Effect of Overcooked Soybean Meal on Chicken Performance and Amino Acid Availability[1]

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ABSTRACT Studies were conducted to evaluate the effect of overcooked soybean meals (SBM) on chick growth and amino acid availability. The SBM were custom-prepared at a commercial processing plant by changing the conditions of a desolventizer-toaster (DT) unit. Six progressively overcooked meals (designated SBM1 to 6 with SBM1 as normal, and SBM6 overcooked) were produced by increasing temperature by up to 50% and extending retention time by up to 75% above normal.

The meals measured .05, .03, .01, .09, .00, and .00 ΔpH of urease activity; 6.10, 5.01, 4.62, 4.83, 2.32, and 1.78 mg/g SBM of trypsin inhibitor activity; 92, 89, 91, 88, 81, and 81% of protein solubility in .2% KOH; and 46, 43, 41, 40, 23, and 19% of protein solubility in .1 *M* borate at 40 C, respectively. Glucose content in the hydrolysate of the soluble carbohydrate extract did not differ among the meals, indicating no differences in the degradation of sucrose, raffinose, and stachyose with increasing heat treatment.

In a chick growth experiment with a methionine-adequate, low-protein diet, chicks fed SBM1 showed significantly greater weight gain than chicks fed SBM3, 5, or 6. The SBM1, 2, 5, and 6 were chosen for a study of amino acid availability. No differences were observed in amino acid content. There were significant differences in apparent amino acid availability to growing chicks, but not in true amino acid availability by adult roosters among the four meals. The results suggest that the temperature or the retention time of a DT unit may be increased by 50% over the usual operating conditions without reducing amino acid availability from SBM.

(*Key words*: overcooked soybean meal, chicken, amino acid availability, body weight, heat-damaged protein)

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INTRODUCTION

Soybean meal (SBM) is a major protein source in poultry diets. Proper heat processing is required to destroy antinutritive factors naturally present in raw soybeans. However, excessive heat treatment may lower amino acid availability. Proteins undergo a number of physical-chemical changes due to heat, which adversely affect the nutritional value of proteins (Bjarnason and Carpenter, 1969; Hurrell *et al.*, 1976; Sternberg *et al.*, 1975; Mauron, 1981). These include derivatization of lysine, oxidation of sulfur in cysteine and methionine, and crosslinkages at amides and carboxyls.

Compared with other plant-source proteins, SBM is particularly high in lysine, which is the amino acid most susceptible to damage by heat treatment. The brown color change occurring during moist heat

[1]The use of trade names in this publication does not imply endorsement of the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned.

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TABLE 1. Cooking conditions of soybean meals[1]

Cooking conditions	Soybean meal[2] 1	2	3	4	5	6
Meal temperature of top deck, C	66	99	104	104	104	104
Meal temperature of discharge, C	107	107	116	116	116	116
Retention time, min	38	36	37	40	55	65

[1]Cooking conditions of the three-deck desolventizer-toaster unit.

[2]Meals 1 and 2 produced on the same day; Meals 3 to 6 produced on another day.

cooking of proteins may be due partly to the Maillard reaction, in which lysine reacts with reducing sugars and loses its nutritional availability by forming an insoluble brown pigment, melanoidin (Mauron, 1981).

Hexane, a solvent used in soybean processing to extract oil from soybeans, is expensive and may be an environmental pollutant. Therefore, SBM processors would like to reduce the temperature and increase retention time (RT) in the desolventizer toaster (DT) unit in order to minimize energy utilization and to maximize hexane recovery. Animal nutritionists are interested in SBM quality. They are concerned that the protein of SBM may be heat-damaged by the extent of the thermal processing. Ferket and Jones (1989) reported that a few years ago many soybean crushers installed new energy-efficient equipment and pollution control equipment, which resulted in a modification of the toasting process. This resulted in meals of lower urease and protein solubility. Therefore, updated values for lysine availability and other amino acids availabilities to poultry are needed on the SBM currently produced.

Most previous studies on the nutritional evaluation of SBM were performed on meals prepared using laboratory autoclaves to simulate the cooking conditions of a commercial DT unit. There is limited similarity of laboratory autoclaves to commercial DT units. The objectives of the present studies were 1) to evaluate the effect on chick performance of overcooked SBM custom produced in a commercial facility; 2) to determine amino acid availability from these meals by chicks; 3) to relate *in vitro* measures to biological performance, and 4) to investigate a new *in vitro* protein solubility assay to assess proper processing of SBM.

MATERIALS AND METHODS

Soybean Meal Preparation

The SBM was custom prepared at a commercial solvent extraction facility[3] by varying the temperature of the top deck and the meal RT in the three-deck DT unit. The six differently cooked meals produced were designated SBM1, SBM2, SBM3, SBM4, SBM5, and SBM6. Meals SBM1 and SBM2 were produced on one day and meals SBM3-6 on another. Meal SBM1 represented the typically processed meal with the steam supply and rate of meal passage through the DT unit in accordance with usual operating conditions at the time. The other meals were the progressively cooked meals by increasing temperature and RT. Processing conditions for the six SBM are summarized in Table 1.

In vitro Assays

Urease activity (UA) (American Oil Chemists Society, AOCS, 1980), trypsin inhibitor activity (TI) (Hamerstrand *et al.*, 1981), protein solubility in .2% KOH (PSK) (Dale *et al.*, 1987), protein solubility in borate (PSB) (Lee and Garlich, 1989), and glucose content in the hydrolysate of soluble carbohydrates (Glc) extracted from the meal were measured. For TI analysis, the sample was extracted for 3 h at room temperature after initially adjusting the pH

[3]Cargill, Inc., Raleigh, NC 27611.

of the extraction preparation to pH 10. In order to facilitate clarification of the extract before dilution for TI analysis, an aliquot of the extract was mixed with an equal volume of Tris buffer at pH 8.4 and centrifuged to remove insoluble materials. The SBM, ground to pass a United States standard sieve Number 100 in particle size, was used for both protein solubility tests. For PSB, 1.00 g of SBM was suspended in 50 mL of .1 *M* sodium tetraborate (pH 9.2). The suspension was stirred for 20 min on a magnetic stirrer at a rate that just fails to form a vortex. Temperature control at 40 C was maintained in a water bath heated by an immersion heater, and the temperature of the meal suspension was checked during the extraction period.

After the slurry separated, a portion of the supernatant was transferred to a 50-mL centrifuge tube. The tube was centrifuged for 10 min at 1,655 × *g*. A 15-mL aliquot was taken for determination of crude protein by Kjeldahl digestion. Protein solubilities were expressed as a percentage of the total crude protein in the SBM. To determine Glc, carbohydrates were extracted from SBM by the method of Saravitz (1986). One hundred milligrams of SBM was taken in 5 mL of 80% aqueous ethanol (vol/vol) in a centrifuge tube. The tube was placed in a boiling water bath for 5 min with frequent stirring. After cooling, the tube was centrifuged and the supernatant was collected. Ethanolic extraction was repeated two more times. Supernatant from each sample were combined and taken to dryness *in vacuo*. The contents were dissolved in 50 mL of water. To the extracted carbohydrates, 5 mL of 12 *N* HCl was added and set aside for 25 h at room temperature. The solution was neutralized with sodium carbonate and diluted to 100 mL. Glucose content was determined by the glucose oxidase method using diagnostic kit Number 510.[4] *In vitro* assays were conducted in duplicate for each meal.

Chicken Growth Experiment

All animal experimentation was conducted in accordance with the Guide for the Care and Use of Laboratory Animals (National Research Council, 1978). At the end of the growth experiment, the chicks were euthanatized with carbon dioxide. Two hundred and twenty 1-day-old male chicks (Arbor Acres × Arbor Acres) were housed in electrically heated Petersime[5] battery brooders with raised wire floors and thermostatically controlled temperature. The chickens were fed a corn and SBM basal diet for the first 5 days. At the end of this period the chicks were weighed and 192 chickens were allotted to six dietary treatments with four replicates per treatment and eight chicks per replicate. Chicks were allotted on the basis of weight so that the overall weight and weight range were similar for each replicate group. Experimental diet composition and calculated nutrient content are shown in Table 2. The SBM was used as the sole source for protein at the 15% level to make the diet limiting in protein and more sensitive to amino acid quality. DL-methionine was supplemented. Dehulled SBM was adjusted on the basis of nitrogen content of each SBM so that diets were isocaloric and isonitrogenous. The experimental diet was fed for the period of 3 wk (from 6 days to 27 days of age). Feed and water were provided for *ad libitum* consumption. Individual body weight and group feed consumption were recorded weekly.

Amino Acid Availability Study

Meals SBM1, SBM2, SBM5, and SBM6 were chosen for the study. The SBM were analyzed for dry matter and crude protein content by Association of Official Analytical Chemists (1984) procedures. Amino acid content of SBM was determined (Table 3). Hydrolysates for analysis of amino acids were prepared by the methods of Elkin and Griffith (1985). Samples were subjected to performic acid oxidation prior to acid hydrolysis to convert methionine and cysteine to methionine sulfone and cysteic acid, respectively. Amino acid analysis was conducted by the Degussa Corporation[6] using ion-exchange chromatography.

Apparent amino acid availability (AAAA) was determined by the procedures of Hill *et al.* (1960). Excreta were collected each 12 h on the last 2 successive days during the 2nd wk of the experimental

[4]Sigma Chemical Co., St. Louis, MO 63178-9916.
[5]Petersime Incubator, Gettysburgh, OH 45328.
[6]Degussa Corp., Allendale, NJ 07660-2100.

TABLE 2. Composition of experimental diet and calculated nutrient analysis

Ingredients and calculated content	Percentage
Dehulled soybean meal[1]	31.00
Corn starch	61.20
Cottonseed oil[2]	2.00
Dicalcium phosphate	2.50
Limestone	1.40
Salt	.30
DL-methionine	.30
Choline chloride	.10
Vitamin premix[3]	.10
Trace mineral premix[4]	.10
Chromic oxide premix[5]	1.00
Calculated nutrients	
ME, kcal/kg	3,200
Ca, %	1.16
P (nonphytate), %	.57
Protein, %	15.00
TSAA, %	.95
Lysine, %	.99
Threonine, %	.59
Leucine, %	1.18

[1]Dehulled soybean meal content of the diet was adjusted on the basis of N content to provide 15% crude protein in all diet.

[2]Ethoxyquin was incorporated at .01% of diet.

[3]Vitamin premix provided the following per kilogram of diet: vitamin A, 13,200 IU; cholecalciferol, 4,400 ICU; vitamin E, 33 IU; niacin, 67.1 mg; riboflavin, 14.3 mg; d-pantothenic acid, 22 mg; thiamin, 2.02 mg; folic acid, 1.21 mg; vitamin B_6, 6.6 mg; menadione, 2.2 mg; biotin, 165 μg; vitamin B_{12}, 24.2 μg; Se, .2 mg.

[4]Trace mineral premix provided the following per kilogram of diet: manganese, 150 mg; zinc, 120 mg; iron, 40 mg; copper, 6 mg; iodine, 1.5 mg.

[5]Chromic oxide premix was prepared (30%) in corn starch.

period in the chicken growth experiment. Chromic oxide was used as an indigestible reference by inclusion in each diet at a level of .3%. Excreta were placed in plastic freezer bags and frozen immediately after each collection. Successive collections were added to the respective bags to provide a single frozen composite for each pen. For processing, the material was thawed and homogenized in a large blender with added water and with the addition of 3.6 *N* sulfuric acid to adjust to pH 5.4. A sample of the homogenate was freeze-dried, ground by a pestle and mortar, and stored at 4 C for further analysis. The chromium determination was made using the method of Czarnocki *et al.* (1961).

True amino acid availability (TAAA) was determined by the true metabolizable energy method of Sibbald (1979). The Single Comb White Leghorn roosters were fasted for 48 h prior to force-feeding them 30 g of SBM. The excreta voided during the subsequent 48 h were collected quantitatively, frozen, freeze-dried, and weighed. Four roosters were used for each meal. Excreta from each rooster were analyzed for amino acid content. A nitrogen-free diet was fed to estimate the quantities of endogenous amino acids (Green *et al.*, 1987). Excreta from each rooster fed the nitrogen-free diet were analyzed for amino acid content. The mean values of amino acids from four replicate roosters were used as an estimate of metabolic fecal and endogenous urinary amino acid excretion. Amino acid analyses were carried out on single samples from each replicate.

Statistical Analysis

Data were subjected to the ANOVA procedure with a completely randomized design. Treatment means were compared by least significant difference when significant ($P<.05$) *F* values were obtained (SAS Institute, 1982).

RESULTS AND DISCUSSION

The results of the four *in vitro* assays showed progressive decreases in values of UA, TI, PSK, and PSB among the six commercially produced meals (Table 4). The UA of the meals decreased with processing from .05 to .00 ΔpH with the exception of SBM4, which had a value of .09. More than 50% increase in RT with 50% increase in T over the usual processing conditions brought UA down to 0. For many years, the American Feed Manufacturers Association (AFMA) suggested the values of .05 to .20 increase in pH of UA as a standard for properly processed SBM (AFMA, 1979). According to the AFMA original recommended range of UA values for adequate processing, SBM2, SBM3, SBM5, and SBM6 used in the study were overcooked and SBM1 and SBM4 were adequately cooked.

The TI values also decreased with cooking (Table 4). From the regression

TABLE 3. Amino acid content of soybean meals

Composition, %	Soybean meal 1	2	5	6
Dry matter	91.88	91.04	91.63	92.45
Crude protein	49.32	49.21	48.60	48.86
Amino acids[1]				
Methionine	.69	.70	.66	.71
Cysteine	.78	.81	.68	.78
Lysine	3.32	3.25	2.95	3.16
Threonine	1.84	2.00	1.79	1.89
Arginine	3.92	3.97	3.59	3.97
Valine	2.89	2.77	2.64	2.88
Proline	2.74	3.13	2.87	2.97
Leucine	4.33	4.30	4.15	4.29
Isoleucine	2.52	2.53	2.42	2.50
Aspartic acid	6.13	6.32	5.55	6.07
Glutamic acid	10.36	10.33	9.91	10.36
Alanine	2.72	2.54	2.53	2.67
Glycine	2.33	2.37	2.45	2.36
Serine	2.06	2.42	2.03	2.23
Total	46.63	47.44	44.22	46.84

[1]Dry matter basis: values represent the mean of four subsamples.

equation derived by Garlich (1987) with 23 commercial SBM samples, TI (milligrams per gram of SBM) = 3 + 13 UA, it was calculated that a TI of 3.65 to 5.60 corresponded with UA range of .05 to .20. The TI values of SBM2, SBM3, and SBM4 were in this range. The SBM5 and SBM6 could be evaluated as overcooked and SBM1 could be suspected as undercooked.

The values of both protein solubility tests decreased with processing (Table 4). The PSB showed a greater decrease than PSK (27 versus 11% difference between SBM1 and SBM6). Dale *et al.* (1987) suggested the range of 73 to 85% for adequate processing by PSK assay. By this criterion, none of meals herein were overcooked. When the values of these two protein solubility tests were compared, SBM was less soluble at pH 9.2, but the difference among the progressively overcooked meals were greater at pH 9.2 than at pH 12.5. Adequately cooked or slightly overcooked meals were well solubilized at pH 9.2, 40 C, but overcooked meals were not well solubilized under these conditions. The condition of pH 12.5 provided by .2% KOH was able to extract protein from overcooked SBM as well as adequately cooked SBM, resulting in a smaller range in protein solubility among the progressively overcooked meals.

TABLE 4. *In vitro* characterization of soybean meals

Variable	Soybean meal 1	2	3	4	5	6
Urease activity, ΔpH	.05[b]	.03[c]	.01[cd]	.09[a]	.00[d]	.00[d]
Trypsin inhibitor, mg/g	6.10[a]	5.01[b]	4.62[b]	4.83[b]	2.32[c]	1.78[c]
Protein solvent in KOH, %	92[a]	91[a]	89[b]	88[b]	81[c]	81[c]
Protein solvent in borate, %	46[a]	43[b]	41[bc]	40[c]	23[d]	19[e]
Glucose, mg/g[1]	32.8	32.1	35.1	35.9	35.9	34.9

[a–e]Means within a row with no common superscripts are significantly different (P<.05).

[1]Glucose content in the hydrolysate of the soluble carbohydrate extract representing sucrose, raffinose, and stachyose.

No change was observed in Glc of the meals (Table 4). This glucose value is proportional to the sum of the sucrose, raffinose, and stachyose in the meals. Meals SBM1 and SBM2 had lower Glc than SBM3, SBM4, SBM5, and SBM6, indicating the differences between the two different times of preparation and, probably, in the source of original soybeans.

In the animal growth experiment (Table 5), body weight gain (BWG) and gain:feed ratio (GF) at 6 to 20 days of age were not well correlated with processing. At 27 days of age, chickens fed SBM1 showed significantly greater BWG than chicks fed SBM3, SBM5, or SBM6, but no statistical significance was obtained in GF among these groups. The chicks fed SBM3 showed the poorest BWG and poor GF throughout the experimental period, yet SBM3 was not subjected to as much heat treatment as SBM4 and SBM5.

There was not much difference in dry matter and CP contents among the four meals selected for amino acid analysis (Table 3). The SBM5 contained smaller amounts of amino acids than did the other meals even though CP values of these four meals did not differ. Meal SBM5 showed smaller values of each amino acid so that the total content of amino acids determined in the present study was about 2.5% less than those of the other meals on a dry matter basis. Amino acid content was not reduced in SBM6, which was cooked more than SBM5.

The results of AAAA determined with chicks are shown in Table 6. Methionine was highly digestible, about 95%, because supplemental DL-methionine supplied 58% of the total methionine in the diet. Cysteine, arginine, valine, and glycine availabilities from SBM1 were significantly greater than those from SBM5 but not from SBM6. A similar trend was observed for the mean value of the total amino acids, but the differences were not statistically significant. Lysine availability from SBM1 was significantly greater than from the other three meals, but by only 2%. The mean value of all AAAA of the four meals was 88%.

The TAAA determined with adult cockerels did not differ among the meals (Table 7). Meal SBM5 showed numerically lower values in amino acid content, AAAA, and TAAA. Overall mean value of TAAA was 91.5%, which is in agreement with the data of Parsons *et al.* (1981), Sibbald (1986), and Green (1987).

General

The SBM custom-prepared for the study showed relatively low UA. A UA of .05 was measured for SBM1, which was prepared as the control under the usual processing conditions of the DT unit. Urease itself is not detrimental to poultry. It is used as an index for estimating the extent of processing because of its unusually high concentration in soybeans and the ease with which it can be detected (Caskey and Knapp, 1944). Adequate heat treatment improves the biological value of the soybean proteins by denaturing storage proteins and by destroying protease inhibitors. The urease enzyme is simultaneously inactivated. The urease assay was developed to detect inadequately heated, namely, undertoasted meals. The feed industry has long used UA to predict overcooked meals (AFMA, 1979). The correlation of UA values and animal performance is controversial (Balloun *et al.*, 1953; De Schrijver, 1977; McNaughton *et al.*, 1981). Although criticisms have been raised concerning the reliability of UA assay, it has remained the most popular test and the principal indicator for assessing the extent of undercooking (undertoasting) in research work or in samples collected from industrial production.

Seven *in vitro* assays have been developed to assess the adequate processing of SBM: UA, TI, protein dispersibility index (AOCS, 1980), nitrogen solubility index (AOCS, 1980), dye binding test (Moran *et al.*, 1963), Hunterlab color index (McNaughton *et al.*, 1981), and PSK. The present study employed UA, TI, and PSK, and added PSB, which was recently developed in the authors' laboratory. The objective underlying the development of PSB was to identify and eliminate sources of variability (Morr *et al.*, 1985). To do this, the conditions such as pH of solvent, temperature, ratio of SBM to solvent, duration of time, particle size, and intensity of stirring were defined. A buffer solution, .1 *M* sodium tetraborate, pH 9.2, was used to overcome the buffering effect of

TABLE 5. Performance ($\bar{x}$ ± SE) of chicks from 6 to 27 days of age

Soybean meal	Variable	Performance 6 to 13 days	6 to 20 days	6 to 27 days
1	Weight gain, g	92 ± 3	283 ± 8	520 ± 9[a]
	Gain:feed, g:g	.477 ± .016	.471 ± .018	.471 ± .005
2	Weight gain, g	90 ± 5	276 ± 4	494 ± 11[ab]
	Gain:feed, g:g	.461 ± .026	.465 ± .021	.462 ± .020
3	Weight gain, g	79 ± 6	256 ± 13	468 ± 13[b]
	Gain:feed, g:g	.412 ± .015	.433 ± .021	.431 ± .008
4	Weight gain, g	88 ± 4	261 ± 6	485 ± 12[ab]
	Gain:feed, g:g	.448 ± .018	.455 ± .019	.464 ± .013
5	Weight gain, g	83 ± 4	259 ± 8	480 ± 3[b]
	Gain:feed, g:g	.448 ± .013	.449 ± .023	.447 ± .011
6	Weight gain, g	89 ± 2	264 ± 9	471 ± 12[b]
	Gain:feed, g:g	.454 ± .015	.462 ± .019	.460 ± .010

[a,b]Within a column and variable, means with no common superscripts are significantly different (P<.05).

soybean proteins and atmospheric carbon dioxide throughout the extraction step.

A progressive decrease in Glc (Table 4) would be predicted if the soluble sugars, sucrose, raffinose and stachyose, were participants in reactions that produce the brown color change of meals during heat processing, e.g., the Maillard reaction (Mauron, 1981) or carmelization (Shallenbeger and Birch, 1975). Soluble sugars account for 10% of dry weight in mature soybean seeds (Hymowitz *et al.*, 1972). Sucrose, raffinose, and stachyose constitute more than 99% of the soluble sugars in the seed (Kawamura, 1967) and are present in a ratio of approximately of 8:1:4 (Hymowitz *et al.*, 1972). The glucose residue of these oligosaccharides is calculated to be 3 to 5% in defatted SBM. The Maillard reaction requires reducing sugars and free amino groups, mainly ε-amino group of lysine in proteins. Only reducing sugars can take part in Maillard reaction, as they provide the necessary carbonyl groups (Spark,

TABLE 6. Apparent amino acid availability (%)[1]

Amino acids	Soybean meal 1	2	5	6
Methionine	94.74 ± .27	94.15 ± .50	94.44 ± .24	94.81 ± .46
Cysteine	78.70 ± .69[a]	73.46 ± .22[bc]	70.62 ± 2.01[c]	76.71 ± 1.79[ab]
Lysine	92.59 ± .25[a]	90.90 ± .34[b]	90.16 ± .64[b]	90.96 ± .58[b]
Threonine	83.54 ± .92	83.38 ± 2.30	84.87 ± 1.25	84.59 ± 1.82
Arginine	94.00 ± .17[a]	93.04 ± .44[ab]	92.49 ± .44[b]	94.08 ± .29[a]
Valine	89.57 ± .19[a]	87.60 ± .57[ab]	86.43 ± .95[b]	89.43 ± .75[a]
Proline	88.21 ± .37	87.21 ± .61	86.08 ± .97	87.94 ± .97
Leucine	90.14 ± .16	89.56 ± .69	89.58 ± .60	90.90 ± .75
Isoleucine	89.59 ± .04	89.46 ± .71	89.32 ± .65	90.43 ± .92
Aspartic acid	88.60 ± .40	87.17 ± .78	86.45 ± .77	87.45 ± 1.06
Glutamic acid	91.94 ± .22	90.62 ± .37	89.07 ± 1.07	91.28 ± .94
Alanine	87.04 ± .41	83.98 ± 1.03	81.30 ± 2.56	86.50 ± 1.33
Glycine	82.89 ± .55[a]	80.53 ± .70[ab]	78.49 ± 1.52[b]	82.28 ± 1.17[a]
Serine	87.05 ± .75	87.19 ± 1.97	88.95 ± 1.18	88.00 ± 1.65
$\bar{x}$	88.47 ± .31	87.02 ± .59	86.30 ± .78	88.24 ± .86

[a–c]Means within a row with no common superscripts are significantly different (P<.05).

[1]Values are expressed as $\bar{x}$ ± SE.

TABLE 7. True amino acid availability (%)[1]

Amino acids	Soybean meal 1	2	5	6
Methionine	93.36 ± 1.32	92.98 ± .76	92.77 ± .81	93.69 ± 1.58
Cysteine	86.51 ± 4.19	91.28 ± 1.60	83.90 ± 1.33	87.98 ± .81
Lysine	92.04 ± .97	90.64 ± 1.44	88.54 ± .86	90.90 ± .54
Threonine	89.93 ± 2.81	90.85 ± 2.10	87.06 ± .40	89.28 ± .94
Arginine	86.82 ± 2.24	88.79 ± .98	88.83 ± 1.89	90.92 ± 2.31
Valine	91.27 ± 1.31	91.27 ± 1.09	92.00 ± .82	93.84 ± .77
Leucine	93.08 ± 1.34	94.28 ± 1.43	94.43 ± .81	93.70 ± .50
Isoleucine	94.06 ± 1.99	93.46 ± 1.04	93.43 ± .53	95.11 ± .90
Aspartic acid	93.91 ± 1.20	93.79 ± 1.21	90.82 ± .09	92.30 ± .56
Glutamic acid	94.30 ± .98	94.23 ± .40	94.33 ± .43	95.70 ± .36
Alanine	89.93 ± 1.06[ab]	87.05 ± 1.05[b]	89.73 ± .36[ab]	91.63 ± 1.11[a]
Serine	92.32 ± 4.05	93.78 ± 2.28	88.61 ± 1.00	90.89 ± 1.30
$\bar{x}$	91.46 ± 1.76	91.88 ± .99	90.37 ± .39	92.16 ± .79

[a,b]Means within a row with no common superscripts are significantly different (P<.05).

[1]Values are expressed as $\bar{x}$ ± SE.

1969). Sucrose, as a nonreducing sugar, should not be involved in the Maillard reaction as such but after hydrolysis of β-1,4 linkage between fructose and glucose the resulting free glucose could react with lysine (Hurrell and Carpenter, 1977). Raffinose and stachyose like sucrose can provide free glucose. However, the result in Table 4 showed no progressive loss of soluble sugars with progressive heat treatment (prolonged retention time).

Animal growth depression was observed with SBM5 and SBM6, which were overcooked to .00 ΔpH of UA, 2.32 mg/g SBM of TI, 81% of PSK, and 23% of PSB or less (Table 4). However, SBM3 also resulted in poor growth (Table 5), although UA was .01, TI was 4.62, and PSK was 8%. It is unknown why chicks performed poorly with SBM3, which was judged to be slightly overcooked based upon processing conditions and the results of *in vitro* assays. A preliminary chick experiment with 23% dietary protein showed a similar result for the group fed SBM3 (data not shown). Dale *et al.* (1986) has shown that meals with .00 of UA do not necessarily have impaired nutritive value. Cravens and Siops (1958) and Veltmann *et al.* (1986) also compared *in vitro* and *in vivo* measures of soybean meal quality. In general, amino acid content (Table 4) and amino acid availability differed little or not at all among the four meals compared in the current study. Also, amino acid availability revealed no particular amino acids such as lysine, which were progressively reduced by heat treatment (Tables 6 and 7). Soybean meal supplemented with methionine as the sole source of dietary protein at the 15% level provided 74, 82, and 87% of National Research Council (1984) requirement for threonine, lysine, and leucine, respectively (Tables 3 and 5).

Along with no differences in lysine availability, the observation of no change in the Glc or soluble oligosaccharide content suggests that no progressive Maillard reaction occurred with the increasing heat treatment used in this study. Bjarnason and Carpenter (1969) indicated that isopeptide bond formation between the ε-amino group of lysine and aspartic acids or glutamic acids, more likely, the amide groups of asparagine or glutamine (Bjarnason and Carpenter, 1970), are the most likely reaction responsible for poor digestibility of heat-damaged proteins in the absence of reducing sugars or oxidizing fat. Hurrell *et al.* (1976) suggested that crosslinkages such as isopeptides reduced the rate of protein digestion, possibly by preventing enzyme penetration, or by masking the sites of enzyme attack. Overall TAAA was not progressively reduced with cooking of the four meals.

In summary, the attempt to produce overcooked SBM by increasing temperature and RT of a DT unit was made at a commercial processing plant. The commer-

cially processed SBM for the present study were not overcooked enough to affect the amino acid utilization. The results suggest that temperature or RT of a DT unit may be increased by 50% without reducing amino acid availability of SBM.

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REFERENCES

American Feed Manufacturers Association, 1979. Dehulled soybean meal. Page 91 *in*: AFMA Feed Ingredient Guide. Currently, American Feed Industry Association, Arlington, VA.

American Oil Chemists Society, 1980. Official and Tentative Methods of the American Oil Chemists Society 3rd ed. American Oil Chemists Society, Champaign, IL.

Association of Official Analytical Chemists, 1984. Official Methods of Analysis. 14th ed. Association of Official Analytical Chemists, Washington, DC.

Balloun, S. L., E. Johnston, and L. K. Arnold, 1953. Laboratory estimation of the nutritive value of soybean meals. Poultry Sci. 32:517–527.

Bjarnason, J., and K. J. Carpenter, 1969. Mechanisms of heat damage in proteins. 1. Model with acylated lysine units. Br. J. Nutr. 23:859–868.

Bjarnason, J., and J. J. Carpenter, 1970. Mechanism of heat damages in proteins. 1. Chemical changes in pure proteins. Br. J. Nutr. 24:313–329.

Caskey, C. D., Jr., and F. C. Knapp, 1944. Method for detecting inadequately heated soybean-oil meal. ind. Eng. Chem. Anal. Ed. 16:640–641.

Cravens, W. W., and E. Slops, 1958. Soybean oil meal. Pages 369–382 *in*: Processed Plant Protein Foodstuffs. A. A. Altschul, ed. Academic Press, Inc., New York, NY.

Czarnocki, J., I. R. Sibbald, and E. V. Evans, 1961. The determination of chromic oxide in samples of feed and excreta by acid digestion and spectrophotometry. Can. J. Anim. Sci. 41:167–179.

Dale, N. M., M. Araba, and E. Whittle, 1987. Protein solubility as an indicator of optimum processing of soybean meal. Pages 88–95 *in*: Proceedings Georgia Nutrition Conference, Athens, GA.

Dale, N., O. W. Charles, and S. Duke, 1986. Rellability of urease activity as an indicator of overprocessing of soybean meal. Poultry Sci. 65(Suppl. 1): 164.(Abstr.)

De Schrijver, R., 1977. An evaluation of the urease activity test for determining the quality of soybean oil meal. Vlaams Diergeneeskd. Tijdschr. 46:333–339.

Elkin, R. G., and J. E. Griffith, 1985. Hydrolysate preparation for analysis of amino acids in sorghum grains: Effect of oxidative pretreatment. J. Assoc. Off. Anal. Chem. 68:1117–1121.

Perket, P. R., and F. T. Jones, 1989. Soybean meal quality trends 1980 to 1988. Pages 11–15 *in*: North Carolina Poultry Feed Ingredients Annual Quality Report 1988. Department of Poultry Science, North Carolina State University, Raleigh, NC.

Garlich, J. D., 1987. Urease-trypsin inhibitor relationship of commercially produced soybean meals. Poultry Sci. 66(Suppl. 1):103.(Abstr.)

Green, S., 1987. Digestibilities of amino acids in foodstuffs for poultry and pigs. Digestibility report 8/87. A.E.C.-Rhône Poulenc, Nutrition Laboratories, 03600 Commentry, France.

Green, S., S. Bertrand, M. Duron, and R. Maillard, 1987. Digestibilities of amino acids in maize, wheat and barley meals, determined with intact and caecectomised cockerels. Br. Poult. Sci. 28: 631–641.

Hamerstrand, G. E., L. T. Black, and J. D. Glover, 1981. Trypsin inhibitors in soy products: Modification of the standard analytical procedure. Cereal Chem. 58(1):42–45.

Hill, F. W., D. L. Anderson, R. Renner, and L. B. Carew, Jr., 1960. Studies of the metabolizable energy of grain and grain products for chickens. Poultry Sci. 39:573–579.

Hurrell, R. F., and J. J. Carpenter, 1977. Mechanisms of heat damage in proteins. 8. The role of sucrose in the susceptibility of protein foods to heat damage. Br. J. Nutr. 38:285–297.

Hurrell, R. R., K. J. Carpenter, W. J. Sinclair, M. S. Otterburn, and R. S. Asquith, 1976. Mechanisms of heat damage in proteins. 7. The significance of lysine-containing isopeptides and lanthionine in heated proteins. Br. J. Nutr. 35:383–395.

Hymowitz, T., W. M. Walker, F. I. Collins, and J. Panczner, 1972. Stability of sugar content in soybean strains. Commun. Soil Sci. Plant Anal. 3:367–373.

Kawamura, S., 1967. Quantitative paper chromatography of sugars of the cotyledon, hull and hypocotyl of soybeans of selected varieties. Tech. Bull. Fac. Agric. Kagawa Univ. 15:117–131.

Lee, H., and J. D. Garlich, 1989. Protein solubility of soybean meal. Poultry Sci. 68(Suppl. 1): 83.(Abstr.)

Mauron, J., 1981. The Maillard reaction in food: A critical review from the nutritional standpoint. Prog. Food Nutr. Sci. 5:5–35.

McNaughton, J. L., F. N. Reece, and J. W. Deaton, 1981. Relationship between color, trypsin inhibitor contents, and urease index of soybean meal and effects on broiler performance. Poultry Sci. 60:393–400.

Moran, E. L., Jr., L. S. Jensen, and J. McGinnis, 1963. Dye binding by soybean and fish meal as an index of quality. J. Nutr. 79:239–244.

Morr, C. V., B. German, J. E. Kinsella, J. M.

Regenstein, J. P. Van Buren, A. Kilara, B. A. Lewis, and M. E. Mangino, 1985. Collaborative study to develop a standardized food protein solubility procedure. J. Food Sci. 50:1715–1718.

National Research Council, 1978. Gulde for the Care and Use of Laboratory Animals. Institute of Laboratory Resources. National Academy Press, Washington, DC.

National Research Council, 1984. Nutrient Requirements of Poultry. 8th rev. ed. National Academy Press, Washington, DC.

Parsons, M. C., L. M. Potter, and R. D. Brown, Jr., 1981. True metabolizable energy and amino acid digestibility of dehulled soybean meal. Poultry Sci. 60:2687–2696.

Saravitz, D. M., 1986. Oligosaccharides in soybean seeds. M. S. thesis, Department of Horticultural Science, North Carolina State University, Raleigh, NC.

SAS Institute, 1982. SAS® User's Guide: Statistics. 1982 Edition. SAS Institute Inc., Cary, NC.

Shallenbeger, R. S., and G. G. Birch, 1975. Pages 169–178 *in*: Sugar Chemistry. AVI Publishing Company, Inc., Westport, CT.

Sibbald, I. R., 1979. A bioassay for available amino acids and the metabolizable energy in feedingstuffs. Poultry Sci. 58:668–673.

Sibbald, I. R., 1986. The T.M.E. system of feed evaluation: Methodology, feed composition data and bibliography. Technical Bulletin 1986-4E. Animal Research Center, Research Branch, Agriculture Canada, Ottawa, ON, Canada.

Spark, A. A., 1969. Role of amino acids in nonenzymic browning. J. Sci. Food Agric. 20: 308–316.

Sternberg, M., C. Y. Kim, and F. J. Schwende, 1975. Lysinoalanine: presence in foods and food ingredients. Science 190:992–994.

Veltmann, J. R., Jr., B. C. Hansen, T. D. Tanksley, Jr., D. Knabe, and S. S. Linton, 1986. Comparison of the nutritive value of different heat-treated commercial soybean meals: Utilization by chicks in practical type rations. Poultry Sci. 65: 1561–1570.