Available online at www.sciencedirect.com

SCIENCE DIRECT®

Food Chemistry 100 (2007) 198–202

Food Chemistry

www.elsevier.com/locate/foodchem

Effects of moisture, temperature and level of pea grits on extrusion behaviour and product characteristics of rice

Baljit Singh [a,*], K.S. Sekhon [a], Narpinder Singh [b]

[a] Department of Food Science and Technology, Punjab Agricultural University, Ludhiana 141 004, India
[b] Department of Food Science and Technology, Guru Nanak Dev University, Amritsar 143 005, India

Received 2 February 2004; received in revised form 20 September 2005; accepted 25 September 2005

Abstract

A study was conducted to investigate the effect of feed moisture (18–24%), extrusion temperature (130–170 °C) and level of pea grits (0–30%) on the extrusion behaviour and extrudate properties of rice grits. The extruder die pressure, specific energy consumption, expansion ratio, density, water absorption index, and water solubility index were studied. Second-order polynomials were compared for extruder parameters and product characteristics as a function of feed moisture, extrusion temperature and pea grit level.
© 2005 Elsevier Ltd. All rights reserved.

Keywords: Extrusion; Rice grits; Pea grits; Die pressure; SEC; Expansion ratio; Density; WAI; WSI

1. Introduction

Recently, extrusion cooking has become one of the most popular technologies in food processing. It is a low cost, high temperature short time (HTST) process, used worldwide for processing of a number of food products (Frame, 1994; Harper, 1981; Smith & Singh, 1996). Cereals have excellent expansion properties because of their high starch content and are well suited to thermal extrusion (Singh, Sekhon, & Nagi, 1994; Singh, Cairns, Morris, & Smith, 1998a; Singh, Smith, & Frame, 1998b). Remarkable progress has been made in the utilization of new protein sources, such as oilseeds, leguminous seed and single cell proteins (Kinsella, 1978). Among legumes, pea has a very important position and is an important source of nutrients particularly proteins and essential amino acids. The blending of peas with cereals can complement each other so that protein in the resulting product more nearly resembles that of a complete or balanced protein.

* Corresponding author.
E-mail address: baljitsj@yahoo.co.in (B. Singh).

0308-8146/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2005.09.042

2. Materials and methods

2.1. Rice and pea grits

Milled rice of cultivar PR-106 was procured from the local market. Garden peas of two cultivars (Pb-87 and Pb-88) were procured from the field of a grower. Pea pods of both the cultivars were harvested 125 days after sowing. Pods were shelled manually; grains were blanched in 0.5% KMS (Pot. metabisulfite) solution at 90 °C for 5 min and dehydrated at 65 °C to a final moisture content of less than 10% in a hot air cabinet drier. Other lot of peas of both the cultivars were allowed to mature on the plant until the plant foliage dried and harvested, pods were dried in the shade for a few days and shelled manually; and grains were further dried in the shade to a moisture content of less than 10%. Pea grains were milled to *dhal* using a mini *dhal* mill developed by the Central Food Technological Research Institute, Mysore (India). Rice and pea (*dhal*) were ground in a laboratory grinder to pass through a 20 mesh sieve.

2.2. Preparation of blends

Blends were prepared by mixing rice and pea grits in the ratios of 100:0, 85:15 and 70:30. The blended samples were conditioned to 18%, 21% and 24% moisture by spraying with a calculated amount of water and mixing continuously in a laboratory mixer (Model N-50, Hobart, USA). 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 conditioned samples was carried out in a single screw extruder (Model 2003 C. W. Brabender, Hackensack, NJ USA) with 1.9 cm barrel diameter and 20:1 barrel length and diameter ratio. The extruder was fitted with a die nozzle with 3.75 mm diameter. The feed and compression zone temperatures were maintained at 100 and 130 °C, respectively, while die zone temperature was kept either at 130, 150 and 170 °C. The extruder screw and feeding screw were run at a constant speed of 100 rpm. Die pressure was measured using a pressure transducer (Dynisco Ltd. USA) just before the orifice. Readings were recorded every 10 s for at least 2 min and average values were expresed as kPa. SEC was calculated, using expression described by Mason and Hoseney (1986):

$$\text{SEC}\ \left(\text{Whkg}^{-1}\right) = (\text{Amperes} \times \text{Volts})/\left(\text{kgh}^{-1}\ \text{throughput}\right).$$

2.4. Extrudate characteristics

The diameter of extrudates was measured using a vernier caliper. Expansion ratio was calculated as the ratio of diameter of extrudates to the diameter of die nozzle. Density of extrudates was calculated as mass per unit volume, using the expression:

$$\text{Density}\ \left(\text{g/cm}^{-3}\right) = \text{Mass (g)}/\pi r^2 l\ \left(\text{cm}^{-3}\right).$$

Water absorption index (WAI) and water solubility index (WSI) were determined by the method of Anderson, Conway, Pfeiffer, and Griffin (1969). The extrudates were ground to a mean particle size of approximately 180–250 μm. A 2.5 g sample was dispersed in 25 g of distilled water, using a glass rod to break up any lumps. After stirring for 30 min, the dispersions were rinsed into tared centrifuge tubes, made up to 32.5 g and centrifuged at 5000 rpm for 10 min. The supernatant was decanted for determination of its solids content and the sediment was weighed. WAI and WSI were calculated using the expressions,

$$\text{WAI (g/g)} = \text{weight of sediment/weight of dry solids},$$

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

2.5. Statistical analysis

Second-order polynomials were computed using Minitab statistical software (Minitab Inc., State College, PA, USA). Feed moisture, extrusion temperature and level of replacement of rice grits with pea grits were taken as independent variables. The variables had values of X_1 (feed moisture), 18, 21, 24; X_2 (extrusion temperature), 130, 150, 170; and X_3 (level), 0, 15, 30. The polynomials were fitted to the measured dependent variables (yi) such as die pressure, SEC, expansion, density, WAI, WSI. The equation used was as follows (Singh & Smith, 1997):

$$yi = Bo + \sum_{i=1}^{3} BiXi + \sum_{i=1}^{3}\sum_{j=1}^{3} BijXiXj,$$

where yi is the response, Xij the dependent variables and Bo, Bi and Bj are the regression coefficients. The equations obtained for different parameters were tested for adequacy and fitness using analysis of variance. The significance of each coefficient in the regression model was determined using the p values.

3. Results and discussion

3.1. Die pressure

Die pressure decreased with increase in moisture content and temperature. Addition of pea grits to the rice grits resulted in a decrease in die pressure in all the blends during extrusion. The regression models for die pressure (Table 1) correlate well with the measured data, with R^2 values above 96%. All three variables had significant effects on die pressure. Temperature had a significant effect on die pressure, both in linear and squared terms, which is particularly more pronounced in the feed material containing Pb-88 grits. The feed material containing Pb-87 pea

Table 1
Coefficients of regression models for die pressure

Term	Pb-87		Pb-88	
	Mech-dried	Field-dried	Mech-dried	Field-dried
Constant	5915.76	11191.00	11908.66	−1905.58
X_1	−10.28	−207.04	−989.38*	−565.59
X_2	59.14	16.18	115.19*	241.46**
X_3	−114.19**	−169.69***	−66.02	6.36
$X_1 \times X_1$	−12.86*	−4.79	6.49	−2.28
$X_2 \times X_2$	−0.56**	−0.36*	−0.83**	−1.23***
$X_3 \times X_3$	0.48*	0.36	−0.01	0.71*
$X_1 \times X_2$	2.56**	1.62*	3.71**	3.40**
$X_1 \times X_3$	1.12	2.96*	2.01	1.53
$X_2 \times X_3$	0.25*	0.32*	0.02	−0.60*
R^2 (%)	98.41	98.26	96.60	97.19

X_1, feed moisture; X_2, extrusion temperature; X_3, pea grit level.
* $p \leqslant 0.2$.
** $p \leqslant 0.02$.
*** $p \leqslant 0.001$.

grits showed greater effect on die pressure than its counterparts containing Pb-88 pea grits. Feed moisture content, in interaction with temperature, showed a significant effect on die pressure during extrusion cooking of various feed materials.

Decrease in die pressure, with an increase in moisture level and temperature of extrusion, may be attributed to decrease in viscosity of the melt due to fragmentation of swollen and gelatinized starch granules (Akdogam, Towas, & Oliveira, 1997). These results are in agreement with earlier reported findings (Kirby, Ollett, Parker, & Smith, 1988; Singh & Smith, 1997). Decrease in die pressure with increase in level of pea grits may be attributed to the increase in amylose content of feed material. Unlu and Faller (1998) observed a decrease in die pressure with increase in level of high amylose corn starch in the feed.

3.2. Specific energy consumption (SEC)

SEC decreased with increase in moisture content and temperature. Addition of pea grits to feed material resulted in decrease of SEC, this decrease was more pronounced with Pb-88 pea grits. Table 2 shows a high correlation ($R^2 = 95–98$) with the actual observations. Addition of pea grits showed a significant effect on SEC, both in linear and squared terms, and was more significant with Pb-88 than with Pb-87 grits. The effect of feed moisture content in interaction with pea grit level on SEC was found to be highly significant.

SEC decreased with increase in moisture which could be due to decrease in friction in the extruder barrel. The changes in SEC with the change in feed moisture and temperature were found to be comparable with values reported earlier for rice–potato grits extrusion using the same extruder (Singh, Singh, Sandhu, Bawa, & Sekhon, 1996). Similar effects of increasing feed moisture and temperature during extrusion of different cereals with twin and single screw extruders have been reported previously (Antila, Seiler, & Linko, 1983; Singh et al., 1994). Decrease in SEC with increase in level of pea grits may be due to their higher amylose content. Unlu and Faller (1998) observed a decrease in torque with increase in level of high amylose corn starch in feed.

3.3. Expansion ratio

The expansion ratio of extrudates decreased with an increase in moisture content. The expansion ratio was found to be highest at 150 °C. A decrease in expansion with increase in the level of pea grits in feed material was observed. The regression models for expansion ratio showed R^2 in the range of 98.2–99.6% (Table 3). Moisture content and temperature had highly significant effects on expansion ratio of extrudates, both in linear and squared terms, followed by level of pea grits. Moisture content, in interaction with temperature, had a significant effect on expansion ratio of extrudates.

The expansion occurring in a food material depends on the pressure differential between the die and atmosphere. Foods with lower moisture tend to be more viscous than those with higher moisture and, therefore, the pressure differential would be smaller for higher moisture foods, leading to a less expanded product. Chinnaswamy and Hanna (1990) reported that low moisture content in feed may restrict flow of the material and increase shearing rate and residence time, which might increase the degree of gelatinization and expansion. Batisuti, Barros, and Areas (1991) optimized the extrusion cooking process for chickpea flour and reported significant effects of both temperature and moisture content on expansion ratio. They observed maximum expansion with 13% moisture at 130 °C for chickpea flour.

Table 2
Coefficients of regression models for specific energy consumption

Term	Pb-87		Pb-88	
	Mech-dried	Field-dried	Mech-dried	Field-dried
Constant	1066.47	1204.34	265.72	597.57
X_1	−24.70	−22.85	0.44	−38.94*
X_2	−3.27	−5.16*	4.02*	4.98
X_3	−4.82*	−7.68**	−12.10***	−9.99***
$X_1 \times X_1$	−0.09	−0.01	−0.30	0.31
$X_2 \times X_2$	0.00	0.01	−0.02*	−0.02*
$X_3 \times X_3$	0.02	0.00	0.03*	0.04*
$X_1 \times X_2$	0.10*	0.06	−0.01	0.08*
$X_1 \times X_3$	0.23***	0.22**	0.28***	0.29**
$X_2 \times X_3$	−0.01	0.01	0.02*	−0.00
R^2 (%)	95.35	95.55	98.34	96.47

X_1, feed moisture; X_2, extrusion temperature; X_3, pea grit level.
* $p \leqslant 0.2$.
** $p \leqslant 0.02$.
*** $p \leqslant 0.001$.

Table 3
Coefficients of regression models for expansion ratio

Term	Pb-87		Pb-88	
	Mech-dried	Field-dried	Mech-dried	Field dried
Constant	−7.9564	−8.2477	−11.5022	−8.0361
X_1	0.5579***	0.5311***	0.7629***	0.6448***
X_2	0.0750***	0.0826***	0.0936***	0.0644***
X_3	−0.0119*	−0.0026	−0.0380**	−0.0206***
$X_1 \times X_1$	−0.0154***	−0.0150***	−0.0184***	−0.0175***
$X_2 \times X_2$	−0.0002***	−0.0002***	−0.0003***	−0.0002***
$X_3 \times X_3$	0.0001*	−0.0000	0.0001	0.0002***
$X_1 \times X_2$	−0.0002*	−0.0001	−0.0008**	−0.0002*
$X_1 \times X_3$	−0.0001	−0.0001	0.0007*	0.0001
$X_2 \times X_3$	0.0000	0.0000	0.0001*	0.0000*
R^2 (%)	99.40	99.42	98.19	99.64

X_1, feed moisture; X_2, extrusion temperature; X_3, pea grit level.
* $p \leqslant 0.2$.
** $p \leqslant 0.02$.
*** $p \leqslant 0.001$.

An inverse relationship between feed moisture and expansion from different materials has also been reported (Bhattacharya & Hanna, 1987; Faubion & Hoseney, 1982). Decrease in expansion with increase in level of pea grits may be due to the higher protein and fibre and lower starch content of the feed material. Jones, Chinnaswamy, Tan, and Hanna (2000) reported that an increase in protein and fibre content in feed material resulted in a decrease of expansion ratio.

3.4. Density

The extrudates having lower expansion showed higher density and vice versa. Data with respect to coefficients of regression models for density as a function of feed moisture, temperature and pea grit level are presented in Table 4. Regression models for density of extrudates were highly correlated (R^2 above 92) with the actual observations. Temperature showed a highly significant effect on the density of extrudates obtained from all types of feed materials, both in linear and squared terms. Effect of moisture content in interaction with temperature on density was also significant. An inverse relationship between expansion ratio and density of extrudates has been earlier reported (Singh et al., 1996).

3.5. Water absorption index (WAI)

An increase in both feed moisture and temperature resulted in increase of WAI. It has been observed that incorporation of pea grits in feed material decreased the WAI. Table 5 shows the data with respect to coefficients of regression models for WAI. Correlation between observed data and regression models was higher for feed materials containing Pb-88 in comparison to Pb-87 pea grits. The effect of replacement of rice with pea grits on WAI was found to be significant in both linear and squared terms. Moisture content of the feed material had a significant effect on WAI. Moisture content in interaction with pea grit level showed a significant effect on WAI. An interaction between temperature and pea grit level was found to be significant with the feed materials containing Pb-88 pea grits.

Gujska and Khan (1990) reported a threefold increase in WAI by extrusion cooking of the high starch fraction of beans compared to non-extruded samples. Protein denaturation, starch gelatinization and swelling of the crude fibre, which occurred during extrusion, could all be responsible for the increased WAI of extrudates. It has been reported earlier by Gujska and Khan (1991) that WAI increased significantly with increasing moisture for garbanzo and pinto bean high starch fractions. William, Horn, and Rugule (1977) indicated maximum WAI for yellow corn grits extruded at a moisture content of 27% and temperature of 135 °C. The changes in extrudate properties by moisture and temperature variations may be attributed to variation in starch degradation. Maximum water absorption at a barrel temperature of 170 °C and extrusion moisture content of 14% and 25% has been reported earlier (Anderson et al., 1969). A decrease in WAI with addition of pea grits may be due to the dilution of starch in rice pea blends. Jones et al. (2000) reported a decrease in WAI with decrease in starch content. Colonna, Tayeb, and Mercier (1989) reported only a small little change in WAI for high amylose starches, even with temperature up to 200 °C.

3.6. Water solubility index (WSI)

WSI of extrudates increased with decrease in feed moisture and increase in temperature. In general, addition of pea grit reduced the WSI of extrudates. Regression models for WSI, given in Table 6, correlate well with the observed data, with R^2 values of more than 95%. The pea grits

Table 4
Coefficients of regression models for density

Term	Pb-87		Pb-88	
	Mech-dried	Field-dried	Mech-dried	Field-dried
Constant	1.786606	1.753472	1.270662	1.208069
X_1	−0.006931	−0.017912	−0.021769*	−0.014574
X_2	−0.019129***	−0.017085***	−0.010069***	−0.010387***
X_3	−0.000022	0.000230	−0.001456	−0.002027*
$X_1 \times X_1$	−0.006931	−0.017912	−0.021769*	−0.014574*
$X_2 \times X_2$	−0.019129***	−0.017085***	−0.010069***	−0.010387***
$X_3 \times X_3$	−0.000022	0.000230	−0.001456	−0.002027*
$X_1 \times X_2$	0.000032*	0.000068**	0.000058*	−0.000003
$X_1 \times X_3$	0.000009	0.000011	0.000052	0.000087*
$X_2 \times X_3$	−0.000009	−0.000003	0.000011*	0.000009*
R^2 (%)	97.21	96.08	93.29	92.65

X_1, feed moisture; X_2, extrusion temperature; X_3, pea grit level.
* $p \leqslant 0.2$.
** $p \leqslant 0.02$.
*** $p \leqslant 0.001$.

Table 5
Coefficients of regression models for water absorption index

Term	Pb-87		Pb-88	
	Mech-dried	Field-dried	Mech-dried	Field-dried
Constant	−14.7473	−12.8305	−5.7536	−7.5083
X_1	−0.0130	0.7492*	0.4650	0.5417*
X_2	0.2366*	0.1073	0.0520	0.0665
X_3	0.0141	0.0748*	0.0802*	0.0656*
$X_1 \times X_1$	0.0058	−0.0177*	−0.0068	−0.0077
$X_2 \times X_2$	−0.0007*	−0.0004*	−0.0001	−0.0001
$X_3 \times X_3$	0.0011*	0.0003	0.0004*	0.0005*
$X_1 \times X_2$	−0.0006	0.0010	−0.0000	−0.0004
$X_1 \times X_3$	−0.0005	−0.0024*	−0.0017*	−0.0020*
$X_2 \times X_3$	−0.0003	−0.0003	−0.0004**	−0.0005**
R^2 (%)	74.13	78.35	88.81	94.23

X_1, feed moisture; X_2, extrusion temperature; X_3, pea grit level.
* $p \leqslant 0.2$.
** $p \leqslant 0.02$.

Table 6
Coefficients of regression models for water solubility index

Term	Pb-87		Pb-88	
	Mech-dried	Field-dried	Mech-dried	Field-dried
Constant	41.8568	44.6494	81.9813	84.4968
X_1	−2.3918	−0.8655	−2.0783	−4.4054*
X_2	0.1645	−0.0862	−0.3636	−0.1146
X_3	−0.6996**	−0.3292*	−0.69993*	−0.9411**
$X_1 \times X_1$	0.0446	−0.0009	0.0276	0.0947*
$X_2 \times X_2$	−0.0001	0.0005	0.0014	0.0009
$X_3 \times X_3$	−0.0004	−0.0004	−0.0022	0.0057*
$X_1 \times X_2$	−0.0007	0.0013	0.0006	−0.0025
$X_1 \times X_3$	−0.0010	0.0000	0.0051	0.0025
$X_2 \times X_3$	0.0025*	0.0013*	0.0015	0.0029*
R^2 (%)	96.17	95.60	95.33	95.47

X_1, feed moisture; X_2, extrusion temperature; X_3, pea grit level.
* $p \leqslant 0.2$.
** $p \leqslant 0.02$.

incorporation in feed material significantly affected the WSI of extrudates. Temperature, in interaction with pea grit level significantly affected the WSI of extrudates.

Gujska and Khan (1990) reported a significant increase in WSI with increase in extrusion temperature for the high starch fraction of different beans. Increase in WSI, with decrease in moisture content, may be attributed to higher degradation of starch (Anderson et al., 1969). Similar effects of decreasing feed moisture on WSI have been previously reported for starch, maize grits, rice and wheat (Bryant, Kadan, Champagrte, Vinyard, & Boykin, 2001; Kirby et al., 1988; Singh & Smith, 1997). The importance of specific mechanical energy (SME) in starch solubilisation has been demonstrated in other studies. Meuser, Pfaller, and Van (1987) related WSI to SME and product temperature using a Contima 37 Werner and Pfleiderer twin-screw extruder. Changes in WSI with incorporation of pea grits can be attributed to change in composition of the feed. Jones et al. (2000) reported that fibre, starch and protein contents affect WSI. Bryant et al. (2001) found that, in comparison to waxy rice, high amylose rice exhibited lower WSI.

References

Akdogam, H., Towas, R. L., & Oliveira, J. C. (1997). Rheological properties of rice starch at high moisture content during twin screw extrusion. *Lebensmittel Wissenschaft Und Technology, 30*, 488–496.

Anderson, R. A., Conway, H. F. M., Pfeiffer, V. F., & Griffin, E. J. (1969). Gelatinization of corn grits by roll and extrusion cooking. *Cereal Science Today, 14*, 4–12.

Antila, J., Seiler, K., & Linko, P. (1983). Production of flat bread by extrusion cooking using different wheat/rye ratios, protein enrichment and and grain with poor baking ability. *Journal of Food Engineering, 2*, 189–210.

Batisuti, J. P., Barros, R. M. C., & Areas, J. A. G. (1991). Optimization of extrusion cooking process for chickpea (*Cicer arietinum* L.) defatted flour by response surface methodology. *Journal of Food Science, 56*, 1695–1698.

Bhattacharya, M., & Hanna, M. A. (1987). Influence of process and product variables and extrusion energy and pressure requirements. *Journal of Food Engineering, 6*, 153–163.

Bryant, R. J., Kadan, R. S., Champagrte, E. T., Vinyard, B. T., & Boykin, D. (2001). Functional and digestive characteristics of extruded rice flour. *Cereal Chemistry, 78*, 131–137.

Chinnaswamy, R., & Hanna, M. A. (1990). Relationship between viscosity and expansion properties of various extrusion-cooked grain components. *Food Hydrocolloids, 3*, 423–434.

Colonna, P., Tayeb, J., & Mercier, C. (1989). Extrusion cooking of starch and starchy products. In P. Mercier, P. Linko, & J. M. Harper (Eds.), *Exxtrusion cooking* (pp. 247–319). St. Paul, MN, USA: AACC.

Faubion, J. M., & Hoseney, R. C. (1982). High temperature short time extrusion cooking of wheat starch and flour. I: Role of moisture and flour type in the production of extrudates. *Cereal Chemistry, 59*, 533–543.

Frame, N. D. (1994). *The technology of extrusion cooking*. London: Blackie Academic and Professional.

Gujska, E., & Khan, K. (1990). Effect of temperature on properties of extrudates from high starch fraction of navy, pinto and garbanzo beans. *Journal of Food Science, 55*, 466–469.

Gujska, E., & Khan, K. (1991). Feed moisture effects on functional properties, trypsin inhibitor and hemagglutinating activities of extruded bean high starch fractions. *Journal of Food Science, 56*, 443–447.

Harper, J. M. (1981). Extrusion of starches and starches materials. In J. M. Harper (Ed.). *Extrusion of food* (Vol. 2, pp. 41–60). Boca Raton: CRC Press.

Jones, D., Chinnaswamy, R., Tan, Y., & Hanna, M. (2000). Physicochemical properties of ready-to-eat breakfast cereals. *Cereal Food World, 45*, 164–168.

Kinsella, J. E. (1978). Texurized proteins: fabrication, flavouring, and nutrition. *CRC Critical Reviews in Food Science Nutrition, 10*, 147–161.

Kirby, A. R., Ollett, A. L., Parker, R., & Smith, A. C. (1988). An experimental study of screw configuration effects in the twin screw extrusion cooking of maize grits. *Journal of Food Engineering, 8*, 247–272.

Mason, W. R., & Hoseney, R. C. (1986). Factor effecting the viscosity of extrusion cooked wheat starch. *Cereal Chemistry, 63*, 436–441.

Meuser, F., Pfaller, W., & Van, L. B. (1987). Technological aspects regarding specific changes to characteristic properties of extrudates by HTST extrusion cooking. In C. O. Connor (Ed.), *Extrusion technology for food industry*. London: Elsevier Applied Science.

Singh, N., Sekhon, K. S., & Nagi, H. P. S. (1994). Effect of temperature on extrusion behaviour of sound and sprouted wheat flour. *Journal of Food Science Technology, 31*, 505–507.

Singh, N., Singh, B., Sandhu, K. S., Bawa, A. S., & Sekhon, K. S. (1996). Extrusion behaviour of wheat, rice and potato blends. *Journal of Food Science Technology, 31*, 291–294.

Singh, N., & Smith, A. C. (1997). A comparison of wheat starch, whole wheat meal and oat flour in the extrusion process. *Journal of Food Enginering, 34*, 15–32.

Singh, N., Cairns, P., Morris, V. J., & Smith, A. C. (1998a). Physical properties of extruded wheat starch-additive mixtires. *Cereal Chemistry, 75*, 325–330.

Singh, N., Smith, A. C., & Frame, N. D. (1998b). Effect of process variables and glycerol mono stearate on the extrusion behaviour of maize grits using two sizes of extruders. *Journal of Food Engineering, 35*, 91–109.

Smith, A. C., & Singh, N. (1996). New applications of extrusion technology. *Indian Food Industry, 15*, 14–23.

Unlu, E., & Faller, J. F. (1998). Formation of resistant starch by a twin screw extruder. *Cereal Chemistry, 75*, 346–350.

William, M. A., Horn, R. E., & Rugule, R. P. (1977). Extrusion-indepth look at a versatile process. I. *Food Engineering, 49*, 99–109.