Survey of Soybean Oil and Meal Qualities Produced by Different Processes

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ABSTRACT: Soybean oil and meal produced by extruding–expelling (E–E) are believed to have unique characteristics compared with products produced by solvent extraction (SE). A survey was conducted to compare quality characteristics of the oils and meals produced from different types of soybean processing methods. Soybean oil and meal samples were collected three different times within a 1-yr period from 13 E–E mills, 8 SE plants, and 1 continuous screwpress (SP) plant. Properties of oil and meal varied considerably between different types of plants and among plants of the same type and sampling times. In general, settled crude E–E and SP oils had significantly greater peroxide values than those of SE oils. E–E oils contained less free fatty acid and phosphorus than did SE and SP oils. The oxidative stability (AOM) of E–E oil was less than that of SE oil, and that of SP oil was intermediate. E–E and SP meals had higher oil and lower protein and moisture contents than those of SE meals. Protein dispersibility indices were lower for E–E and SP meals. Protein solubilities in KOH were similar for E–E and SE meal, but higher than that of SP meal (62%). Rumen bypass protein values were higher for the SP meal.

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KEY WORDS: Extraction, extruding–expelling, screw pressing, solvent extraction, soy meal, soybean oil, soybean meal quality, and soybean oil quality.

Increasingly, soybean producers are building "mini" soybean mills to produce crude oil for edible and industrial products and meal for livestock feed in their local areas. In this way, farmers add value to the soybeans that they produce. These mini mills employ recently developed extruding–expelling (E–E) technology (1,2) to produce soybean oil and meal with perceived unique qualities (3,4) compared with products produced by more widely used solvent extraction (SE). The E–E technology is marketed as the Express System® (InstaPro Div., Triple "F", Inc., Des Moines, IA). SE involves high capital investment, high energy demand, large seed tonnage, use of a flammable solvent, and increasingly more restrictive government regulations on volatile emissions. In the "natural" and "organic" foods industry, the oil and meal obtained by SE are considered chemically treated because of the exposure to hexane during extraction.

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The E–E facility, on the other hand, is relatively small and inexpensive to construct and operate (5,6). It is particularly suitable for processing identity-preserved soybeans due to its low seed tonnage requirement and ability to rapidly switch seed sources with little cross contamination. In E–E processing, dry extrusion is used as a pretreatment just prior to entering the screw press. The extruder replaces the conditioning and flaking steps of soybean preparation in SE mills and the cooking or drying in screw press (SP) mills, thus eliminating the need for steam generation. A significant amount of the antinutritional factors is inactivated, and bulk proteins are partially denatured during the high-temperature and short-time treatment. A SP is used to press out the oil and to obtain a meal with high energy content and good nutritional value; but less oil yield is produced compared with SE. The E–E process is completely mechanical or physical; the oil and meal have the potential to be further refined or processed by natural or physical means to produce value-added soybean products to meet the growing consumer demand for natural and organic products (7).

Instead of competing in oil and meal markets where SE operations have economy of scale advantages, E–E processors are more interested in finding niche markets for their products where higher value returns are possible on smaller volumes. To facilitate identifying value-added opportunities, we conducted a survey to evaluate and compare the qualities of oils and meals produced by E–E, SE, and SP mills.

EXPERIMENTAL PROCEDURES

Oil and meal samples. Thirteen E–E mills, nine SE plants, and one SP plant participated in the survey. The E–E and SE participants were located in Iowa, Illinois, Indiana, Minnesota, Missouri, and Wisconsin. There are very few SP plants processing soybeans, and only one, located in Iowa, was willing to participate. Crude soybean oils and meals were collected three times during a 1-yr period (July 1998, October 1998, and Febuary 1999) involving two crop years. Duplicate samples were analyzed for various quality factors according to standard methods of the American Oil Chemists' Society (8) or the Association of Official Analytical Chemists (9). All samples were stored at 5°C until analyzed. All oil analyses were completed within 4 wk of collection.

Compositional and chemical analyses. The oils were evaluated for peroxide value (PV; AOCS Cd 8-53) (8), free fatty

acid content (FFA; AOCS Ca 5a-40) (8), phospholipid content (AOCS Ca 12-55) (8), total tocopherol content (AOCS Ce 8-89) (8), oxidative stability (AOM; AOCS Cd 12-57) (8), color (AOCS Cc 13b-45) (8), and moisture content (AOCS Ca 2c-25) (8).

The meal samples were analyzed by a commercial laboratory (Woodson-Tenent Laboratories, Des Moines, IA). The tests performed were urease activity (AOCS Ba 9-58) (8), protein dispersibility index (PDI; AOCS Ba 10-65) (8), rumen bypass or rumen undegradable protein (RUP) [an ammonia release procedure by Herold *et al.* (10)], trypsin inhibitor activity [TI; AOCS Ba 12-75 (8), and a method by Hamerstrand (11)], moisture content (AOCS Ba 2a-38) (8), residual oil content (AOCS Ba 3-38) (8), protein content (AOCS Ba 4a-38) (8), fiber content (AOCS Ba 6-84) (8), color (Hunter Labscan colorimeter, Reston, VA), and amino acid (AA) profiles (AOAC 994.12) (9).

To determine protein solubility under alkaline (KOH) conditions, an in-house method of Woodson-Tenent was used. Two grams of finely ground soybean meal sample was mixed with 100 mL of 0.2% KOH solution for 20 min. The mixture was then centrifuged, and the protein content of the supernatant was determined by Kjeldahl method. The KOH solubility was then calculated from the amount of protein dissolved in KOH solution and the total amount present in the sample.

Statistical analyses. Statistical analysis was performed to determine the significance of the effects of processing type and sampling time on oil and meal qualities. A general linear models procedure of SAS (12) was used for the analysis of variance, and least significant difference at $P = 0.05$ was used for comparing means. The experimental design was a factorial treatment with processing method (three types) as one factor and sampling time (three levels) as the other.

RESULTS AND DISCUSSION

Oil quality. The qualities of the three types of soybean oils are compared in Table 1. Statistically, there were no interactions between processing type and sampling time, except for phosphorus content. Therefore, it is adequate to examine only the main effects of the type and time. In this study, only one SP plant participated in the survey; thus, there is no standard deviation among the plants of the same processing type. In addition, the July SP oil was actually degummed oil, so the data were not used for statistical analysis.

PV is a measure of primary lipid oxidation products in the oil. The PV of the crude E–E oils (1.73 meq/kg) were significantly higher than those of the crude SE oils (0.96 meq/kg), which we attribute to the high temperature used in the E–E process, the long period allowed for oil cooling, and/or the poor oil storage conditions and longer storage time at the E–E mills. The oil exiting the press is typically in the range of 70–80°C, and E–E plants do not usually cool the oil before placing it into storage tanks. Because of the low production rate, shipping the oil is less frequent and the oil is stored for longer periods before refining. The crude SP oil (1.76 meq/kg) had a PV similar to the mean of the E–E oils. Hill (3) reported a lower PV in crude E–E oil than in crude SE oil, but he sampled only one E–E plant and one SE plant. His E-E oil sample was obtained immediately after exiting the press, and it was chilled and stored under refrigeration until analyzed. There was no description about how the SE oil was obtained and handled. Our findings are more representative of the two types of oil found in commerce.

Peroxide molecules cause autooxidation of the oil; therefore, their formation should be minimized during oil extraction and subsequent handling of the oil. To prevent oil oxidation in E–E mills, oil collected from the press should be cooled rapidly, and nitrogen could be used to fill the headspace of the storage tank. The oil should then be shipped or refined as quickly as possible.

FFA content is a measure of hydrolytic degradation during seed storage and oil extraction, and higher FFA values result in higher refining losses during subsequent oil refining. The FFA contents of the E–E oils (0.21%) were significantly lower than those of the SE oils (0.31%), which may be due to the rapid inactivation of lipases during extrusion. SP oil contained 0.33% FFA, which was similar to that of the SE oils. This higher FFA content could be due to oil hydrolysis caused by storing beans under poor conditions at high moisture or caused by poorer quality seed at harvest. The FFA values of the July samples were significantly higher than those of the other two sampling periods for all three types of processing, which indicates seed quality deterioration during storage.

Phospholipids (PL), also referred to as gums, are polar lipids in the oil. They help stabilize the oil against autooxidation, but also increase refining loss. PL contents of the oils after natural settling were much lower in E–E oils (75 ppm phosphorus) than in SE oils (277 ppm phosphorus). SP oil had much higher PL contents (463 ppm phosphorus) than did SE oils. PL in E–E oil may be more hydratable and easier to settle, which we attribute to the rapid heat inactivation of the phospholipases. With inactivation of the enzymes, the formation of phosphatidic acid, which complexes with calcium and magnesium to form unhydratable PL, is minimized. In well-managed E–E plants, the PL content in the light oil phase (the top clear oil after settling) can be as low as 10 ppm phosphorus, which is well below the standard of 200 ppm phosphorus for degummed oil. This oil may not need to be degummed and can be directed to the next processing step. There were considerable variations of PL contents among mills of the same type, and even within the same type of mills, among the three sampling times. This was particularly true for E–E mills, which have greater variations in processing conditions and oil-handling procedures than SE plants.

Tocopherols are a group of natural compounds possessing antioxidant activity. Their concentration and composition influence the oxidative stability of the oil and have known health benefits. Total tocopherol contents of the E–E oils were slightly, but statistically significantly, lower than those of the SE oils (1257 vs. 1365 ppm, respectively). This result contra-

TABLE 1
Quality Characteristics of Soybean Oils Produced from Extruding—Expelling (E—E), Solvent Extracting (SE), and Screw-Press (SP)[a]

		July 1998 CY[b] 1997	October 1998 CY 1998	February 1999 CY 1998	Main effect
PV (meq/kg)	E–E	1.70 ± 1.34	2.17 ± 1.23	1.32 ± 0.51	1.73 a
	SE	0.53 ± 0.36	1.24 ± 0.46	1.07 ± 0.55	0.96 b
	SP	—	1.96	1.86	1.76 a
	Main effect	1.25 B	1.80 A	1.25 B	
FFA (%)	E–E	0.34 ± 0.14	0.13 ± 0.08	0.17 ± 0.23	0.21 b
	SE	0.39 ± 0.10	0.26 ± 0.12	0.29 ± 0.14	0.31 ab
	SP	—	0.32	0.36	0.33 a
	Main effect	0.36 A	0.20 B	0.22 B	
Phosphorus (ppm)	E–E	98 ± 106	78 ± 117	60 ± 84	75 c
	SE	172 ± 160	266 ± 148	333 ± 151	277 b
	SP	—	477	434	463 a
	Main effect	127 A	182 A	183 A	
AOM stability (h)	E–E	41.7 ± 16.5	15.7 ± 7.0	15.2 ± 5.7	23.9 b
	SE	58.4 ± 5.7	29.7 ± 11.1	33.3 ± 8.6	39.8 a
	SP	—	35.7	37.4	36.2 a
	Main effect	48.2 A	22.6 B	23.2 B	
Moisture (%)	E–E	0.15 ± 0.05	0.03 ± 0.01	0.05 ± 0.02	0.08 a
	SE	0.14 ± 0.05	0.05 ± 0.03	0.06 ± 0.04	0.08 a
	SP	—	0.06	0.03	0.05 b
	Main effect	0.15 A	0.04 B	0.05 B	
Tocopherolds (ppm)	E–E	1324 ± 58	1268 ± 77	1179 ± 92	1257 b
	SE	1460 ± 26	1369 ± 62	1279 ± 79	1365 a
	SP	—	1238	1175	1217 b
	Main effect	1376 A	1303 B	1218 C	
Color (red)	E–E	9.5 ± 0.8	10.4 ± 1.4	10.6 ± 1.6	10.2 b
	SE	10.0 ± 1.5	12.1 ± 3.2	11.5 ± 1.4	11.1 b
	SP	—	17.7	17.1	17.5 a
	Main effect	9.7 B	11.6 A	11.2 A	

[a]The main effects with different letters are significantly different at 5%, and the values presented are means ± standard deviation. Capital letters are for time main effect comparison; lowercase letters are for processing type main effect comparison.
[b]CY denotes crop year; PV, peroxide value; FFA, free fatty acid; AOM, active oxygen method.

dicts that reported by Hill (3) who found that the amount of tocopherols was higher in crude E–E oil than in crude SE oil. On the other hand, Hill (3) also showed that the unsaponifiable matter in crude E–E oil was lower than that in crude SE oil. SP oil had similar tocopherol content as E-E oils (1217 ppm).

Oxidative stabilities, as measured by the Active Oxygen Method (AOM), of the E–E oils (23.9 h) were significantly lower than those of the SE oils (39.8 h), probably due to the higher PV and the lower contents of phosphorus and tocopherol of the E–E oils. PL have been shown to have antioxidant activity (13,14). The AOM value of the SP oil (36.2 h) was greater than that of E–E oils due to its higher PL content, but less than that of the SE oils.

Multivariate regression was performed, and we found significant (at 1%) correlation among AOM, PV, and PL and total tocopherol contents. The effects of these variables on AOM could be expressed as follows:

$$\text{oxidative stability (AOM h)} = -38.752 - 3.634 \times \text{PV in meq/kg} + 0.042 \times \text{phosphorus in ppm} + 0.050 \times \text{Tocopherol in ppm} \quad [1]$$

One factor that was not examined in this study was the transition metal contents of the oils. E–E oils may contain higher amounts of transition metals, particularly iron, which can negatively affect oil stability. A higher iron content in E–E oil has been reported (15).

The colors of the E–E (10.2 red) and SE oils (11.2 red) were not statistically different, although SE oils tended to be slightly darker than E–E oils. SP oil (17.4 red) was much darker in color than the other two types of oils, possibly due to the more severe heat treatment before pressing.

Moisture contents of the two types of oils were not significantly different (both 0.08%). But the July samples had significantly higher moisture content than the other two sam-

TABLE 2
Compositional Characteristics of Soybean Meals Produced from E—E, SE, and SP[a]

		July 1998 CY 1997	October 1998 CY 1998	February 1999 CY 1998	Main effect
Moisture	E–E	6.53 ± 1.35	6.86 ± 1.74	7.42 ± 1.59	6.94 b
(%)	SE	11.44 ± 0.80	11.80 ± 0.42	11.69 ± 0.63	11.65 a
	SP	11.94	10.56	10.60	11.03 a
	Main effect	8.57 A	8.95 A	9.23	
Oil[b]	E–E	6.7 ± 0.7	7.3 ± 1.3	7.6 ± 1.3	7.2 a
(%)	SE	1.2 ± 0.2	1.3 ± 0.3	1.2 ± 0.3	1.2 b
	SP	8.0	5.4	5.6	6.3 a
	Main effect	4.7 A	4.8 A	5.0 A	
Protein[b]	E–E	42.4 ± 1.5	42.9 ± 1.8	42.4 ± 1.4	42.5 b
(%)	SE	47.8 ± 0.5	49.0 ± 1.1	49.6 ± 0.5	48.8 a
	SP	41.7	44.2	43.7	43.2 b
	Main effect	44.3 B	45.4 A	45.3 A	
Color	E–E	5.3 ± 0.8	5.1 ± 0.6	5.7 ± 0.6	5.4 a
(red)	SE	3.7 ± 0.4	3.9 ± 0.6	3.5 ± 0.4	3.7 b
	SP	5.9	5.7	6.0	5.9 a
	Main effect	4.7 B	4.6 A	4.8 A	

[a]The main effects with different letters are significantly different at 5% (see Table 1 for details). The values presented are means ± standard deviation.
[b]Percentages are based on 12% moisture content. See Table 1 for abbreviations.

pling times, likely due to higher relative humidities in summer.

Meal quality. The quality characteristics of the soybean meals are presented in Tables 2 and 3. There were no statistically significant interactions between processing type and sampling time for all quality parameters except for rumen bypass protein and Hunter color "L" and "b." Therefore, the main effects are generally discussed here.

Moisture contents were significantly higher in the SE meals (11.7%) and SP meals (11.0%) than in the E-E meals (6.9%). Residual oil, protein, and fiber contents were all reported based on 12% moisture content. SP was slightly more efficient in oil recovery than E-E, leaving 6.3% oil, compared with a mean of 7.2% for E–E meals. These values are considerably higher than those of the SE meals (1.2%). The large amounts of oil remaining in the E–E meals make them good energy sources but reduce oil yield (instead of 164 kg/metric ton by SE, only 104 kg/metric ton is recovered by E–E). The protein and fiber contents of the E-E meal were 42.5 and 5.4%, respectively, whereas the values for SE meal were 48.8 and 3.7%, respectively. SP meal had similar protein (43.2%) and fiber contents (5.9%) as those of E–E meals. Although dehulling is practical to do on a small scale, soybeans for E–E and SP processing are not usually dehulled, to minimize capital investment; this accounts for the higher fiber contents of the E–E meals compared with SE meals. The absence of dehulling and the higher residual oil contents of E–E processing account for the lower protein contents of E–E meal and SP meal vs. SE meal.

Hunter color "L", "a", and "b" values indicate that E–E meals were darker (low "L" value) ("L" = 65.8 vs. 69.2), less red (low "a" value) ("a" = 0.4 vs. 2.0), but more yellow (high "b" value) ("b" = 16.6 vs. 15.7) than the SE meals. SP meal was much darker ("L" = 51.5), more red ("a" = 4.8), and less yellow ("b" = 14.8) than the other types of meals. The color differences are due to differences in heat treatment and oil contents of the meals. Darker and more red colors are indicative of more severe heat treatment.

The degree of protein denaturation in soybean meal is typically measured by determining protein solubility under alkaline (KOH) conditions, urease activity, and PDI. KOH solubilities of E–E and SE meals were not significantly different (88.1 vs. 89.1%), nor were urease activities (0.07 vs. 0.04 pH units), indicating the amounts of heat exposure for feed purposes were equivalent. SP meal had 61.6% KOH solubility and 0.03 pH unit urease activity, suggesting much greater protein denaturation. PDI values of E–E meals (18.1) were much lower than those of the SE meals (44.5), indicating higher degrees of protein denaturation of the E–E meals. The SP meal had a PDI of 10.6. Relationships between PDI and KOH solubilities were observed, but they were different for the E-E and SE meals (Fig. 1).

Protein solubility has been used as an indicator of under- and overprocessing of soybean meals for poultry (16,17). These values are closely correlated with chick performance and parallel TI concentrations in the meals. Urease is more heat-sensitive than TI, and with total denaturation of this enzyme, TI activity still remains (as much as 45% of activity of the raw meal). Therefore, urease activity is not a reliable measure of adequate heating of soy meal. Protein solubility (in KOH) values in excess of 85% or less than 70% indicate under- or overprocessing of soybean meal, respectively (16,17). Based on these criteria, most E–E and SE meals in this study were undercooked, but the SP meal was over-

TABLE 3
Quality Characteristics of Soybean Meals Produced from E—E, SE, and SP[a]

		July 1998 CY 1997	October 1998 CY 1998	February 1999 CY 1998	Main effect
Urease	E–E	0.5 ± 0.03	0.08 ± 0.15	0.08 ± 0.08	0.07 a
(ΔpH)	SE	0.04 ± 0.01	0.04 ± 0.02	0.05 ± 0.05	0.04 a
	SP	3.00	0.03	0.03	0.03 a
	Main effect	0.05 A	0.07 A	0.06 A	
KOH solubility	E–E	89.8 ± 5.4	86.7 ± 5.3	87.9 ± 3.5	88.1 a
(%)	SE	89.4 ± 4.5	88.8 ± 2.9	89.0 ± 2.0	89.1 a
	SP	60.6	60.6	63.4	61.6 b
	Main effect	88.3 A	86.4 A	87.3 A	
PDI	E–E	20.4 ± 6.8	17.0 ± 5.0	17.1 ± 5.9	18.1 b
(%)	SE	45.7 ± 9.3	43.1 ± 8.0	44.8 ± 8.6	44.5 a
	SP	9.7	10.5	11.6	10.6 c
	Main effect	29.1 A	26.9 A	27.7 A	
Rumen bypass	E–E	30.8 ± 15.3	43.2 ± 9.1	38.7 ± 4.6	37.6 b
(%)	SE	42.1 ± 13.0	40.5 ± 4.7	26.1 ± 5.0	36.0 b
	SP	59.9	49.1	35.4	48.1 a
	Main effect	36.3 B	42.4 A	33.6 B	
Hunter "L"	E–E	69.5 ± 2.5	69.5 ± 1.7	58.8 ± 4.7	65.8 a
	SE	71.5 ± 1.9	69.6 ± 2.1	66.5 ± 4.3	69.1 a
	SP	53.1	56.6	44.7	
	Main effect	69.5 A	68.9 A	61.2 B	
Hunter "a"	E–E	0.4 ± 0.6	0.7 ± 0.5	0.1 ± 0.4	0.4 c
	SE	1.8 ± 0.5	2.3 ± 0.8	1.9 ± 0.5	2.0 b
	SP	5.3	5.4	3.7	4.8 a
	Main effect	1.1 B	1.5 A	1.0 B	
Hunter "b"	E–E	17.3 ± 1.0	17.4 ± 0.9	15.2 ± 1.2	16.6 a
	SE	15.6 ± 1.1	16.0 ± 0.8	15.7 ± 1.5	15.8 a
	SP	15.9	16.3	12.3	
	Main effect	16.6 A	16.9 A	15.3 B	
Trypsin inhibitor					
(mg/g)	E–E	5.52 ± 0.28			
	SE	5.46 ± 0.41			
	SP	0.30			
(TIU/g)	E–E	12254 ± 1639			
	SE	5275 ± 532			
	SP	2000			

[a]The main effects with different letters are significantly different at 5%, and the values presented are means ± standard deviation (see Table 1 for details). PDI, protein dispersibility index; TIU, trypsin inhibitor units; KOH, alkaline. See Table 1 for other abbreviations.

cooked (KOH solubility of 61%) for poultry feed. SP meal may be more suitable for ruminant animals for which more protein denaturation is desired.

Dudley-Cash (18) compared methods for analyzing the quality of soybean meal as poultry feed and demonstrated that PDI was more sensitive than were urease activity and KOH solubility for determining the optimal amount of heat processing of soybean meals. This author showed (18) that either KOH solubility or PDI can be used as a good measure of protein denaturation. But two samples with similar KOH solubilities may have different PDI values, depending on how the samples are heat treated (Fig. 1).

Rumen bypass or RUP is an important measure of potential protein utilization by ruminant animals. The higher the bypass protein value, the more protein that will escape from rumen bacterial fermentation and be utilized by the animals. An ammonia release procedure was used for RUP determination in this study. This method gives good results, which are highly correlated ($r = 0.92$) with values obtained by the *in situ* polyester bag method (19). There are many alternative techniques for measuring nutrient digestion and RUP in ruminant animals, but it is more useful to obtain relative measurements than to compare absolute values due to various difficulties (19).

It was surprising that RUP values were similar for E-E and SE meals (37.6 vs. 36.0%, respectively), which had different degrees of protein denaturation as measured by PDI (18.1 vs. 44.5%, respectively). Figure 2 is a scatter plot between RUP

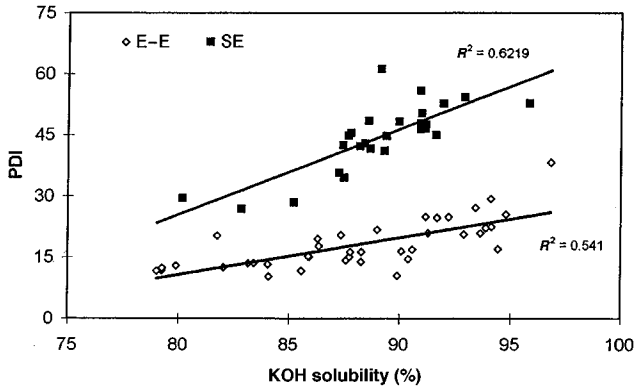

FIG. 1. Correlation between protein dispersibility index (PDI) and alkaline (KOH) solubilities of soybean meals.

and PDI. The SP meals had higher rumen bypass values (48.2%) than either E-E or SE meals. It was expected that E–E meals, which had more protein denaturation than SE meal (as shown by low PDI), would have high RUP values. But the very brief heat exposure of E–E processing (about 30 s) may not have produced the kind of denaturation needed for passing through the rumen intact. It is common practice to hold the beans at an elevated temperature after roasting to allow more thorough heat treatment in order to produce feed ingredients for lactating dairy cows. Holding soybeans for at least 30 min post-roasting without cooling increased RUP to 66%, compared to 48% without holding (20).

It should be noted that PDI is normally used to predict protein functionality in a food system and not for feed. Thus we would expect E–E meal to have even poorer functional properties than SE meal.

By carefully examining the scatter plot (Fig. 2), a general relationship can be identified. There seems to be a minimum RUP value at a PDI value of *ca.* 30%. Below this PDI, the lower the PDI, the higher the RUP values; above this PDI, the higher the PDI, the higher the RUP values. When not adequately denatured, the protein may not be readily available to rumen bacteria; therefore, a higher percentage of the protein is released from the rumen than if the protein is ideally denatured and becomes more digestible by the bacteria.

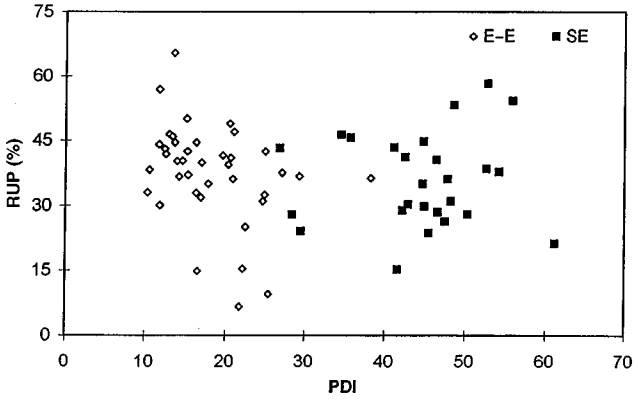

FIG. 2. Scatter plot illustrating the relationship between PDI and rumen undegradable protein (RUP) of soybean meals. See Figure 1 for abbreviation.

TI activity is an important quality parameter of soybean meal, especially if the meal is fed to monogastric animals. Urease activity is usually used as an indicator for TI activity. Our urease data showed that there were no differences between the E–E (0.07 pH unit) and SE meals (0.04 pH unit), and these low values suggested that the antinutritional factors should be sufficiently inactivated. It is known that TI and urease have different sensitivities to heat denaturation. To illustrate this, one batch of meal samples (July 1998 sampling) was sent to two laboratories for TI activity analysis, using two different methods. One laboratory used a method that is a modification of a standard AACC 71-10 method (11,21) and is frequently used in Europe. It expresses the results as mg TI/g dry sample. Woodson-Tenent laboratories (Des Moines, IA) uses the standard AOCS method, and its results are expressed as TI units (TIU)/g dry sample. The standard AACC method was reported to give erroneously high values, whereas values obtained by the modified AACC procedure are usually considered to more accurately estimate TI activity (11).

The TI data in Table 3 indicate that there were no differences between E–E and SE meals (5.5 mg/g for both) with the modified method, but the standard method gave much higher TI activities in E–E meals (12,254 TIU/g) than in the SE meals (5,275 TIU/g). The TI activities of SP meal from the two methods were 0.3 mg/g and 2,000 TIU/g, respectively. The mg/g TI values were plotted against the other measures of protein denaturation, and no relationships were found. When the TIU/g TI values were plotted, strong correlations of TI activities with KOH solubilities and PDI values were observed (Fig. 3). Although the SE meals were less heat denatured than the E-E meals (as judged by PDI), their TI activities were much less than those of E–E meals. These data confirm that the kinetics of denaturation of storage protein and TI are very different. TI inactivation may require not only adequate temperature but also relatively long heating time, whereas the storage proteins may be denatured rapidly once exposed to high temperature.

Figure 3 also shows the correlation between TI activities and RUP values. TI values of E-E meals correlated negatively with RUP values, whereas TI values of SE meals seemed positively correlated with the RUP values. The reason for this observation is similar to that discussed above.

Anderson and Wolf (22) found that TI values in raw and fully toasted soy flour were about 58 and 16 mg/g of protein, respectively. When converting the TI data (in mg/g) from this study to the weight of protein basis, E-E and SE meals had 13.0 and 11.2 mg/g protein TI activities, which represented a 77.5 and 80.6% reduction for E-E and SE meals, respectively. A TI activity reduction of 80% is generally required for optimal animal growth (23).

AA profiles of the soybean meals were analyzed, and the essential AA compositions are presented in Table 4. Statistically, there was no interaction between processing type and

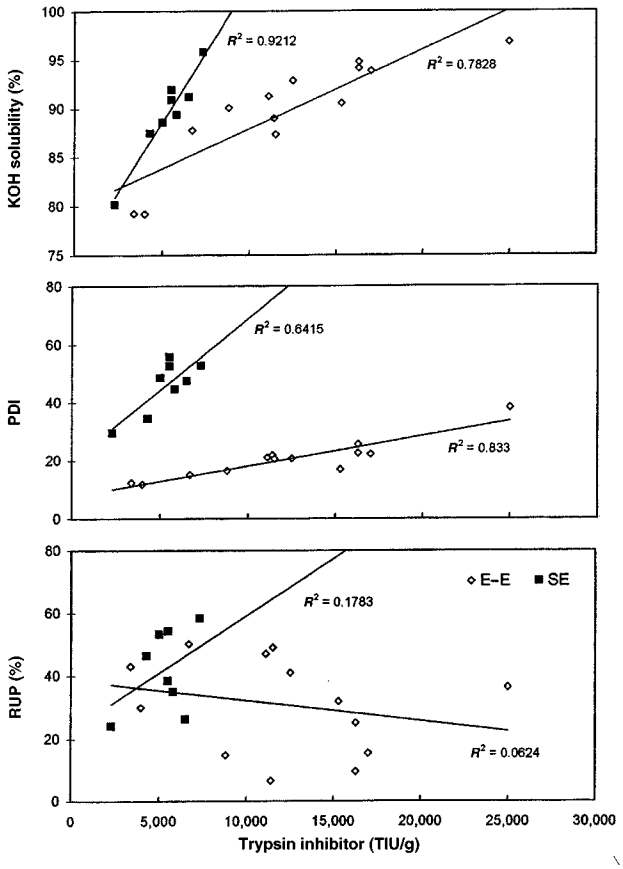

FIG. 3. Correlation between trypsin inhibitor (TI) activity and alkaline (KOH) solubility, PDI, and RUP of soybean meals. See Figures 1 and 2 for other abbreviations.

sampling time for all the essential AA, except for lysine and phenylalanine. Therefore, only the main effect of processing type is discussed in this report. Generally, the AA compositions of E–E and SE soy meals were not as different as either of them compared with SP meal. Arginine, cysteine, and lysine percentages of pressed meal were considerably lower than the others, suggesting degradation of these AA under severe heat treatment. Heating generally increases digestibility of AA. But when exposed to excessive heat, the AA digestibility could be reduced, especially for lysine and cystine (17). AA composition data in this report were similar to the results of others (24).

Quality variation among types of processing. The standard deviation for each mean listed in Tables 1, 2, and 3 describes quality variation among the plants of the same type and at specific sampling times. Generally, the variation among E–E mills was greater than that of SE plants, with the exceptions of oil phosphorus content and meal PDI, for which SE caused greater variation than E–E.

TABLE 4
Essential Amino Acid Composition (as % of total protein) of Soybean Meals[a]

Amino acid	E–E meal	SE meal	SP meal
Arginine	7.45 a	7.56 a	7.27 b
Cysteine	1.73 a	1.60 b	1.51 b
Histidine	2.77 a	2.76 a	2.75 a
Isoleucine	4.64 a,b	4.54 b	4.70 a
Leucine	7.92 b	7.92 b	8.03 a
Lysine	6.50 a	6.49 a	6.01 b
Methionine	1.49 a,b	1.48 b	1.54 a
Phenylalanine	5.18 a	5.15 a	5.21 a
Tyrosine	3.60 a	3.59 a	3.60 a
Threonine	3.94 a	3.97 a	4.01 a
Tryptophan	1.47 a	1.44 a	1.45 a
Valine	4.93 a,b	4.86 b	5.03 a

[a]The row values with different letters are significantly different at 5%. See Table 1 for abbreviations.

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