Selected Properties of Extruded Potato and Chicken Meat

ING-JENQ JEAN, RICHARD WORK, MARY ELLEN CAMIRE, JACK BRIGGS, ANN H. BARRETT, and ALFRED A. BUSHWAY

ABSTRACT

Chicken thigh meat (CTM), (0–40%) was mixed with instant mashed potato and twin-screw extruded. Feed moisture content (FMC), (15 or 20%) and screw speed (SS) (250 or 300 rpm) were varied. CTM affected expansion, bulk density, mean cell size, plateau stress, fracturability and solubility. Protein, fat, free fatty acid and ash increased and carbohydrate decreased as CTM increased. Extrudates produced at low feed moisture (15%) had higher compressive resistance, fracturability and solubility. Extrudates produced at high feed moisture (20%) had higher bulk density and mean cell size. Screw speed had no influence except on expansion degree ($p \leq 0.05$). Increased CTM changed microstructure from rough, thread-like sheets to a flat, agglomerated carbohydrate-protein laminar phase. Panelists reported no differences in overall acceptability among 0% CTM extruded at 20% FMC, 20% CTM extruded at 15% FMC and 20% CTM extruded at 20% FMC.

Key Words: extrusion, chicken, instant potato, snack

INTRODUCTION

EXTRUSION COOKING to produce snack products is usually associated with cereal grains, sometimes supplemented with vegetable proteins (Falcone and Phillips, 1988; Batistuti et al., 1991; Laarhovewn and Staal, 1991; Vargas-Lopez et al., 1991). However, cereal-based snacks lack some essential amino acids, such as threonine, tryptophan, and lysine. Chen (1989), and Park et al. (1993) investigated the characteristics of potential nutritious snack products by adding chicken breast meat and beef to formulations. Our objective was to investigate the properties of extruded potato and chicken using a Werner and Pfleiderer twin screw extruder. The effects of processing variables [feed moisture content (FMC), screw speed] and chicken thigh meat (CTM) content on chemical composition, physical characteristics, and sensory attributes of extrudates were investigated.

MATERIALS & METHODS

Raw materials preparation

Instant mashed potato (Carnation Co., Los Angeles, CA) and CTM (Hannaford Bros., Scarborough, ME) were mixed to yield formulations with 0, 20 and 40% CTM (Table 1). Skinned and hand-deboned CTM was preground to a homogeneous mass using a Hobart silent cutter Model 84141 (Hobart Corp., Troy, OH). The meat was mixed with instant mashed potato, normal corn starch, and sodium chloride in a Hobart mixer Model A-200 FT (Hobart Corp., Troy, OH). The mixture was ground to fine particles in a silent cutter. A total of 18.2 kg of mixture was prepared for each formulation. The mixtures were delivered to Natick RD&E Center, Natick MA in styrofoam boxes containing frozen gel packs, then were freeze dried upon receipt using a Virtis freeze dryer (Virtis Co., Gardiner, NY) and stored at −18°C until extrusion.

Experimental design

A split-split plot random complete block design was used. Three chicken formulations were the main blocks. For each formulation, the freeze dried mixture was adjusted to 15 and 20% moisture content and extruded both at 250 and 300 rpm in two replicate cycles. A 2*2 factorial sets of moisture and screw speed were assigned in duplicate in each main block (Table 2).

Authors Jean, Work, Camire, and Bushway are with the Dept. of Food Science & Human Nutrition, Univ. of Maine, 5736 Holmes Hall, Orono, ME 04469-5736. Authors Briggs and Barrett are with AFB, TAD, FED, U.S. Army NRDC, Natick, MA 01760-5018. Address inquiries to Dr. A.A. Bushway.

Extrusion parameters

A Werner & Pfleiderer co-rotating twin screw extruder Model ZSK 30 (Ramsey, NJ) with 4 mm diameter die was used for extrusion. The barrel bore diameter was 30.9 mm, screw outside diameter 30.7 mm, screw length 879 mm. The screw configuration consisted of 42° forward conveying elements for the first 480 mm, 90 mm of 28° conveying elements, and 20° forward elements were used for the remainder of the screw with a 14/7 igel at 600 mm, right-handed 45° kneading blocks at 720, 754, 794 and 845 mm, and left-handed conveying elements at 814 and 874 mm. This screw configuration had been recommended by the manufacturer for corn meal and was not modified for the potato flour and chicken formulations. Tap water was fed into the first barrel section of the extruder to maintain feed moisture contents of 15 and 20% (total weight basis). The temperature barrel profile, from feed to die, was 38, 50, 72, 115, 135, and 149°C. Screw speeds were 250 and 300 rpm. The dry ingredient feed rate was 6.2 kg/hr. A cutter was not used. These conditions were selected based on a preliminary study. After extrusion, extrudates were dried in a forced air oven (Proctor and Schwartz, Inc., Philadelphia, PA) at 105°C to a moisture content <5%. Extrudates were vacuum-sealed in tin cans for image analysis, compression testing and sensory evaluation. Remaining extrudates were packed in 3 mil Ziploc bags (Dow Chemical, Inc., Indianapolis, IN) and stored at room temperature (≈23°C).

Proximate analysis

Three extrudate samples were taken from each extrusion variable of each of 2 replications. The extrudates were ground in a Thomas Wiley Lab Mill (Model 4, Arthur H. Thomas, Philadelphia, PA) to pass a 1 mm screen. Moisture, protein and fat contents were analyzed according to procedures of AOAC (1990) methods 950.46 B, 960.39 A and 928.08, respectively. Moisture and protein determinations were performed in triplicate; a single fat analysis was conducted for each sample. Ground

Table 1—Extrudate formulation[a]

Chicken	Mashed potato	Corn starch	NaCl
0%	96.2%	1.9%	1.9%
20%	76.2%	1.9%	1.9%
40%	56.2%	1.9%	1.9%

[a] Unit: % total weight

Table 2—Extrusion parameters[a]

Chicken (%)	Moisture (%)	Screw speed (rpm)	Melt temp (°C)	Torque (%)	Die pressure (KPa)
0	15	250	152 ± 4.2	59 ± 3.2	1695 ± 97
0	15	300	152 ± 3.0	53 ± 2.9	1178 ± 63
0	20	250	149 ± 2.1	43 ± 3.5	1609 ± 105
0	20	300	146 ± 3.6	44 ± 2.5	1984 ± 79
20	15	250	146 ± 3.2	49 ± 1.9	3225 ± 135
20	15	300	148 ± 2.9	45 ± 2.7	2015 ± 109
20	20	250	146 ± 3.3	38 ± 3.1	1812 ± 93
20	20	300	143 ± 2.0	41 ± 1.7	2281 ± 89
40	15	250	145 ± 1.6	44 ± 1.5	2560 ± 115
40	15	300	147 ± 2.6	39 ± 2.2	1929 ± 104
40	20	250	146 ± 3.1	32 ± 1.5	1705 ± 76
40	20	300	143 ± 1.9	34 ± 1.6	2005 ± 99

[a] Each value is the mean of two replicates.

Table 3—Effect of chicken thigh meat, feed moisture content and screw speed on extrudate composition

	Experimental treatment											
Chicken (%)	0	0	0	0	20	20	20	20	40	40	40	40
Moisture (%)	15	15	20	20	15	15	20	20	15	15	20	20
Screw speed (rpm)	250	300	250	300	250	300	250	300	250	300	250	300
Moisture after extrusion (%)	7.7^{b}	7.3^{b}	11.7^{a}	12.5^{a}	7.1^{b}	8.5^{b}	13.1^{a}	12.7^{a}	8.7^{b}	8.6^{b}	12.8^{a}	12.7^{a}
Protein (%)	8.0^{c}	8.4^{c}	9.0^{c}	8.9^{c}	14.4^{b}	14.4^{b}	13.3^{b}	13.7^{b}	19.7^{a}	20.1^{a}	20.3^{a}	20.1^{a}
Lipid (%)	0.18^{b}	0.24^{b}	0.17^{b}	0.19^{b}	0.16^{b}	0.23^{b}	0.15^{b}	0.24^{b}	0.54^{a}	0.48^{a}	0.50^{a}	0.50^{a}
Free fatty acid[g]	5.0^{f}	8.8^{def}	12.9^{cde}	8.6^{ef}	14.4^{cde}	14.6^{cd}	18.3^{bc}	16.1^{bc}	20.8^{b}	21.4^{b}	20.6^{b}	27.4^{a}
Ash (%)	4.78^{ef}	5.19^{cd}	4.85^{def}	4.60^{f}	5.26^{bc}	5.11^{cde}	5.03^{cde}	5.07^{cde}	5.60^{ab}	5.64^{a}	5.53^{ab}	5.55^{ab}
Carbohydrate (%)	85.0^{a}	83.6^{ab}	82.1^{b}	82.6^{ab}	77.4^{c}	77.9^{c}	75.4^{c}	75.6^{c}	70.5^{d}	71.1^{d}	70.5^{d}	70.0^{d}

[a-f] Means with same superscript letter within a row are not significantly different at 95% confidence level using Duncan's Multiple Range Test.
[g] Unit: mg KOH equivalent/100g extrudate

extrudate (2g) was incinerated in a Barber-Coleman furnace (Barber-Coleman Co., Rockford, IL) at 650°C for 6 hr to determine ash content. The ash residue was weighed and dissolved in a boiling 5% hydrochloric acid solution. The solution was added to a 100 mL volumetric flask and brought to volume with deionized water. The mineral content (Ca, K, Al, Mn, Cu, Mg, P, Fe, B, and Zn) of the solution was determined using a Jarrell-Ash Plasmaspectrometer Model 975 (Jarrell-Ash Co., Franklin, MA). Sodium was determined using an Atomic Absorption Spectrophotometer Video 12 (Instrumentation Laboratory, Inc., Wilmington, MA). Ash and mineral determinations were performed in duplicate. The carbohydrate content was determined by difference.

Free fatty acid (FFA)

FFA content was analyzed according to AOAC (1990) method 939.05. FFA was calculated as 20*(titration-blank) and expressed as mg KOH equivalent/100g sample.

Expansion ratio

The diameter of six extrudates/treatment was measured with a caliper (Dial Type 6921, KWB, Switzerland). The degree of expansion was calculated as the ratio: extrudate diameter/die diameter.

Bulk density

Extrudate bulk density was measured in quadruplicate following the method of Barrett and Peleg (1992b). A 5 cm long cylindrical section of extrudate was weighed and the diameter was measured using a caliper. Bulk density was calculated as: weight of extrudate/volume of extrudate.

Cell size

For each extrudate variable, mean cell area was determined according to the procedure of Barrett and Ross (1990), in which the area of each cell in a cut (radial) section was individually measured using an Olympus Cue 2 image analysis system. Two sections of low moisture samples and three sections of high moisture samples were analyzed, and these replicates pooled into combined cell size distributions containing 10 to 30 cells. The mean cell area for each sample was calculated using Minitab statistical software.

Average compressive stress and fracturability

Average compressive stress and fracturability were measured using a Texture Technologies TXT2 texture press. Twelve mm cylindrical sections were uniaxially compressed to 50% strain using a crosshead speed of 0.2 mm/min and a data acquisition rate of 12.5 points/sec. Force readings were converted to stress values, which were averaged within the middle 2/3 of the data file. Compression of porous, cellular material typically yields a "plateau" region of generally nonincreasing overall stress (neglecting oscillations due to fracturing) at intermediate levels of strain (Gibson and Ashby, 1988). This technique was used to evaluate extrudate strength by Barrett and Peleg (1992b), Barrett et al. (1994a) and Barrett et al. (1995).

Fracturability, evidenced by the "jaggedness" or oscillating behavior of stress-strain functions, was quantified by a cumulative fracture stress measurement according to the procedure of Barrett et al. (1994b). Cumulative fracture stress was calculated by summing the magnitude of all fractures occurring during compression. Fractures were identified by reductions in stress, i.e., by negative differences between subsequent data points.

All calculations were made using Minitab statistical software.

Solubility

Water solubility of ground extrudate was determined in triplicate following the method of Anderson et al. (1969). Ground extrudate (2.5g) was suspended in 30 mL of water in a centrifuge tube, stirred for 30 min, and centrifuged at 3000 × g for 10 min using a Beckman Model TJ-6 Centrifuge (Beckman Instruments, Inc., Pala Alto, CA). The supernatant was carefully poured into a moisture dish. The dish was dried in a forced air oven at 105°C for 16 hr. The remaining solid was weighed and the weight divided by 0.25 to determine % solubility.

Microstructure

Cross-sectional surfaces of extrudates were cut with a razor. Each sample was attached to aluminum stubs and sputter-coated with 200 Angstroms of gold. Extrudates were examined with an AMR 1000A Scanning Electron Microscope (Amray Co., Bedford, MA) with accelerating voltage of 5 kv and magnification of 20×, 1000× and 5600×. Kodak Polaroid photo papers were used.

Sensory evaluation

Twelve samples could not be evaluated simultaneously, therefore, informal screening excluded samples with obvious low acceptability. Five extrudate samples prepared from 20 and 40% CTM extruded at both FMC and 0% CTM extruded at 20% FMC were assigned a three-digit number. Four samples in randomized order were presented to 78 panelists who were faculty, staff and students at the University of Maine. Panelists evaluated samples by using a nine-point hedonic scale (Peryam and Giradot, 1952) for extrudate color, texture, flavor and overall acceptability.

Statistical analysis

The effects of chicken thigh meat, feed moisture content, screw speed and interactions on chemical compositions and physical characteristics were determined with the General Linear Model (SAS Institute, Inc., 1989). The model $1 = X_1 + X_2 + X_3 + X_1X_2 + X_1X_3 + X_2X_3 + X_1X_2X_3$ yielded coefficients of determination and significance of factors and interactions, where X_1 = chicken thigh meat content, X_2 = feed moisture content, X_3 = screw speed. Duncan's multiple range test at 95% confidence level was used to identify levels of effect. Pearson's correlation was determined using the SAS Statistical Analysis System (SAS Institute, Inc., 1989).

RESULTS & DISCUSSION

EFFECTS OF CTM, FMC and SS on extrudate composition were compared (Table 3). CTM affected extrudate composition ($p \leq 0.05$) (Table 4) with exception of moisture content after extrusion. FMC was the most important factor affecting moisture content after extrusion, and also was a significant ($p \leq 0.05$) but minor factor affecting free fatty acid, ash and carbohydrate contents. Screw speed had no effect on extrudate composition and

Table 4—Effects of process variables on extrudate composition by analysis of variance

Source	df	Moisture after extrusion	Protein	Lipid	Free fatty acid	Ash	Carbohydrate
CTM	2		528.84****	103.38****	58.41****	63.07****	266.92****
FMC	1	246.09[a]****			5.21*	11.19**	12.81**
CTM*FMC*SS	2				4.52*	4.22*	
Model		23.33****	96.11****	19.55****	12.12****	13.84****	50.15****

[a] F-value

**** = $p \leq 0.0001$ *** = $p \leq 0.001$ ** = $p \leq 0.01$ * = $p \leq 0.05$

significant interactions only occurred in CTM, FMC and SS for free fatty acid and ash contents.

Moisture content after extrusion (MCE) and drying (MCD)

High FMC resulted in a higher (p≤0.05) average moisture retained in the extrudate after extrusion. Since barrel temperature was constant, high FMC lowered melt temperature. Extrusion cooking resulted in 47% reduction in moisture when extruded at low FMC and only 37% reduction in moisture when extruded at high FMC.

Extrudates were dried in a forced air oven from 10 to 30 min, depending on treatment, to maintain final product moisture <5%. All products were brittle, but there may have been slight variations in moisture retained in extrudates.

Protein content

Extrudates had protein contents of about 9, 14, and 20% when prepared from formulations containing 0, 20 and 40% CTM, respectively (Table 3). Chicken level and overall model had significant effects on protein content (Table 4).

Lipid and free fatty acid (FFA) contents

Although the amount of chicken affected lipid content overall, no difference in lipid content was found between extrudates prepared from 0 and 20% CTM. Lipid-protein interactions may have prevented complete extraction by petroleum ether (Izzo and Ho, 1989). Formation of amylose-lipid complexes might be partially responsible for the lower lipid content in extrudates.

FFA was different (p≤0.05) among extrudates from CTM. Higher FMC also resulted in a higher FFA (p≤0.05). Since FFA were more volatile as temperature increased, higher FMC could reduce extrusion temperature and losses in FFA content. Effect of higher screw speed (300 rpm), due to shorter residence time, could also reduce the loss in FFA content. The maximum FFA content was observed in extrudates prepared from 40% CTM extruded at high FMC and high screw speed (Table 3).

Ash and mineral contents

Ash content increased in the extrudate prepared from 20 and 40% CTM from the added CTM (Table 3). Low FMC generally resulted in higher ash content in the extrudate. This could result from the wearing of the alloys comprising the barrel and screw when extruding at low moisture content.

Higher amounts of Mg and Fe (p≤0.05) were found in the extrudate prepared from 0% CTM (Table 5). Higher Fe was possibly due to increased friction on the screw when chicken was not in the formulation. Higher amounts of P, Na and Zn (p≤0.05) were found in the extrudate with 40% CTM and these were due to the P, Na and Zn in CTM (USDA, 1980).

Degree of expansion

Extrudates from 20% CTM had the highest degree of expansion (p≤0.05) (Table 6). Addition of soy protein at up to 10% to wheat starch (Faubion and Hoseney, 1982) and soy protein isolate at 15% to corn meal (Camire and King, 1991) increased expansion of extrudates. Addition of wheat gluten to wheat starch (Faubion and Hoseney, 1982) and porcine or bovine offals to soy grit (Mittal and Lawrie, 1984; 1986) decreased extrudate expansion. Differences in effects of protein on expansion were due to different compositions and effects of protein on hydration rates during starch gelatinization (Camire et al., 1990). The increased expansion degree in the 20% CTM formulation could be due to the hydrophilic nature of chicken proteins in facilitating potato starch gelatinization. In the 40% CTM formulation the excess protein might interfere with gelatinization due to competition between protein and starch for water and the formation of protein bodies (Chandrashekar and Kirleis, 1988). In addition, when extruding, formulations containing 20% CTM had higher average die pressures. The higher pressure could cause more moisture evaporation leading to higher expansion degree (Chinnaswamy and Hanna, 1987; 1988).

Table 5—Effect of chicken thigh meat content on iron and magnesium concentration

Chicken (%)	Fe (ppm)	Chicken (%)	Mg (ppm)
0	52.0[a]	0	1109[a]
20	45.9[b]	40	849[b]
40	33.7[c]	20	808[c]

[a-c] Effect is significant and means with the same superscript letter are not significantly different at 95% confidence level using Duncan's Multiple Range Test.

Low SS (250 rpm) resulted in a higher (p≤0.05) expansion degree but the effect was smaller than the effect of CTM (Table 6). Low SS caused a higher pressure and resulted in a higher shear stress as indicated by a higher average torque value (Table 2). Higher torque would increase the storage of energy in the elastic mass promoting radial expansion (Alvarez-Martinez et al., 1988) but higher pressure would promote moisture evaporation to expand the extrudate.

CTM and SS were responsible for 47.8% (Table 8) of the variability in expansion degree. When interaction effects were taken into consideration, a total of 89.9% (Table 8) of the variability was accounted for. Significant interactions occurred in CTM-FMC and CTM-SS (p≤0.05) (Table 7). Significantly higher degrees of expansion were observed in extrudates prepared from 20% CTM extruded at two levels of FMC and from 0% CTM extruded at high FMC and 20% CTM extruded at low SS.

Bulk density

CTM and FMC had major effects on bulk density, accounting for 82.2% of variability while the interaction effect was minor (Tables 7, 8). The 20% CTM extrudate had the lowest bulk density due to its high expansion and large cell size. The dense areas and thick cell walls (arrows in Fig. 1c; 4c) of the extrudate prepared from the 40% CTM formulation indicate its high bulk density. High FMC resulted in a higher bulk density (p≤0.05) (Table 6). This confirmed results of Badrie and Mellowes (1991) and Barrett and Ross (1990).

When extrusion proceeded both at high level of CTM (40%) and FMC (20%), the combined effect of CTM and FMC resulted in bulk density that was not statistically different. Interaction occurred between CTM and SS and a higher bulk density was observed when the formulation containing 40% CTM was ex-

Table 6—Effect of chicken thigh meat content, feed moisture content and screw speed on extrudate characteristics

Chicken (%)	Moisture (%)	Screw speed (rpm)	Expansion degree	Bulk density (g/cm^3)	Mean cell area size (mm)	Average compressive resistance (kg/cm^2)	Fracturability (kg/cm^2)	Solubility (%)
0	15	250	2.70^{d}	0.131^{def}	1.4^{ef}	2.38^{b}	16.9^{bcd}	68.9^{a}
0	15	300	2.18^{e}	0.158^{cdef}	1.2^{f}	5.54^{a}	28.2^{a}	60.9^{ab}
0	20	250	3.54^{ab}	0.165^{cde}	5.2^{bde}	0.48^{c}	8.2^{d}	56.5^{bc}
0	20	300	2.84^{d}	0.191^{bc}	5.0^{bcd}	1.05^{c}	16.7^{bcd}	51.2^{bc}
20	15	250	3.78^{a}	0.110^{f}	5.5^{bc}	0.65^{c}	8.0^{d}	48.3^{cd}
20	15	300	3.16^{bcd}	0.121^{ef}	3.6^{cde}	0.90^{c}	11.6^{cd}	57.0^{bc}
20	20	250	3.44^{ab}	0.176^{bcd}	7.9^{a}	0.60^{c}	10.2^{cd}	37.2^{e}
20	20	300	3.34^{abc}	0.173^{cde}	7.4^{ab}	0.57^{c}	11.2^{cd}	40.1^{de}
40	15	250	2.92^{cd}	0.226^{b}	2.8^{def}	2.46^{b}	22.5^{ab}	37.0^{e}
40	15	300	3.09^{bcd}	0.158^{cdef}	3.6^{cde}	1.00^{c}	13.1^{bcd}	38.7^{de}
40	20	250	2.69^{d}	0.294^{a}	4.3^{cd}	1.20^{c}	18.9^{abc}	24.1^{f}
40	20	300	2.74^{d}	0.282^{a}	4.1^{cd}	1.01^{c}	17.7^{bcd}	30.4^{ef}

[a-f] Values with same superscript letter are not significantly different at 95% confidence level using Duncan's Multiple Range Test.

Table 7—Effects of process variables on extrudate physical characteristics by analysis of variance[a]

Source	df	Expansion degree	Bulk density	Cell size	Plateau stress	Fracturability	Solubility
CTM	2	21.57***	46.13****	17.29***	32.73****	8.09**	69.21****
FMC	1		55.72****	39.90****	76.36****		45.44****
SS	1	9.10*					
CTM*FMC	2	13.49**		4.42*	37.01****		
CTM*SS	2	6.95*	4.86*		30.79****	6.28*	4.00*
FMC*SS	1						
CTM*FMC*SS	2				18.82***		
Model		8.94***	15.37****	8.00***	28.98****	3.61*	17.71****

[a] F-value
**** = $p \leq 0.0001$ *** = $p \leq 0.001$ ** = $p \leq 0.01$ * = $p \leq 0.05$

Table 8—Coefficient of determination of General Linear Model procedure on extrudate characteristics

Source	df	Expansion degree	Bulk density	Cell size	Plateau stress	Fracturability	Solubility
CTM	2	0.395	0.512	0.319	0.199	0.319	0.673
FMC	1		0.310	0.415	0.232		0.221
SS	1	0.083					
CTM*FMC	2	0.247		0.089	0.224		
CTM*SS	2	0.127	0.054		0.187	0.247	0.039
FMC*SS	1						
CTM*FMC*SS	2				0.114		
Total R^2		0.899	0.939	0.888	0.967	0.783	0.947

truded at low SS. Maximum bulk density was observed in the extrudate prepared from 40% CTM extruded at low SS and high FMC.

Mean cell area

FMC was more important than CTM in affecting mean cell area (Table 7). Extrudates prepared from 0 and 40% CTM had similar expansions (Table 6) and a large difference in bulk density (Table 6), but they were not different in mean cell size (Table 6). Thick cell walls, dense areas and low porosity in the extrudate prepared from 40% CTM formulation (arrows in Fig. 1c; 4c) could explain such differences. The extrudate prepared from 20% CTM had a larger mean cell size ($p \leq 0.05$) (Table 6) as a result of its high expansion degree and low bulk density.

Higher FMC resulted in a higher mean cell size ($p \leq 0.05$) (Table 6). This confirmed results of Barrett and Ross (1990) for corn meal (although they observed decreasing cell size with moisture content at >20%), but was different from results observed by Miller (1985). The difference in cell sizes we found and the data of Miller (1985) was because Miller controlled extrusion variables in order to maintain constant product bulk density, thus leading to a lower cell size at higher moisture content. Interaction ($p \leq 0.05$) (Table 7) was observed between CTM and FMC, but the effect was minor (Table 8). A larger cell size ($p \leq 0.05$) (Fig. 4) was observed in the extrudate prepared from 20% CTM when extruded at high FMC.

The cell size distributions were skewed to the right for extrudates prepared from each extrusion condition. The degrees of skew were >1 in all extrudates which indicates there was a preponderance of small cells in each extrudate, confirming observations by Barrett and Peleg, 1992a.

Average compressive resistance

CTM and FMC ($p \leq 0.05$) (Table 8) were responsible for 43.1% (Table 8) of the variability in plateau stress and interactions were more important accounting for more than half the variability (Table 8). The 20% CTM extrudate had the lowest (Table 6) average compressive stress possibly because its high expansion and low bulk density created thin cell walls resulting in a soft and fragile texture (Barrett and Peleg, 1992b).

The higher ($p \leq 0.05$) (Table 6) compressive resistance of extrudates produced at low FMC could be a result of reduction in plasticity and elasticity during low moisture extrusion. Another factor could be the large number of small, subdivided cells in low moisture extrudates which were more resistant to compression than extrudates with fewer but larger cells when extruded at high moisture content (Barrett et al., 1994a).

Interactions occurred in CTM-FM and CTMC-SS ($p \leq 0.05$) (Table 8). Murray and Stanley (1980) reported that compression force was strongly dependent on protein/feed moisture ratio. Maximum force occurred when the extrudate was prepared from the lowest protein/feed moisture ratio during extrusion of fish protein and soy blends. In our results, a higher average compressive stress ($p \leq 0.05$) was observed when the lowest protein content (extrudate prepared without CTM) was extruded at low moisture content. The difference in moisture content could be explained by the different functions of moisture in forming extrudates. In studies by Murray and Stanley (1980), high moisture content was supplemented to achieve a cohesiveness in product texture. In our work a relatively low moisture content was needed to produce an expanded, brittle snack product. Screw speed increased protein textural response by affecting residence time leading to changes in exposure of protein to heat for improved texture (Maurice and Stanley, 1978). The extrudate prepared from 20% CTM, extruded at low SS was observed as

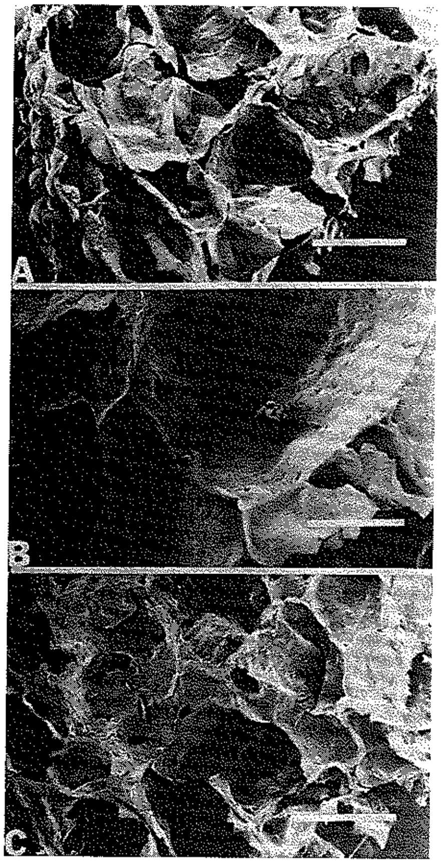

Fig. 1—SEM micrographs of cross sections of snack products prepared from instant mashed potato and various chicken thigh meat contents including A: 0%, B: 20% and C: 40% and extruded at 15% moisture content and screw speed of 250 rpm. (Magnification: 21×, Bar = 1000 μm).

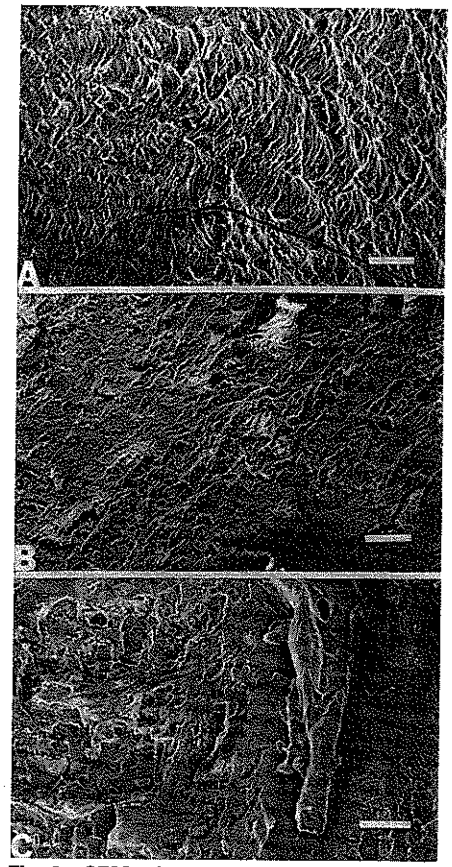

Fig. 2—SEM micrographs of cross sections of the snack products prepared from instant mashed potato and various chicken thigh meat contents including A: 0%, B: 20% and C: 40% and extruded at 15% moisture content and screw speed of 250 rpm. (Magnification: 1000×, Bar = 10 μm).

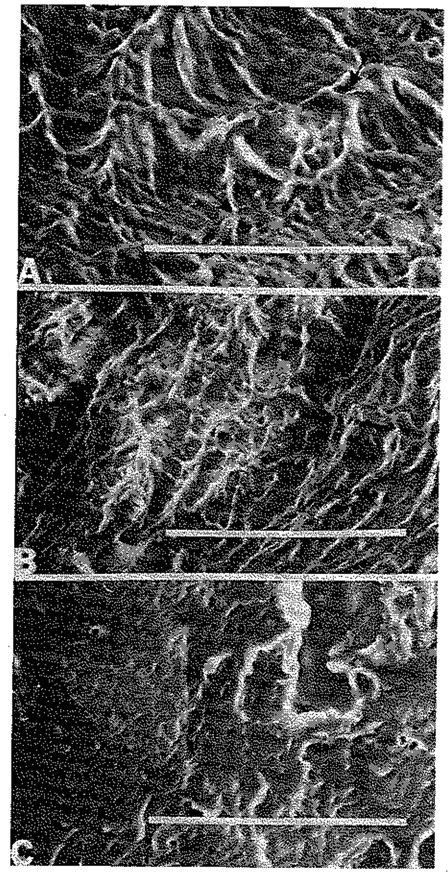

Fig. 3—SEM micrographs of cross sections of the snack products prepared from instant mashed potato and various chicken thigh meat contents including A: 0%, B: 20% and C: 40% and extruded at 15% moisture content and screw speed of 250 rpm. (Magnification: 5700×, Bar = 10 μm).

being soft and crispy and having a lower plateau stress. In addition, the maximum plateau stress was observed in the extrudate prepared without CTM extruded at low moisture content and high screw speed.

Fracturability

The extrudate prepared from the 40% CTM formulation had the highest ($p \leq 0.05$) cumulative fracturability while that from 20% CTM had the lowest (Table 6). Fracturability was measured as the summation of all fractures occurring in the sample and increases with either a greater number of fractures or increasing magnitude of fractures (Barrett et al., 1994a). The reason for high fracturability of the 40% CTM sample could be its thick cell walls and dense area formations. The extrudate prepared from 20% CTM, being the most expanded with few and large cells, would expectedly generate a less jagged compressive curve with fewer distinct brittle fractures. Interaction occurred between SS and CTM ($p \leq 0.05$) (Table 7). Higher fracturabilities were observed at 40% CTM-low SS and 0% CTM-high SS.

Solubility

CTM and FMC accounted for 89.4% of the variability (Table 8). Interaction ($p \leq 0.05$) (Table 7) occurred in CTM and SS but the effect was minor (Table 8). The soluble carbohydrate/total carbohydrate ratios were 0.71, 0.60 and 0.46 in extrudates prepared from 0, 20 and 40% CTM, respectively. Incorporating CTM might interfere with starch gelatinization leading to decreased fragmentation ratios (Gomez and Aguilera, 1984). Increased solubility in an extrudate was a result of increased fragmentation ratio when extruding at low FMC (Gomez and Aguilera, 1983; Wen et al., 1990). A higher solubility ($p \leq 0.05$) was observed in extrudates prepared without CTM, extruded at low screw speed. This could be due to dextrinization of potato starch leading to an increase in fragmentation and solubility under higher shear stresses at lower screw speeds (Gomez and Aguilera, 1983; Chinnaswamy and Hanna, 1988).

Microstructure

Extrudates produced at 15% FMC and 250 rpm SS were compared (Fig. 1, 2, 3). Low magnification (21×) showed that the extrudate prepared from 20% CTM had larger and elongated cells with thin walls (Fig. 1b) and that extrudates from 0 and 40% CTM had more but smaller cells (Fig. 1a; 1c) with thicker cell walls (arrow Fig. 1c). At 1000×, extrudate microstructure showed a jagged, protruding, and continuous thread-like appearance with unidirectional waving (Fig. 2a; 2b). The extrudate prepared from 40% CTM showed a laminar, rupture-like agglomeration of the protein-carbohydrate phase (Fig. 2c). At 5700×, the surface of the extrudate prepared without CTM appeared as a convex and concave starch sheet with protruding granules (arrows Fig. 3a). The extrudate from 40% CTM formulation (Fig. 3c) had a flat and laminar protein-carbohydrate phase in which previously observed convex and concave structures were not present.

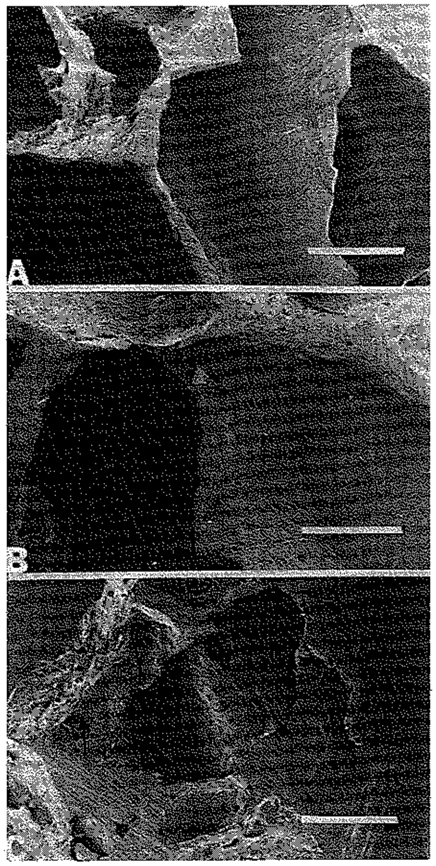

Fig. 4—SEM micrographs of cross sections of the snack products prepared from instant mashed potato and various chicken thigh meat contents including A: 0%, B: 20% and C: 40% and extruded at 20% moisture content and screw speed of 250 rpm. (Magnification: 21×, Bar = 1000 μm).

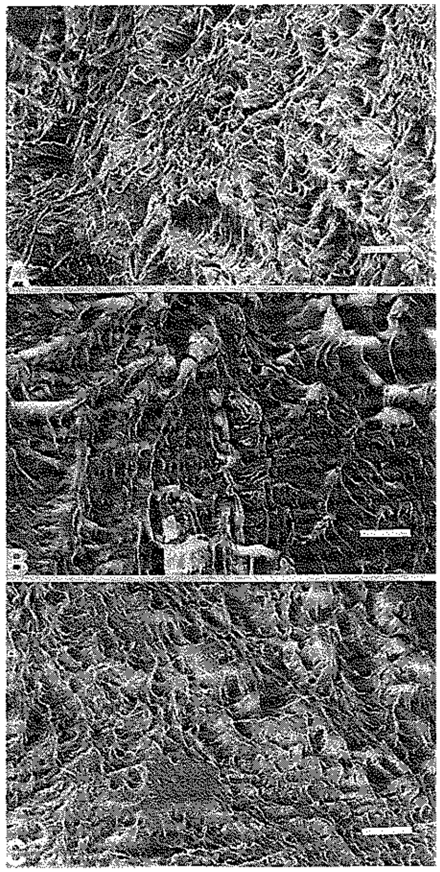

Fig. 5—SEM micrographs of cross sections of the snack products prepared from instant mashed potato and various chicken thigh meat contents including A: 0%, B: 20% and C: 40% and extruded at 20% moisture content and screw speed of 250 rpm. (Magnification: 1000×, Bar = 10 μm).

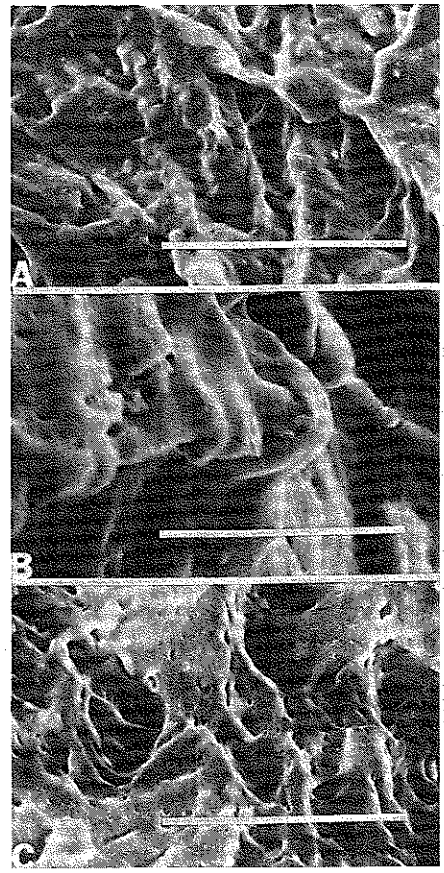

Fig. 6—SEM micrographs of cross sections of the snack products prepared from instant mashed potato and various chicken thigh meat contents including A: 0%, B: 20% and C: 40% and extruded at 20% moisture content and screw speed of 250 rpm. (Magnification: 5700×, Bar = 10 μm).

Extrudates produced at 20% FMC and 250 rpm SS were also compared (Fig. 4, 5, 6). At low magnification (21×), the extrudates from high FMC had fewer and larger cells with thicker walls (Fig. 4a; 4b; 4c) as compared to those from low FMC (Fig. 1a; 1b; 1c). Especially dense areas and "essential solid materials" (Lai et al., 1985) appeared in the extrudate from 40% CTM formulation (arrow Fig. 4c). At 1000×, higher FMC produced extrudates with more protruding edges and roughness (Fig. 5a; 5b; 5c). At 5700×, Fig. 4a and 4b showed larger protruding materials and Fig. 4c showed that extrudate microstructure was a rippled and multilayered protein and carbohydrate phase.

Better organization, orientation and more fiber in the microstructure after extrusion were generally observed with SEM by Maurice and Stanley (1978), Stanley and deMan (1978), and Harris et al. (1988). At 5700×, the microstructure of extrudates prepared with 40% CTM, extruded at 15 and 20% FMC (Fig. 3c, 6c) appeared as smooth, flat, and laminar. This was different from that of extrudates prepared without CTM, extruded at 15 and 20% FMC (Fig. 3a, 6a). Alignment and fiber formation of protein during extrusion might lead to definite organization and orientation of extrudate microstructures (Fig. 1c and 4c) as reported by Stanley and deMan (1978). In addition, extrudates from high FMC (compared to low FMC) appeared more multilayered, protruding and rough, causing extrudates to be more dense and compacted. Average compressive stress was correlated highly with fracturability ($r=0.801$, $p\leq0.0001$). Extrudates that had higher expansion and smaller cell size were generally associated with lower textural forces.

Sensory evaluation

Extrudates prepared from 0% CTM extruded at 20% FMC (#1), 20% CTM extruded at 15 (#2) and 20% FMC (#3) and 40% CTM extruded at 15 (#4) and 20% FMC (#5) were compared (Fig. 7). Extrudate 1 and 3 had higher ($p\leq0.05$) sensory color scores (like slightly to like moderately) due to their light yellow color. Extrudates 4 and 5 had lower ($p\leq0.05$) scores due to darker color. No differences in flavor acceptability were observed among extrudates, but mean scores were in the middle of the range. Although no differences in texture acceptability between 1 and 2 were observed, Extrudate 2 had the highest mean score (6.3). Panelists liked extrudates with light, soft and slightly sticky texture, such as that prepared from 20% CTM and extruded at 15% FMC. Extrudate 5 was disliked by panelists because of hard texture. No significant difference in overall acceptability was found among Extrudates 1, 2 and 3 and 5 was liked least overall.

CONCLUSIONS

THE EFFECT OF CTM was the most important factor affecting extrudate composition and characteristics. FMC was second in importance while SS only affected expansion degree. Interactions between CTM and SS and between CTM and FMC affected expansion, average compressive stress and fracturability. Extrudates prepared from higher levels of CTM had higher levels of protein, fat, free fatty acid and ash and those prepared with CTM (20%; 40%) were high in P, Na and Zn. The extru-

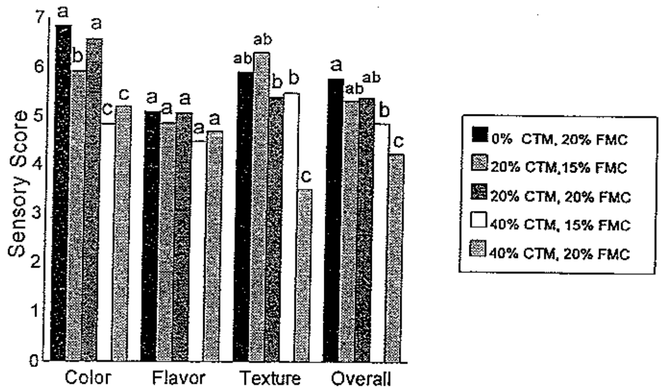

Fig. 7—Means with the same letter are not significantly different at the 95% confidence level using Duncan's Multiple Range Test. Each value represents the mean of 62 evaluations.

date prepared from 20% CTM had the highest degree of expansion and lowest bulk density. Mean cell area increased with increasing expansion, resulting in lower textural forces and a crispy, crunchy texture in extrudates from 20% CTM. Extrudates with higher expansion and larger mean cell size were generally associated with lower textural force. Dextrinization associated with a sticky mouth feel occurred in samples extruded at low FMC. Twenty percent CTM formulation produced the desired textural properties for nutritious and low-fat snack products.

REFERENCES

Alvarez-Martinez, L., Kondury, K.P., and Harper, J.M. 1988. A general model for expansion of extruded products. J. Food Sci. 53: 609–615.

Anderson, R.A., Conway, H.F., Pfeifer, V.F., and Griffin Jr., E.L. 1969. Gelatinization of corn grits by roll- and extrusion-cooking. Cereal Sci. Today 14: 4–5.

AOAC. 1990. *Official Methods of Analysis.* 15th ed. 1990. Association of Official Analytical Chemists. Arlington, VA.

Badrie, N. and Mellowes, W.A. 1991. Effect of extrusion variables on cassava extrudates. J. Food Sci. 56: 1334–1337.

Barrett, A.H. and Peleg, M. 1992a. Cell size distribution of puffed corn extrudates. J. Food Sci. 57: 146–148 & 154.

Barrett, A.M. and Peleg, M. 1992b. Extrudate cell structure-texture relationship. J. Food Sci. 57: 1253–1257.

Barrett, A.H. and Ross, E.W. 1990. Correlation of extrudate infusibility with bulk properties using image analysis. J. Food Sci. 55: 1378.

Barrett, A.M., Normand, M.D., Peleg, M., and Ross, E. 1992. Characterization of the jagged stress-strain relationships of puffed extrudates using the Fast Fourier Transform and Fractal Analysis. J. Food Sci. 55: 227–235.

Barrett, A.H., Cardello, A.V., Lesher, L.L., and Taub, I.A. 1994a. Cellularity, mechanical failure and textural perception of corn meal extrudates. J. Text. Stud. 25: 77–95.

Barrett, A.H., Rosenberg, S., and Ross, E.W. 1994b. Fracture intensite distrubitions during compression of puffed corn meal extrudates: New method for quantifying fracturability. J. Food Sci. 59: 617–620.

Barrett, A.H., Kaletunc, G., Rosenberg, S., and Breslauer, K. 1995. Effect of sucrose on the structure, mechanical strength and thermal properties of corn extrudates. Carbohydrate Polymer. In press.

Batistuti, J.P., Barros, R.M.C., and Areas, J.A.G. 1991. Optimization of extrusion cooking process for chickpea (*Cicer arietinum*, L.) defatted flour by respose surface methodology. J. Food Sci. 56: 1695–1698.

Camire, M.E., Camire, A., and Krumhar, K. 1990. Chemical and nutritional changes in food during extrusion. Critical Reviews in Food Sci. and Nutr. 29: 35–57.

Camire, M.E. and King C.C. 1991. Protein and fiber supplementation effects on extruded cornmeal snack quality. J. Food Sci. 56: 760763.

Chandrashekar, A. and Kirleis, A.W. 1988. Influence of protein on starch gelatinazation in sorghum. Cereal Chem. 65: 457–462.

Chen, T.A. 1989. Properties of an extruded snack food prepared from potato flakes and chicken breast meat. p. 1–72. Master's Thesis. Department of Food Science, University of Maine.

Chen, J., Serafin, F.L., Pandya, R.N., and Daun, H. 1991. Effects of extrusion conditions on sensory properties of corn meal extrudates. J. Food Sci. 56: 84–89.

Chinnaswamy, R. and Hanna, M.A. 1987. Nozzle dimension effects on the expansion of extrusion cooked corn starch. J. Food Sci. 52: 1746–1747.

Chinnaswamy, R. and Hanna, M.A. 1988. Optimum extrusion cooking conditions for maximum expansion of corn starch. J. Food Sci. 53: 836–840.

Falcone, R.G. and Phillips, R.D. 1988. Effects of feed composition, feed moisture and barrel temperature on the physical and rheological properties of snack-like products prepared from cowpea and sorghum flours by extrusion. J. Food Sci. 53: 1464–1469.

Faubion, J. M. and Hoseney, R.C. 1982. High temperature short time extrusion cooking of wheat starch and flour. II. Effect of protein and lipid on extrudate properties. Cereal Chem. 59: 533–537.

Gibson, L. and Ashby, M.F. 1988. *Cellular Solids.* Pergamon Press.

Gomez, M.H. and Aguilera, J.M. 1983. Changes in the starch fraction during extrusion-cooking of corn. J. Food Sci. 48: 378–381.

Gomez, M.H. and Aguilera, J.M. 1984. A physicochemical model for extrusion of corn starch. J. Food Sci. 49: 40–43, 63.

Harris, P.L., Cuppett, S.L., and Lee, K.W. 1988. A scanning electron microscope study of maize gluten meal and soy coextrudates. Cereal Chem. 65: 228–238.

Izzo, M.T. and Ho, C.T. 1989. Protein-lipid interaction during single screw extrusion of zein and corn oil. Cereal Chem. 66: 47–51.

Kenawi, M.A., Sinha, N.K., Ofoli, R.Y., and Cash, J.N. 1992. Development and sensory characteristics of extruded ready-to-eat prebaked potatoes. J. Food Processing Preservation 16: 175–183.

Laarhoven, G.J.M. and Staal, G. 1991. Rheology of the paste from gelatinization by extrusion during the production of third-generation snack. J. Food Eng. 14: 53–70.

Lai et al., 1985.

Maurice, T.J. and Stanley, D.W. 1978. Texture-structure relationships in texturized soy protein. IV. Influence of process variables on extrusion texturization. Can. Inst. Food Sci. Technol. J. 11: 1–6.

Miller, R.C. 19185. Low moisture extrusion: Effects of cooking moisture on product characteristics. J. Food Sci. 50: 249–253.

Mittal, P. and Lawrie, R.A. 1984. Extrusion studies of mixtures containing certain meat offals: Part I - Objective properties. Meat Sci. 10: 101–116.

Mittal, P. and Lawrie, R.A. 1986. Extrusion studies of mixtures containing certain meat offals: Part II - Textural properties. Meat Sci. 16: 143–160.

Murray, B.P. and Stanley, D.W. 1980. Improved utilization of fish protein-coextrusion of mechanically deboned salted minced fish. Can. Inst. of Food Sci. and Technol. J. 13: 125–130.

Park, J., Rhee, K.S., Kim, B.K., and Rhee, K.C. 1993. Single-Screw extrusion of defatted soy flour, corn starch and raw beef blends. J. Food Sci. 58: 9–20.

Peryam, D.R. and Girardot, N.F. 1952. Advanced taste test method. Food Eng. (NY) 24: 58–61.

SAS Institute, Inc., 1989. *SAS® User's Guide. 1989 ed. Statistical Analysis System,* SAS Institute, Inc., Cary, NC.

Stanley, D.W. and deMan, J.M. 1978. Structural and mechanical properties of textured proteins. J. Text. Stud. 9: 59–76.

USDA. 1980. *Composition of Foods.* Agriculture Handbook No. 8, U.S. Government Printing Office, Washington, DC.

Vargas-Lopez, J.M., Paredes-Lopez, O., and Ramirez-Wong, B. 1991. Physicochemical properties of extrusion-cooked amaranth under alkaline conditions. Cereal Chem. 68: 610–613.

Wen, L.F., Rodis, P., and Wasserman, B.P. 1990. Starch fragmentation and protein insolubilization during twin screw extrusion of corn meal. Cereal Chem. 67: 268–275.

Ms received 7/10/95; revised 2/28/96; accepted 3/11/96.

Manuscript number 1973 of the University of Maine Agricultural & Forest Experiment Station.