Soybean Checkoff-funded Research

Project Title: Nutritional value of U.S. dehulled soybean meal and Non-dehulled Soybean Meals from Brazil and India in pigs

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Introduction

Soybean meal (SBM) is one of the most important protein sources for poultry and swine diets in most of the world. Corn-soy based commercial compound diets may contain SBM as much as 35% for broilers (NRC, 1994) and 23-24% for swine (NRC, 1998).

Korean feed industry annually consumes about two million MT of SBM to produce 15 million MT of compound feed. About 45% of the demand is being supplied from local crushers using soybeans mainly from the U.S. The remaining portion of the demand is supplied by imported SBMs. The origins of the imported SBMs are India, South America, U.S. and China. SBM from the U.S. is in dehulled form while the other imported SBMs are non-dehulled.

Quality of SBM varies depending upon the origin of soybeans and processing technology. Soybeans harvested from regions close to equator generally contain more crude protein contents than other region. Quality evaluation of SBM may be discussed from two viewpoints. One would be the quantity of nutrient and the other would be the digestibility or bioavailability of nutrient. Quantity of nutrient can be measured by chemical analysis for each nutrient such as crude protein, crude fat, crude fiber, amino acids and minerals. It will be desirable if given SBM provides more nutrient than other SBMs do. However, the SBM will be devaluated if animal cannot fully utilize the nutrient from the SBM because of poor digestibility. Therefore, digestibility or bioavailability of nutrient should be more taken into account than quantity of each nutrient in evaluating quality of SBM.

Raw soybeans contain anti-nutritional compounds such as trypsin inhibitors, lectins, lipoxigenase and others. These anti-nutritional factors reduce digestibility or bioavailability of nutrient in SBM. Fortunately, most of the anti-nutritional compounds in soybeans are destroyed by heat treatment. Proper heat treatment of soybean or SBM destroys these anti-nutritional compounds and improves digestibility of all amino acids. If heat treatment is insufficient, anti-nutritional compounds are still active and this reduces amino acids digestibility. Overheating results in destruction of amino acids and the formation of biologically unavailable amino acid-carbohydrate complexes and thus reduces amino acids digestibility, especially Lys and Cys. Many researches have demonstrated that proper heat treatment of SBM improves performance in growing pigs (Robinson, 1930; Jimenez et al., 1963; Combs et al., 1967; Young, 1972; Crebshaw and Danielson, 1985) and broilers (Parsons et al., 1991: Batal et al., 2002).

Relatively simple and reliable methods evaluating the heat treatment of SBM have been developed and NOPA (National Oilseeds Processors Association) uses it as a part of the SBM quality specifications for fair trade of SBM. Urease activity index as measured by the increase in pH of the mixture of SBM and urea in water (A.O.C.S., 1980), that is indirect measurement of the presence of the trypsin inhibitor, to estimate the under heat processing and the protein solubility in a solution of 0.2% to estimate over heat processing (Araba and Dale, 1990) is generally accepted (Kohlmeier, 1993; Swick, 1998, Ward, 1996).

While urease activity index is useful for detecting undercooking of SBM, but is of limited use for detecting overcooking (Araba and Dale, 1990; Parsons et al., 1991). Moreover, the recommended maximum level of urease activity index is controversial, with acceptable values varying from 0.2 or less (McNaughton and Reece, 1981) to 0.5 units of pH change (Waldroup et al., 1985). The fact that the urease activity index is not linear and that it rapidly falls from approximately 2.0 units of pH change to near zero as SBM is heated contributes to the difficulty in determining a precise maximum acceptable level of urease.

Araba and Dale (1990) reported that KOH protein solubility was useful for detecting both over- and under-processing of SBM. However Anderson-Haferman et al. (1992) later concluded that KOH protein solubility was not very accurate for assessing under processing of SBM. The slope of KOH protein solubility for SBMs under-heated is not sharp enough to distinguish quality of the SBMs.

Another method that is often used in ruminant and human nutrition to monitor optimum heat processing of soy products is Protein Dispersibility Index (PDI; AOCS, 1980). The PDI measures protein solubility in water with high speed blending. Batal et al. (2000) suggested that PDI is a more consistent and sensitive indicator of minimum adequate heat processing of SBM than urease activity index or KOH protein solubility.

Although *in vitro* determination of SBM quality is being widely applied to practical situation, more direct quality determination can be obtained from metabolic study to measure bioavailability of nutrient in SBM and energy utilization of SBM.

This study is designed to measure bioavailability of differently heat-processed soy flakes, in terms of nitrogen balance and energy utilization, and to compare the bioavailability measurements with that of commercially available imported SBMs in Korea. The purpose of this study also includes evaluating economic feasibility of the U.S. dehulled SBM in growing pig diets as compared to other imported SBMs.

Materials and Methods

1. Sample preparation and analysis

Dehulled, solvent extracted soy flakes (SF; prior to desolventizer-toaster) were obtained from a local crushing company. The SF was steamed for various time periods at different temperatures to produce five differently heat-treated SF. The steaming conditions for each sample of SF were no heat-treatment (SF-1), 5 minutes at 95 °C (SF-2), 5 minutes at 110 °C (SF-3), 15 minutes at 110 °C (SF-4) and 60 minutes at 110 °C (SF-5) at 1.5 kg/cm^2. Initial moisture content of the SF was about 8% before the steaming and 13% after the steaming. The SFs heat-treated for various time periods were then air-dried for three days. After air-dry, the SF were applied to the experimental diets. The SFs were steamed and air-dried at a local plant in Kongju city. Experimental diets were mixed at a local feed mill located in Incheon city based on the formula described later.

SBMs from the U.S., Brazil and India were also provided from local feed mills. U.S. SBM was in dehulled type, while the other SBMs were in non-dehulled type. The SBMs were used in the experimental diets.

The SFs and SBMs were analyzed for urease activity index (pH increase), protein solubility in 0.2% KOH solution, protein digestibility in 0.02% pepsin solution and protein dispersibility index (PDI). Urease activity index and PDI were determined by the methods described in American Oil Chemists Society (1980). The KOH protein solubility was measured by the method of Araba and Dale (1990). Pepsin digestibility was determined by the method of AOAC (1980).

2. Nitrogen balance and energy utilization

The experiment was carried out at a research farm located in Chun-An City, Chung Nam Province, Korea.

A total of 32 castrated piglets (Y×L×D) weighing about 14 kg were assigned to 8 treatments with 4 replicates (Table 1). The piglets were housed in individual stainless wire cage and fed the experimental diets.

Eight experimental diets were least-cost formulated to contain 21.7% crude protein using the five SF and three commercial SBMs. Vitamins and minerals were included to meet or exceed the nutrient requirements suggested by NRC (1998). The compositions of the experimental diets are shown in Table 2.

Each period consisted of a 3-day adjustment to diet, followed by 4 day of total feces and urine collection. Chromic oxide (0.25%) was included in the diets as a visible marker to determine the onset and ending of fecal collection. Feces and urine were daily collected at 18:00 during the experiment.

Piglets were limit-fed at 06:00 and 18:00. Daily feed intake was about 5% of the piglet's body weight, 700 g/d. The daily amount of feed was constant for all piglets during the adjustment phase and during the fecal collection phase. Immediately before feeding, water was added to each diet and mixed to enhance consumption.

Nitrogen balance and DE and ME values over the total digestive tract were calculated from values based on the total collection of feces and urine.

Data were analyzed by ANOVA as a completely randomized block design. All statistical analyses were computed using the ANOVA procedure of SAS (1998). Differences among the means of treatment were tested by Duncan's New Multiple Range Test (Duncan, 1955). The standard errors of means were calculated from the treatments with replicates.

3. Growth performance

The experiment was also carried out at a research farm located in Chun-An City, Chung Nam Province, Korea. A total of 192 castrated piglets (Y×L×D) weighing about 12 kg were assigned to 8 treatments with 6 replicates (Table 3). Eight experimental diets were least-cost formulated to contain 19.1% crude protein using the five SF and three commercial SBMs described above. Vitamins and minerals were included to meet or exceed the nutrient requirements suggested by NRC (1998). The compositions of the experimental diets are shown in Table 4. Piglets were allowed for free access to the experiment diets and water for 42 days. Body weight and feed intake were measured at day 0, 14, 28 and 42. Average daily gain and feed efficiency were calculated. All general management of growers was followed to management rules of the laboratory.

The data were analyzed by ANOVA as a completely randomized block design. All statistical analyses were computed using the ANOVA procedure of SAS (1998).
Differences among the means of treatment were tested by Duncan's New Multiple Range Test (Duncan, 1955). The standard errors of means were calculated from the treatments

with replicates.

4. Economic feasibility of U.S. dehulled soybean meal in grower diet

Economic analyses were conducted to determine feasibility of using U.S. dehulled SBM in grower diets. Using the data obtained from the growth performance study, feed cost per pig production and feed cost per weight gain of the pigs were calculated. Based on the equal feed cost per weight gain, relative values of SF and SBMs were estimated.

Results and Discussion

1. *In vitro* quality analyses of SF and SBM

The chemical composition and amino acid profile of the soy flake and three commercial soybean meals are provided in Table 5. Crude protein content of U.S. dehulled soybean meal was the highest (47.25%) among the imported SBMs. This measurement was slightly lower than the NOPA specification for dehulled SBM (47.5 – 49.0%). Indian SBM contained 46.85% of crude protein although it is non-dehulled meal. This would be explained from the general idea that soybeans harvested in region close to the equator contain higher crude protein than other region. Crude protein level of the Brazilian SBM was the lowest with 44.63%.

Crude fiber content of U.S. dehulled SBM was about half (3.48%) of the other SBMs (6.24 and 6.67%). Because fiber dilutes nutrient density of SBM in non-ruminants, the less fiber contents are accepted as the more desirable.

Crude fat contents of U.S. dehulled SBM and Brazilian SBM were close to each other. Indian SBM contained less crude fat than the other SBMs meaning that it was more severely extracted.

Amino acids contents of U.S. dehulled SBM was more than Brazilian and Indian SBMs for all amino acids. There was not any difference between Brazilian and Indian SBMs.
SF contained much less moisture (7.66%) than the SBMs compared. Crude protein content (53.50%) was more than the SBMs. Crude fiber level (3.10%) was lower than the SBMs while amino acids content was higher than the SBMs.

Images of soy flakes heat-treated under different conditions are illustrated in Figure 2. The density of color of the soy flakes became darker as the extent of heat-treatment was conducted, from steaming for less time at a lower temperature to steaming for more time at a higher temperature. Colors of commercial soybean meals were also compared to those of soy flakes variously heat-treated.

Urease activity index (UA) dropped abruptly from 1.95 to 0.10 and then to 0.02 as the raw soy flake was steamed for 5 min at 95 °C and 5 min at 110 °C, respectively (Table 2 and Figure 1). Further heat-treatment did not result in any noticeable changes in UA values. This suggests that UA may be used only for measuring insufficient heat-treatment of the soybean meal. The UA values of all heat-treated soy flakes and commercial soybean meals were within an appropriate range with the exception of the raw soy flake (SF-1).

The KOH protein solubility values of soy flakes decreased as soy flakes were heated (Table 6 and Figure 1). The KOH protein solubility value of soy flakes heat-treated at 110 °C for 60 min (SF-5) was exceptionally low (41.70%) implying that SF-5 is extremely over-heated. U.S. dehulled SBM showed higher (80.60%) KOH protein solubility than Brazilian and Indian SBMs (74.83 and 74.31%). All the commercial SBMs were within the normal KOH protein solubility. The slope of correlation curve of KOH protein solubility over the extent of heat-treatment was steeper in the range between SF-4 (110 °C for 15 min) and SF-5 (110 °C for 60 min) than the other range between SF-1 (raw soy flakes) and SF-4 suggesting that KOH protein solubility is more sensitive to over-heating (Figure 1).

Pepsin digestibility (PD) measurements of heat-treated soy flakes and commercial soybean meals were not sensitive enough to indicate the extent of heat-treatment although the values decreased as heat-treatment was conducted (Table 6 and Figure 1). This result suggests that PD is not a proper index to represent soybean meal quality during heat-treatment. This result is in contrast with the report that PD exhibited a very high correlation with true available amino acids (Hung and Kermorgant, 1992). One possible explanation of this poor sensitivity in this study may be the concentration of pepsin solution. The concentration of pepsin in this study was 0.02% as recommended by the American Official Analytical Chemistry (AOAC).

The PDI values of the soy flakes also decreased as heat-treatment was applied (Table 6 and Figure 1). The highest value was approximately eight times that of the lowest value in PDI measurement while the highest KOH protein solubility was only 2.3 times of the lowest value. This suggests that PDI is a more sensitive soybean meal quality index than KOH protein solubility and other indices tested. However, as discussed above, within an excessive heat-treatment range, KOH protein solubility had more sensitivity than did PDI. The PDI values of commercial soybean meals ranged from 17.50 to 22.20% with the value of U.S. dehulled SBM being the highest.

2. Nitrogen balance and energy utilization

The summary of the nitrogen balance data of pigs fed with the heat-treated soy flakes and commercial soybean meals is listed in Table 7. As feed intake (FI) was restricted to 700 g per day, dietary nitrogen intake among treatments was equal (23.10 to 24.05 g/d). However, fecal nitrogen excretion was lowest in the SF-4 group followed by the SF-3, SF-2, SF-5, and

SF-1 groups. Therefore, nitrogen digestibility of the SF-4 group, as expressed in total dietary nitrogen intake percentage, was highest followed by SF-3, SF-5, SF-2, and SF-1 groups. Urinary nitrogen excretion was not significantly different among treatments (Table 7). Nitrogen retention, as expressed in total dietary nitrogen intake percentage, was highest in the SF-4 group followed by the SF-3, SF-5, SF-2, and SF-1 groups similar to the trend observed in nitrogen digestibility. Nitrogen digestibility and nitrogen retention of the commercial SBMs were the highest in U.S. dehulled meal group (89.99% digestibility and 72.29% nitrogen retention) followed by Brazilian and Indian SBMs.

Energy utilization is summarized in table 8. Energy digestibility of experimental diets was significantly high in SF-4 group (88.07%) followed by SF-3, SF-5, SF-1 and SF-2. Among commercial SBMs, the energy digestibility of U.S. dehulled SBM (88.58%) was significantly higher than Brazilian and Indian SBMs. The energy digestibility of Brazilian SBM (85.17%) was higher than that of Indian SBM (82.39%). Energy retention was also significantly higher in SF-4 group (87.70%) followed by SF-3, SF-5, SF-1 and SF-2. The energy retention of U.S. dehulled SBM (88.18%) was also significantly higher than that of Brazilian (84.80%) and Indian SBMs (81.98%).

The data for nitrogen balance and energy utilization suggests that SF-4 is more properly heat-treated than the other SFs. The data also suggests that U.S. dehulled SBM is more bioavailable than Brazilian and Indian SBMs in terms of protein digestibility, protein retention and energy utilization.

3. Growth performance

Body weight and average daily gain of the pigs fed experimental diets containing heat-treated soy flakes and commercial soybean meals are listed in Tables 9 and 10. Body weight and average daily gain were significantly higher in the SF-4 group (110 °C for 15 min) and the SF-3 group (110 °C for 5 min) compared to other heat-treated soy flakes. The more or the less heat-treatment conducted than the SF-3 and the SF-4, the less the pigs gained weight. The SF-1 (raw soy flake) group gained much less weight than the other heat-treated soy flakes suggesting that anti-nutritional factors in raw soy flakes were still active and these active anti-nutritional factors reduced digestibility of not only soy flakes but also other ingredients. Among commercial SBM-fed pigs, the U.S. dehulled SBM fed group gained more body weight than did the pigs fed non-dehulled SBMs (Brazil and India). These results were expected as KOH protein solubility and PDI values of U.S. dehulled SBM were higher than those of Brazilian and Indian SBMs. In addition, U.S. dehulled SBM contained more crude protein and less fiber than Brazilian and Indian SBMs. As experimental diets were isocaloric and isonitrogenous, more attention should be placed on the excellent bioavailability of U.S. dehulled SBM as expressed in KOH protein solubility and PDI values in explaining the faster growth of the U.S. dehulled SBM fed pigs. Average daily gain of

pigs fed Brazilian and Indian SBMs was not significantly different.
Average daily feed intake (ADFI) and feed efficiency (FE) of pigs were not significantly different among dietary treatments with the exception of the SF-1 group (Tables 11 and 12). FE values of both SF-1 and SF-5 (110 °C for 60 min) fed pigs were lower than those of pigs fed with other heat-treated soy flakes. Between the SF-1 and SF-5 groups, the FE of SF-1 was worse than that of SF-5 implying that active anti-nutritional factors in raw soy flake (SF-1) decreased the availability of soy flakes and other ingredients in test diets. Although nutrients in SF-5 are destroyed by excessive heat-treatment, there are still other ingredients supplying substitute nutrients and the activity of anti-nutritional factors in soy flakes is completely destroyed. This suggests that raw soy flake is more hazardous for pigs than over-cooked soy flakes. Among commercial soybean meals, U.S. dehulled SBM had significantly better FE than did Brazilian and Indian SBMs.

In line with the data for nitrogen balance and energy utilization, this growth data suggests that SF-4 is the more appropriately heat-processed than the other SFs. The more or the less SFs heated, the growth performance was declining. The data also suggests that U.S. dehulled SBM is better heat-treated than Brazilian and Indian SBMs.

4. Economic feasibility of U.S. dehulled soybean meal in growers

Table 13 shows the result of economic evaluation of SFs heat-treated for various time periods based on weight gain and feed cost. Feed production cost of diet containing SF-1 was higher (346.7 Won/kg) than diets containing SF-2, SF-3, SF-4 and SF-5 (334 Won/kg).
Feed cost per pig was the lowest in SF-1 group (12,340.5 Won) followed by SF-2, SF-3, SF-5 and SF-4. At first glance, it looks like that diet containing SF-1 is the most economic diet. However feed cost per pig is not a meaningful figure because body weights of pigs among treatments are different. Instead, feed cost per weight gain is more representative figure for economic evaluation. Feed cost per weight gain was the lowest in SF-3 group (596.1 Won/kg) followed by SF-4, SF-2, SF-5 and SF-1.

When feed cost per weight gain is set equal at 907.4 Won/kg, the highest feed cost per weight gain in SF-1, relative values of feed and SFs can be estimated. Estimated feed value and relative SBM value were in the same order as feed cost per weight gain, SF-3, SF-4, SF-2, SF-5 and SF-1. Relative value of SF-3 was more than double that that of SF-1, meaning that proper heat treatment increases relative value of SF.

Table 14 shows the result of economic evaluation of SBM of different origins based on weight gain and feed cost. Although feed production cost (237.6 Won/kg) and feed cost per pig (11,065.5 Won) were the highest in U.S. dehulled SBM group, feed cost per weight gain (412.8 Won/kg) was the lowest in U.S. dehulled SBM group followed by Brazilian and Indian SBM groups. Estimated feed value at equal feed cost per weight gain at 445.7

Won/kg of the Indian SBM group was the highest in U.S. dehulled meal-containing diet (256.5 Won/kg). Relative value of U.S. dehulled SBM was 27% - 40% more than that of Brazilian and Indian SBMs.

Summary

In conclusion, U.S. dehulled SBM was validated as a high quality protein source in growing pig diets than Brazilian and Indian SBMs. This result proved that SBM quality varies according to the origin of SBM as well as its processing conditions. Also, it was well demonstrated that the U.S. dehulled SBM has an excellent nutrient profile and a higher energy values and contains more digestible nutrients compared to other country originated SBMs (Swick, 1995; Swick, 1998). In this experiment, it is proven that U.S. dehulled SBM has not only nutritional advantages but economical feasibility in growing pig diets. Therefore it is recommendable to include the U.S. dehulled SBM in growing pig diets to improve growth performance, resulting in reduced feed cost for swine production.

Table 1. Piglets assignment in experiment for nitrogen balance and energy utilization

Treatment	SF / SBM	Steaming condition		Replicates	Total number of piglets
		Temp.	Time		
1	SF-1	None	None	4	4
2	SF-2	95 °C	5 min	4	4
3	SF-3	110 °C	5 min	4	4
4	SF-4	110 °C	15 min	4	4
5	SF-5	110 °C	60 min	4	4
6	U.S.dehulled[1]			4	4
7	Brazil[2]			4	4
8	India[3]			4	4
				Total	32

[1] Dehulled soybean meal from U.S.

[2] Non-dehulled soybean meal from Brazil.

[3] Non-dehulled soybean meal from India.

Table 2. Composition of experimental diets for nitrogen balance and energy utilization

	SF-raw	SF-heated	U.S.	Brazil	India
Soy flake - raw	22.53	-	-	-	-
Soy flake - heated	-	23.81	-	-	-
U.S. soybean meal	-	-	25.94	-	-
Brazil soybean meal	-	-	-	26.97	-
Indian soybean meal	-	-	-	-	26.89
Alpha Pro[1]	20.00	20.00	20.00	20.00	20.00
Milk replacer	17.00	17.00	17.00	17.00	17.00
Corn	15.14	15.14	15.14	15.14	15.14
Starch	6.26	4.51	1.42	0.18	0.30
Full fat soybean	5.00	5.00	5.00	5.00	5.00
SPC	3.40	3.40	3.40	3.40	3.40
Tallow	2.90	3.40	4.40	4.63	4.59
DCP	2.19	2.15	2.08	2.05	2.05
Potato protein	1.90	1.90	1.90	1.90	1.90
Molasses	1.00	1.00	1.00	1.00	1.00
Limestone	0.72	0.73	0.76	0.77	0.77
Dried fat	0.40	0.40	0.40	0.40	0.40
Salt	0.22	0.22	0.22	0.22	0.22
Minerals[2]	0.20	0.20	0.20	0.20	0.20
Vitamins[3]	0.20	0.20	0.20	0.20	0.20
L-Lys-HCl	0.18	0.18	0.18	0.18	0.18
Antibiotics[4]	0.20	0.20	0.20	0.20	0.20
DL-Met	0.09	0.09	0.09	0.09	0.09
Choline	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00
Crude Protein, %	21.7	21.7	21.7	21.7	21.7
ME, kcal/kg	3370	3370	3370	3370	3370
Ca, %	0.86	0.86	0.86	0.86	0.86
P, %	0.53	0.53	0.53	0.53	0.53

[1]Extruded corn:SBM=50:50, Easy Bio Co., Ltd., Seoul, Korea

[2]provides followings per kg diet: $FeSO_4H_2O$ 120 mg, $CuSO_4H_2O$ 122 mg, Met-chelated Cu 14 mg, $ZnSO_4H_2O$ 68 mg, Met-chealated Zn 8 mg, $MnSO_4H_2O$ 40 mg, $CoSO_4H_2O$ 0.5 mg, $Ca(IO_3)_2H_2O$ 1.0 mg and Na_2SeO_3 0.3 mg.

[3]provides followings per kg diet: Vit. A 10,000 IU, Vit. D_3 2,000 IU, Vit. E 80 mg, Vit. K_3 2.0 mg, Vit. B_1 2.0 mg, Vit. B_2 6.0 mg, Vit. B_6 4.0 mg, Vit. B_{12} 40 mcg, Biotin 0.1 mg, Folic acid 1.0 mg, Ca Di Pentothenate 20 mg, Niacin 40 mg and Ethoxyquin 13.4 mg.

[4]provides 0.10% of Chlorotetracycline, 0.05% Cabadox and 0.05% Tiamulin

Table 3. Piglets assignment in the growth performance experiment

Treatment	SF / SBM	Number of Growers per pen	Replicates	Total number of growers
1	SF-1	4	6	24
2	SF-2	4	6	24
3	SF-3	4	6	24
4	SF-4	4	6	24
5	SF-5	4	6	24
6	U.S.dehulled[1]	4	6	24
7	Brazil[2]	4	6	24
8	India[3]	4	6	24
			Total	192

[1] Dehulled soybean meal from U.S.

[2] Non-dehulled soybean meal from Brazil.

[3] Non-dehulled soybean meal from India.

Table 4. Composition of experimental diets for growth performance

	SF-raw	SF-heated	U.S.	Brazil	India
Soy flake - raw	26.63	-	-	-	-
Soy flake - heated	-	28.15	-	-	-
U.S. soybean meal	-	-	30.67	-	-
Brazil soybean meal	-	-	-	31.89	-
Indian soybean meal	-	-	-	-	31.80
Corn	47.84	47.84	47.84	47.84	47.84
Starch	7.63	5.55	1.90	0.44	0.58
Tallow	4.35	4.95	6.13	6.40	6.35
Wheat	4.00	4.00	4.00	4.00	4.00
Molasses	2.00	2.00	2.00	2.00	2.00
DCP	1.73	1.68	1.61	1.57	1.57
Rice bran	1.50	1.50	1.50	1.50	1.50
Corn gluten feed	1.50	1.50	1.50	1.50	1.50
Wheat bran	1.00	1.00	1.00	1.00	1.00
Limestone	0.75	0.77	0.79	0.81	0.81
Salt	0.25	0.25	0.25	0.25	0.25
Minerals[1]	0.20	0.20	0.20	0.20	0.20
Vitamins[2]	0.20	0.20	0.20	0.20	0.20
L-Lys-HCl	0.15	0.15	0.15	0.15	0.15
Antibiotics[3]	0.15	0.15	0.15	0.15	0.15
DL-Met	0.06	0.06	0.06	0.06	0.06
Choline	0.05	0.05	0.05	0.05	0.05
Total	100.0	100.00	100.00	100.00	100.00
Crude Protein, %	19.1	19.1	19.1	19.1	19.1
ME, kcal/kg	3390	3390	3390	3390	3390
Ca, %	0.78	0.78	0.78	0.78	0.78
P, %	0.47	0.47	0.47	0.47	0.47

[1]provides followings per kg diet: $FeSO_4H_2O$ 120 mg, $CuSO_4H_2O$ 122 mg, Met-chelated Cu 14 mg, $ZnSO_4H_2O$ 68 mg, Met-chealated Zn 8 mg, $MnSO_4H_2O$ 40 mg, $CoSO_4H_2O$ 0.5 mg, $Ca(IO_3)_2H_2O$ 1.0 mg and Na_2SeO_3 0.3 mg.

[2]provides followings per kg diet: Vit. A 10,000 IU, Vit. D_3 2,000 IU, Vit. E 80 mg, Vit. K_3 2.0 mg, Vit. B_1 2.0 mg, Vit. B_2 6.0 mg, Vit. B_6 4.0 mg, Vit. B_{12} 40 mcg, Biotin 0.1 mg, Folic acid 1.0 mg, Ca Di-Pentothenate 20 mg, Niacin 40 mg and Ethoxyquin 13.4 mg.

[3]provides 0.10% of Chlorotetracycline and 0.05% Cabadox

Table 5. Proximate analyses of soy flake and soybean meals from various origins

	SF	U.S.	Brazil	India
Moisture, %	7.66	12.05	11.80	11.48
Crude protein, %	53.50	47.25	44.63	46.85
Crude fat, %	0.66	1.46	1.75	0.90
Crude fiber, %	3.10	3.48	6.67	6.24
Gross Energy, kcal/kg	4,180	4,374	4,220	4,228
Amino acids, %				
Arg	3.48	3.44	3.31	3.32
His	1.28	1.26	1.22	1.22
Ile	2.16	2.13	2.05	2.06
Leu	3.66	3.62	3.48	3.49
Lys	3.02	2.98	2.87	2.88
Met	0.67	0.66	0.64	0.64
Phe	2.39	2.36	2.27	2.28
Thr	1.85	1.83	1.76	1.76
Val	2.27	2.24	2.16	2.16
Cys	0.74	0.73	0.70	0.71
Tyr	1.82	1.80	1.73	1.73
Trp	0.65	0.64	0.62	0.62

Table 6. Quality indexes of soy flakes heat-treated for varios time periods and soybean meals from various origins

	SF-1	SF-2	SF-3	SF-4	SF-5	U.S.	Brazil	India
UA[1]	1.95	0.10	0.02	0.03	0.01	0.05	0.09	0.10
KOH[2], %	96.12	84.78	79.06	76.99	41.70	80.60	74.83	74.31
Pepsin[3], %	95.25	95.07	94.72	94.54	93.29	94.11	93.89	93.80
PDI[4], %	65.37	33.75	22.59	21.10	8.64	22.20	20.20	17.50

[1] Urease Activity Index, evaluated by method of AOAC (1980).

[2] Evaluated by method of Araba and Dale (1990).

[3] Pepsin digestibility, evaluated by method of AOAC (1990)

[4] Protein Dispersibility Index, evaluated by method of AOAC. (1980).

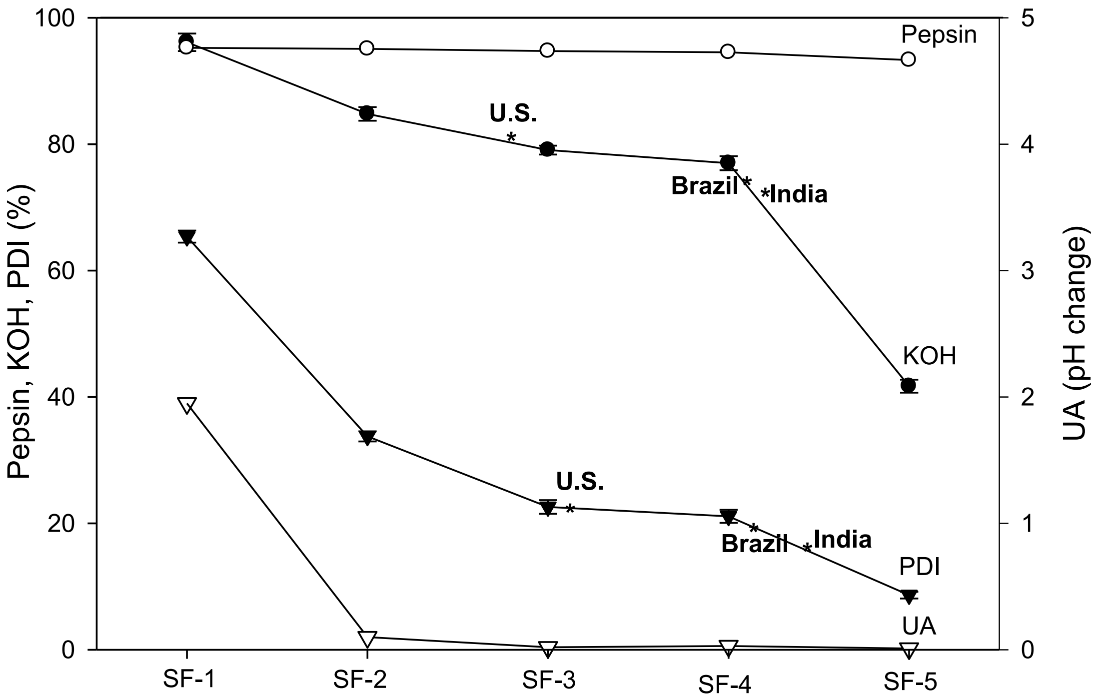

Figure 1. Protein quality measurements of heat-treated soy flakes. SF1: Raw soy flake; SF2: Steamed at 95 ºC for 5 min; SF3: Steamed at 110 ºC for 5 min; SF4: Steamed at 110 ºC for 15 min; SF5: Steamed at 110 ºC for 60 min. U.S.: U.S. dehulled soybean meal; Brazil: Brazilian soybean meal; India: Indian soybean meal.

Table 7. Nitrogen balance of piglets fed experimental diets

	N intake, g/d	Fecal N, g/d	N digestibility, %	Urinary N, g/d	N retention, %
SF-1	23.22±0.27	5.61±0.25^{a}	75.86±0.94^{e}	4.27±0.26	57.49±1.88^{d}
SF-2	23.10±0.78	3.52±0.04^{b}	84.70±0.49^{d}	4.05±0.26	67.21±0.34^{c}
SF-3	24.03±0.18	3.04±0.10^{c}	87.34±0.48^{b}	4.20±0.07	69.86±0.43^{abc}
SF-4	24.05±0.11	2.52±0.07^{d}	89.52±0.26^{a}	4.30±0.15	71.64±0.67^{a}
SF-5	23.97±0.25	3.54±0.07^{b}	85.22±0.19^{cd}	4.25±0.17	67.46±0.62^{c}
U.S.	24.01±0.12	2.41±0.15^{d}	89.99±0.67^{a}	4.25±0.14	72.29±1.01^{a}
Brz.	24.01±0.20	2.94±0.03^{c}	87.74±0.24^{b}	4.17±0.09	70.36±0.70^{ab}
Ind.	23.59±0.37	3.20±0.10^{bc}	86.41±0.61^{bc}	4.32±0.19	68.11±0.50^{bc}

Mean ± standard error

^{a,b,c,d,e} Different superscript in the same column means significantly different determined by ANOVA and Duncan's New Multiple range test ($p<0.05$)

Table 8. Energy utilization of piglets fed experimental diets

	Energy intake, kcal/d	Fecal energy, kcal/d	Energy Digestibility, %	Urinary energy, kcal/d	Energy Retention, %
SF-1	2252.0±25.9	374.4±19.6^{ab}	83.38±1.69^{cd}	9.56±0.35	82.94±1.71^{cd}
SF-2	2239.8±75.7	376.4±6.7^{ab}	83.12±1.43^{cd}	9.06±0.11	82.72±1.47^{cd}
SF-3	2330.4±16.9	328.3±8.7^{c}	85.90±0.83^{b}	8.25±0.34	85.55±0.84^{b}
SF-4	2331.8±10.9	278.0±6.9^{d}	88.07±0.53^{a}	8.81±0.59	87.70±0.57^{a}
SF-5	2324.7±23.6	371.9±12.8^{ab}	83.99±1.26^{cbd}	8.55± 0.13	83.62±1.26^{bcd}
U.S.	2328.5±11.6	265.6±12.7^{d}	88.58±1.19^{a}	9.31±0.17	88.18±1.19^{a}
Brz.	2328.3±19.9	344.5±21.9^{bc}	85.17±2.10^{bc}	8.81±0.41	84.80±2.12^{bc}
Ind.	2287.8±36.1	402.1±9.8^{a}	82.39±1.31^{d}	9.37±0.26	81.98±1.32^{d}

Mean ± standard error

^{a,b,c,d} Different superscript in the same column means significantly different determined by ANOVA and Duncan's New Multiple range test ($p<0.05$)

Table 9. Body weight (kg/pig) of piglets fed experimental diets

	Initial	2nd week	4th week	6th week
SF-1	12.13±0.35	14.79±0.78^{e}	19.82±1.18^{d}	25.72±1.71^{d}
SF-2	12.19±0.36	18.17±0.74^{bcd}	26.14±0.71^{c}	35.49±1.39^{c}
SF-3	12.15±0.34	18.48±0.72^{bc}	27.33±1.10^{bc}	36.65±1.51^{bc}
SF-4	12.21±0.35	18.88±0.71^{b}	28.34±1.04^{ab}	38.47±1.70^{ab}
SF-5	12.19±0.35	18.27±0.72^{bc}	26.13±1.32^{c}	35.31±2.14^{c}
U.S.	12.22±0.34	19.69±0.68^{a}	29.19±0.87^{a}	39.03±1.25^{a}
Brz.	12.20±0.33	17.79±0.79^{cd}	26.54±1.26^{c}	34.95±1.81^{c}
Ind.	12.05±0.41	17.38±0.74^{d}	25.83±1.08^{c}	35.13±1.50^{c}

Mean ± standard error

^{a,b,c,d,e} Different superscript in the same column means significantly different determined by ANOVA and Duncan's New Multiple range test ($p<0.05$)

Table 10. Average daily gain (ADG, g/d) of piglets fed experimental diets

	~ 2nd week	2nd ~ 4th Week	4th ~ 6th week	**Total**
SF-1	190.65±33.07^{e}	358.69±30.86^{c}	421.91±43.12^{c}	323.75±33.09^{d}
SF-2	426.79±30.57^{bcd}	569.46±14.01^{b}	668.17±50.12^{ab}	554.81±25.33^{c}
SF-3	451.96±30.60^{bc}	632.68±34.22^{ab}	665.39±45.33^{ab}	583.34±28.57^{bc}
SF-4	476.37±27.21^{b}	675.48±27.70^{a}	723.54±48.20^{a}	625.13±32.34^{ab}
SF-5	433.69±28.19^{bcd}	561.85±46.03^{b}	655.79±66.47^{ab}	550.44±43.09^{c}
U.S.	533.04±26.20^{a}	678.63±40.89^{a}	702.90±36.36^{a}	638.19±24.09^{a}
Brz.	399.05±33.88^{cd}	624.94±39.29^{ab}	601.13±52.73^{b}	541.71±36.47^{c}
Ind.	380.30±32.79^{d}	603.51±39.07^{ab}	664.61±30.43^{ab}	549.47±27.82^{c}

Mean ± standard error

^{a,b,c,d,e} Different superscript in the same column means significantly different determined by ANOVA and Duncan's New Multiple range test ($p<0.05$)

Table 11. Average daily feed intake (ADFI, g/d) of piglets fed experimental diets

	~ 2nd week	2nd ~ 4th Week	4th ~ 6th week	**Total**
SF-1	541.88±40.73^{b}	883.54±70.72^{c}	1117.46±130.38^{b}	847.63±78.26^{b}
SF-2	657.02±51.87^{a}	1068.27±58.08^{ab}	1391.67±136.60^{a}	1038.99±80.90^{a}
SF-3	713.48±56.39^{a}	1022.53±63.99^{bc}	1386.71±115.02^{a}	1040.91±67.78^{a}
SF-4	700.86±55.20^{a}	1187.98±70.30^{a}	1494.35±157.65^{a}	1127.73±91.80^{a}
SF-5	690.89±56.76^{a}	1037.44±59.80^{ab}	1459.78±186.97^{a}	1062.71±92.98^{a}
U.S.	719.38±69.50^{a}	1130.67±76.97^{ab}	1477.20±132.03^{a}	1109.08±90.36^{a}
Brz.	671.01±75.45^{a}	1157.26±85.67^{ab}	1413.99±149.53^{a}	1080.75±95.79^{a}
Ind.	715.77±68.90^{a}	1142.86±109.29^{ab}	1522.35±143.65^{a}	1126.99±102.23^{a}

Mean ± standard error

^{a,b} Different superscript in the same column means significantly different determined by ANOVA and Duncan's New Multiple range test ($p<0.05$)

Table 12. Feed efficiency (gain/feed) of piglets fed experimental diets

	~ 2nd week	2nd ~ 4th Week	4th ~ 6th week	**Total**
SF-1	0.34±0.04^{d}	0.41±0.01^{b}	0.38±0.02^{c}	0.38±0.01^{d}
SF-2	0.66±0.04^{b}	0.54±0.03^{a}	0.49±0.02^{ab}	0.54±0.02^{abc}
SF-3	0.64±0.02^{bc}	0.62±0.03^{a}	0.49±0.02^{ab}	0.56±0.02^{ab}
SF-4	0.69±0.03^{ab}	0.57±0.01^{a}	0.50±0.02^{a}	0.55±0.02^{ab}
SF-5	0.63±0.02^{bc}	0.54±0.02^{a}	0.46±0.01^{ab}	0.52±0.01^{bc}
U.S.	0.76±0.04^{a}	0.61±0.05^{a}	0.49±0.03^{ab}	0.59±0.04^{a}
Brz.	0.61±0.03^{bc}	0.55±0.03^{a}	0.43±0.03^{b}	0.51±0.02^{bc}
Ind.	0.54±0.05^{c}	0.54±0.03^{a}	0.45±0.03^{ab}	0.50±0.03^{c}

Mean ± standard error

^{a,b,c} Different superscript in the same column means significantly different determined by ANOVA and Duncan's New Multiple range test ($p<0.05$)

Table 13. Economic analyses of soy flakes heat-treated for various time periods in growing pig diets

Item	SF-1	SF-2	SF-3	SF-4	SF-5
Feed production cost, Won/kg	346.7	334.0	334.0	334.0	334.0
Feed intake, g/d	847.6	1,039.0	1,040.9	1,127.7	1,062.7
Feed cost per pig, Won	12,340.5	14,576.0	14,602.6	15,820.3	14,908.4
Weight gain, g/d	323.8	554.8	583.3	625.1	550.4
Feed cost per weight gain, Won/kg	907.4	625.5	596.1	602.6	644.9
Estimated feed value at equal feed cost per weight gain (907.4 Won/kg), Won/kg	346.7	484.5	508.5	503.0	470.0
Relative SF value at equal feed cost per weight gain (907.4 Won/kg)	100.0	207.0	224.0	220.1	196.6

Table 14. Economic analyses of soybean meal from different origins in growing pig diets

Item	U.S. dehulled	Brazil	India
Feed production cost, Won/kg	237.6	214.6	217.3
Feed intake, g/d	1,109.1	1,080.8	1,127.0
Feed cost per pig, Won	11,065.5	9,742.8	10,287.1
Weight gain, g/d	638.2	541.7	549.5
Feed cost per weight gain, Won/kg	412.8	428.2	445.7
Estimated feed value at equal feed cost per weight gain (445.7 Won/kg), Won/kg	256.5	223.4	217.3
Relative SBM value at equal feed cost per weight gain (445.7 Won/kg)	140.2	109.9	100.0

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