Uniquely Textured Products Obtained by Coextrusion of Corn Gluten Meal and Soy Flour[1]

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ABSTRACT

Although nutritionally advantageous, the blending of corn and soy proteins in foods is limited by their distinctly different functional properties. Chemically bonding these proteins by altering their molecular conformation and linking them together through disulfide bonds was explored by means of coextrusion. Wet-milled corn gluten or decolorized corn gluten (DCG), (pH 7.0 and 30–35% moisture) were mixed with a similarly hydrated, untoasted, defatted soy flour (DSF) at different proportions and extruded under the proper conditions to yield textured products. When rehydrated in boiling water, DCG:DSF extrudates possessed poultry white meatlike color and unique meatlike texture but had water-holding capacities (WHC) that were less than that of DSF extrudate. Scanning electron microscopy showed that DCG:DSF extrudates had a more disrupted fiber structure than DSF extrudate. Sequential extraction of protein from DCG, DSF, and 46:54 DCG:DSF extrudate with a series of nonreducing and reducing solvents indicated that intermolecular disulfide bonds were formed during extrusion. Amperometric titration data established that other derivatives of cysteine present in DCG were maintained during coextrusion. Calculated protein efficiency ratios based on in vitro digestibility tests and amino acid analyses for 52:48, 46:54, and 40:60 DCG:DSF extrudates were 1.63, 1.76, and 1.97, respectively.

Corn gluten meal is the concentrated protein coproduct (70% protein, db) obtained from the wet-milling of corn. The protein has poor nutritional quality because of deficiencies in both lysine and tryptophan. Neumann et al (1984a) reported that heat-dried corn gluten meal did not meet maintenance requirements of rats when incorporated into diets at a 10% level of protein for determination of protein efficiency ratio (PER). Increased demand for starch-based products and concern over possible restriction of export markets for wet-milling coproducts (Staley News 1982) has stimulated interest in increasing their use. Improved nutritional and functional quality could increase the use of corn gluten meal in food or feed products.

Wet-milling is facilitated by steeping whole corn in SO_2 solution, which disrupts the endosperm protein matrix so that starch can be separated from insoluble protein components. During steeping, SO_2 converts many of the protein's cysteine residues to S-sulfo derivatives of cysteine (James et al 1969, Neumann et al 1984b). The consumption of SO_2-modified protein might have human health consequences that need to be considered if corn gluten meal is to be used as a food ingredient. Despite the partial chemical modification of cysteine, corn gluten has long been successfully used in animal feed as a protein supplement. Sasse and Baker (1973) reported that the cysteine and methionine in corn gluten meal were 99% nutritionally available to growing chicks.

Blending of corn and soy proteins to improve nutritional quality of feeds is well established, but their use in food systems has been limited by their distinctly different functional properties. Chemically linking these proteins through covalent bonds might impart unique and homogeneous functional properties to the blend. Extrusion texturization of soy protein results in fiber formation as a result of protein alignment and development of intermolecular covalent bonds (Holay and Harper 1982). Disulfide bond interchange has been implicated as a determinant of texturization by Cumming et al (1972) and Rhee et al (1981), while others have suggested the importance in texturization of amide bond formation between free amino and carboxyl side groups of the protein (Simonsky and Stanley 1982).

[1]The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

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The purpose of the present study was to investigate coextrusion processing of wet-milled corn gluten and defatted soy flour and to characterize the physical, chemical, and nutritional properties of the products. Previous work (Neumann et al 1984b) suggested that nonheat-treated corn gluten (CG) would be functionally superior to heat-dried corn gluten meal for extrusion purposes.

MATERIALS AND METHODS

Materials

Nonheat-treated CG (60% moisture; pH 3.6) obtained from a large wet-milling operation and commercially available untoasted, defatted soy flour (DSF) were the starting materials for extrusion experiments. Corn gluten and DSF were stored at −20°C before use.

Proximate Composition

Moisture contents were determined by vacuum oven-drying, by AOAC method 14.003 (AOAC 1980). Nitrogen determinations were made by macro- or micro-Kjeldahl techniques—AOAC methods 2.036 and 47.021, respectively. Nitrogen-to-protein conversion factors of 6.25 for CG and 5.66 for DSF (Morr 1982) were used. Fat, fiber, and ash contents were determined by AOCS official methods Ba3-38, Ba6-61, and Ba5-49, respectively (AOCS 1973). Starch was determined by a polarimetric method (Corn Industries Research Foundation 1957). Results are the averages of duplicate analyses.

Decolorization of CG

Corn gluten was decolorized in a manner similar to that described by Phillips (1977). Corn gluten was extracted with a 2:1 (solvent–CG) ratio of ethyl acetate by stirring for 1 hr at room temperature. The slurry was filtered through Whatman No. 3 filter paper in a Buchner funnel under vacuum. The retentate was suspended in distilled water (2:1, water–CG), stirred at 40°C for 15 min, and refiltered. Ethyl acetate extraction followed by washing with warm distilled water was repeated twice. The CG was then washed with warm distilled water, filtered, and slurried with distilled water (2:1, water–CG). The pH of the slurry was adjusted to 7.0 with 6*N* NaOH. The slurry was then frozen, lyophilized, and milled to a fine flour, which subsequently will be referred to as decolorized CG (DCG).

Extrusion

Extrusion was performed with a Brabender Plasti-Corder model PLV-300 equipped with a three-temperature-zone barrel and a

3/4-in.-diameter screw with 3:1 compression and a length-to-diameter ratio of 25:1. Extrusion was conducted without the restriction die at the orifice as described by Feldbrugge et al (1978) for manufacture of textured vegetable protein. Corn gluten adjustment to pH 7.0 with 6*N* NaOH prevented isoelectric precipitation of soy protein in the blends. Corn gluten or DCG and DSF were hydrated separately to 25–35% moisture, blended in the proper proportions, and extruded. Blend ratios 52:48, 46:54, and 40:60 DCG:DSF (db) had feed moistures of 33–35% and were extruded at 145°C and a screw speed of 60 rpm.

Protein Extraction

Protein was sequentially extracted from 5.0 g (db, <60 mesh) of ground DCG, DSF, and DCG:DSF (46:54) extrudate by the procedure of Neumann et al (1984b), using the prescribed volumes of each extractant. In sequence I, the sample was sequentially extracted with 0.5*M* NaCl (saline), 70% aqueous ethanol (EtOH), 70% aqueous ethanol + 0.6% 2-mercaptoethanol (EtOH + ME), and 0.5% sodium dodecyl sulfate + 0.6% 2-mercaptoethanol in pH 10.0, 0.025*M* borate buffer (SDS + ME). Sequence II extractions consisted of saline, EtOH, 0.5% sodium dodecyl sulfate in pH 10.0, 0.025*M* borate buffer (SDS), and SDS + ME. The DCG:DSF (46:54) extrudate was exhaustively extracted in sequences I and II with the last solvent, SDS + ME. Extractions were performed in duplicate.

Amperometric Titration

Cysteine and half-cystine in DCG, and 46:54 DCG:DSF extrudate were determined by amperometric titration with silver ion in the absence and presence of sulfite, respectively (Neumann et al 1984b). These values were expressed as molar percentages of compounds determined by amino acid analysis as cysteic acid in protein after performic acid oxidation and acid hydrolysis (Neumann et al 1984b). S-sulfocysteine was estimated indirectly as the difference between the cysteine + half-cystine content determined amperometrically and those compounds yielding cysteic acid in performic acid-oxidized samples. Since S-sulfocysteine was determined indirectly, it will be reported as other derivatives of cysteine (ODCys). All results are the average of duplicate analyses.

Scanning Electron Microscopy

Scanning electron microscopy of extrudates was performed with International Scientific Instruments model SS130 equipment. Samples were prepared by immersing in liquid nitrogen, fracturing, and mounting on a stage. Some extrudates were hydrated in boiling distilled water for 5 min, immersed in liquid nitrogen, fractured, lyophilized, and mounted. Mounted samples were coated with gold-palladium and viewed at ×50.

Water-holding Capacity

Water-holding capacity (WHC) of extrudates was determined by two methods. Water-holding capacity at ambient temperature was determined by weighing 1.00 g of sample (db, <60 mesh) in a tared 50-ml centrifuge tube, adding 10.0 ml of distilled water, mixing at low speed with a vortex mixer for 30 sec, and allowing the mixture to stand for 60 min at room temperature (24°C). The tubes with contents were then centrifuged at 5,000 × *g* for 30 min, and supernatants were decanted into tared 125-ml Erlenmeyer flasks. The tubes plus pellets were then weighed. Blanks containing 10.0 ml of distilled water were run to determine the amount of water adhering to interior walls of the centrifuge tubes. The decantate was dried overnight in an air oven at 100°C, and then for 3 hr at 130°C. The cooled flasks with decantate solids were weighed. Water-holding capacity was determined as:

$$\frac{\text{Wet pellet wt (g)} - \text{water retained by blank (g)}}{\text{Total solids (g)} - \text{decantate solids (g)}} = \text{WHC}$$

TABLE I
Proximate Composition of CG, DCG, and DSF (db)

	Percent Composition		
Component	CG	DCG	DSF
Protein[a]	69.4	72.1	48.5
Fat	4.3	0.2	0.5
Starch	17.5	18.4	ND[b]
Fiber	0.6	0.2	3.3
Ash	0.9	1.9	7.2
Other carbohydrate[c]	7.3	7.2	40.5

[a] Kjeldahl factors: CG and DCG, 6.25; DSF, 5.66.
[b] ND = not determined.
[c] Determined by difference.

Fig. 1. Typical defatted soy flour extrudate.

Fig. 2. Typical pH 7.0 corn gluten–defatted soy flour (50:50, db) extrudate.

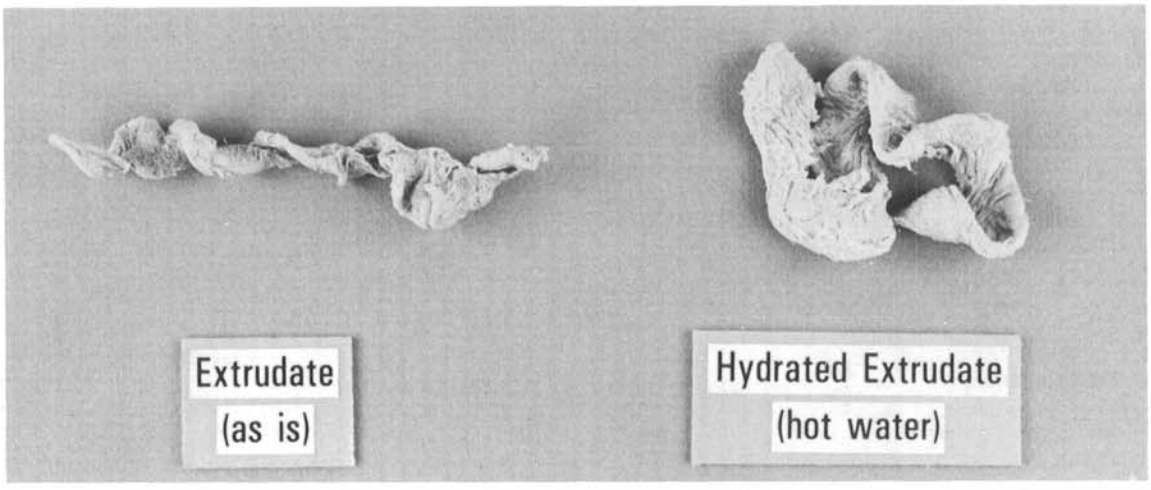

Fig. 3. 40:60 decolorized corn gluten–defatted soy flour extrudate before (**left**) and after (**right**) hot water hydration.

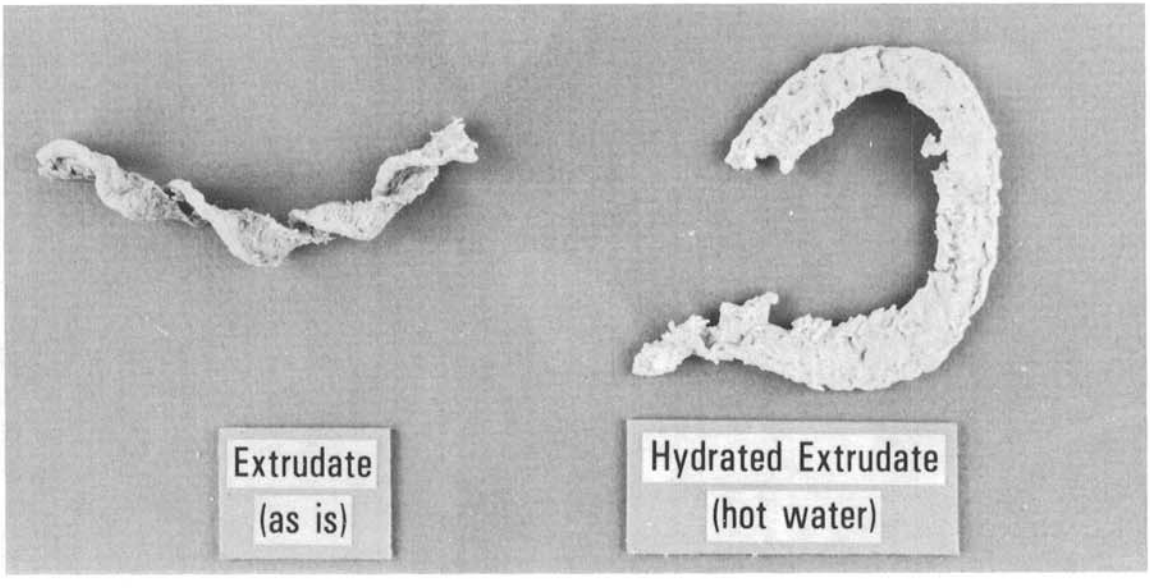

Fig. 4. 46:54 decolorized corn gluten–defatted soy flour extrudate before (**left**) and after (**right**) hot water hydration.

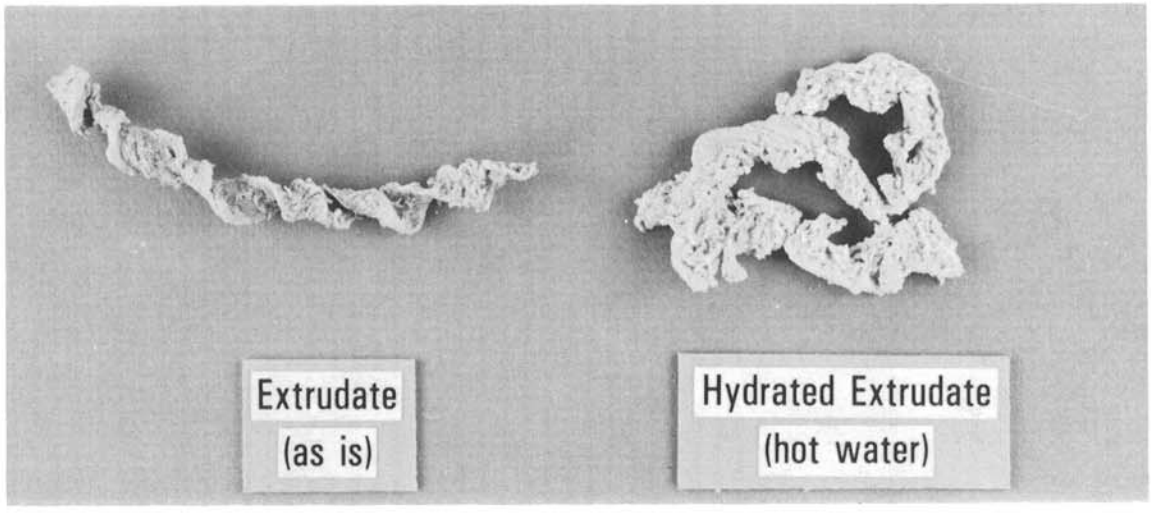

Fig. 5. 52:48 decolorized corn gluten–defatted soy flour extrudate before (**left**) and after (**right**) hot water hydration.

Samples also were autoclaved for 15 min at 121°C, allowed to cool to room temperature for 45 min, and centrifuged. Water-holding capacity was determined on the autoclaved samples as previously described. Data are the average of duplicate determinations and the mean deviation.

Nutritional Evaluation

Amino acid analysis and in-vitro digestibilities were determined, and calculated values of protein efficiency ratios (C-PER's) were derived from these data as described in AOAC methods 43.C10-43.C18, Official First Action (Satterlee et al 1982).

RESULTS

Decolorization of Corn Gluten

Corn gluten has an intense yellow color because of its high xanthophyll content (Wall and Paulis 1978). The pigment is difficult to mask and can restrict use of CG in food systems. Mild extraction with ethyl acetate (Phillips 1977) proved effective for removing pigment from CG so that it was indistinguishable from DSF in color. Ethyl acetate in trace amounts is allowed in food products. Ethyl acetate extraction also removed some off-flavor components of CG. Less than 5% of the total protein was removed during the process, mainly in the water wash. Ethyl acetoacetate was equally effective as a decolorizing agent.

TABLE II
Ambient and Autoclaved Water-holding Capacity (WHC)[a] of Extrudates

Extrudate (%)	Ambient WHC	Autoclaved WHC
52:48 (DCG:DSF)	3.74 ± 0.04	4.16 ± 0.05
46:54 (DCG:DSF)	3.70 ± 0.01	4.47 ± 0.04
40:60 (DCG:DSF)	3.89 ± 0.03	4.87 ± 0.01
100 (DSF)	4.36 ± 0.08	5.38 ± 0.03

[a] Results are the mean of two determinations per sample plus or minus the deviation from that mean.

Proximate Composition

Proximate compositions of CG, DCG, and DSF are shown in Table I. DCG contains a higher level of protein than CG due to removal of fat by ethyl acetate extraction. The ash content of DCG is higher than that of CG as a result of pH adjustment with NaOH.

Extrusion

Extrusion was performed without a restricting die at the orifice. This process for the manufacture of textured vegetable protein, described by Feldbrugge et al (1978), is referred to as low-pressure extrusion because pressures of only 100–200 psi are produced. Low-pressure extrusion was used for coextrusion of pH 7.0 CG or DCG with DSF, because difficulty was encountered in obtaining uniform product flow when any type of restriction was placed in the orifice, due to high back pressures. Uniform product flow was obtained after the die was removed.

Figures 1 and 2 show typical DSF and pH 7.0 CG:DSF (50:50, db) extrudates. The yellow pigmentation of CG remained in the pH 7.0 CG:DSF extrudate and masked browning that was observed in the DSF extrudate. The pH 7.0 CG:DSF extrudate did not expand or cohere as well as the DSF extrudate, but textures of both extrudates had similarities including fibrous structures. Extrusion of pH 7.0 CG or DCG alone did not yield fibrous products.

The extrudates of 40:60, 46:54, and 52:48 DCG:DSF are shown in Figs. 3, 4, and 5, respectively. When these extrudates were placed

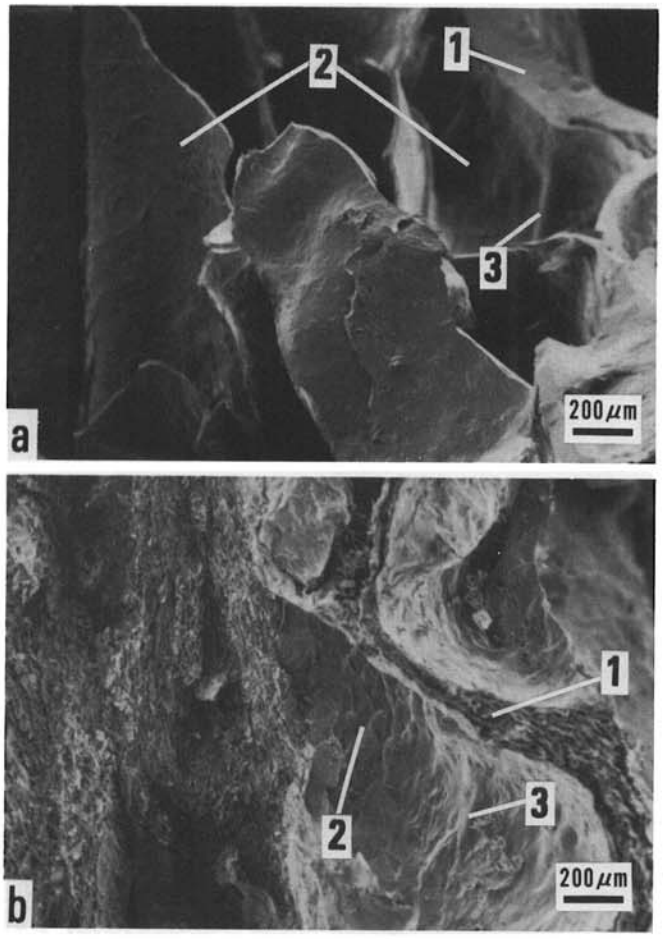

Fig. 6. Scanning electron micrographs of defatted soy flour. **a,** Extrudate (×50); and **b,** hydrated extrudate (×50). 1 = section through fiber, 2 = surface of fiber, 3 = fibrils.

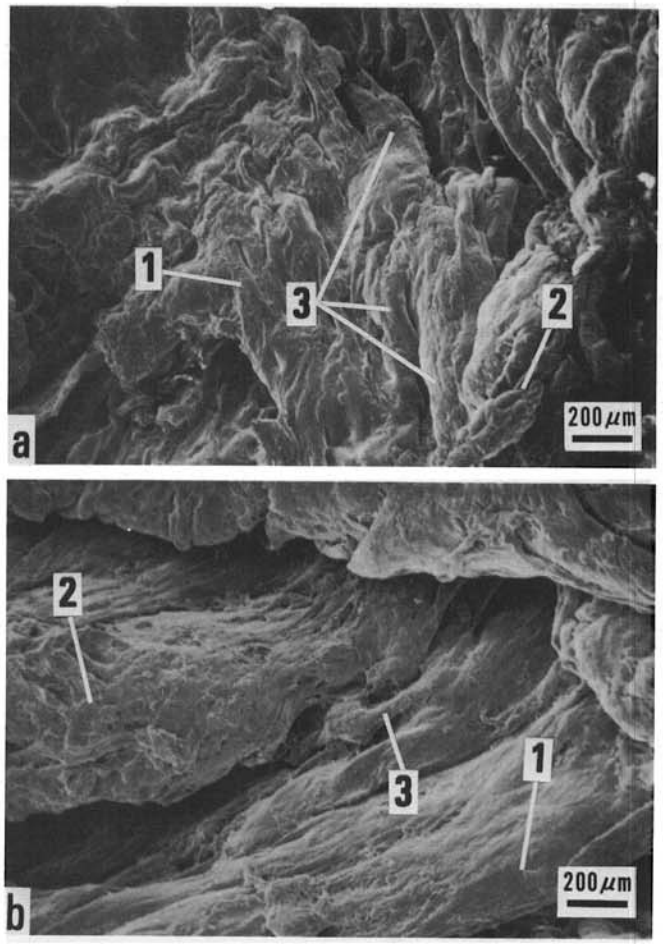

Fig. 7. Scanning electron micrographs of 40:60 decolorized corn gluten–defatted soy flour. **a,** Extrudate (×50); and **b,** hydrated extrudate (×49). 1 = surface of fiber, 2 = rough surface, 3 = fibrils.

in hot water (>80° C), they hydrated rapidly to form products with color and texture similar to poultry white meat. The hydrated products in Figs. 3, 4, and 5 were prepared by boiling in distilled water for 5 min.

Scanning electron micrographs (SEM's) of extrudates from DSF and 40:60 and 52:48 blends of DSG:DSF and their extruded forms are shown in Figs. 6, 7, and 8, respectively. The fragments reveal extrudate surfaces and cleavage planes that are mostly parallel to fiber alignment, but some views also show a few cleavage planes across several fibers. The extruded DSF in Fig. 6a shows such surfaces of cleaved fibers. The fibers appear to consist of homogeneous, tightly organized structures. After hydration (Fig. 6b), the fibers swell, the surface becomes more irregular, and smaller fibrils partially separate from the larger fibers. In contrast, in Fig. 7a the dry extruded 40:60 DCG:DSF blend exhibits considerable irregularity; the material appears to be more disrupted after leaving the extruder, indicating that it was not as cohesive as extruded DSF. Upon hydration, the 40:60 DCG:DSF blend extrudate (Fig. 7b) shows more evidence for the larger fibers disrupting into thin fibrils than does the DSF extrudate. Evidently, the introduction of DCG into the blend diminishes the lateral cohesion between protein molecules. These trends are further accentuated as the DCG level is increased to 52%. Figure 8a shows that the dry extruded DCG:DSF consists of thin sheets or highly fibrous structures oriented in one direction. Upon hydration, this material (Fig. 8b) is even more extensively disrupted into finely fibrous materials. The inclusion of DCG into the blends promotes a finer fiber structure contributing to meatlike texture; however, excessive DCG results in a lack of strength on boiling with breakdown of the structure of the large fibers.

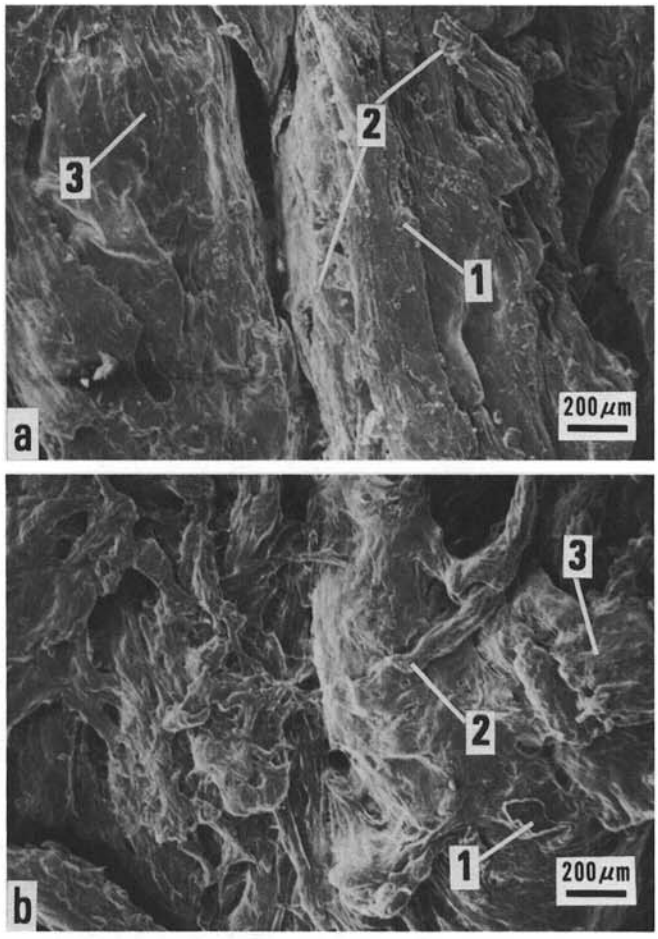

Fig. 8. Scanning electron micrographs of 52:48 decolorized corn gluten–defatted soy flour. **a,** Extrudate (×49); and **b,** hydrated extrudate (×50). 1 = surface of fiber, 2 = fibrils, 3 = laminar sheets.

Water-holding Capacity

Water-holding capacity was determined under ambient conditions and after autoclaving to allow us to study the relationship of WHC to changes in texture observed after hot water hydration (Table II). The 52:48, 46:54 DCG:DSF extrudates had similar ambient WHC. The 40:60 DCG:DSF extrudate had a slightly higher ambient WHC, and that of DSF extrudates was greater than any of the blends. After autoclaving, WHC's were greater than the ambient determinations and increased with increasing DSF concentration in the blend. Defatted soy flour extrudate had a higher autoclaved WHC than any of the DCG:DSF extrudates. Hot water is necessary for maximum penetration and complete hydration of the extrudates. The relationship of DSF concentration to autoclaved WHC of the blends does not appear to be linear.

The hydrophobic nature of DCG protein should contribute to lower WHC of the blends as compared to that of DSF alone. The porous, microfiber structure observed by SEM of the hydrated DSF extrudate (Fig. 6b) might also hold more water than the less porous, denser structure observed in SEM's of hydrated DCG:DSF extrudates (Figs. 7b and 8b).

Protein Extraction

Protein was sequentially extracted from DCG, DSF, and 46:54 DCG:DSF extrudate so that we could better understand the molecular basis of association of DCG and DSF and the changes that result from coextrusion of the blend. Results of sequence I and II extractions are shown in Figs. 9 and 10, respectively.

Defatted soy flour protein is largely saline-soluble (77.7%). In sequence I, essentially all of the remaining protein is extracted by

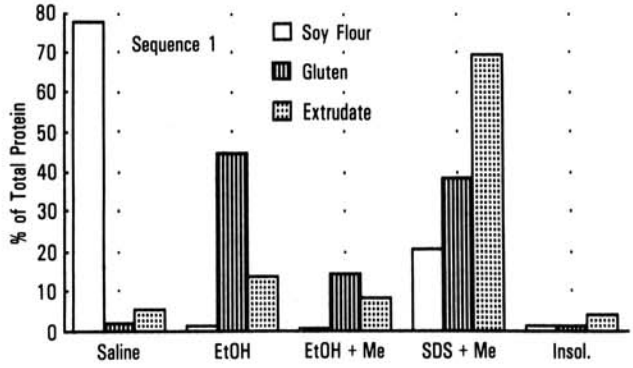

Fig. 9. Yield of protein fractions from defatted soy flour, decolorized corn gluten, and 46:54 DCG:DSF extrudate obtained by sequence I extraction.

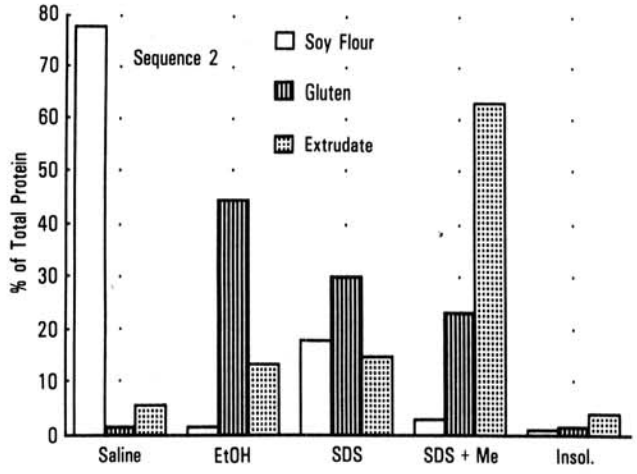

Fig. 10. Yield of protein fractions from defatted soy flour, decolorized corn gluten, and 46:54 DCG:DSF extrudate by sequence II extraction.

SDS + ME (20.3%), whereas in sequence II, most of it is extracted by SDS (18.0%), with a smaller portion being soluble in SDS + ME (2.6%). Negligible quantities of protein were extracted by EtOH or EtOH + ME. Saline-insoluble DSF proteins were aggregated primarily by hydrophobic associations as evidenced by their appreciable solubility in SDS and to a lesser extent by intermolecular disulfide bonds as indicated by solubility in SDS + ME (sequence II).

Saline extraction removed only a small fraction of the protein (1.4%) from DCG. Aqueous ethanol removed the largest protein fraction from DCG (44.6%), which consists of zein and zeinlike proteins present in the corn endosperm. Sequence I extraction with EtOH + ME removed some alcohol-soluble-reduced protein (14.1%), which may consist of alcohol-soluble-reduced glutelin (Paulis and Wall 1971). Sequence II extraction with SDS removed a large fraction of protein (29.7%) associated by hydrophobic bonds. These results are in agreement with previous findings on extraction of CG with the same series of solvents (Neumann et al 1984b), which suggested that cleavage of glutelin disulfide bonds during SO_2 steeping increased solubility of CG protein in SDS as compared to native endosperm protein. Extraction of sequence I and II residues with SDS + ME removed almost all of the remaining protein (38.4 and 23.3%, respectively). The sequence II SDS + ME fraction yield indicates the amount of protein in DCG linked by intermolecular disulfide bonds.

Sequence I and II extraction of the DCG:DSF (46:54) extrudate reveals changes in protein solubility due to protein interaction during coextrusion. The extrudate contains appreciable quantities of saline-soluble (5.2%), EtOH-soluble (13.2%), and EtOH + ME-soluble (8.0%) or SDS-soluble (15%) proteins. However, most of the protein is soluble in SDS + ME. The large yield of this fraction compared to that obtained from DCG and DSF is evidence that protein denaturation was accompanied by intermolecular disulfide bond formation during coextrusion of DCG and DSF. After exhaustive extraction with SDS + ME, the extrudate residue still contained a higher level of insoluble protein than DCG or DSF (4.0% compared to approximately 1% for DCG and DSF).

To further investigate disulfide bond content and fate of other derivatives of cysteine (ODCys) during coextrusion, sulfhydryl and disulfide groups (contained in cysteine and half-cystine residues, respectively) in DCG, and 46:54 DCG–DSF extrudate were determined by amperometric titration and compared with the results obtained by Neumann et al (1984b) for CG and pH 7.0 CG. Adjustment of pH and decolorization decreased the amount of sulfhydryl groups (cysteine) and resulted in concomitant increases in disulfide content (half-cystine) (Table III). ODCys contents of CG (pH 7.0 CG) and DCG were similar. The 46:54 DCG:DSF extrudate contained a small amount of cysteine, and approximately three-quarters of the compounds yielding cysteic acid were present as disulfides (half-cystine). About one-quarter of the cysteic acid-yielding compounds were estimated to be ODCys. The calculated amount of ODCys in the blend (if it did not react during extrusion) would be 22.5% of the compounds yielding cysteic acid. The higher-than-calculated level of ODCys may be partly due to heat-induced oxidation of small amounts of cysteine/cystine during extrusion to partially or completely oxidized forms (Satterlee and Chang 1982). However, ODCys present in DCG do not decompose to form disulfides during thermal extrusion. The ODCys content may partly explain the appreciable solubility of extrudate protein in SDS.

TABLE III
Cysteine, Half-Cystine, and ODCys in CG, pH 7.0 CG, DCG, and 46%:54% (DCG:DSF) Extrudate[a]

Sample	Cysteine	Half-Cystine	ODCys
CG[b]	9.9	41.4	48.7
pH 7.0 CG[b]	5.3	45.4	49.3
DCG	2.5	48.6	48.9
46%:54% (DCG:DSF)	1.0	74.7	24.3

[a] Determined by amperometric titration and expressed as mole percent of cysteic acid determined from analysis of performic acid-oxidized samples.
[b] From Neumann et al 1984b.

TABLE IV
Lysine, Methionine + Cystine (M + C), and Tryptophan Content of DCG, DSF, and DCG:DSF Extrudates

	Grams of Amino Acid/16 g of Nitrogen		
Sample	Lysine	M + C	Tryptophan
DCG	1.70	4.20	0.45
DSF	7.37	3.10	1.21
52%:48% (DCG:DSF)	3.84	3.67	0.75
46%:54% (DCG:DSF)	4.10	3.58	0.77
40%:60% (DCG:DSF)	4.51	3.40	0.82

Protein Nutritional Qualities

Protein nutritional qualities of DCG:DSF extrudates were assessed from amino acid composition and in-vitro digestibility determinations by computation of C-PER. Decolorized corn gluten is severely limiting in lysine and tryptophan, while DSF is deficient in the sulfur amino acids, methionine, and cystine (Table IV). Table IV lists the lysine, methionine + cystine (M + C), and tryptophan contents of DCG, DSF, and 52:48, 46:54, and 40:60 DCG:DSF extrudates.

In-vitro digestibilities and C-PER's are shown in Table V. Satterlee et al (1982) reported that an interlaboratory collaborative study determined that texturized soy protein had an in-vitro digestibility of 86.64% and a C-PER of 2.07. The texturized DCG-DSF blends used in this study had satisfactory in-vitro digestibilities (Table V) similar to that of the extruded soy. The DCG in-vitro digestibility (86.62%) was also similar. The DCG:DSF blend ratios used in these extrusion studies did not maximize C-PER; DCG:DSF extrudates with blend ratios of 52:48, 46:54, and 40:60 had C-PER's of 1.63, 1.76, and 1.97, respectively. Data in Table V suggest that DCG:DSF extrudates with blend ratios between 33:67 and 28:72 would have protein quality superior to that of textured soy protein and the extruded prepared blends.

DISCUSSION

The physical and chemical changes in the protein during coextrusion of DCG and DSF involve alteration of molecular conformation and formation of intermolecular disulfide bonds. These changes result from shear forces, heat, and pressure encountered in the extruder. The extent of DCG:DSF protein–protein interactions (ie, DCG:DCG, DCG:DSF, and DSF:DSF protein interactions) was not determined. DCG:DSF interaction appears to differ from the pH 7.0 CG:DSF interaction, as evidenced by distinctive texture differences between the extrudates. Removal of lipid material from CG by ethyl acetate extraction may be responsible, in part, for the unique meatlike texture of DCG:DSF extrudates. CPC International (1979) described products obtained when a deoiled, destarched corn protein isolate derived from wet-milled CG was coextruded with defatted soy flour at a nutritionally optimal level (86:14 soy-corn protein isolate). In contrast to results reported here, they concluded

TABLE V
In Vitro Digestibility and C-PER of Extrudates

Blend Ratio (DCG:DSF)	In Vitro Digestibility (%)	C-PER
52:48	86.06	1.63
46:54	85.83	1.76
40:60	86.17	1.97
33:67[a]	86.02	2.23
28:72[a]	86.02	2.33
22:78[a]	86.02	1.97
Casein (reference)	89.33	2.50

[a] Amino acid profiles calculated from components and in-vitro digestibility are the mean of the first three determinations.

that there were no significant differences between the extrudibility of soy flour alone and that of the blend. No unique textural properties were reported for the blend extrudate.

Intermolecular disulfide bond formation during extrusion was clearly demonstrated by the sequential extraction of protein from the DCG:DSF extrudate, as compared to DCG and DSF. The large yield of protein soluble in SDS + ME would implicate intermolecular disulfide cross-links as a texture determinant, as suggested by Rhee et al (1981). However, ODCys in the DCG:DSF extrudate reduce disulfide bond formation during extrusion and may contribute to the protein solubility in nonreducing SDS solvent.

The DCG:DSF extrudates used in this study had C-PER's less than those reported for textured soy protein by Satterlee et al (1982), but these blends would be nutritionally better than DCG alone. Calculations from amino acid profiles and in-vitro digestibilities for DCG:DSF blends with increased DSF concentration showed that C-PER maximized at a 28:72 DCG:DSF blend ratio would be greater than that of textured soy protein (2.33 compared to 2.07). Determinations of PER in vivo are needed to critically evaluate the nutritional quality of DCG:DSF extrudate protein.

The Select Committee on GRAS Substances (FASEB 1981) has evaluated the health aspects of CG. The committee concluded that there was no available evidence that CG constitutes a hazard when used as a food ingredient in the manner now practiced or as might reasonably be expected to be practiced in the future. They point out that, although subcutaneous administration of free S-sulfocysteine to young rats has been shown to cause neuronal lesions, similar lesions have also resulted from subcutaneous injection or gavage feeding of free L-cysteine. The available evidence indicated that the metabolic products of S-sulfocysteine are also metabolites of common dietary constituents and that ingestion in the protein-bound form does not cause adverse effects. However, recent reports of allergic responses to free sulfite in the diets of some individuals indicate that further study of CG use in foods should be explored from this health aspect.

The process for making extruded products from blends of soy flour and CG is now undergoing pilot-plant investigation to establish preparation and extrusion parameters that optimize their nutritional and textural properties. These extrudates will be evaluated for textural quality after hot-water hydration by tensile strength and shear-press measurements, and sensory evaluation by a taste panel.

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