCLUSION

The effect of extrusion variables on the colour of bean-based extrudates was studied. The average colour differences (*ΔE* values) between the extruded and non-extruded samples ranged from 11.92 to 21.15. Statistical analysis showed that the barrel temperature and moisture content had an effect on the total colour differences (P<0.05) whereas the screw speed and screw compression ratio had no effect on the colour.

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