

Extrusion Puffing of Pork Meat-Defatted Soy Flour-Corn Starch Blends to Produce Snack-like Products

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Abstract

To produce expanded, minimally hard extrudates from blends of raw pork meat (20%), defatted soy flour (25%), and corn starch using a single-screw extruder, various combinations of feed moisture, process temperature, and screw speed were evaluated. First series of extrusion runs were conducted according to a central composite rotatable design/response surface methodology (RSM). Upon assessing the full model for each response, insignificant terms were eliminated to determine final response surface models. Screw speed within the range evaluated was found to have no significant effect on expansion ratio (ER) or shear force (SF) of extrudates. Since examinations of the response surfaces and their generated grids of predicted values indicated that maximum ER and minimum SF were likely to be attained with a moisture-temperature combination outside the RSM experimental range, the second series of extrusion runs were conducted with several selected combinations of moisture and temperature to determine a practical optimum extrusion condition. The combination of 22.78% feed moisture, 160°C process temperature, and 170 rpm screw speed was chosen as such a condition, and used in the final extrusion. The final product required less force to break than did commercial pretzel sticks.

Key words: extrusion, puffing, pork, soy flour, corn starch, snacks, process optimization

INTRODUCTION

Snacks account for 15% of the total caloric intake of children and adolescents, according to a USDA survey (1). Overall, the consumption of snacks continues to increase. The per capita consumption in 1997 was 21.6 pounds in the United States, a 2% increase over 1996 (2). Thus, enhancing the nutritional value of snack foods may have a positive impact on the overall nutritional quality of the diet of the general public. Meat can provide substantial nutrients to consumers, but meat snacks comprised only 1% of the total snacks consumed in the United States in 1997 (2). Nutrient-rich ingredients of animal and plant sources may be introduced to cereal-based snacks, which are widely consumed and cheaper than meat snacks, as a means of increasing the nutritional contribution of snack consumption.

Extrusion cooking is a versatile process where a food material or a mixture of ingredients (called feed) is subjected to various conditions of mixing, heating and shear, and the cooked mass is forced to flow through a die designed to form or puff-dry the extrudate. Extrusion cooking, although flexible, is complex and sophisticated, because it requires close control of many variables over a wide range of conditions. Thus, new sets of optimum process conditions are required for each set of new circumstances, and these must be determined empirically because there is no fully developed theory to predict the effects of available process variables on various

complex raw materials and their mixtures (3). Nevertheless, extrusion cooking has been successfully applied to the development of directly expanded (rather than oil-puffed) snack-like products from blends of raw/non-dehydrated meat (beef, chicken, pork, lamb, mutton) or fish and non-meat ingredients (4-10). However, it should be emphasized that any change in feed composition, which is influenced by the type of ingredients as well as the amount of each ingredient, and any process variable that affects physical or chemical transformations of macromolecules during extrusion can influence extrusion performance and quality of the extrudate.

Defatted soy flour (DSF) and corn starch were used as the non-meat ingredients in some (4,5,8) of the aforementioned studies involving extrusion of blends of meat and non-meat ingredients. DSF is a high-protein ingredient. However, if used at relatively high levels, it may adversely affect the extrudate flavor. When DSF was used at ~50% level in the feed with 22% corn starch and 20~29% meat, some members of a trained sensory panel detected beany or hay-like flavors in the extrudate (5,8). Such off-flavor notes could be avoided by moderately reducing the DSF content (e.g., to 25% of feed). This study entails the first part of our research where such a level of DSF was used with pork meat and corn starch to produce nutritious, snack-like expanded extrudates with no apparent beany flavor notes. The specific objective of this study was to determine the combination of feed moisture, process temperature and screw speed that would produce ex-

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panded, minimally hard extrudates from blends of 20% raw pork meat, 25% DSF, and appropriate amounts of corn starch. A die with a larger nozzle diameter--6.35 mm, rather than 3.175 mm as in the study by Park et al. (5)--was used to produce extrudates that would look more snack-like. Pork was used as the meat source in this study as well as in the subsequent study (11), because it is less utilized than beef and poultry (12).

MATERIALS AND METHODS

Ingredients

Pork boston butts were obtained from a local meat processor. After removing bone and separable fat, lean meat pieces were ground twice (first through a plate with 1.27-cm diameter holes, then through a plate with 0.32-cm holes) and thoroughly hand-mixed. The ground pork meat was vacuum-packaged in 500-g portions and held at -20°C until needed. Prior to preparation of feed mixtures, the frozen meat was tempered overnight at 4°C, without breaking the vacuum seal. A high-amylose corn starch product (Hylon® VII) containing about 70% amylose was obtained from National Starch and Chemical Co. (Bridgewater, New Jersey), and DSF (200/70 Defatted Soy Flour) from Cargill Protein Products (Cedar Rapids, Iowa). Table 1 shows the proximate composition of each ingredient.

Preparation of feed mixtures

Preliminary extrusion runs were conducted to select the pork meat and DSF levels. The levels chosen based on cursory bite tests (for hardness) of extrudates were 20% pork meat and 25% DSF. The amounts of corn starch and water required to attain a predetermined/target feed moisture level were determined using the User Friendly Feed Formulation program (13).

Ground pork was finely chopped in a food processor for 2 min. Water, DSF and corn starch (the latter two mixed together) were added to the meat, and the mixture was blended for 2 min in the food processor. Uniformity of the particle size of each feed mixture was achieved by repeatedly screening through a US #14 sieve. Feed mixtures were placed in Ziploc® freezer bags and stored in a 4°C refrigerator overnight for moisture equilibration. Prior to extrusion, they were removed from the refrigerator and held for 1 hr at ambient temperature.

Extrusion in general

A single-screw laboratory extruder (Type 1503) from C.W. Brabender Instruments, Inc. (South Hackensack, New Jersey) was used. Diameter of the extruder barrel was 1.91 cm and

its length-to-diameter ratio was 15 : 1. A screw with a compression ratio of 4 : 1 and a die with a nozzle diameter of 6.35 mm were used. Feeder speed, temperature of the first zone (feeding section) of the barrel, and temperature of the second zone (mixing section) were set constant at 50%, 20°C and 150°C, respectively. Temperature of the third zone (metering section) of the barrel and screw speed were varied according to experimental design or objective. Extrudates were cooled at room temperature, cut into 6-cm strands, and dried for 8 hr in a 65°C oven. Through this drying step, extrudates became crisp and reached an ultimate/minimum moisture level needed for crunch extruded snacks. The dried extrudates were placed in Ziploc® freezer bags and kept at -20°C until analyzed.

First series of extrusion runs: RSM experiment

The three independent variables we selected for the RSM experiment were feed moisture (X_1), process temperature (X_2) and screw speed (X_3). Treatments were arranged according to a central composite rotatable design (14), which required 20 combinations of the three variables--8 or 2^3 factorial points, 6 extra points (star points) and 6 replicates of the center point to determine experimental error. A range for each variable was selected based on results from preliminary extrusion runs. The coded levels and actual values (in the original units) of the variables for the 20 extrusion runs are shown in Table 2, with their feed formulations given in Table 3. The extrusion runs were randomly assigned to six processing days (3 or 4 runs/day), with one of the center portion runs being included each day. The dependent variables (responses) measured on extrudates were expansion ratio (ER),

Table 2. Combinations of feed moisture (x_1), process temperature (x_2) and screw speed (x_3) used for the RSM extrusion runs

Run	Coded level			Actual level		
	x_1	x_2	x_3	x_1	x_2	x_3
Factorial points						
1	-1	-1	-1	25.30	170	160
2	1	-1	-1	32.70	170	160
3	-1	1	-1	25.30	190	160
4	1	1	-1	32.70	190	160
5	-1	-1	1	25.30	170	180
6	1	-1	1	32.70	170	180
7	-1	1	1	25.30	190	180
8	1	1	1	32.70	190	180
Star points						
9	-1.68	0	0	22.78	180	170
10	1.68	0	0	35.22	180	170
11	0	-1.68	0	29.00	163	170
12	0	1.68	0	29.00	197	170
13	0	0	-1.68	29.00	180	153
14	0	0	1.68	29.00	180	187
Center point (6 replicates)						
15	0	0	0	29.00	180	170
16	0	0	0	29.00	180	170
17	0	0	0	29.00	180	170
18	0	0	0	29.00	180	170
19	0	0	0	29.00	180	170
20	0	0	0	29.00	180	170

Table 1. Proximate composition of ingredients

	Moisture (%)	Fat (%)	Protein (%)
Pork meat	72.83	7.17	25.31
Corn starch	11.47	-	-
Defatted soy flour	5.36	≤1.20 ¹⁾	≥50 ¹⁾

¹⁾From supplier's nutritional analysis report.

Table 3. Feed formulations for the RSM extrusion runs

Run	Variable coded level ¹⁾			Formulation (%)			
	x ₁	x ₂	x ₃	Corn starch	Pork lean	Defatted soy flour	Added water
1	-1	-1	-1	51.52	20.00	25.00	3.48
2	1	-1	-1	43.16	20.00	25.00	11.84
3	-1	1	-1	51.52	20.00	25.00	3.48
4	1	1	-1	43.16	20.00	25.00	11.84
5	-1	-1	1	51.52	20.00	25.00	3.48
6	1	-1	1	43.16	20.00	25.00	11.84
7	-1	1	1	51.52	20.00	25.00	3.48
8	1	1	1	43.16	20.00	25.00	11.84
9	-1.68	0	0	54.36	20.00	25.00	0.64
10	1.68	0	0	40.31	20.00	25.00	14.69
11	0	-1.68	0	47.34	20.00	25.00	7.66
12	0	1.68	0	47.34	20.00	25.00	7.66
13	0	0	-1.68	47.34	20.00	25.00	7.66
14	0	0	1.68	47.34	20.00	25.00	7.66
15	0	0	0	47.34	20.00	25.00	7.66
16	0	0	0	47.34	20.00	25.00	7.66
17	0	0	0	47.34	20.00	25.00	7.66
18	0	0	0	47.34	20.00	25.00	7.66
19	0	0	0	47.34	20.00	25.00	7.66
20	0	0	0	47.34	20.00	25.00	7.66

¹⁾ x₁ = feed moisture; x₂ = process temperature; x₃ = screw speed.

bulk density (BD), shear force (SF), and Hunter color *L* value (HCL).

Data analyses were conducted using the Statistical Analysis System (SAS) software, version 6.11 (15). The RSREG Procedure was used in initial analysis. Then, the full predictive models were reduced by backward elimination, using the STEPWISE Procedure with the BACKWARD option selected for model. Three-dimensional plots were generated by the G3D Procedure using the reduced models. The CORR Procedure was used to determine correlation coefficients between variables. Significance was established at $p \leq 0.05$ unless otherwise indicated.

Second series of extrusion runs

Assessment of the reduced models from the RSM experiment indicated the necessity of further exploration of areas outside the RSM experimental region to attain minimal SF and high ER values for the extrudate. Thus, additional extrusion runs were conducted using six selected combinations of feed moisture and process temperature (i.e., 22.78% or 25.30% feed moisture with 160°, 165° or 170°C process temperature). These two variables were the ones found to have significant effects on ER and SF according to the final (reduced) models, which will be discussed subsequently. Screw speed was kept constant at 170 rpm. The data from these extrusion runs were analyzed by the GLM Procedure (15) with the six moisture-temperature combinations regarded as six treatments. Means were separated by the Student-Newman-Keuls test, at $p \leq 0.05$.

Analytical methods

Proximate compositions of raw materials

Moisture (by oven drying) and protein content were determined by AOAC (16) procedures. Lipids were extracted

from pork meat according to the procedure of Folch et al. (17) and total fat content was determined gravimetrically on aliquots of the lipid extract.

Determination of physical properties of extrudates

To determine the ER of an extrudate strand, diameters at several different locations along the strand were measured first, using a Vernier caliper (Precision Plastic Measuring Instruments, Switzerland), and ER was calculated by dividing the average diameter of the strand by the diameter of the die nozzle. ER was measured on 20 strands/product.

For BD, the length and average diameter of an extrudate strand were measured using the caliper. Then, the length of the strand was multiplied by its average cross-sectional area to estimate the extrudate volume. BD was calculated by dividing the weight (g) of the strand by its estimated volume (L). BD was determined on 20 strands/product.

To determine SF, three 6-cm strands were placed perpendicular to the blade slots of an Allo-Kramer shear compression cell with 10 parallel blades. The cell was mounted on an Instron Universal Testing Machine (Model 1011; Instron Engineering Corp., Canton, Massachusetts). Full scale load was 500 kg and crosshead speed was 200 mm/min. SF was calculated by dividing the maximum shear force (kg) of the sample by its weight (g). Ten measurements were made for each product.

To determine the lightness (in color) of a product, a relatively large amount of the product was finely ground before sampling, in order to minimize sample variation. Hunter color *L* values (100 = perfect white; 0 = black) were measured on finely ground extrudates, using a Hunterlab tristimulus colorimeter (Model D25M-9; Hunter Associates Laboratory, Inc., Reston, Virginia). Each product was analyzed in triplicate.

RESULTS AND DISCUSSION

Preliminary extrusion runs

At the outset, we planned to use less DSF in feed formulation than the amount used in the study by Park et al. (5)—47.6% DSF, along with 29.3% beef meat (knife-separable lean) and 22% cornstarch—to avoid potential flavor problem due to a high level of DSF. Our initial runs were designed with some modifications of the conditions used in the aforementioned study, where extrusion was done at 29.1% feed moisture, 162°C process temperature and 170 rpm screw speed, using a die of smaller nozzle diameter (3.175 mm vs. 6.35 mm in the current study) but the very same extruder and screw. Initial feed formulations consisting of 30% DSF, 30% pork meat, corn starch, and added water—with the amounts of the latter two being varied to attain 26~35% target moisture—yielded very dense and compact extrudates. The major problem here was that it was not possible to closely predict the extent to which the extrusion performance would be affected by the feed composition

changes (i.e., a reduced amount of DSF, accompanied by an increased amount of corn starch). This was not entirely unexpected, because there is no fully developed theory to predict the extrusion performance or extrudate properties when changes are made in either feed composition or process variable (3). Additionally, there was the possibility that the performance of our extruder might have changed since it was used in the study by Park et al. (5). Extruder performance can decline with time as the machine wears (18). Eventually, numerous preliminary extrusion runs led us to use the combination of 29% feed moisture, 180°C process temperature, and 170 rpm screw speed as the extrusion condition for the center portion of the RSM design (Table 2).

RSM extrusion runs

ER, BD, SF and HCL values of extrudates produced under different combinations of feed moisture level, process temperature and screw speed are shown in Table 4. In the full models describing the response surfaces, only very few of the regression coefficients (none in the case of HCL) were significant (Table 5). Moreover, none of the individual linear coefficients was significant. However, the analysis of variance (ANOVA) for the fit of experimental data to the full models indicated a significant effect of the linear term in the ER and BD models (Table 6). These suggested that some of the terms in full model might be predicting the same effect on the response. The only case where the model seemed to be genuinely non-significant was with HCL, since none of the terms in the model was significant (Tables 5 and 6) and the coefficient of determination (R^2) also was low (Table 6). Lack of fit was not significant for the ER, BD and HCL models, but significant for the SF model (Ta-

Table 4. Expansion ratio (ER), bulk density (BD), shear force (SF) and Hunter color L (HCL) values of extrudates from the RSM extrusion runs

Run	Variable coded level ¹⁾			ER	BD (g/L)	SF (kg/g)	HCL
	x_1	x_2	x_3				
1	-1	-1	-1	0.728	323	37.96	72.45
2	1	-1	-1	0.548	562	51.69	70.78
3	-1	1	-1	0.703	273	37.60	69.51
4	1	1	-1	0.449	538	49.53	68.55
5	-1	-1	1	0.752	297	26.61	71.77
6	1	-1	1	0.499	569	54.53	70.84
7	-1	1	1	0.664	258	43.89	70.49
8	1	1	1	0.436	510	50.22	69.14
9	-1.68	0	0	0.859	289	39.17	70.87
10	1.68	0	0	0.678	683	40.87	72.05
11	0	-1.68	0	0.595	459	32.49	70.66
12	0	1.68	0	0.540	369	50.14	69.86
13	0	0	-1.68	0.533	418	68.68	70.05
14	0	0	1.68	0.572	397	48.09	71.41
15	0	0	0	0.557	395	48.04	70.19
16	0	0	0	0.585	438	50.59	71.46
17	0	0	0	0.569	369	52.86	70.36
18	0	0	0	0.512	428	59.21	69.98
19	0	0	0	0.580	428	52.96	71.27
20	0	0	0	0.608	355	55.01	71.17

¹⁾ x_1 = feed moisture; x_2 = process temperature; x_3 = screw speed.

Table 5. Regression coefficients and equations¹⁾ of full response surface models

Coefficient	Response ²⁾			
	ER	BD	SF	HCL
β_0	-3.235	219.617	-1052.531	83.927
β_1	-0.235	-87.996	32.154	-1.172
β_2	0.035	3.154	15.611	0.314
	0.054	11.323	-9.624	-0.228
β_{11}	0.005****	1.833**	-0.373*	0.013
β_{21}	-0.0002	0.020	-0.079	0.001
β_{22}	-0.00008	-0.003	-0.045*	-0.002
β_{31}	-0.0002	0.068	0.029	0.001
β_{32}	-0.00003	-0.030	0.019	0.003
β_{33}	-0.0001	-0.025	0.014	-0.0008

¹⁾ Response $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3$, where $Y = ER, BD, SF$ or HCL , X_1 = value for feed moisture, X_2 = value for process temperature, X_3 = value for screw speed.

²⁾ * $p < 0.05$; ** $p < 0.01$; *** $p < 0.005$; **** $p < 0.001$.

Table 6. Analysis of variance for the fit of experimental data to full response surface models

Source	df	Sum of square ¹⁾			
		ER	BD	SF	HCL
Model	9	0.1846***	227300****	1308*	10.1322
Linear	3	0.1188****	217650****	504	7.9626
Quadratic	3	0.0651***	9524*	696*	1.5443
Cross product	3	0.0007	126	108	0.6253
Residual	10	0.0255	8280	465	8.0552
Lack of fit	5	0.0201	2285	393*	6.0465
Pure error	5	0.0053	5995	73	2.0087
R^2		0.88	0.97	0.74	0.56

¹⁾ * $p < 0.05$; ** $p < 0.01$; *** $p < 0.005$; **** $p < 0.001$.

ble 6). Table 7 shows the final predictive equations obtained through elimination of insignificant terms from the full models. The R^2 values and the significance levels of F-statistics from ANOVA indicated adequacy of the reduced models for ER, BD and SF. For HCL, the model accounted for only 36% of the variability, although the two terms in the model were significant.

Effects of independent variables on physical properties of extrudates

None of the responses was significantly affected by screw speed within the test range (153~187 rpm), as shown by the absence of the X_3 term in any of the final (reduced) models (Table 7). The non-effect of screw speed could be due in part to the particular ranges chosen for the other two extrusion variables (feed moisture and processing temperature), in conjunction with the screw speed range. It is not known whether the outcome could have been different if a much wider range of screw speed had been evaluated.

Hunter color L value

Although R^2 for the HCL model was low (0.36) (Table 7), the correlation coefficient between HCL and process tem-

Table 7. Final (reduced model) predictive equations for responses

Response	Predictive equation ¹⁾	R ²	Sig. level ²⁾
ER	Y = 5.7342 - 0.2999X ₁ - 0.0027X ₂ **** **** * + 0.0048X ₁ ² ****	0.86	****
BD	Y = 1412.909 - 74.002X ₁ - 2.359X ₂ **** * *** + 1.853X ₁ ² ****	0.96	****
SF	Y = - 1873.714 + 23.483X ₁ + 17.145X ₂ ** ** * - 0.384X ₁ ² - 0.047X ₂ ² * *	0.61	***
HCL	Y = 83.065 - 0.069X ₂ **** **	0.36	***

¹⁾The significance level of each term in an equation is denoted by asterisks under the term : *p < 0.05; **p < 0.01; ***p < 0.005; ****p < 0.001. X₁ = feed moisture; X₂ = process temperature; X₃ = screw speed.

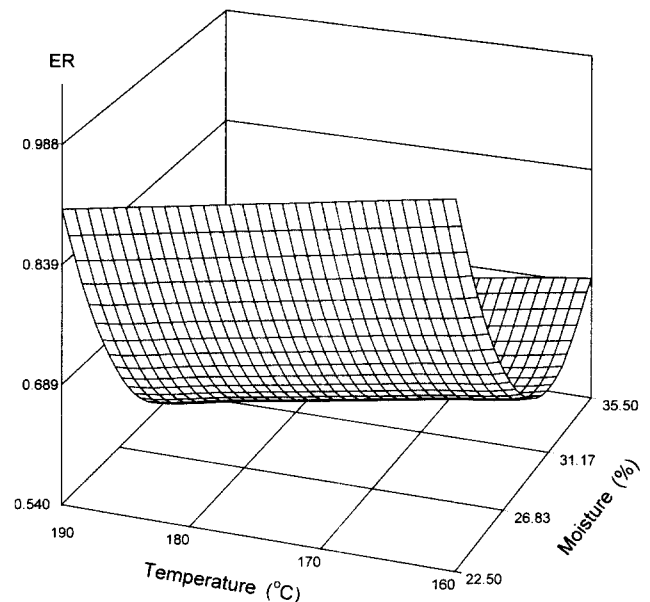
²⁾Significance level (p value) for F-statistic from analysis of variance : ***p < 0.005; ****p < 0.001.

perature was -0.60 (p = 0.005). Such correlation seems logical in light of the fact that heat accelerates non-enzymatic browning reactions, which readily occur in the low-moisture extruded foods (19). To some extent, the decreased lightness of extrudates with temperature increase could also be due to decreased expansion of extrudates; elevating processing temperature decreased both product expansion and lightness, with HCL (lightness) values of extrudates correlated (r = 0.57; p < 0.01) to their ER values. The potential relationship between lightness and expansion of extrudates was also pointed out in a corn meal extrusion study (20).

Expansion ratio

Feed moisture (X₁) was the dominant factor influencing ER (Table 7). Moisture had a quadratic effect on ER. When considering moisture as the sole variable, the response surface was a parabola facing upward with a minimum (Fig. 1). ER decreased as moisture increased, reaching a minimum at ~31% moisture, then increased again when moisture increased further. However, products of higher feed moisture levels would be meat-like in texture. For example, Kristensen et al. (21) reported that, to produce meat-like chunks from blends of slaughterhouse by-products and potato starch, feed moisture in the 40~50% range would be needed. Likewise, single-screw extrusion of DSF to produce textured soy flour required ~33% feed moisture (22). When an expanded (puffed) product is desired, lower feed moisture levels are required. For expanded ready-to-eat cereals, extrusion cooking is accomplished at >20% moisture; however, for highly expanded cereal snacks, extrusion is done at low feed moisture (<15%), high-shear, and high-temperature conditions that cause significant damage to starch (22).

Process temperature (X₂) added a second dimension to the parabola and the surface looked like a trough (Fig. 1). Its small, negative coefficient (Table 7) tilted the trough slightly

**Fig. 1.** Response surface for the effects of feed moisture and process temperature on expansion ratio (ER).

upward (higher ER values) toward lower temperature. When holding moisture constant, one would need a 30°C change to effect an ER change of 0.1. From inspection of the surface (Fig. 1) and its generated grid of predicted values (not shown), maximum ER values were to be obtained in a region outside the range of experimentation--i.e., at ~22.5% feed moisture in combination with 160°C process temperature.

Bulk density

Feed moisture was the dominant factor for BD as well, as seen from the magnitudes of its coefficients in the model (Table 7). There was a quadratic relationship between BD and feed moisture. The entire response surface looked like a trough, but only half of it was seen within the test ranges of feed moisture and process temperature (Fig. 2). Lower BD values were to be obtained by lowering feed moisture. The negative estimate of process temperature (Table 7) tilted the trough downward (lower BD values) toward higher temperature. With moisture held constant, a 30°C increase would decrease BD by 70 g/L.

Shear force

Both feed moisture and process temperature had quadratic effects on SF (Table 7). The response surface looked like a dome, with lower SF values seen at the edges of the dome (Fig. 3). Examination of the surface and its generated grid of predicted values (not shown) indicated that minimum SF was to be attained with ~22.5% feed moisture and 160°C process temperature. Note that this also was the region where maximum ER was predicted.

Region of optimal response vs. final extrusion condition selected

Since maximum ER and minimum SF values were pre-

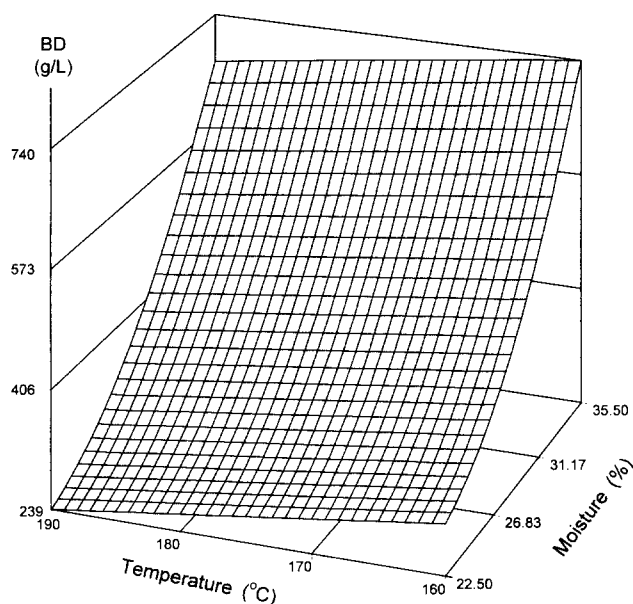


Fig. 2. Response surface for the effects of feed moisture and process temperature on bulk density (BD).

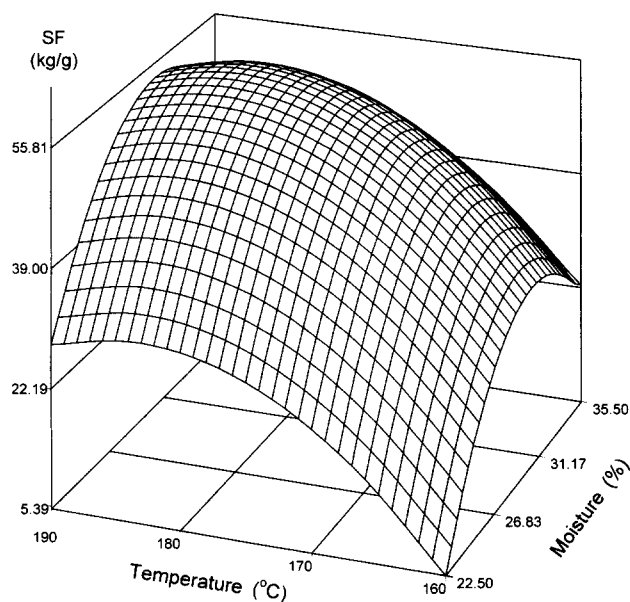


Fig. 3. Response surface for the effects of feed moisture and process temperature on shear force (SF).

dicted to be at a feed moisture-process temperature combination of ~22.5% and 160°C, a region outside the RSM experimental range, the second series of extrusion runs were designed around this area—i.e., 22.78% or 25.30% feed moisture in combination with 160°, 165° or 170°C process temperature—to pinpoint the optimum moisture-temperature combination. Upon assessing the ER and SF results from these extrusion runs and experimental constraints, we selected the combination of 22.78% feed moisture and 160°C processing temperature for final extrusion. Although SF values of extrudates were only numerically (not statistically) lower with this moisture-temperature combination than with the 22.78%-

165°C combination, ER was significantly higher. The experimental constraints or practical matters we considered were related to feed moisture. Although the results (Fig. 4 and 5) implied that lowering feed moisture beyond 22.78% could increase ER and decrease SF of extrudates, 22.78% was the lowest moisture attainable when using 20% pork meat in feed, due to the moisture contributed by the meat. Also, the minimum feed moisture that the extruder can tolerate had to be considered. It appeared that the extruder might not tolerate feed moisture less than 22.78% under the circumstances of our study. Even at 22.78% moisture, we encountered some difficulty in feeding.

Thus, the final extrusion runs were conducted with 22.78% feed moisture, 160°C process temperature and 170 rpm screw speed. (Although we selected 170 rpm, theoretically, any screw speed within the range of the RSM experiment could be used without drastically altering extrudate properties.) The

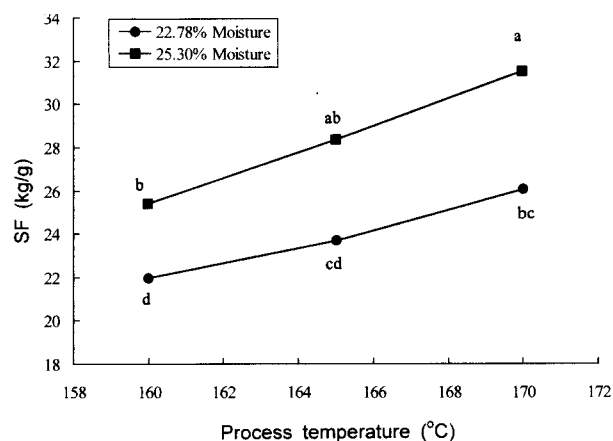


Fig. 4. Plot of shear force values for different combinations of feed moisture and process temperature used in the second series of extrusion runs. Means without a common letter are significantly different ($p < 0.05$).

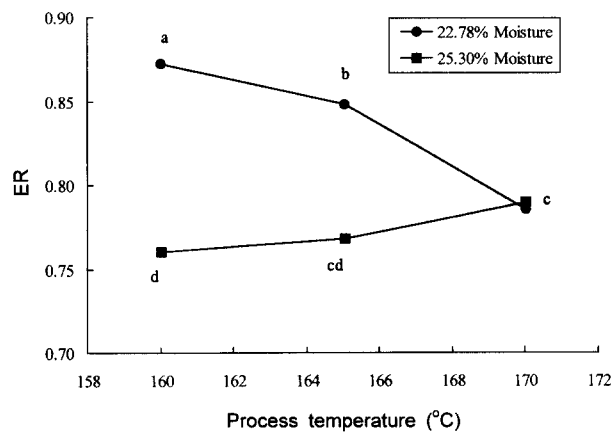


Fig. 5. Plot of expansion ratios for different combinations of feed moisture and process temperature used in the second series of extrusion runs. Means without a common letter are significantly different ($p < 0.05$).

mean ER and SF values of the final product were 0.86 and 18.75 (kg/g), respectively. The final product required less force to break (lower SF values) than any of the products from the RSM runs (Table 4) and commercial pretzel sticks (Rold Gold Pretzel Sticks from Frito-Lay, Plano, Texas) with a mean SF value of 27.28. In our subsequent study (11), 20% pork meat-25% DSF-corn starch blends were extruded with or without additional non-meat ingredients, at the condition finally selected in the current study (i.e., 22.78% feed moisture, 160°C process temperature and 170 rpm screw speed), and the resultant products were evaluated for various quality traits.

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