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Extrusion behaviour of grits from flint and sweet corn

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Abstract

Studies were conducted to investigate the effect of feed moisture, extrusion temperature and screw speed on the extrusion behaviour and product characteristics of flint and sweet corn grits. The extruder die pressure and extrudate properties, such as expansion and water solubility index (WSI), were analyzed. Second order polynomials were computed to describe the extruder response and product properties of grits from both corn types as a function of feed moisture, extrusion temperature and screw speed. Among feed moisture, extrusion temperature and screw speed, feed moisture showed the most pronounced effect on die pressure, expansion and WSI. Die pressure of the extruder was significantly greater for sweet corn than flint corn grits. The grits from both the corn types differ significantly with respect to extrusion behaviour and product characteristics under similar extrusion conditions. The particle size distribution revealed that flint corn grits had more fine and opaque particles and resulted in extrudates with lower WSI and expansion than those from sweet corn grits which had fewer fine particles. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Extrusion; Corn grits; Feed moisture; Extrusion temperature; Screw speed

1. Introduction

Extrusion cooking is used worldwide for the production of expanded snack foods, modified starch, ready-to-eat cereal foods, pet foods and porridge (Frame, 1994; Harper, 1981; Smith & Singh, 1996). Extrusion variables, composition of feed material, particle size distribution and additives, significantly affect extrusion parameters and product properties (Ryu, Neumann, & Walker, 1993; Singh, Cairns, Morris, & Smith, 1998; Singh, Kaur, Singh, & Sekhon, 1999; Singh & Smith, 1997). Corn meal is a major ingredient for extruded foods, such as ready-to-eat breakfast cereals and snacks. The effect of various process variables on extrusion behaviour of corn grits have been extensively studied (Fletcher, Richmond, & Smith, 1985; Hsieh, Peng, & Hukk, 1990; Singh, Smith, & Frame, 1998). De Muelenaere and Buzzared (1969) extruded degermed corn grits and whole corn meal and found that degermed corn grit had much greater expansion than whole corn. Zhang and Hoseney (1998) reported extrusion behaviour of corn meal with poor and good expansion properties. They reported large particle size alone caused poor expansion, however, the differences in particle between good and poor corn meals was relatively small and not completely responsible for differences in expansion. Matz (1993) reported the importance of particle size of material during extrusion cooking of puffed snacks; however, they reported no details. Huber and Rokey (1990) reported that a soft texture product resulted from a fine granulation and a coarse meal led to a more crunchy product. In North India, grits milled from flint and sweet corn are utilized by the extruded snack industry. Flint corn grits are considered better by millers because of more recovery of grits while the sweet corn grits are preferred by the snack industry because of their richer colour. The literature reveals that no information is available on the extrusion behaviour of grits milled from flint and sweet corn.

The present investigation was undertaken to study the effect of feed moisture, extrusion temperature and screw speed on extrusion behaviour and product characteristics of grits from flint and sweet corn.

2. Materials and methods

2.1. Materials

Corn grits from flint and sweet corn were supplied by BNF Mills (Batala, Amritsar). Water solubility index

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(WSI) and WAI of raw flint and sweet corn grits were determined as described earlier by Anderson, Conway, Pfeiffer, and Griffin (1969). WAI and WSI were calculated by the equations:

$$\text{WAI} = \text{weight of sediment}/\text{weight of dry solids}$$

$$\text{WSI} = \text{weight of dissolved solids in supernatant} \times 100/\text{weight of dry solids}$$

The fat content of corn grits was determined using AACC (1992) methods.

2.2. Preparation of samples

Feed moistures of grits samples were adjusted to desired moisture content by spraying calculated amounts of distilled water and mixing continuously in a Hobart mixer (Model, N-50). The samples were packed in polyethylene bags and kept in the refrigerator overnight to equilibrate the moisture. The samples were brought to room temperature before extrusion cooking.

2.3. Extrusion cooking

Extrusion cooking of differently conditioned samples was carried out in a single screw extruder (Model 2003, C. W. Brabender, Hackensack, NJ) with a 1.9 cm diameter and 20:1 barrel length to dia ratio (Singh, Sharma, & Singh, 2000). The extruder was fitted with a die nozzle having 3.75 mm diameter. The feed zone temperature was maintained at 85°C while the compression and die zone temperature was kept either at 125, 150 or 175°C. The extruder feeder screw was run at a constant speed of 100 rpm. Die pressure was measured using a Dynisco pressure transducer (Dynisco Ltd., Alton, UK) just before the discharge orifice. Readings were recorded every 10 s for at least 2 min and average were reported as kPa.

2.4. Extrudate quality

The diameter of extrudates was measured with the help of a vernier caliper. WSI was determined using the method of Anderson et al. (1969).

2.5. Statistical analysis

The second order polynomials were computed using Minitab statistical software (Minitab Inc., State College, PA, USA). Feed moisture, extrusion temperature and screw speed were used as independent variables. These variables had values of X_1 (feed moisture), 16, 20, 24; X_2 (extrusion temperature), 125, 150, 175; and X_3 (screw speed), 100, 125, 150. The dependent variables were die pressure, expansion and WSI. The equations obtained for different parameters were tested for adequacy and fitness using analysis of variance. The effects of feed moisture, extrusion temperature and screw speed are shown using response surface contour plots plotted using Minitab Statistical Software (State College, PA).

3. Results and discussion

WSI and WAI of raw flint corn grit were 2.2 and 2.6%, respectively, against 3.0 and 2.1%, respectively, for sweet corn grits. The particle size distributions of flint and sweet corn grits are shown in Table 1. The flint corn grit had more fine particles than sweet corn grits. The retention of particles on a 44 mesh sieve was 83% for flint corn grits against 96% for sweet corn grits. Visual examination revealed that flint corn grits had more opaque particles than sweet corn grits. The fat content was significantly higher for flint corn grits (0.85%) than sweet corn grits (0.70%).

The regression analysis was performed to predict the effect of feed moisture, extrusion temperature and screw speed on extrusion behaviour and extrudate characteristics of flint and sweet corn grits. The regression model between the dependent variables (Y) and independent variables was:

$$Y = B_0 + \sum_{i=1}^{3} B_i X_i + \sum_{I=1}^{3} \sum_{j=1}^{3} B_{ij} X_i X_j$$

All the regression models correlated well with measured data and were statistically significant. The significance of each coefficient in the regression models was determined using t-values. The t-values for different regression coefficient are shown in Table 2. A higher t-value of a coefficient in a model show its greater contribution towards the dependent variables.

Table 1
Particle size distribution of flint and sweet corn grits

Mesh size	Flint (% retention)	Sweet (% retention)
22	0.08	2.145
25	33.34	49.47
30	21.67	24.26
36	28.38	20.11
44	0.115	0.15
60	15.12	3.65
72	0.62	0.025
85	0.06	0.01
Through 85	0.04	0.01

3.1. Die pressure

The regression models for die pressure, for extruding both types of corn grits, were highly significant, as revealed by P and R^2 values (Table 3). The effects of feed moisture and extrusion temperature on die pressure of extruder for sweet and flint corn grits are illustrated in Figs. 1 and 2. Feed moisture showed the most pronounced effect on the die pressure of extruder followed by extrusion temperature and screw speed. Die pressure decreased with the increase in feed moisture and extrusion temperature and increased with the increase in screw speed. The effects of extrusion temperature on die pressure are consistent with earlier published data (Kirby, Ollett, Parker, & Smith, 1988; Singh, Sekhon, & Nagi, 1994; Singh et al., 2000; Singh, Smith, & Frame, 1998b). Flint corn showed lower die pressure than sweet corn grits under similar extrusion conditions. The lower die pressure for grits from flint corn may be attributed to incomplete water absorption by large particles, that resulted in more availability of water to the plasticized part and decreased the viscosity of the plastic melt at the die, resulting in decreased pressure (Zhang & Hoseney, 1998).

3.2. Expansion

The regression models for expansion of grits from both the corn types were highly significant and had R^2 values in the range of 92.6–95.7% (Table 3). Expansion of extrudates decreased with the increase in feed moisture and extrusion temperature. The effects of feed moisture and extrusion temperature on expansion of extrudates from sweet and flint corn grits are shown in Figs. 3 and 4. An increase in screw speed resulted in an increase in expansion. Feed moisture showed highly significant effect on expansion of extrudates from both types of corn grits. Harper and Tribelhorn (1992) also reported a decrease in expansion with respect to increasing extrusion temperature and moisture for maize flours. Extrudates from sweet corn had greater expansion than extrudates from flint corn. Lower expansion of extrudates from flint corn may have resulted from a non-homogeneous dough because of the

Table 2
T-values for different coefficients in regression models

Coefficient	Sweet corn			Flint corn		
	Pressure	Expansion	WSI[a]	Pressure	Expansion	WSI
Feed moisture	−7.86	−5.50	−6.277	−4.96	−15.298	−3.15
Extrusion temperature	−6.59	−0.54	4.649	−4.48	−1.029	3.24
Screw speed	3.03	0.85	−1.909	1.82	6.40	3.27
Feed moisture×feed moisture	5.38	5.69	4.765	4.0	14.13	4.27
Extrusion temperature×extrusion temperature	4.92	0.83	−5.935	3.65	1.59	−2.81
Screw speed×screw speed	−1.94	0.45	2.282	0.17	−5.96	−2.23
Feed moisture×extrusion temperature	6.53	−0.42	2.555	3.45	0.72	−1.19
Feed moisture×screw speed	−1.68	−1.29	−1.416	−3.3	2.189	−3.05
Extrusion temperature×screw speed	−1.37	−2.08	1.447	−1.88	−5.45	0.49

[a] WSI, water solubility index.

Table 3
Coefficient of regression models for dependent variables

Term	Sweet corn			Flint corn		
	Pressure	Expansion	WSI[a]	Pressure	Expansion	WSI
Constant	21 169.2	22.69	20.71	16 353.3	22.388	−21.78
Feed moisture	−991.6***	−1.301***	−2.972***	−666.0***	−1.861***	−2.04**
Extrusion temperature	−151.3***	−0.024	0.401***	−109.4***	−0.023*	0.38***
Screw speed	61.3**	0.032*	−0.145*	39*	0.125***	0.34***
Feed moisture×feed moisture	14.8***	0.029***	0.049***	11.7***	0. 038***	0.06***
Extrusion temperature×extrusion temperature	0.3***	0.000*	−0.002***	0.3***	0.000*	−0.00**
Screw speed×crew speed	−0.1*	0.000	0.001**	0.0	−0.000***	−0.00**
Feed moisture×extrusion temperature	2.0***	−0.000	0.003**	1.1***	0.000*	−0.00*
Feed moisture×screw speed	−0.5*	−0.001*	−0.002*	−1.1***	0.001**	−0.00**
Extrusion temperature×screw speed	−0.1*	−0.001**	0.000*	−0.1*	−0.000***	−0.00
R^2	98.3%	97.3%	98.5%	98.1%	99.2%	95.1%

[a] WSI, water solubility index.
$*P \leqslant 0.5$; $**P \leqslant 0.05$; $P \leqslant 0.005$.

presence of greater amounts of opaque and finer particles which act as capillaries; hence less water was available for hydration of vitreous particles. The grits from sweet corn had a lower percent of finer particles which resulted in a more homogeneous mass which uniformly plasticized and resulted in a more expanded product. Zhang and Hoseney (1998) reported that, if the material being extruded were fully melted and therefore, homogeneous, expansion appeared to be controlled by a balance between material viscosity at the die and pressure drop across the die. The materials with high viscosity require high pressure for an ideal expansion and vice versa. Harper (1982) reported that finer granulation gave a harder and more dense collet. Flint corn grits showed lower expansion than those from sweet corn which may be attributed to lower WSI. Kirby et al. (1988) confirmed that the breakdown of maize structure is necessary for higher solubility and high expansion which increased with decrease in moisture.

3.3. Water solubility index

The regression models for WSI of extrudates from both corn types were significant and had sufficiently high R^2 value (Table 3). The effects of feed moisture, extrusion temperature and screw speed on WSI of extrudates from sweet and flint corn grits are illustrated in Figs. 5–8. WSI decreased with the increase in feed moisture and increased with the increase in extrusion temperature and screw speed. Feed moisture showed the most pronounced effect followed by extrusion temperature and screw speed in sweet corn grits, while all three

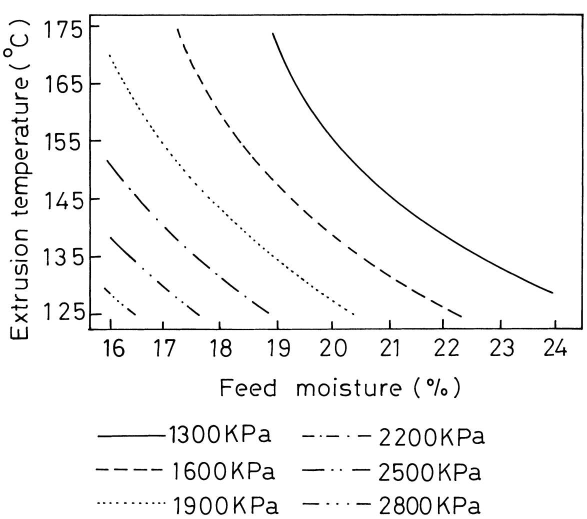

Fig. 1. Response surface contour plot showing the effect of feed moisture and extrusion temperature at 125 screw speed on die pressure of extruder for sweet corn grits.

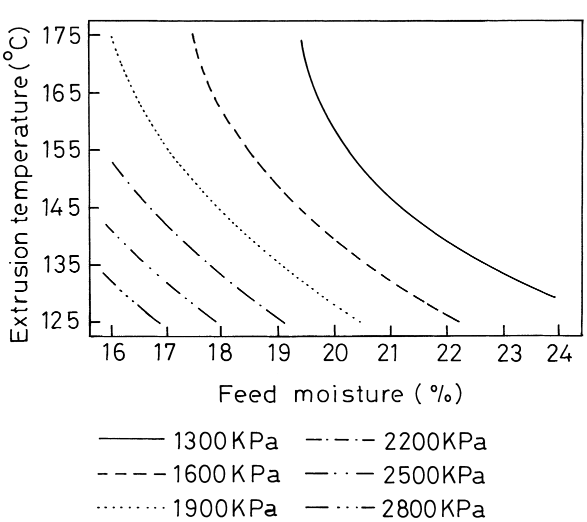

Fig. 2. Response surface contour plot showing the effect of feed moisture and extrusion temperature at 125 screw speed on die pressure of extruder for flint corn grits.

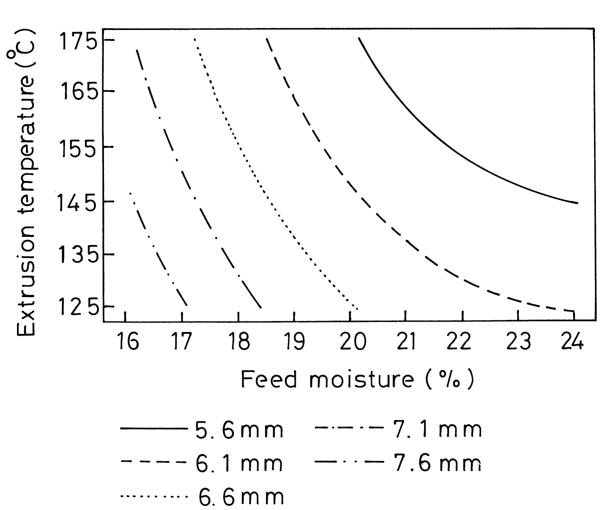

Fig. 3. Response surface contour plot showing the effect of feed moisture and extrusion temperature at 125 screw speed on expansion of extrudates for sweet corn grits.

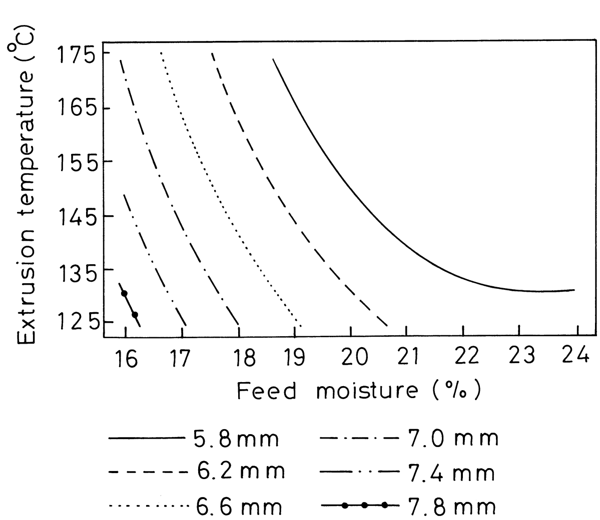

Fig. 4. Response surface contour plot showing the effect of feed moisture and extrusion temperature at 125 screw speed on expansion of extrudates for flint corn grits.

variables showed equal effect on WSI of flint corn grits. WSI of extrudates from sweet corn was higher than those from flint corn under similar extrusion conditions. Similar effects of moisture, extrusion temperature and screw speed on WSI during extrusion cooking of corn grits have been reported earlier (Jin, Hsieh, & Huff, 1995; Kirby et al., 1988; Singh et al., 2000; Singh, Smith, & Frame, 1998). The increase in WSI with the decrease in feed moisture may be attributed to higher specific mechanical energy (SME) consumption of extruder. The importance of SME in starch solubilisation has been demonstrated in a number of studies. Kirby et al. (1988) reported a linear increase in WSI in the extrusion of corn grits. Wen, Rodis, and Wasserman (1990) reported that screw speed had a direct effect on polysaccharide size distribution and a higher screw speed resulted in more fragmentation than a lower screw speed. An increase in screw speed also led to a higher product temperature and, hence, a higher WSI (Jin et al., 1995).

In conclusion, the second order polynomials can be used as a tool to predict the extrusion behaviour of corn grits as a function of feed moisture, extrusion temperature and screw speed. Experimental data clearly indicate that the corn type had a significant influence on die pressure of extruder as well as expansion and WSI of extrudates. The particle size distribution revealed that the grits from flint corn with more fine and opaque particles resulted in extrudates with lower WSI and

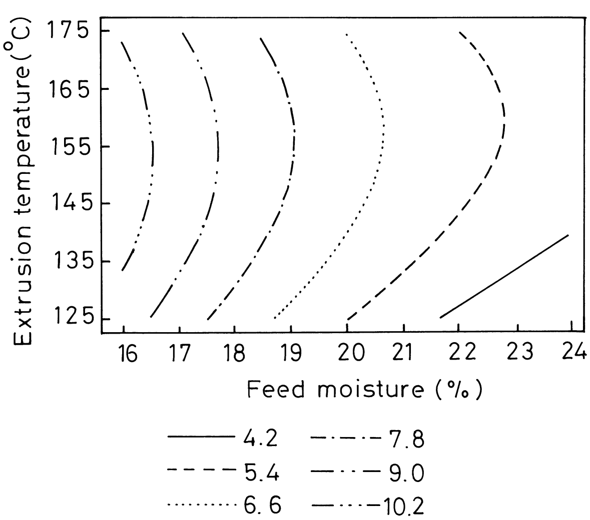

Fig. 5. Response surface contour plot showing the effect of feed moisture and extrusion temperature at 125 screw speed on the water solubility index of extrudates for sweet corn grits.

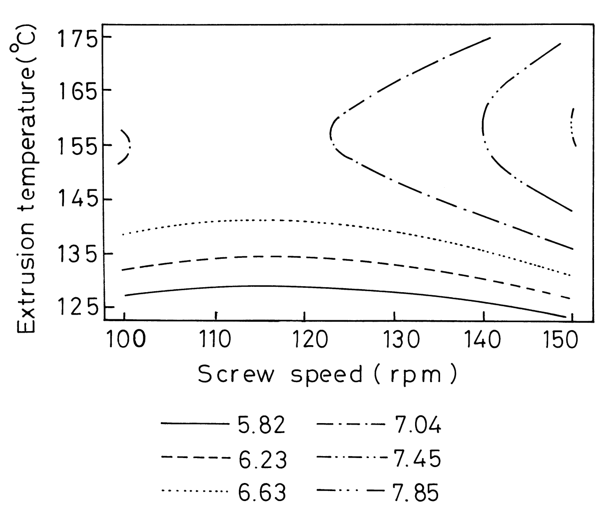

Fig. 7. Response surface contour plot showing the effect of extrusion temperature and screw speed at 20% feed moisture on the water solubility index of extrudates for sweet corn grits.

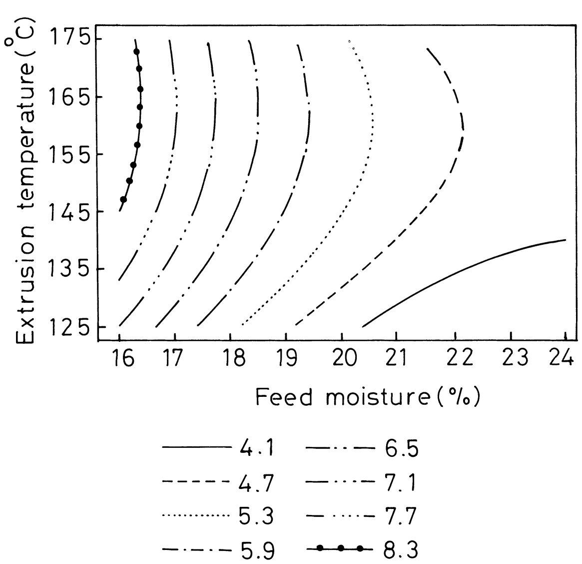

Fig. 6. Response surface contour plot showing the effect of feed moisture and extrusion temperature at 125 screw speed on the water solubility index of extrudates for flint corn grits.

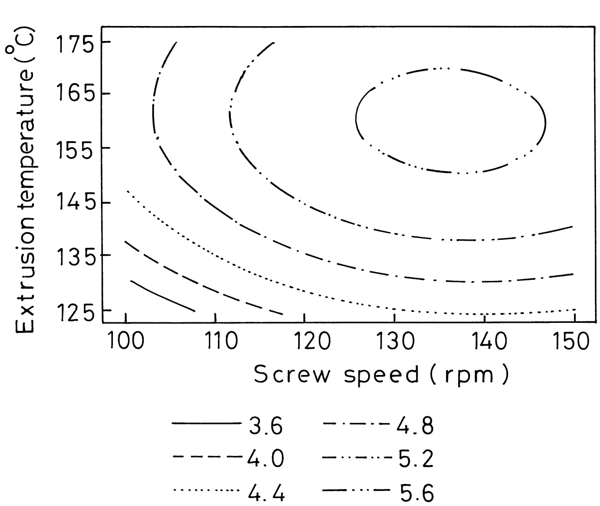

Fig. 8. Response surface contour plot showing the effect of extrusion temperature and screw speed at 20% feed moisture on the water solubility index of extrudates for flint corn grits.

expansion than those from sweet corn with less fine particles.

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