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EFFECTS OF FEED MOISTURE AND BARREL TEMPERATURE ON THE RHEOLOGICAL PROPERTIES OF EXTRUDED COWPEA MEAL[1]

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ABSTRACT

Decorticated cowpea meal was adjusted to 20, 30, and 40% moisture and extruded in a Wayne pilot-scale extruder at barrel temperatures of 150, 175 and 200°C. The resulting products were subjected to rheological evaluation using the Instron Universal Testing Machine equipped with standard tensile jaws, the Warner-Bratzler shear device and the Kramer Shear Press. Regression equations relating rheological properties to feed moisture and barrel temperature were computed from the data, and response surfaces were generated from these models. Tensile strength of extrudates was greatest for the dense products produced in the low moisture-low temperature region and declined at higher moistures and temperatures. Shear strength as determined by either the Warner-Bratzler or Kramer devices exhibited a ridge of high values extending from 20%-150°C to 30%-200°C, and declined for brittle, expanded products made at low moisture and high temperature and for soft products made at high moisture.

[1]Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warrant by the University of Georgia and does not imply approval of a product to the exclusion of others that may be suitable.

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INTRODUCTION

The importance of cowpeas as a source of protein and B vitamins in developing countries of West Africa has been well established (Dovlo *et al.* 1976). However, neither cowpeas nor other starchy legumes have been incorporated to a significant extent into a commercially manufactured foods in developed countries. These seeds contain approximately 50% starch and 25% protein, levels similar to those which might be chosen for cereal/oilseed meal blends. In addition, the protein quality is superior to that of cereals and comparable to that of oilseed meals. For these reasons, cowpeas would appear to be a promising food ingredient if coupled with an appropriate technology for conversion to food products.

Thermoplastic extrusion is particularly efficient and versatile process for producing finished or intermediate food products from raw ingredients (Harper 1981a,b). It is employed on a large scale in the production of precooked cereal and tuber flours, snacks, and ready-to-eat cereals from starchy substrates; and for producing texturized protein products from defatted oilseed meals. A number of experimental studies have featured the application of extrusion cooking to starchy legumes, including cowpeas, and the evaluation of the resulting products for nutritional and functional properties (Elias *et al.* 1976; Jorge Joao *et al.* 1981; Aguilera *et al.* 1984; Pham and Del Rosario 1984a, 1984b).

When the goal of extrusion is to cook and form the ingredients into a coherent food product, understanding the factors which control texture are of primary importance. Numerous researchers have examined the effects of extrusion conditions on the textural properties of extruded cereal and oilseed meals. Mercier and Feillet (1975) reported that the maximum shearing force required for extruded corn grits containing an initial moisture content[1] of 18.2% declined from 3000 to 1000 kg as extrusion temperature was increased from 170 to 250°C. Cumming *et al.* (1972) used both tensile and shear tests to evaluate the texture of soybean meal extrudates as a function of extrusion temperature (110 to 200°C) at 30% initial feed moisture. They reported that breaking tensile force increased to a maximum value at approximately 160°C, then declined, while required shearing force increased in a sigmoidal fashion over the temperature range. Aguilera and Kosikowski (1976) studied the effects of feed moisture, process temperature and screw speed on Warner-Bratzler shear force values of extruded soybean meal. The resulting data were fit to a quadratic polynomial equation and presented as surface-response diagrams. The resulting model predicted that shear force declined with increasing moisture (25-45%), and with increasing temperature (120-170°C) when moisture

[1]All moisture content values are expressed in terms of wet basis unless otherwise specified.

was > 35%. Below 35% moisture, shear force was relatively independent of extrusion temperature. Maurine and Stanley (1978) examined the effects of protein content (35-38%), and screw speed (60-100 rpm). as well as feed moisture (24-30%) and extrusion temperature (160-180°C) on Warner-Bratzler values of extruded soy protein materials. They found that the required shearing force for these proteinaceous extrudates increased with increasing temperature rather than declined as was observed with starchy products (Mercier and Feillet 1975). Despite these and other efforts, a systematic model of the effects of extrusion variables on the texture of even the most studied substrate, soybean meal, does not exist (Holay and Harper 1982). Further, there is very little information on texture of starchy legume extrudates.

We have previously described the extrusion cooking of cowpea meals over a range of initial moistures and barrel temperatures, and have reported the general physical characteristics of the resulting products, including product temperature at the die, residence time, throughput, product moisture, expansion, bulk density, and tristimulus color values (Phillips *et al.* 1984). In this paper, we present the results of a study of the rheological properties of these extrudates.

MATERIALS AND METHODS

Extrusion Processing

The preparation of cowpea meal and the details of the extrusion process have been described previously (Phillips *et al.* 1984). Briefly, whole cowpea seed were decorticated and adjusted to moisture contents of 20, 30 and 40% by adding the required amounts of water, agitating for one hour and equilibrating for approximately 20 h at 10°C. The hydrated seeds were chopped to a coarse meal in a Hobart Silent Cutter. The meals were extruded on a pilot scale extruder (Wayne Machine and Die Company, Totowa, NJ) equipped with a 19 mm dia (nominal) barrel (25:1 length to diameter ratio), a 5:1 compression ratio screw with constant pitch and increasing root diameter, and a cylindrical die, 4.76 mm dia × 22 mm length. The specific dimensions of the screw based on Harper's (1981a) terminology were: Lead (l) = 19.05 mm; Axial flight width (b) = 4.60 mm; Helix angle (θ) = 18°; Feed section flight height (depth, H) = 3.48 mm; Metering section flight height = 0.69 mm; Half-diametral screw clearance (δ) = 0.01 mm. The void space between the screw nose and the tapered inner die surface was 0.482 cm^3, and the length of the cylindrical segment of the die was 17.80 mm. A schematic of the Wayne pilot scale extruder is given in Phillips *et al.* (1984). Extrusion was carried out at set (nominal) barrel temperatures of 150°, 175 ° and 200°C and a screw

.3'

speed of 180 rpm. Product temperature was determined by a thermocouple mounted in the barrel adjacent to the die which was in contact with the product stream. The 20% moisture meal was fed into the extruder with a vibrating hopper; the 30% and 40% meals were doughy and had to be manually introduced into the feed port with the aid of a wooden plunger. In each case the machine was choke fed.

Triplicate extrusion runs corresponding to each of the nine combinations of initial moisture (20, 30, 40%) and set barrel temperature (150, 175, 200°C) were performed. After steady state operation was achieved, as characterized by the absence of surging and hesitation and by constant barrel and product temperature, samples corresponding to 2-5 min operation were collected separately in open pans and allowed to cool for 5 min then sealed in polyethylene bags and stored at −20°C until evaluated. Extrudates were labeled and will be referred to in terms of the initial moisture and set barrel temperature, e.g. 20-150 represents the product produced from feed material adjusted to 20% moisture content extruded at a barrel temperature of 150°C.

Rheological Evaluations of Extrudates

Extrudates were evaluated at conditions as similar to those immediately following extrusion and cooling as possible (Phillips *et al.* 1984). They were thawed from −20°C and allowed to equilibrate to room temperature in sealed bags. As the goal was to characterize the textural range of extruded products that could be made from cowpea meal, moisture was not adjusted prior to evaluation.

Tensile and shear properties of extrudates were determined using an Instron Universal Testing Machine, Table Model 1130 (Instron Corporation, Canton, MA), and the appropriate attachments. Tests were carried out on a minimum of six replicates from each extrusion run, yielding a set of 18 observations for each combination of initial moisture and barrel temperature. Force-deformation curves were recorded on a strip chart recorder at 20 cm/min. Force, F, was recorded in kg and converted to Newtons, N, and deformation, ΔL, was recorded in centimeters, and converted to meters.

Tensile properties were measured by mounting 5.5 cm lengths of extrudate in Instron standard fiber jaws and stretching at a rate of 5 cm/min until failure occurred. In cases in which the extrudate was too brittle to be held in the fiber jaws, sections were coated on each end with a rubber caulking compound to produce resilient "boots" which could then be mounted. Data from samples which failed near the jaws were discarded.

Mean diameter of each extrudate section was determined from six measurements taken with vernier calipers along the length of the sample.

The force required to shear individual strands to extrudate was measured using the Warner-Bratzler shear cell. Cross-head speed was 5 cm/min. Extrudate diameter at the narrow section where shearing occurred was determined with calipers. In addition, shear properties of bulk extrudate were measured using the Kramer Shear Press. One gram of extrudate segments was placed in the cell at right angles to the shearing bars, and the interdigitating plates were forced through the product at a speed of 12.7 cm/min.

The following rheological parameters were calculated from the data for each test to which they were applicable:

(1) Stress at failure

$\sigma = F/A$

Where A is the cross-section area, m^2

(2) Modulus of Elasticity

$E = \sigma/(\Delta L/L)$

Where L = original length (m)

(3) Total energy (mJ)

$E_T = F\Delta L$

Total energy is area under the force deformation curve and was determined by planimeter.

The results were analyzed using the SAS stepwise procedure (Helwig and Council 1979). The initial model was considered to be of fourth order of the following form:

$$y = b_0 + b_1T + b_2M + b_3T^2 + b_4M^2 + b_5TM + b_6T^2M + b_7TM^2 + b_8T^2M^2$$

Where T = nominal barrel temperature (°C)
M = % moisture in the feed;
y = F, σ, E, or E_T

The final models obtained from the SAS stepwise regression procedure were employed in generating response surfaces using the SAS plot/contour procedure (Helwig and Council 1979).

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RESULTS AND DISCUSSION

Tensile Test

Table 1 contains measured (computed from experimental data) and predicted (from regression models) values for tensile parameters of extrudates, Table 2, regression coefficients of equations derived from the data, and Fig. 1, response surfaces generated from these models.

Variations in measured tensile properties values at a given set of conditions were large as seen in Table 1. The general physical properties of these extrudates have been described previously (Phillips *et al.* 1984). They exhibited inconsistencies in micro structure, including the tendency to form an annular void which sometimes opened to the outside of the rod-shaped extrudate, and surface breaks which would be especially noticeable in determining tensile properties on 5.5 cm long sections. The observed scatter was doubtless a major factor in the low values of R^2 obtained for the regression equations (Table 2). Despite these inconsistencies, the mean predicted values are, in most cases, reasonably close to the mean observed values. However, there are substantial deviations at higher moistures and barrel temperatures, especially for modulus of elasticity.

The force required to break individual strands of extrudate, and the stress at failure (force/cross section area) exhibited very similar patterns (Table 1. Fig. 1a,b). This reflected a consistency and homogeneity in the produce despite the large-scale structural inconsistencies mentioned above.

Tensile force and stress (Fig. 1a,b) were highest for the dense twisted extrudate produced at low levels of moisture and barrel temperature (Phillips *et al.* 1984) and declined as both independent variables increased. This decrease can be rationalized in terms of the increased tendency to expand and fissure as temperature increases and to become softer as moisture increases. For example at 20% initial moisture, increasing barrel temperature from 150 to 200°C produced a more expanded, brittle and finally fissured product, while at 150°C barrel temperature, increasing initial moisture from 20 to 40% produced a softer, more pliable, product. Proceeding from 20-150 to 30-175 the extrudates became both softer and more fissured and at 40-200, much softer and more granular (Phillips *et al.* 1984).

Cumming *et al.* (1972) extruded soy flour containing 30% moisture, dry basis, (23%, wet basis) over a range of barrel temperatures from 110° to 190°C, and measured the tensile break force. The results were expressed as g force/g sample. If their results are recalculated (assuming the constant extrudate diameter to be 3.18 mm as implied by these authors) maximum force values range from .76 to 1.44 N compared to the range observed with cowpea extrudate of 1 to 16 N. Force was observed to increase with temperature from 110 to 160°C then to decrease from 160 to 190°C. Stress

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Table 1. Measured and predicted values[1] of force at failure, stress at failure, total energy and modulus of elasticity from the tensile test applied to cowpea meal extrudates

Feed Moisture	Barrel Temperature	Force at Failure N		Stress at Failure kPa		Total Energy mJ		Modulus of Elasticity kPa	
		Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted
20%	150	16 ± 6	16	502 ± 224	509	110 ± 59	100	3579 ± 2954	3795
	175	11 ± 7	11	401 ± 250	367	20 ± 14	23	11367 ± 8156	11799
	200	4 ± 2	6	155 ± 81	214	9 ± 41	11	2624 ± 1666	3280
30%	150	9 ± 5	10	328 ± 179	351	117 ± 90	134	1128 ± 1424	1445
	175	7 ± 3	6	263 ± 98	258	75 ± 52	77	920 ± 651	1524
	200	5 ± 3	4	202 ± 97	174	35 ± 28	40	976 ± 1007	1880
40%	150	4 ± 3	3	152 ± 96	131	17 ± 12	25	968 ± 603	1505
	175	1 ± 1	2	83 ± [illegible]	104	17 ± 14	25	360 ± 247	1276
	200	2 ± 1	2	114 ± 55	118	14 ± 6	18	611 ± 619	1920

[1]Mean ± SD

Table 2. Coefficients of regression equations predicting tensile properties of cowpea extrudate to initial feed moisture and nominal barrel temperature

Coefficient	Force at Failure N	Stress at Failure kPa	Total Energy mJ	Modulus of Elasticity kPa
b_0	8.961 E1	1.135 E3	4.002 E3	-2.338 E6
b_1	-4.000 E-1		-5.425 E1	2.754 E4
b_2	-1.274 E0		-1.039 E2	1.357 E5
b_3		-2.222 E-2	1.663 E-1	-7.899 E1
b_4				-1.918 E3
b_5			2.020 E0	-1.598 E3
b_6	2.713 E-5		-7.118 E-3	4.585 E0
b_7		-7.200 E-3	-1.525 E-2	2.259 E1
b_8		3.400 E-5	6.988 E-5	-6.482 E-2
R^2	.57	.45	.49	.56

Where: $y = b_0 + b_1T + b_2M + b_3T^2 + b_4M^2 + b_5TM + b_6T^2M + b_7TM^2 + b_8T^2M^2$

T = Nominal barrel temperature °C
M = % moisture in the feed

Regression models are significant at the 0.0001 level, and coefficients are significant at the 0.05 level.

was also calculated from these authors' data (assuming a constant diameter of 3.18 mm). The values increased from 123 kPa at 110°C to 163 kPa at 150-160°C then decreased to 88 kPa at 190°C. Values for cowpea extrudate ranged from 83 to 500 kPa. These changes in force and stress over the latter part of the range agree with our findings.

Finkowski and Peleg (1981) extruded soy flour containing 22-29% moisture over temperature of 100 to 140°C and at 50 and 150 rpm screw speed. Their extruder geometry was similar to that used in the present study except the screw had a 2:1 compression ratio. They also applied the tensile test to the resulting extrudates. Although it is difficult to identify the particular extrusion conditions which match the reported values of stress at failure in this paper, the range was 300 to 900 kPa (again recalculating from the authors' data). Although regression equations are not presented by the authors, they found moisture to be a more influential

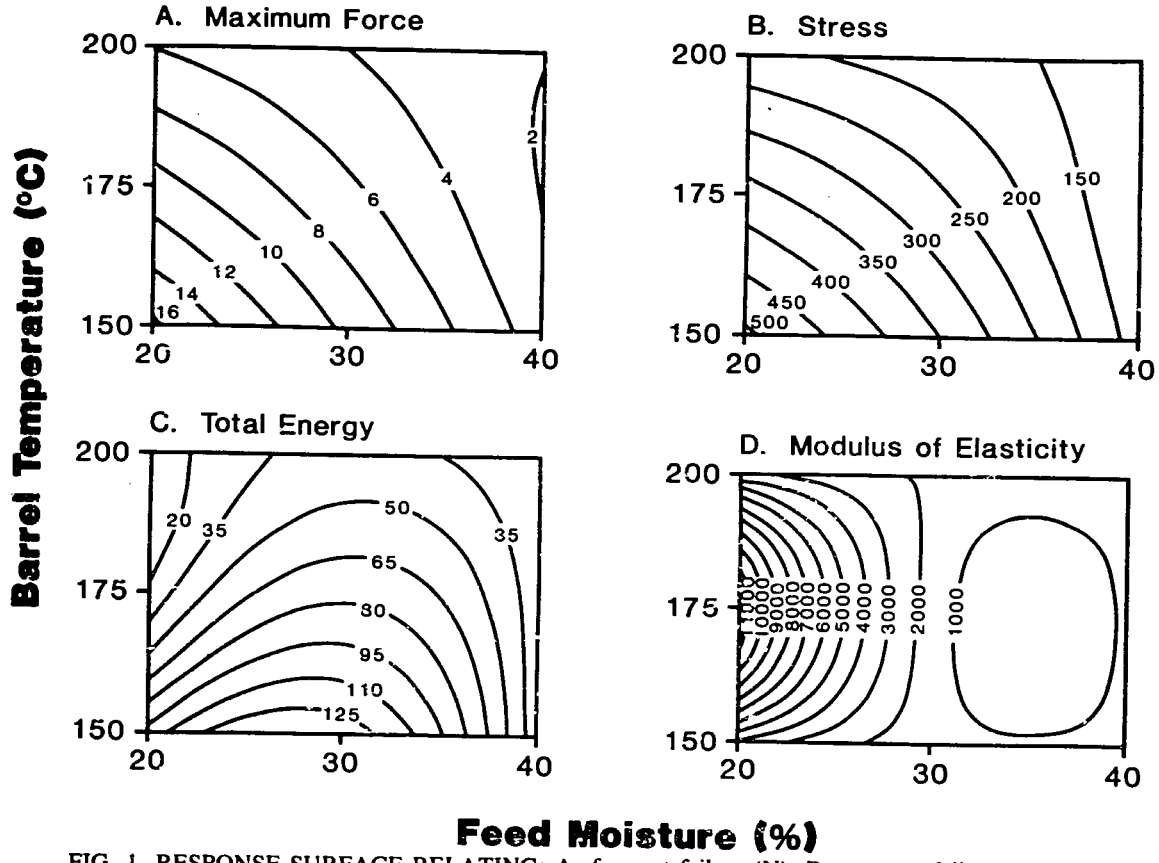

FIG. 1. RESPONSE SURFACE RELATING: A. force at failure (N); B. stress at failure (pKa); C. total energy (mJ); and D. modulus of elasticity (kPa) from the tensile test to feed moisture and barrel temperature.

factor in extrudate strength than temperature or screw speed. Although equipment and feed materials were similar, these stress values are much larger than those of Cumming *et al.* (1972) and overlap the high end of the range seen for extrudates in the present study. It is not known why these two studies on soy extrudates produced such different pictures for tensile properties. Furthermore, there is insufficient information in the literature to indicate what the tensile properties of soy extrudates versus those made from a starchy legume should be.

The total energy required to stretch-to-breaking strands of extrudate (Table 1, Fig. 1c) presented a somewhat different picture. The region requiring maximum energy to break strands of extrudate occurred at initial moistures of 20-30% and a barrel temperature of 150 °C. Values declined with increasing barrel temperature from this region, relatively rapidly at 20% and 40%, and more gradually at approximately 30% initial moisture. This shift in the maximum compared to force and stress may be interpreted in terms of the force pattern (Fig. 1a) and deformation. The 20% extrudates were relatively dry and brittle (Phillips *et al.* 1984) and exhibited sharp narrow force deformation curves, while the 30% moisture extrudate were more moist and deformable and exhibited lower, broader curves. The 40% moisture extrudate required relatively small energies to stretch regardless of extrusion temperature. That is, they were soft and "short" requiring little force to deform and breaking at intermediate deformations.

The modulus of elasticity values are given in Table 1 and also illustrated by the response surface in Fig. 1d. The mean predicted values differ greatly from the mean observed values for high feed moisture contents. However, some general statements about the modulus of elasticity of the extrudates can still be made. The maximum modulus value occurred at 20% initial moisture and 175 °C barrel temperature, and declined for all values of moisture and temperature from that point (Fig. 1c). This maximum modulus corresponded to the highly expanded cowpea extrudate (Phillips *et al.* 1984). At 20-200, the force had declined so as to produce a lower modulus, while at 20-150 the product was more capable of stretching prior to failure. A similar explanation can be applied to the other extrudates. Obviously for the modulus to be about the same for all the 30% moisture extrudate, deformation declined at about the same rate as stress did. This was the case due to the greater frequency of fissures and flaws in the product as temperature increased (Phillips *et al.* 1984). Modulus values for extruded soybean meal were calculated from the data of Finkowski and Peleg (1981). They ranged from 7,000 kPa to 61,000 kPa compared to approximately 400-11,000 kPa in this study.

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Warner-Bratzler Shear Test

Measured and predicted values of shear parameters from the Warner-Bratzler (W-B) test are given in Table 3, coefficients for the regression equations computed from this data in Table 4, and the resulting response surfaces in Figure 2. As with the tensile data, experimental variation at each extrusion condition is rather large (Table 3), resulting in low values

Table 3. Measured and predicted values of maximum force, maximum stress and total energy from the Warner-Bratzler Shear Test applied to cowpea meal extrudates

Feed Moisture	Barrel Temperature	Maximum Force Measure. N	Maximum Force Pred. N	Maximum Stress Measure. kPa	Maximum Stress Pred. kPa	Total Energy Measure. mJ	Total Energy Pred. mJ
20%	150°C	136 ± 36	134	4228 ± 1363	4116	323 ± 133	312
20%	175°C	68 ± 36	69	2413 ± 1538	2591	137 ± 102	133
20%	200°C	40 ± 12	38	1182 ± 585	1066	101 ± 48	91
30%	150°C	96 ± 30	97	3845 ± 1172	3755	255 ± 71	253
30%	175°C	91 ± 18	86	4155 ± 1024	4265	189 ± 51	173
30%	200°C	89 ± 27	89	4870 ± 1142	4775	157 ± 59	148
40%	150°C	24 ± 13	21	2247 ± 636	1174	62 ± 31	51
40%	175°C	31 ± 18	31	1983 ± 1451	1834	77 ± 44	71
40%	200°C	34 ± 15	31	2446 ± 1179	2494	73 ± 24	61

Mean ± SD

of R^2 for regression models (Table 4). However, predicted values for each parameter are generally in good agreement with observed means. As with the tensile test, generally maximum force occurs with extrudates produced at 20% initial moisture and 150°C barrel temperature. When force is corrected for extrudate diameter (stress), this trend becomes clearer (Fig. 2b). A saddle-shaped ridge of high shear strength extends from 20-150 to 30-200. This area represents tough extrudates which vary from dense and hard at 20-150 to expanded and layered in structure at 30-200 (Phillips *et al.* 1984). The pattern is very different from that seen for tensile stress. Since a relatively narrow cross-section of extrudate is examined in the

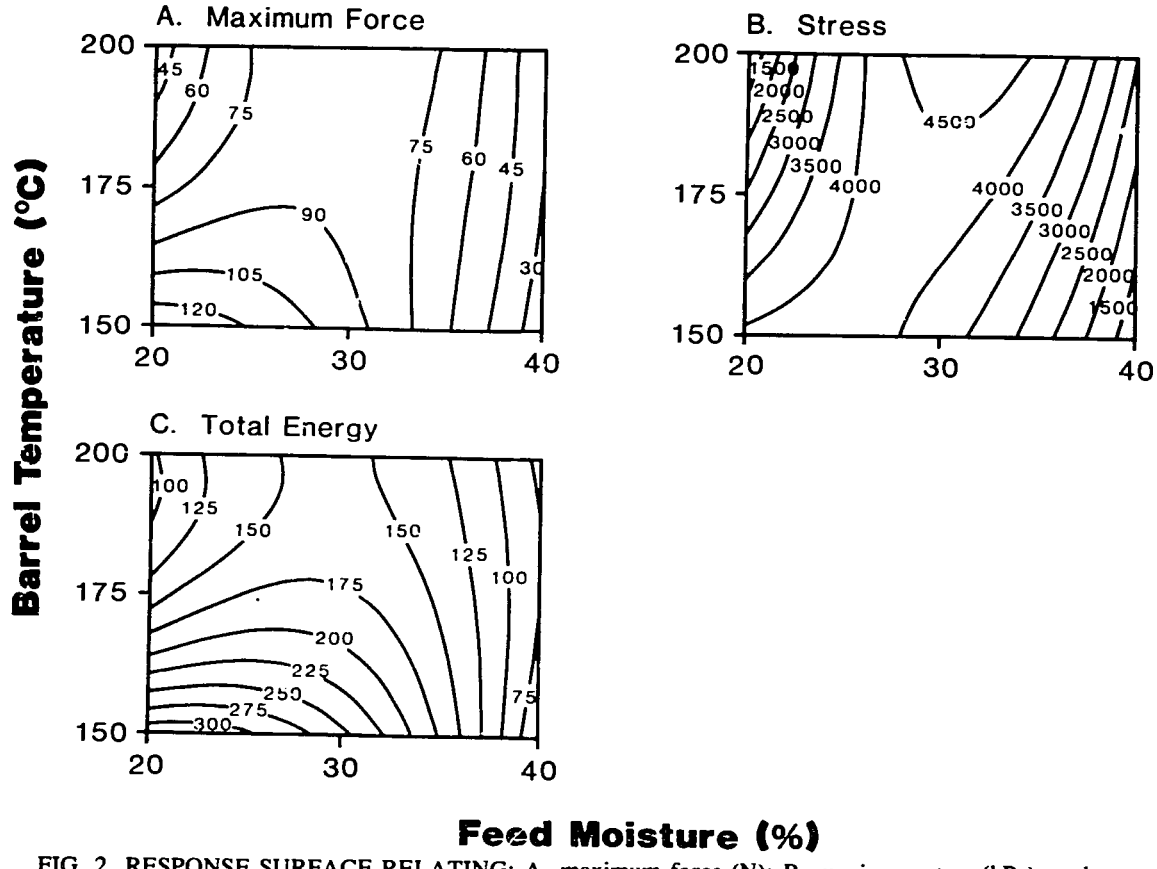

FIG. 2. RESPONSE SURFACE RELATING: A. maximum force (N); B. maximum stres (kPa); and C. total energy (mJ) from the Warner-Bratzler Shear test to feed moisture and barrel temperature.

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Table 4. Coefficients of regression equations relating Warner-Bratzler Shear Test Properties of extruded cowpea meal to initial feed moisture and nominal barrel temperature

Coefficient	Maximum Force N	Maximum Stress kPa	Total Energy mJ
b_0	3.441 E3	6.568 E4	8.764 E3
b_1	-3.170 E1	-4.500 E2	-9.537 E1
b_2	-1.269 E2	-3.530 E3	-2.079 E2
b_3	6.265 E-2		2.467 E-1
b_4	9.808 E-1	4.545 E1	-7.123 E-1
b_5	1.146 E0	2.699 E1	2.598 E0
b_6	-1.747 E-3		-6.762 E-3
b_7	-7.135 E-3	-3.770 E-1	
b_8			
R^2	0.69	0.58	0.59

Where: $y = b_0 + b_1T + b_2M + b_3T^2 + b_4M^2 + b_5TM + b_6T^2M + b_7TM^2 + b_8T^2M^2$

and y = Maximum Force, Maximum Stress, or Total Energy
T = Nominal Barrel Temperature °C
M = % Moisture in the Feed

Regression models are significant at the 0.0001 level, and coefficients are significant at the 0.05 level.

shear test, breaks and flaws could be more easily avoided than with the tensile test. For this reason the Warner-Bratzler results are probably a more reliable representation of extrudate texture than those from the tensile test. The decline in shear strength at higher feed moisture and at low feed moisture and high barrel temperature can be explained by the soft, "short" texture of products from the former conditions and the expanded, brittle nature of the latter (Phillips *et al.* 1984). The smaller rate of decline in tensile stress compared to that of shear stress in the low moisture-high temperature region (Fig. 1b) reveals the greater impact of product brittleness on shearing failure. Total energy required to shear strands of extrudate is relatively larger than that required to stretch-to-breaking, but the general shape of the response surfaces is similar (Fig. 1c,2c). However, the high-shear ridge is still evident in the greater skewing of the diagram in a low moisture/low temperature-to-intermediate moisture/high temperature direction, and in the slower decline in energy contours on the shear energy surface.

The Warner-Bratzler shear test is probably the rheological evaluation most often applied to extruded products. A number of authors have studied the texture of soy extrudates using it. Cumming *et al.* (1972) extruded defatted soy meal at an initial moisture of 23% (wet basis) and barrel temperature of 110 to 200°C. The W-B shear force values were corrected for density by these authors, and exhibited a sigmoidal pattern increasing from low to high temperatures. If the density correction is removed, force and stress increase more or less linearly between 110° and 160°C then decline. The values of force vary from 22 to 36 N, while stress (assuming a constant 3.18 mm diameter) varies from 2,800 to 4,500 kPa. Thus the force values are somewhat smaller than those found for cowpea extrudates, while stress is about the same due to the smaller diameter of the soy extrudates. Aguilera and Kosikowski (1976) extruded soybean flakes at initial moistures of 25, 35, and 45% and process temperatures of 120, 145, and 170°C. Force values ranged from 2 to 65 N. The data was fit to a regression model, and represented as a surface response diagram. Moisture was found to be the major contributor to texture, and the response surface bore little resemblance to the one found for cowpea products. Maurice and Stanley (1978) extruded soybean meal with initial moistures of 24 to 30% and barrel temperatures of 160 to 180°C. Shear force values ranged from 7 to 70 N, which are closer to those observed in this study. The data was fit to a regression model and it was found that protein content (confounded with moisture) was the most important factor in W-B force. The model reported herein for cowpea extrudates is more complex, with both temperature, moisture, and interactions of the two contributing to shear force and stress.

There have been few reports in which intact, starchy extrudates were subjected to rheological examination. Mercier and Feillet (1975) measured breaking strength of corn grits, extruded at an initial moisture of 18.2%, and at temperatures of 65 to 250°C with a device similar to the Warner-Bratzler cell (judging from its description), and reported values of shear force, which decreased from ~2800 to 800 kg (~8000 to ~27500 N) as temperature increased from 170 to 250°C. These values are ten to one hundred times those observed for cowpea extrudates. No information on product diameter was included, making the more meaningful comparison of stress values impossible, however, it is doubtful that diameters could be large enough to make stress values similar to those in the present study. This indicates that starch may contribute to large values of shear force, even in expanded products. Faubion and Hoseney (1982a) found that extruded wheat starch had higher shear force values than extruded wheat flour, and that addition of gluten reduced the strength of extrudates. The values of stress computed from these data, however, ranged only from 175 to 291 kPa.

Kramer Shear Press

The Kramer Shear Press is used to examine rheological properties of bulk samples. Since, in this test, force is not related to produce cross-sectional area it is considered empirical in nature. Nevertheless, it gives useful information of the combined compression and shear behavior of materials. Measured and predicted values of maximum force and total energy from the Kramer test are given in Table 5, coefficients of the regression equations in Table 6, and the surface response diagrams in Fig. 3. General observations made for data from the other tests also apply here. Coefficients of determination are somewhat higher, probably because the use of larger samples eliminates some scatter in the data. Actual values of force and total energy are about ten times larger than for the Warner-Bratzler test for the same reason. The shear force and total energy diagrams (Fig. 3a,b) resemble the corresponding ones for W-B shear test, with the high-strength ridge being evident.

Table 5. Measured and predicted values of maximum force, and total energy from the Kramer Shear Test applied to cowpea meal extrudates

Feed Moisture	Barrel Temperature	Maximum Force Measure. N/g	Maximum Force Pred. N/g	Total Energy Measure. mJ/g	Total Energy Pred. mJ/g
20%	150°C	1185 ± 269	1160	3544 ± 957	3521
20%	175°C	755 ± 348	728	1896 ± 696	1953
20%	200°C	512 ± 139	480	1185 ± 585	1163
30%	150°C	826 ± 262	776	1669 ± 525	1728
30%	175°C	993 ± 225	938	1635 ± 509	1535
30%	200°C	882 ± 186	820	1639 ± 406	1699
40%	150°C	259 ± 175	175	578 ± 284	561
40%	175°C	279 ± 186	186	581 ± 306	644
40%	200°C	342 ± 240	240	690 ± 379	663

Mean ± SD

Aguilera *et al.* (1984) milled and air classified navy beans to produce high starch (17% protein, 50% starch) and high protein (40% protein, 16% starch) flours. Blends of high starch navy bean fraction and corn grits

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Table 6. Coefficients of regression equations relating Kramer Shear Test Properties of extruded cowpea meal to initial feed moisture and nominal barrel temperature

Coefficient	Maximum Force N/g	Total Energy mJ/g
b_0	9.732 E4	8.878 E4
b_1	-1.057 E3	-7.267 E2
b_2	-6.560 E3	-3.697 E3
b_3	2.778 E0	1.298 E0
b_4	1.038 E2	3.612 E1
b_5	7.300 E1	1.747 E1
b_6	-1.944 E-1	-3.377 E-2
b_7	-1.171 E0	-2.199 E-1
b_8	3.145 E-3	
R^2	0.68	0.72

Where: $y = b_0 + b_1T + b_2M + b_3T^2 + b_4M^2 + b_5TM + b_6T^2M + b_7TM^2 + b_8T^2M^2$

and y = Maximum Force, or Total Energy
T = Nominal Barrel Temperature °C
M = % Moisture in the Feed

Regression models are significant at the 0.0001 level, and coefficients are significant at the 0.05 level.

and of high protein navy bean fraction and soy flour were extruded on a Wenger X5 machine. The starchy products were extruded at initial moistures of 10-12% and product temperatures of 85-90°C. Hardness, defined as peak force per unit mass (kg/gm) was measured using the Kramer Shear Press. Values declined from 394 to 15 N (kg × 9.81) as high starch bean flour was increased from 0 to 100% in the mixture. The extrudates were described as highly expanded which would explain the relatively lower hardness. The high protein extrudates were rehydrated and autoclaved prior to texture analysis, making comparison with cowpea extrudates meaningless.

The purpose of this work was to investigate the texturization of cowpea meal, and to measure the textural properties of the resulting products. We have attempted, insofar as possible, to compare these results with those for other experimentally produced extrudates. The literature is so sketchy in this area, even for soy extrudates as to make such comparisons dif-

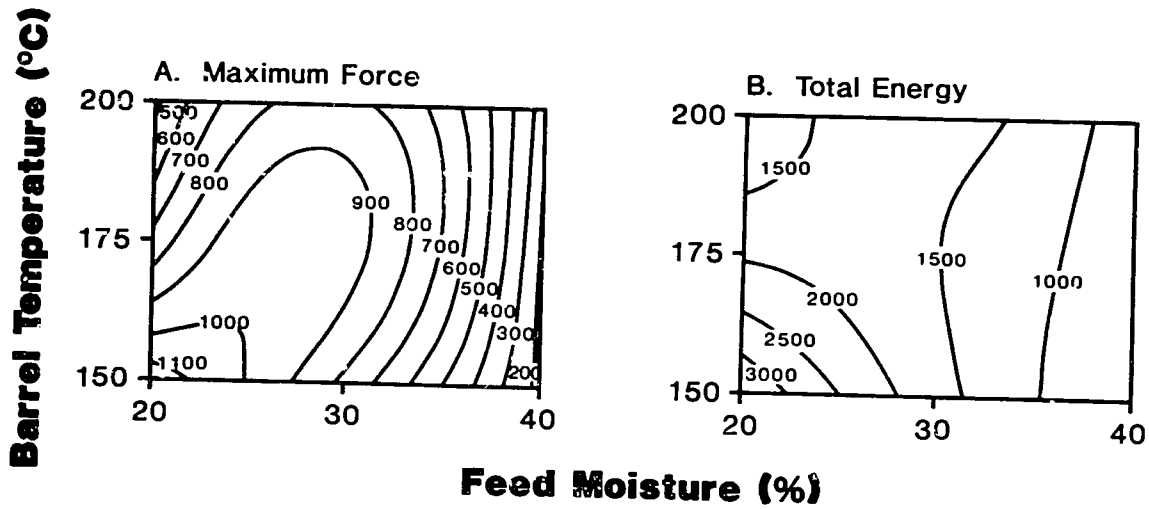

FIG. 3. RESPONSE SURFACE RELATING: A. maximum force (N) and B. total energy (mj) from the Kramer Shear test to feed moisture and barrel temperature.

ficult. The particular combination of major texture producing species in cowpea meal, proteins and starches, and their unique characteristics, are responsible for the resulting textures. For this reason, these products would not be expected to duplicate those made from other ingredients. However, their potential can be assessed only by such comparisons.

The contribution of protein to the texture of starchy (e.g., cereal grain) extrudates, and of carbohydrate to proteinaceous extrudates has not been extensively studied. In the latter case, starch has been considered to interfere with texture information in extruded peanut flour products (Aguilera *et al.* 1980). Faubion and Hoseney (1982a, 1982b) reported that increasing levels of gluten reduced expansion in wheat flour extrudates, while addition of soy isolate at the 5-7% level increased expansion. They also observed that, while wheat flour extrudates required lower shearing force (Warner-Bratzler) than wheat starch extrudates, the addition of soy isolate to wheat starch increased the required shearing force of the resulting extrudates. Paton and Spratt (1984) examined reconstituted wheat systems, and found that addition of gluten increased expansion under some conditions of moisture and temperature, but decreased it under others. The mechanism by which these interactions occur have yet to be elucidated. The known properties of cereal and legume proteins, and the findings that denaturation of soy protein prior to extrusion interferes with texture formation (Rhee *et al.* 1981), suggest that the greater solubility of globulins allow them to become mobilized in the extruder barrel and to contribute to texture while relative inert prolamins and glutelins may act as a physical interference. Current work in this laboratory is seeking to assess the role of the protein and starch fractions in cowpea meal extrusion.

SUMMARY AND CONCLUSIONS

A major research effort is underway in our laboratory to assess the potential of cowpeas, a high-protein, starchy legume, for producing extruded food products. The objective of this study was to examine the rheological properties of cowpea extrudates produced over a range of initial moistures and barrel temperatures. Cowpea meal was successfully extruded into coherent products when initial moisture content ranged from 20 to 40%, and the extruder barrel temperature ranged from 150° to 200°C. The expanded, brittle products resulting at 20% initial moisture, and 175-200°C resembled commercial puffed snack foods, although shear stress values were higher (Falcone 1983). Extrudates produced from 30% moisture dough were tough and chewy, resembling intermediate moisture meat products. Extrudates made from 40% moisture dough were soft, gummy and bread-like.

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These findings demonstrate the potential of this underutilized legume as an ingredient for producing a variety of extruded foods. However much remains to be done before cowpea meal will be accepted as a raw material for manufactured food production. It will be necessary to examine, at higher resolution, the effects of initial moisture and barrel temperature on texture. Blending with other ingredients, may be necessary to optimize textures of products made under various conditions. In addition, no effort was made in this study to examine sensory properties of the extrudates, although flavor and subjective mouth-feel are of great importance in the acceptability of foods. It is intended that future work will address these questions.

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