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Effect of Extrusion Conditions on Colour Coordinates of Apple Incorporated Corn Based Extrudates

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Abstract—*The effect of composition, feed moisture, barrel temperature, and screw speed on color coordinates of corn–based apple incorporated extruded snacks were investigated in a co-rotating twin–screw extruder using response surface methodology. The corn flour obtained from C-6 variety and apple powder obtained from Red-delicious variety were used in study. The composition was set at five levels between 0-40 %, barrel temperature between 110-190℃, screw speed between 150-550 rpm and feed moisture between 12.5-22.5 %. All color coordinates of corn apple blended extrudates evaluated- (L*, a*, b*, c*, ΔE and hue angle) were significantly affected by four process variables. Out of four process variables barrel temperature was most significant factor fallowed by screw speed with quadratic effect on all the six dependent variables (L*, a*, b*, c*, ΔE and hue angle). Response surface regression models were established to correlate the color coordinates of extrudates to the process variables.*

Keywords*: Response surface methodology, extruded snacks, color, barrel temperature, screws speed.*

1. INTRODUCTION

Extrusion technology combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming. Although evolved from a simple conveying device extrusion technology has become very sophisticated in the last decade. Its functions may include conveying, mixing, shearing, separation, heating or cooling, shaping, co-extrusion, venting volatiles and moisture, flavor generation, encapsulation and sterilization. Great possibilities are offered in food processing by the use of extrusion technology to modify physicochemical properties of food components. The extruded foods, besides being preserved, have enhanced biological value, which can be characterized by physicochemical properties superior to the original raw material [9]. Extrusion cooking technology has almost limitless applications in the processing of cereal-based foods and other materials, and is associated with partial or complete gelatinization of the starch, complex formation, transformations and interactions involving biopolymers. Little work has been conducted so far on fruit incorporation in extruded products (6, 7). Therefore the aim of the present study was to develop the corn and apple blended extruded product.

Colour is a basic quality requirement, can be a useful trait for the acceptability of apple incorporated corn based extrudates. Apple incorporation not only supplementextrudates with minerals, vitamins and antioxidants, but also gives alternative colour to the product.

Since extrusion is complicated process, small variation in processing conditions affects the product quality (3). Thus, colour- one of the important quality attribute of extrudates can vary considerably depending on extruder type, screw configuration, feed moisture, and temperature profile in barrel. Session, screw speed and feed rate.

Therefore, in the present study effect of apple incorporation and extrusion variables (barrel temperature, screw speed, feed moisture) on colour coordinated of extrudates was also examined.

2. MATERIALS AND METHODS

The corn (C-6) variety obtained from division of plant breeding and genetics, SKUAST-K and locally procured culled apple (CV: Red delicious) weredried and milled in lab mill model 3030 (Perten, Sweden)to fineness that passes through 200μm sieve.The moisture content was determined by oven drying method (AACC,2000) and approximate amount of water was added to adjust the required moisture content of the blended flour as per the experimental design.

3. EXTRUDER AND PROCESSING CONDITIONS

The extrusion was performed on a co-rotating intermeshing twin screw extruder model BC 21 (Clextral, Firminy, France). The barrel diameter and its length to diameter ratio (L/D) were 2.5 mm and 16:1, respectively. The extruder had four barrel zones, temperature of the 1st, 2nd, and 3rd was maintained at 20, 30 and 40℃, respectively, throughout the study ; while the temperature in last zone (compression and die section) was varied according to experimental design as shown in table 1.

The extruder was equipped with torque indicator which showed percent of torque in proportion the current drawn by drive motor. Raw material was metered into extruder with a single screw volumetric feeder.

The extruder was thoroughly calibrated with respect to combinations of feed rate and screw speed to be used. The feed rate was varied for optimum functioning of extruder barrel corresponding to screw speed. The moisture content of feed was varied by injecting water into the extruder with a water pump. A cutter with four bladed knives and a die (6mm) made of stainless steel were used for shaping the extrudates.

4. EXPERIMENTAL DESIGN

The central composite rotatable design (CCRD) [4] was used to incorporate four independent variables *viz.,* composition, moisture content, screw speed and barrel temperature. The independent variables and variation levels are shown in table-1. The levels of each variable were established on the preliminary trials. The outline ssof experimental design with the actual level is predicted in table-1. Dependent variables were colour coordinates (L*, a*, b*, c*, ΔE and hue angle). Response surface methodology was used to investigate the effect of extrusuion conditions on the product responses. The independent variable levels apple powder incorporation 0-40%, barrel temperature 110-190℃, screw speed 150-550 rpm and feed moisture 12.5-22.50% considered for the study were selected on the basis of preliminary trials. Experiments were randomized in order to minimize the systematic bias in observed responses due to extraneous factors. The individual effect of each variable and the effect of interaction in code levels of variables were determined.

5. COLOUR ANALYSIS

The colour measurement of corn-apple blended extrudates was performed with a hunterlab colorimeter (model) as described by Lambert et al (2006). Each measurement was replicated 6 times and average values were considered. Total colour difference (ΔE).chroma values (c*) and hue angle (°) were evaluated from the colour parameters L* (brightness), a* (redness) and b* (yellowness) using

$$\Delta E = \sqrt{(L - L*)^2 + (b - b*)^2 + (c - c*)^2}$$

$$\text{Chroma } (c^*) = \sqrt{a^2 + b^2}$$

$$\text{Hue angle } (°) = \tan^{-1}\left(\frac{b}{a}\right)$$

The control (c-6) was used as reference to calculate ΔE

6. STATISTICAL ANALYSIS

Responses obtained as a result of the proposed experimental design were subjected to regression analysis in order to assess the effects of composition, moisture content, screw speed and barrel temperature on product characteristics (i,.ecolour coordinates). Second order polynomial regression models were established for the dependent variables to fit experimental data for each response using statistical software Design-Expert 8 (Stat-Ease Inc, Minneapolis, MN, USA).

$$y_i = b_0 + \sum_{i=1}^{4} b_i x_i + \sum_{i=1}^{4} b_{ii} x_i^2 + \sum_{i=1}^{4}\sum_{i=1}^{4} b_{ij} x_i x_j$$

where, xi (i = 1, 2, 3, 4) are independent variables (Composition, Moisture, Screw speed and Barrel temperature respectively) and b0, bi, bii, and bij are coefficient for intercept, linear, quadratic, and interactive effects respectively. Data was analyzed by multiple regression analysis and statistical significance of terms was examined by analysis of variance (ANOVA) for each response. The adequacy of regression model was checked by correlation coefficients. The lack of fit was used to judge the adequacy of model fit.

7. RESULTS AND DISCUSSIONS

The data on mean values of colour coordinates of extrudates revealed that the regression, models for L*, a*, b*, c*, ΔE and hue angle were highly significant($P<0.01$) with a high correlation coefficient (R^2 0.9908, 0.9859, 0.9830, 0.9850, 0.9858, 0.9826 respectively). None of the models showed significant lack of fit, indicating that all second order polynomial models correlated well with the measured data. The predicted R-square was found in reasonable agreement with adjusted R-square for all the parameters. Adequate precision compares the range of predicted values at the design points to average the prediction error. All the parameters showed high adequate precision (table 2). Table 1 shows the color parameters - L*, a*, b* and c* ofextrudates obtained under different extrusion conditions. It also lists the hue angle and total colour difference (ΔE). The brightness of extrudates ranged from 54.16 to 60.58 whereas redness and yellowness were in range of 0.65 to 4.6and 36.38 to 40.01 respectively. These differences in colour parameters were readily observable by human eye.

Table 1: Effect of extrusion conditions on colourcordinates

Run	Extrusion conditions				Product responses					
	composition	moisture	screw speed	Temp.	L*	a*	b*	c*	ΔE	hue angle
	(%)	(%)	(rpm)	(℃)	Mean	Mean	Mean	Mean	Mean	Mean
1	90: 10	15	250	130	56.68	2.01	37.38	37.43	2.22	86.92
2	70:30	15	250	130	56.65	2.08	37.4	37.45	2.14	86.81
3	90:10	20	250	130	56.6	2.2	37.51	37.57	1.98	86.64
4	70:30	20	250	130	56.58	3.41	37.63	37.7	1.83	85.29
5	90:10	15	450	130	58.92	1.9	36.72	36.79	4.61	87.1

6	70:30	15	450	130	58.89	1.4	36.38	36.4	4.4	87.79
7	90:10	20	450	130	58.61	1.6	36.71	36.7	3.63	87.5
8	70:30	20	450	130	58.54	1.9	36.83	36.87	3.71	87.04
9	90:10	15	250	170	54.48	4.58	39.2	39.43	1.6	83.74
10	70:30	15	250	170	54.32	4.5	39.38	39.63	2.5	83.48
11	90:10	20	250	170	54.22	4.6	39.51	39.77	2.08	83.35
12	70:30	20	250	170	54.16	5.8	40.01	40.42	3.06	81.75
13	90:10	15	450	170	55.72	4.6	39.14	39.07	1.2	83.29
14	70:30	15	450	170	54.67	3.6	38.17	38.33	1.02	84.61
15	90;10	20	450	170	54.52	3.3	39.11	38.27	1.58	85.05
16	70;30	20	450	170	54.47	3.5	38.03	38.16	1.35	84.65
17	100:0	17.5	350	150	55.67	3.8	38.24	38.42	0	84.32
18	60:40	17.5	350	150	55.56	4.1	38.37	38.58	0.34	83.9
19	80:20	12.5	350	150	55.78	3.7	38.29	38.47	0.91	84.33
20	80:20	22.5	350	150	55.21	4.3	38.46	38.69	0.71	83.62
21	80:20	17.5	150	150	55.32	3.75	38.41	38.64	2.87	84.46
22	80:20	17.5	550	150	58.65	2.1	36.81	36.84	4.29	86.77
23	80:20	17.5	350	110	60.58	0.65	36.14	36.16	5.89	88.87
24	80:20	17.5	350	190	54.29	5.4	40	40.36	2.74	82.78
25	80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87
26	80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87
27	80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87
28	80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87
29	80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87
30	80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87

The differences in redness and yellowness were also reflected in the values of c*. The fitted models of colour coordinates shown in equation (1) to (4) (all independent variables in coded values), indicated quadratic effects with barrel temperature, screwspeed, moisture and composition on all color coordinates of corn-based apple incorporated extrude snack evaluated-(- L*, a*,b*, c*,ΔE and hue angle).

$$L^* = 55.58 - 0.16M + 0.72S - 1.56T - 0.39ST + 0.31S2 + 0.42T2 \quad (1)$$

$$a^* = 4.20 - 0.45S + 1.14T + 0.28M - 0.21CS - 0.25MS - 0.11\ C2 - 0.098M2 - 0.37S2 - 0.34T2 \quad (2)$$

$$b^* = 39.12 - 0.42S + 0.99T - 0.19CS - 0.21C2 - 0.19M2 - 0.38S2 - 0.27T \quad (3)$$

$$c^* = 39.34 - 0.52S + 1.02T + 0.11CM - 0.13\ CS - 0.13MS - 0.13ST - 0.23C2 - 0.21M2 - 0.42S2 - 0.29T2 \quad (4)$$

$$\Delta E = 0.97 + 0.29S - 0.68T - 0.14CS + 0.25MT - 0.77ST - 0.16C2 + 0.69S2 + 0.87T2 \quad (5)$$

$$\text{Hue angle} = 83.87 - 0.16M + 0.57S - 1.56T - 0.34CM + 0.28\ CS + 0.34\ MS + 0.13C2 + 0.51S2 \quad (6)$$

Fig. 1 to 6 shows the response surface plot of different colour coordinates(- L*, a*,b*, c*,ΔE and hue angle) v/s two independent variables at a time . The barrel temperature was most significant factor affecting all colour coordinates followed by screw speed. The negative coefficient of linear term of temperature (equation1) indicated that brightness decreases with increase in temperature. The extrudates obtained at 170℃ and 250 rpm screw speed were least bright (54.16). In contrast the extrudates obtained at 110℃ and 450 rpm screw speed were most bright (60.58) (Table 1).similar results were reported by other workers [1,10].

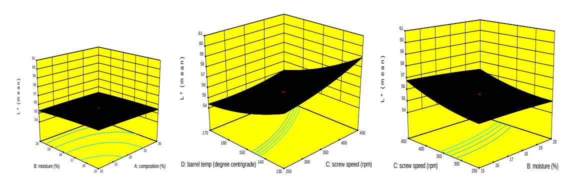

Fig. 1: Effect of moisture, screw speed and barrel temperature on L*

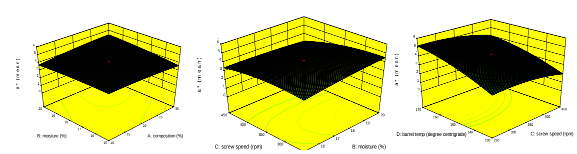

Fig. 2: Effect of moisture, screw speed and barrel temperature on a*

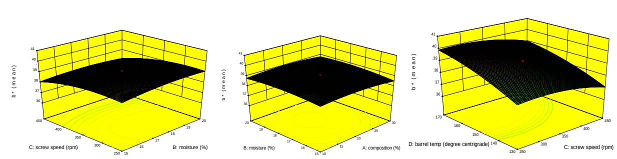

Fig. 3: Effect of moisture, screw speed and barrel temperature on b*

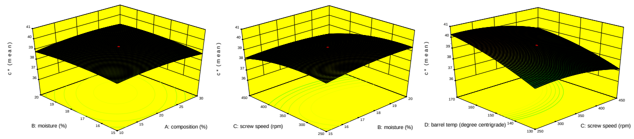

Fig. 4: Effect of moisture, screw speed and barrel temperature on c*

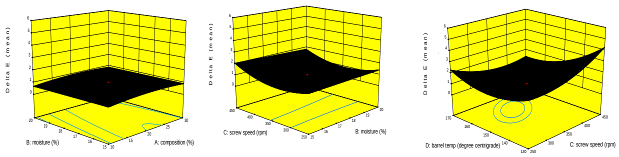

Fig. 5: Effect of moisture, screw speed and barrel temperature on ΔE

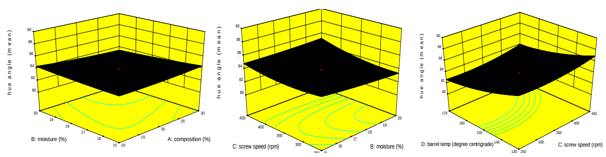

Fig. 6: Effect of moisture, screw speed and barrel temperature on hue angle

The barrel temperature, screw speed and moisture significantly affected redness and yellowness of extrudates. Due to increased values of a* and b*, the chroma (c*) values of extrudates also increased that ranged from 36.16 -40.42.

Table 2: ANOVA and model statistics for the colour coordinates of corn-based apple incorporated extruded snacks

	Response to models					
Term	**L***	**a***	**b***	**c***	**ΔE**	**Hue angle (°)**
F-value	115.74	74.89	62.08	70.45	74.55	60.62
P>F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mean	56.09	3.47	38.28	38.41	2.08	84.91
Std. deviation	0.23	0.21	0.20	0.20	0.24	0.32
CV	0.40	6.05	0.52	0.52	11.38	0.37
R- square	0.9908	0.9859	0.9830	0.9850	0.9858	0.9826
Adjusted R square	0.9823	0.9727	0.9672	0.9710	0.9726	0.9664
Predicted R square	0.9472	0.9188	0.9023	0.9137	0.9184	0.9000
Adequate precision	39.226	35.138	27.28	28.975	33.801	32.821
Lack of fit	NS	NS	NS	NS	NS	NS

The positive coefficients of linear terms of temperature and negative coefficients of screw speed (equations 2-4) indicated that a* (redness), b* (yellowness), and c* (chroma) increased with increase in barrel temperature and decreased with decrease in screw speed. Out of four independent variables (composition, moisture, screw speed and barrel temperature) considered during the experiment, the effect of barrel temperature was highly significant and more pronounced on total colour difference (ΔE) than other 3 variables (equation 5). Intermediate temperature caused the hue angle to decrease indicating that if temperature is allowed to increase to certain level during extrusion, the discoloration could occur (i.e, from yellow to amber) due to Millard type non-enzymatic browning. Park et al., (1993) reported significant interaction effect of barrel temperature on extruded products of defatted soy flour and corn starch.

8. CONCLUSIONS

RSM revealed the significant effects of all the four variables (composition, feed moisture, screw speed and barrel temperature) on colour coordinates of twin screw extruded corn-apple blended extrudates. Within the experimental range barrel temperature was most important factor affecting colour coordinates of extrudates followed by screw speed. The effect of barrel temperature and screw speed was found to be linear on all colour coordinates. The effects of both variables (barrel temperature and screw speed) were found to be on all colour coordinates expect hue angle, which showed only quadratic effect on screw speed.

Extrusion being a complex multivariate process, careful control of processing conditions is therefore required, for the production of apple incorporated corn based snacks with desired colourcharacteristics.

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