Effect of extrusion conditions on the expansion of extruded apple pomace – wheat semolina mixtures

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Abstract
Apple pomace – wheat semolina mixtures were extruded in a laboratory single screw extruder (Brabender 20 DN, Germany) with screw diameter 19 mm and die diameter 5 mm. Effects of apple pomace content in the mixtures, moisture content, screw speed, and barrel temperature on the expansion of the extruded products were studied. Response surface methodology with combinations of apple pomace content in the mixtures (10, 30, 50, 70, 90%), moisture content (17, 20, 23, 26, 29%), screw speed (120, 150, 180, 210, 240 rpm), and barrel temperature (130, 140, 150, 160, 170°C) was applied. Feed screw speed was fixed at 70 rpm. The compression ratio of the screw was 3:1. The temperatures of the feed and kneading zone were 150 and 160°C, respectively. Sectional expansion index (*SEI*), the ratio of diameter of extrudate and the diameter of die, was used to express the expansion of extrudate. The average *SEI* values ranged from 0.827 to 1.637. Statistical analysis showed that apple pomace content in the mixtures, moisture content, and barrel temperature had effect on *SEI* while screw speed had not affect expansion index of the extrudates.
Key words: *apple, pomace, wheat, semolina, extrusion.*

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Introduction

Apple pomace (AP) is the main by-product of cider processing and pose a serious environmental problem due to the large amounts produced every year. AP is composed mainly of carbohydrates and dietary fibre, small amounts of protein, fat and ash [1]. AP is a good source of phytochemicals primarily phenolic acids and flavonoids [2].

The common applications of this by-product are the direct disposal to soil in a landfill and for pectin recovery usage. In recent years, investigations into the incorporation of apple pomace in foods especially in baked foods [1].

Extruded snack products made predominantly from cereal flour tend to be low in protein with low biological value. The incorporation of enriched fibre flours with significant values of antioxidants is a way to improve the nutritional value of these snacks. Apple pomace rich in fibre with significant amounts of antioxidants can be incorporated in human food-chain thus generating new potential functional foods.

Extrudate expansion is a complex phenomenon which occurs usually during high-temperature, low-moisture extrusion cooking. Most extruded foods are actually made out of complex formulations which have different effects on the expansion [3]. Processing conditions and equipment-related variables also have the ability to influence the degree of expansion significantly.

The quality of the end product depends upon how the thermal performance of the extruder is controlled and what the thermomechanical history of the product is inside the extruder [4].

The object of this work was to study the effect of extrusion conditions on the expansion of extruded apple pomace – wheat semolina mixtures.

Materials and methods

Apple pomace is a by-product obtained during juice processing. Commercial apples (Granny Smith variety) were refrigerated and stored until the juice processing. The apple pomaces were dried a laboratory heat dryer at 60°C. The dried pomaces were ground using a hammer mill then mixed with commercial wheat semolina and distilled water to be obtained the desired ratios (Table 1). The prepared wet samples were extruded in a laboratory single screw extruder (Brabender 20 DN, Germany). The feed screw speed was fixed at 70 rpm. The screw speed was according to the experimental design (Table 1). The compression ratio of the screw was 3:1. The temperatures of the feed and kneading zone were 150 and 160ºC, respectively. The temperature of the final cooking zone was 130, 140, 150, 160, 170°C. The die diameter was 5 mm.

Sectional expansion index (*SEI*), the ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate [5, 6]. The diameter of the extrudate was determined as the mean of 10 random measurements. The extrudate expansion index was calculated as

$$SEI = \frac{D_e}{D_d} \qquad (1)$$

where *De* and *Dd* were diameter of the cooled extrudate and diameter of the die, respectively.

The effects of four independent extrusion parameters (variables) apple pomace content (X_1), moisture content (X_2), screw speed (X_3), and barrel temperature (X_4) on the dependent variable (*SEI*) were investigated using central composite rotatable design [5] and response surface methodology (RSM). All variables were controlled at five different levels.

A second-order polynomial equation was used to fit the measured, dependent variable (Y) as a function of the coded, independent extrusion variables (X_i):

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

where b_0 is the value for the fixed response at the central point of the experiment; and b_i, b_j and b_{ij} were the linear, quadratic and cross-product coefficients, respectively. The significance of the effect was given as a p-value. The effect was considered significant if the p-value for each factor or interaction is less than 0.05. SYSTAT statistical software (SPSS Inc., Chicago, USA, version 7.1) and Excel were used to analyze the data results.

Results and discussion

In extrusion cooking, expansion is the primary quality parameter associated with product crispiness, water absorption, and water solubility. During extrusion cooking of biopolymers, the viscoelastic material is forced through the die so that the sudden pressure drop causes part of the water vaporize, giving an expanded porous structure. Extruded products of different physical forms were obtained. The maximum and minimum values of *SEI* of the extrudates were 1.637 and 0.827, respectively (Table 1).

The results of the statistical analysis of variance (ANOVA) for *SEI* show that 4 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 0.93; the standard error of the estimate – 8.44, the mean absolute error – 4.57. 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 [7]. As the R-squared value for the model is more than 80% it can be considered for further analysis.

The regression equation describing the effect of extrusion variables on *SEI* of extruded apple pomace – wheat semolina mixtures is given in Table 2. 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 apple pomace content in the mixture, moisture content, and barrel temperature had an effect on *SEI* ($p<0.05$), whereas screw speed had no effect on *SEI*.

Each of the estimated effects and interactions are shown in the standardized diagram (Figure 1). The linear effect due to apple pomace content in the mixture had mostly influence on *SEI* followed by linear effects due to the moisture content and barrel temperature. The apple pomace content in the mixture, moisture content and barrel temperature had negative effect on *SEI*. When the apple pomaces content increased from 10 to 90%, the degree of expansion decreased almost twice (Table 1). Yagci & Gogus [8]), Yanniotis et al. [9] reported that pectin-rich fruits have a negative effect on the radial expansion of extrudates which is consistent with this work.

The effect of changes in the moisture content and the barrel temperature on *SEI* of the samples is given in Figure 2. Simultaneously raising the barrel temperature and the moisture content leads to decreasing the degree of expansion. Increased feed moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt, resulting in reduced the specific mechanical energy and therefore reduced gelatinization, decreasing the expansion [10]. According to Kokini et al. [11], at 160°C and 26% moisture, expansion index decreased, probably because at high temperatures starch dextrinization occurred. Gujska and Khan [12] found a similar behaviour in navy bean extrudates. They also reported that screw speed did not affect expansion index which is consistent with this work.

Table 1

Central composite rotatable design in coded form and natural units of independent variables and experimental data for sectional expansion index

Run №	Independent variables in coded form				Independent variables in natural units				*SEI* (Y)	
	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4	Experi-mental	Predicted
1	-1	-1	-1	-1	30	20	150	140	1.637	1.630
2	+1	-1	-1	-1	70	20	150	140	1.159	1.078
3	-1	+1	-1	-1	30	26	150	140	1.362	1.373
4	+1	+1	-1	-1	70	26	150	140	0.894	0.921
5	-1	-1	+1	-1	30	20	210	140	1.552	1.566
6	+1	-1	+1	-1	70	20	210	140	1.071	1.012
7	-1	+1	+1	-1	30	26	210	140	1.583	1.471
8	+1	+1	+1	-1	70	26	210	140	0.949	1.017
9	-1	-1	-1	+1	30	20	150	160	1.456	1.431
10	+1	-1	-1	+1	70	20	150	160	1.148	1.156
11	-1	+1	-1	+1	30	26	150	160	1.078	1.033
12	+1	+1	-1	+1	70	26	150	160	0.827	0.857
13	-1	-1	+1	+1	30	20	210	160	1.457	1.326
14	+1	-1	+1	+1	70	20	210	160	1.016	1.049
15	-1	+1	+1	+1	30	26	210	160	0.966	1.090
16	+1	+1	+1	+1	70	26	210	160	1.009	0.912
17	-2.0	0	0	0	10	23	180	150	1.549	1.605
18	+2.0	0	0	0	90	23	180	150	0.871	0.876
19	0	-2.0	0	0	50	17	180	150	1.292	1.386
20	0	+2.0	0	0	50	29	180	150	1.025	0.992
21	0	0	-2.0	0	50	23	120	150	1.053	1.064
22	0	0	+2.0	0	50	23	240	150	1.007	1.056
23	0	0	0	-2.0	50	23	180	130	1.354	1.393
24	0	0	0	+2.0	50	23	180	170	1.069	1.090
25	0	0	0	0	50	23	180	150	1.158	1.109
26	0	0	0	0	50	23	180	150	1.041	1.109
27	0	0	0	0	50	23	180	150	1.104	1.109
28	0	0	0	0	50	23	180	150	1.111	1.109
29	0	0	0	0	50	23	180	150	1.132	1.109

X_1 – apple pomace content in the mixture (C_{pom},%), X_2 – moisture content (W,%), X_3 – screw speed (n, rpm), X_4 – barrel temperature (T_m, °C)

Table 2

Regression equation coefficients and analysis of variance for SEI of extruded

apple pomace – wheat semolina mixtures

Variables	Coefficients	*DF*	*MS*	*p* values
Constant	1178.66			
X_1	-7.84333	1	7971.62	0.0000*
X_2	-5.94505	1	2324.6	0.0001*
X_3	-0.03814	1	1.04167	0.9055
X_4	-9.09125	1	1380.17	0.0006*
X_1X_1	0.00818	1	278.145	0.0683
X_2X_2	0.22074	1	102.405	0.2506
X_3X_3	-0.00136	1	38.9881	0.4718
X_4X_4	0.03312	1	284.553	0.0655
X_1X_2	0.04146	1	99.0025	0.2583
X_1X_3	-0.00008	1	0.04	0.9814
X_1X_4	0.0345	1	761.76	0.0056*
X_2X_3	0.04514	1	264.063	0.0748
X_2X_4	-0.11792	1	200.222	0.1159
X_3X_4	-0.00342	1	16.81	0.6348

*Significant at 95% confidence level, *DF* – degrees of freedom, *MS* – mean square

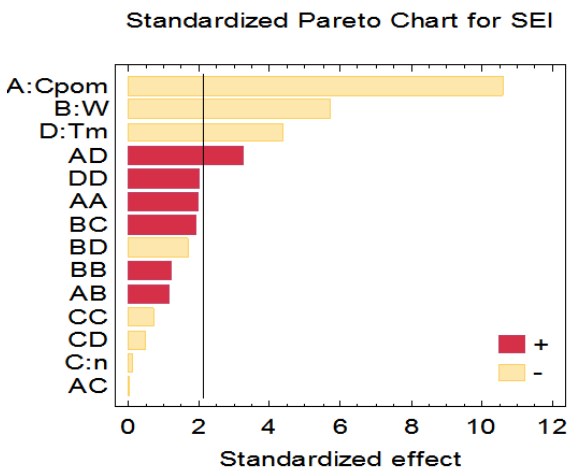

Figure 1. Estimated effects of regression model coefficients on SEI

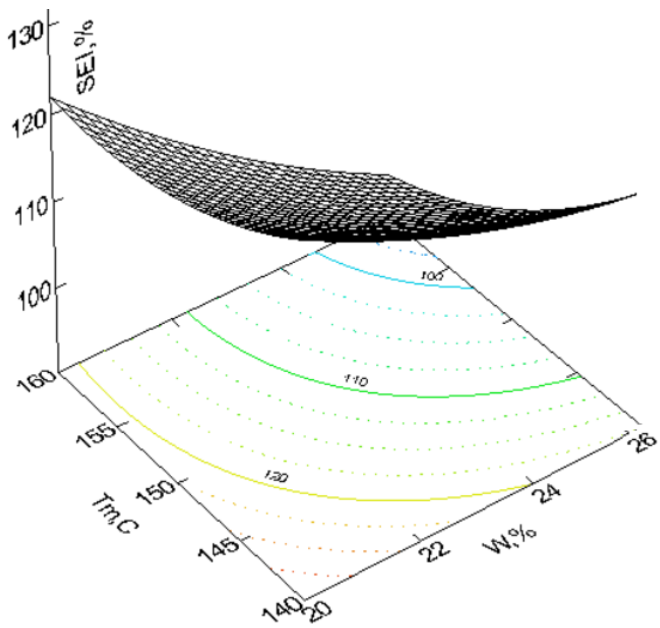

Figure 2. SEI (%) depending on T_m (°C) and W (%) at C_{pom} = 50% and n = 180 rpm

Conclusion

The average *SEI* values ranged from 0.827 to 1.637. Statistical analysis showed that the apple pomace content in the mixture had the highest effect on the expansion. The moisture content and barrel temperature also affected *SEI* while screw speed had not affect expansion index of the extrudates.

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