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Processing Properties of Extruded Corn-Soy Blends

R.P. KONSTANCE, E.D. STRANGE, AND C.I. ONWULATA

ABSTRACT: Extruded corn-soy blend (CSB), is a nutritious, fully cooked product that rehydrates at room temperature. CSB, at 10, 13, and 19% moisture was extruded at 115 °C and dried at 45, 65, and 85 °C. The porosity of the lower moisture samples was higher and dried more rapidly at all temperatures. These samples also exhibited a lower breaking strength that could facilitate grinding and color that approximated that of the standard CSB. Most of the chemically available lysine was retained during processing. There were no differences among the peroxide values (PV) of the extruded and dried products. Extruding at low moisture content, the extrudate can be dried rapidly and provide better storage stability.

Keywords: corn-soy blend, extrusion, drying, storage

Introduction

THE NUTRITIONAL BENEFITS OF CORN/SOY COMBINATIONS have long been recognized (Bressani and Elias 1966). Corn-soy blends have been a part of the Food-for-Peace Program for many years and serve as rations for development and emergency activities, such as refugee camp food distribution (Ranum and Chomé 1997). The CSB formulation that is currently used was developed (Bookwalter and others 1971) over 20 y ago and has served the Program well during that time. Recently, suggestions were made to improve the nutritive value of these blends by significantly increasing the protein and fat content to fully satisfy energy needs (Jacob and others 1996). Konstance and others (1998) determined the formulation needed to achieve these requirements and established that extrusion at relatively low temperature (100 to 115 °C) created a product that was free of trypsin inhibitors and retained most of the chemically available lysine. Strange and others (1998) determined that the moisture specifications should be reduced from 8.5% to approximately 5% (WB) in order to achieve monolayer moisture levels and increase the stability of the samples in storage. Higher fat content of any product increases the susceptibility to lipid oxidation (Lawson 1985) and can impact on its long-term storage stability. Lipid stability in extruded foods, where temperature, pressure, and shear conditions may have deleterious effects, is of concern during both processing and storage (Artz and others 1992). Lundy (1997) noted that soy flour extruded at higher temperatures had higher levels of lipid oxidation products and Cho (1997) established a first order reaction for the oxidation of soybean oil that was dependent upon temperature. Hydroperoxide formation and concomitant development of free radicals are significant because of their self-perpetuating nature. Decomposition of peroxide, by free radical mechanisms, forms aldehydes and ketones that contribute to rancid off flavors (Pennfield and Campbell 1990). The objectives of this study were to determine optimal drying conditions of the extrudate and to evaluate the effects of extrusion and drying on the stability of the extrudate.

Materials and Methods

DEGERMED, ENRICHED CORNMEAL WAS RECEIVED FROM LAUhoff Grain Co. (Decatur, Ill., U.S.A.), raw full-fat soy grits from Natural Products Inc, (Grinnel, Iowa, U.S.A.), Arcon G® soy concentrate from Archer Daniels Midland (Decatur, Ill., U.S.A.), and pure soybean oil (America's Choice, Elgin, Ill, U.S.A.) was purchased locally. The materials were blended using a modification of a formulation (Konstance and others 1998) derived from a previous study (62.35% cornmeal, 14.15% full fat soy grits, 15.15% soy concentrate, and 8.35% soybean oil). The oil was added to the blended solids in a Hobart Mixer (Model C100T; The Hobart Mfg. Co., Troy, Ohio, U.S.A.) using a wire whip and mixed for 10 min, and then mixed for an additional 30 min in a twin-shell dry blender (Model LB817; Patterson Kelly Co., East Stroudsburg, Pa., U.S.A.).

The blend was extruded in a ZSK30 twin-screw extruder (Krupp, Werner & Pfleiderer Co., Ramsey, N.J., U.S.A.) consisting of 9 barrel sections each individually controlled at 35, 35, 50, 50, 75, 80, 95, 100, and 115 °C respectively. The die plate was fitted with 2 circular inserts (3.18 mm dia). The blend was fed into the extruder with a series 6300 digital type 35 twin screw volumetric feeder (K-tron Corp., Pitman, N.J., U.S.A.) at a constant setting of 600 rpm which yielded a feed rate of 78 g/min. The water was added with an electromagnetic dosing pump (Milton Roy, Acton, Mass., U.S.A.) to bring the moisture content of the feed to approximately 11, 13, or 19% moisture (WB). The screw speed of the extruder was maintained at 300 RPM. The screw configuration used has been described (Konstance and others 1998).

The wet extrudate was equilibrated for 48 h, analyzed for moisture content (AOAC 1998) and dried at 45, 65, or 85 °C in a hot-air tray dryer (National Drying Co., Philadelphia, Pa., U.S.A.) using a stainless steel tray (25.4 cm × 25.4 cm) with a bed depth of 15.2 cm. Dryer configuration utilized a downflow air rate of 27 m/s. Weight of extrudate was recorded at specified intervals until approximately 5% moisture (wb) was achieved. Final moisture content was determined using the vacuum oven method (AOAC 1998) and was used to develop the drying curves. Drying rates were determined at specific time intervals as slopes of the drying curves.

Analyses of extrudate

Samples of the extrudate were analyzed for expansion ratio (ER), breaking strength (BS), and porosity. ER is the ratio

of the extrudate dia to the die orifice dia and represents the average of 10 samples. A digital Vernier caliper (Monostat Corp., Merenschwand, Switzerland) was used to measure the dia of the extrudates. BS was the maximum force required to break the extrudate samples and was determined using a Warner-Bratzler shear cell and a TA-XT2 Texture Analyzer (Stable Micro Systems, Surrey, England) with a 500 N load cell. The cross head was operated at 0.2 mm/s. Data is reported as the average of 10 samples. Porosity was determined from volume measurements made with an air pycnometer (Model VM 100; Horiba Instruments Inc., Irvine, Calif., U.S.A.). A 4 g sample of the extrudate (as is) was used to measure the bulk volume (V_b), where V_b represents the sum of the volume of solids (V_s) and the volume of the internal voids (V_{iv}). This measurement ignores the surface connected pores (V_{sc}).

$$V_b = V_s + V_{iv} \quad (1)$$

The same sample was then used to determine the total sample volume (V_{ts})

$$V_{ts} = V_b + V_{sc} \quad (2)$$

by plugging the surface connected pores with a coating with melted paraffin (J. T. Baker Chemical Co., Phillipsburg, N.J., U.S.A.) and removing the excess paraffin with a stream of hot air. Using a separate sample from the same batch, the V_s was determined by measuring the volume of a ground sample and removing the contribution of V_{sc} and V_{iv}. Using V_s and Eq. 1 and 2, the V_{iv} and V_{sc} can then be determined. Total porosity is expressed as a percentage of the volume of the voids divided by the total volume.

Analyses of ground material

The remainder of the samples were ground in a coffee mill (Model 203; Krups North America, Inc., Closter, N.J., U.S.A.) for 45 s. Available lysine was measured using an adaptation of the dye-binding method of Hurrell and others 1979. The samples were ground to pass a 250 µm screen before being weighed. Available lysine was calculated from the difference between the amount of dye bound to the sample that had been reacted with propionic anhydride and the amount of dye bound to an unreacted sample. Dye binding was carried out by 16 h shaking at ambient temperature before dilution and absorbance measurements. Hunter color determinations of the ground extrudate were made using a Colorsphere Color Analyzer (BYK Gardner, Rivers Park, Md., U.S.A.). Color difference measurements, L, a, and b were made on the ground samples using a reference white standard plate (L = 98.33, a = -0.20, b = 0.19) and a CIE Source C illuminant. Total color (ΔE) was calculated as:

$$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2} \quad (3)$$

and compared to ΔE of samples of standard CSB measured under the same conditions.

Peroxide Values were determined by grinding the samples (1 g), to pass a 250 µm screen. The samples were then suspended in 5 mL of water containing 25 mg of α-amylase (EC 3.2.2.2, Type VIII-A; Sigma Chemical Co., St. Louis, Mo., U.S.A.) and shaken overnight at 37 °C, 100 rpm. The slurry was then extracted with 25 mL of CH_2Cl_2:CH_3OH (2:1), in a 60 mL separatory funnel. The lower layer was removed, its volume measured, and its peroxide content determined by the Xylenol Orange method of Piazza and others (1994). The weight of lipid extracted was determined by evaporation of the remaining extract. To remove all traces of interfering substances all glassware was rinsed in ethanolic KOH, deionized water, 0.1 N HCl, and finally in deionized water before air drying and the samples were blanketed with argon during shaking and extraction. Peroxide value is reported as meq/kg sample.

Table 1—Product specifications of Corn-Soy Blends

	Current	Proposed
Calories (per 100 g)	380	400
Protein (N × 6.25) (%)	18	20
Total fat (%)	7	12
Carbohydrates (%)	65	60
Water (%)	10	8

Statistical analysis

Statistical analysis of the full model was accomplished using the SAS system General Linear Methods procedure. Evaluation and separability of means were analyzed using the Bonferroni multiple comparison method (SAS Institute, Inc. 1985). Significant differences were defined at $P \leq 0.05$.

Results and Discussion

Extrusion and drying characteristics

A new CSB formulation, with significantly increased fat and protein contents (Table 1) compared to the current CSB, was extruded. Extruder conditions were set as described by Konstance and others (1998). The temperature and shear were sufficient to ensure complete inactivation of the trypsin inhibitor and to maximize gelatinization assuring a fully cooked product while minimizing detrimental effects to lysine.

The expansion ratio (ER) of extrudates, prepared at varying moisture contents, was not different (Table 2). Drying of the lower moisture extrudates (10.97 and 13.02% moisture) decreased their ER but there were no differences due to drying temperature. Extrudates produced at the highest moisture (19.02% moisture) showed no difference in ER due to drying and no differences in ER due to drying temperature.

Porosity data are presented as total porosity (TP) (TP = surface connected pores + internal voids) because the internal voids contributed only 2% to the TP. There were differences in TP due to moisture content during extrusion. The higher the moisture content used in extrusion the lower the TP (Table 2). Drying at 65 and 85 °C reduced the TP of the extrudates.

The relationship between initial TP of the extrudate and the drying rate at each temperature is shown in Figure 1. There was a much larger increase in drying rate when the drying temperature was increased from 45 to 65 °C than when temperature was increased from 65 to 85 °C. This relationship seemed to be unaffected by increased porosity caused by decreased extrusion moisture. The smaller change in drying rate at the higher temperature may be a result of the smaller ultimate TP of the extrudates dried at 85 °C compared to those dried at 65 °C (Table 3). The largest change in drying rate as a function of TP occurred as the porosity increased from 39 to 41%. This change in TP happened when the extrusion moisture was lowered from 19 to 13%. Additional reduction in the extrusion moisture resulted in large

Table 2—Physical characteristics of corn-soy blend[1]

Extrudate moisture %	Drying temperature °C	ER[2] %	BS[3] N	Porosity %	Color ΔE	Available Lysine mg/g protein	PV[4] meq/kg sample
	Raw feed	n.m	n.m.	n.m.	n.m	41.99	5.66[a]
10.97	Pre-dry	2.48[abc]	20.56[bcde]	49.05[a]	n.m	n.m.	n.m.
	45	2.29[de]	16.48[def]	48.83[a]	39.37[de]	40.22[a]	0.28[b]
	65	2.24[e]	14.85[ef]	42.69[b]	40.80[bc]	37.35[a]	0.26[b]
	85	2.24[e]	13.13[f]	23.90[g]	41.94[abc]		
	38.03[a]	0.27[bc]					
	Raw feed	n.m.	n.m.	n.m.	n.m.		3.01[a]
13.02	Pre-dry	2.59[a]	36.51[a]	41.03[b]	43.33[a]	n.m.	n.m.
	45	2.42[bcd]	20.15[bcde]	40.73[bc]	36.96[f]	40.15[a]	0.17[b]
	65	2.39[cde]	19.14[cdef]	31.73[e]	38.89[def]	37.95[a]	0.18[b]
	85	2.36[cde]	18.75[cdef]	27.73[f]	37.55[ef]	38.99[a]	0.21[b]
	Raw feed	n.m.	n.m.	n.m.	n.m.		3.20[a]
19.02	Pre-dry	2.56[ab]	40.08[a]	38.95[c]	n.m.	n.m	n.m.
	45	2.45[abc]	26.32[b]	38.46[c]	39.88[de]	37.85[a]	0.31[b]
	65	2.42[bcd]	24.21[bc]	35.71[d]	38.48[def]	37.49[a]	0.28[b]
	85	2.50[abc]	22.47[bcd]	21.74[g]	38.75[def]	39.48[a]	0.34[b]
Std. CSB					41.95[abc]		

[1]Values within a column that have no common letters in superscript are significantly different ($P < 0.05$).
[2]ER = Expansion ratio.
[3]BS = Breaking strength.
[4]V = Peroxide Value. n.m. = not measured.

TP increases but non-significant drying rate changes for all temperatures (Figure 1).

The effect of drying temperature on the drying rate is shown in Figure 2. Intermediate and low moisture extrudates showed only slight differences in drying rate at 45 °C and at 65 °C while the high moisture extrudate had slower drying rates at these 2 temperatures. At 85 °C, the effects of extrudate moisture on drying rate were not significant as a whole. The greatest increase in drying rate at all moistures occurred between 45 and 65 °C and there was little difference in rate increase because of moisture differences.

Drying data for the corn-soy extrudates are shown in Table 3 and a typical drying curve is shown in Figure 3. Samples extruded at the low and intermediate moisture content exhibit near constant drying rates for a large portion (50 to 100%) of the total drying time (Table 3). Drying to the requisite 5% moisture obviously occurs more rapidly as the temperature increases and can be accomplished at 85 °C in about one-half the time required for drying at 65 °C, but the impact of this time temperature treatment on the quality of

Table 3—Drying characteristics of corn-soy blend

Extrudate moisture %	Drying temperature °C	Constant drying time min	Constant drying rate g/min	Total drying time min
10.97	45	30	2.27	30
	65	10	5.90	20
	85	10	6.81	10
13.02	45	60	1.89	65
	65	15	5.45	40
	85	20	6.13	20
19.02	45	100	1.09	>360
	65	40	4.54	140
	85	10	5.56	50

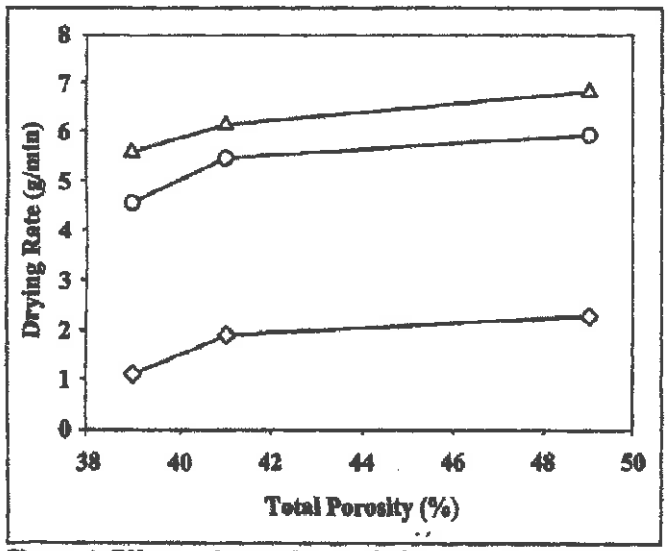

Figure 1—Effects of porosity on drying rate at various drying temperatures 45 °C (◇), 65 °C (○), 85 °C (△).

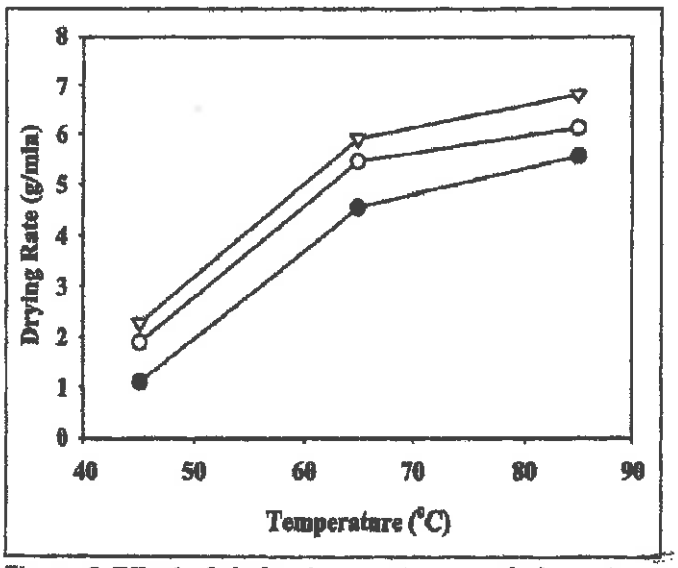

Figure 2—Effect of drying temperature on drying rate at various extrusion moistures. High moisture (●), intermediate moisture (○), low moisture (▽).

the product must be determined.

Product characteristics

Initial load density of the drying trays was 0.11, 0.14, and 0.18 g/cm^3 for the low, intermediate, and high moisture extrudates, respectively. During drying, significant external shrinkage occurred in the low and intermediate moisture extrudates as shown by the ER of the product (Table 2). The internal shrinkage, as measured by the porosity of the samples after drying, was significant ($P \leq 0.05$) in all samples dried at either 65 °C or 85 °C. Reduction in porosity ranged from 13 to 51%, 23 to 32%, and 8 to 44 %, respectively for the low, intermediate, and high moisture extrudates. The implications of this shrinkage are important to increasing the bulk density of the material for subsequent processing (that is, grinding). Equally important in the overall process, is the amount of energy required to grind. A good indication of the ease with which the samples will grind is the breaking strength (BS), shown before and after drying (Table 2). The hardness of the extrudate, after drying, was significantly reduced, and although the pattern indicated a reduction in the BS of all samples as a result of drying temperature, the differences were not statistically significant. Both the low and intermediate moisture samples exhibited the lowest BS.

There were no differences in the chemically available lysine due to drying temperature or extrusion moisture (Table 2). However, the minimum difference needed for significance was quite high (6.47 mg/g protein) and the effects of extrusion and drying on the lysine are apt to be subtle if reasonable conditions are selected.

Color differences were noted in the samples that were extruded at the low moisture content and were dried at either 65 °C or 85 °C. When compared to the standard corn-soy blend that is currently in production, these products exhibited a similar total color.

The peroxide values of the extruded products were very low and there were no differences due to drying temperature. The peroxide values of the raw feeds were, however, higher. This demonstrated that pre-formed peroxide in the raw feed was destroyed during extrusion. Therefore, the low peroxide values in the product do not necessarily indicate an ideal situation. Other methods of determining damage to the lipids that occur during extrusion and drying are needed for CSB and other products.

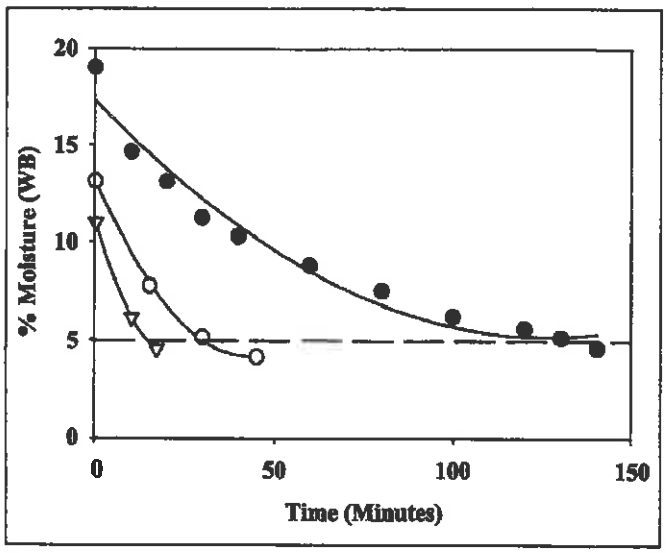

Figure 3–Typical drying curve at 65 °C (% moisture, (WB) against time in min.) at various extrusion moistures. High moisture (●), intermediate moisture (○), low moisture (▽).

Conclusions

CORN-SOY BLEND EXTRUDATE MUST BE DRIED RAPIDLY TO the optimum moisture content (5% wb) at relatively moderate temperatures to assure maximum protection against degradation both during processing and storage. Extruding at approximately 10% moisture provided a sufficient degree of puffing, and subsequent increase in product porosity, to allow the material, at a 15 cm bed depth, to be dried at 65 °C in 20 min. The ability to rapidly dry the extrudate while retaining high levels of lysine availability and acceptable color further established the potential for the use of twin screw extrusion for the creation of corn-soy blends. Since oxidative deterioration, within this experimental scheme, was minimized at lower drying temperatures improved storage stability can also be expected.

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