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Advances in Soybean and Soybean By-Products in Monogastric Nutrition and Health

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1. Introduction

Soybean (*Glycine max*) is a leguminous oilseed and one of the world's largest and most efficient sources of plant protein. United States holds the largest share of soybean production (32%) followed by Brazil (28%), Argentina (21%), China (7%) and India (4%). Although there are variations based on geographical location, the average crude protein (CP) content of soybean is 38% with a rich and balanced amino acid profile. It is therefore a rich source of protein for humans and food animals besides being a rich source of vegetable oil. Soybean meal is the simplest form of soybean protein and a by-product of the oil milling which by National Research Council standards contains 44-48% CP. It contains higher energy [2,460 metabolizable energy (ME) kcal/kg] and protein than other plant protein sources and has an excellent balance of highly digestible amino acids with the exception of methionine which tends to be low. Soybean meal is however rich in the amino acids lysine, tryptophan, threonine, isoleucine, and valine which are deficient in cereal grains such as corn and sorghum most utilized in poultry and swine diets. These are essential amino acids for monogastric animals such as poultry and swine.

Soybeans and soybean meal are also a source of isoflavones which are known to improve growth, promote tissue growth in pigs, and prevent diseases. However, soybean meal possesses anti-nutritional properties which must be overcome to increase its nutritional value. These include antitrypsin inhibitors, oligosaccharides, such as raffinose and stachyose, which are poorly utilized by most food animals. Phytic acid and antigenic factors found in certain soybean proteins cause inflammatory response in the gastrointestinal tract of monogastric animals. Soybeans also contain lectins, compounds that bind with intestinal cells and interfere with nutrient absorption and other compounds such as saponins, lipoxidase, phytoestrogens and goitrogens whose anti-nutritional effects are not known. Soybeans and soybean meal may also be contaminated in the field as a result of using contaminated irrigation water or application of contaminated manure to the growing crop. Since many animal producers use soybean meal as a major constituent of animal feeds, contamination of these feeds with zoonotic foodborne pathogens such as salmonella has increasingly become a global concern.

When properly processed for specific purposes, the soybean and soybean by-products can be utilized by all classes of animals ranging from companion animals, monogastric food

animals such as poultry and swine to aquatic life. Heat processing is required to inactivate trypsin inhibitors. In addition, low trypsin inhibitor soybeans have been developed through classical breeding and genetic engineering of soybeans. The use of microbial phytase enzymes in soy-based diets of swine and poultry increases phosphorus bioavailability and minimizes excess phosphorus excretion. Excess phosphorus in animal manure contributes to environmental pollution in addition to added cost of supplementing soy-based diets with inorganic forms of phosphorus. Soybeans have also been engineered to contain low levels of phytate. Mutant genes which significantly reduce oligosaccharides in soybean have also been identified. Supplementation of soy-based diets with direct-fed microbials has also enhanced the utilization of oligosaccharides. The oligosaccharides serve as prebiotics for these beneficial microorganisms which confer synergistic contributions to the host. Further, implementation of food safety plans on the growing, harvesting, and packing of soybean has the potential to minimize contamination of Soybean as a primary feed ingredient. Rapid and reliable methods for the detection of foodborne pathogens in soybean meal, monitoring of soybean as a raw feed ingredient, and generally good manufacturing practices have been crucial in mitigation efforts in prevention of zoonotic pathogens entering the animal feed processing.

While soybean and soybean meal are readily available in many parts of the world especially where soybean is grown, certain climatic regions are not conducive for soybean production. In these areas alternative protein sources must be sought because soybean becomes expensive attributed to the cost of importation. Under these circumstances animal source proteins or other plant source proteins are sought. Animal protein products such as blood meal have a higher tendency to harbor pathogenic microorganisms such as *Salmonella* when compared to plant protein sources. Therefore, inclusion of feedstuffs that minimize the presence of these pathogenic microorganisms and maintain a healthy gut can increase Monogastric animal production efficiency. Also constraints such as cost, anti-nutritional factors and sometimes low nutritional value of these protein sources dictate substitution, in part, of these feed ingredients with plant source proteins such as soybean.

Blood meal, a by-product of animal rendering, is a potential protein source for poultry. However, full growth and productive performance cannot be achieved without the supplementation of other protein sources, such as soybean meal. Recent studies have shown that substitution of blood meal in diets of laying single comb white leghorn chickens with up to 50% soybean meal in corn-soy based poultry rations did not adversely affect their overall growth and egg production performance when these diets were supplemented with isoleucine. Isoleucine is the primary limiting amino acid in blood meal (less than 1% on a dry-matter basis) and the fourth limiting amino acid after methionine, lysine and tryptophan in corn-soybean based poultry rations. Blood meal contains about 80-88% CP compared to about 44-48% CP in soybean meal. It has a minimum biological availability of about 80% based on the species studied, feeding regimen, housing conditions, and other environmental factors. The methionine and lysine digestibility coefficients are about 90% while those of cysteine and isoleucine are below 80% in blood meal. On the other hand the bioavailability of the amino acids lysine, threonine, and methionine from soybean meal are 88, 81, and 90%, respectively. These factors favor the substitution of other protein sources for soybean meal in diets of monogastric animals.

Soybean meal is also a suitable partial substitute for fishmeal in efforts to reduce cost of feeding and environmental pollution resulting from nutrient (phosphorus and nitrogen) overload in aquaculture. Fish meal which is traditionally the protein source of choice in

aquaculture is expensive. There are reports indicating that soybean meal can replace up to 60% fish meal in fish diets without adversely affecting performance. Soybean meal can also replace 25% fish meal in diets of red snapper without adversely affecting performance. However, higher substitutions require phosphorus supplementation.

In summary, although soybean meal is deficient in methionine and to some extent lysine, it has a rich nutritional value as a protein source in monogastric nutrition. Its value can be enhanced further by its ability to complement other ingredients to overcome key deficiencies. Advancement in processing technology, bioengineering and the use of feed supplements such as enzyme and direct-fed microbials have further added value to soybean meal by increasing the core of its nutrient bioavailability. Nevertheless, there remain limitless opportunities for enhancing the nutritive value and bioavailability of soybean meal protein in monogastric animal nutrition.

2. Nutritional value of soybeans and soybean by-products

Soybean (*Glycine max*) is one of the world's largest sources of plant protein and oil. Soybean protein has high crude protein and a balanced amino acid profile most of which tend to be deficient in cereal grains which constitute large portions of diets of monogastric animals. When compared to other protein sources, soybean boasts being the standard by which other protein sources are compared. Soybean meal, a byproduct of the oil milling industry also has rich nutritive value when compared to other protein sources. Chang et al. (2003) reported relatively high crude protein content of soybean ranging from 44-48 percent. Soybean meal also contains considerably higher energy and lower fiber content than other oilseed meals. The high concentration of protein and energy, and the low fiber content make soybean meal an ideal feed ingredient in formulating balanced rations that provide optimum growth, production and reproductive performance of monogastric animals. Comparisons of the nutritive value of soybean meal with other protein sources are presented in Table 1.

Earlier reports of Holle, (1995) indicate that soybean meal provides the best balance for amino acids which are deficient in most cereal grains when compared with other oilseed meals. Later studies (Zhou et al., 2005) have also shown that soybean meal has a balanced amino acid profile when compared with other oilseed meals, although it is deficient in methionine and lysine (Zhou et al., 2005). Comparisons of the amino acid composition of soybean meal with other protein sources are presented in Table 2.

Among the major oilseed meal sources of protein, soybean ranks highest in value based on quality of protein which is reflective of its balance of amino acids and their digestibility. For instance, the digestibility coefficients of lysine in soybean (Heartland Lysine, 1996; NRC 1994), canola, cotton seed and sunflower meals is estimated at 91, 80, 67, 84%, respectively (NRC, 1994). It has, however, been reported that processing conditions of these meals have a significant effects in reducing the biological value of feed ingredients such as soybean (Papadopoulos et al., 1986). Recent reports (Bandegan et al., 2010) also demonstrated that among the oilseed feed ingredients; soybean meal is the most digestible with its amino acid digestibility values ranging from 83 to 93% for Cysteine and Phenylalanine, respectively.

Other factors that have favored the use of soybean in animal production include (1) consumer food safety concern of the inclusion of animal source protein in animal feeds, especially after the mad cow disease or bovine spongiform encephalopathy and (2) limited production of animal source proteins such as fish meal and (3) the high cost of the animal source proteins such as fish meal and meat and bone meal.

Nutrient	Soybean Meal ²	Soybean Meal ³	Cottonseed Meal ⁴	Canola ^a Meal ⁴	Safflower Meal ³	Peanut Meal ⁵	Sunflower Meal ²
IFN ⁶	5-04-604	5-04-612	5-07-872	5-06-145	5-07-959	5-03-650	5-09-340
Crude Protein, %	44	49	41	38	43	51	32
Energy, kcal/kg	2,230	2,440	2,400	2,000	1,921	2,200	1543
Crude fat, %	0.8	1.0	0.5	3.8	1.3	1.2	1.1
Crude fiber, %	7.0	3.9	13.6	12	13.5	10	24
Calcium, %	0.29	0.27	0.15	0.68	0.35	0.20	0.21
Phosphorus ⁷ , %	0.65	0.62	0.97	1.17	1.29	0.63	0.93
Phosphorus ⁸ , %	0.27	0.24	0.22	0.30	0.39	0.36	0.14
Potassium, %	2.00	1.98	1.22	1.29	1.10	115	0.96
Iron, mg/kg	120	170	110	159	484	142	140
Zinc, mg/kg	40	55	70	71	33	20	100

¹National Research Council 1994.
² seeds, meal solvent extracted.
³ seeds without hulls, meal solvent extracted.
⁴ Seeds, meal pressed solvent extracted.
⁵ Kernels, meal solvent extracted.
⁶ International feed numbers.
⁷ Total phosphorus.
⁸ Non-phytate or available phosphorus.
^a Low erucic acid and low glucosinolates rapeseed cultivars.

Table 1. Comparison of selected nutrient composition of soybean meal and other oilseed meals¹

According to Hardy (2006) soybean meal is less expensive than fishmeal and is readily available for constitution of animal feeds. However, the price of soybean meal is higher than that of other plant source protein such as cotton seed, canola and sunflower meals. This may be attributed to the higher percent crude protein, better quality protein and highly digestible amino acids in soybean meal when compared with other plant source proteins. A recent survey of commodity prices by the University of Missouri (Table 3) revealed a direct correlation between protein content of feedstuffs and their corresponding prices.

There are many personal observations that soybean meal is in fact beneficial as a good source of amino acids (Green et al., 1987; Angkanaporn et al., 1996) given correct processing procedures. Previous reports have shown that soybean composition and processing conditions affect the nutritional quality of soybean meal (Grieshop and Fahey, 2001). On the other hand, Dudley (1999) emphasized the importance of accurate information on soybean meal composition and the availability of key nutrients in formulating balanced animal feeds. These include the quality, balance, and availability of amino acids and the processing conditions that are used in soybean processing to soybean meal or other byproducts.

Methods of processing soybean and variations in processing also contribute to the overall quality of the soybean products. These include extrusion and expelling, solvent extraction (Woodworth et al., 2001; Nelson et al., 1987), roasting and Jet-sploding (Marty et al., 1994; Subuh et al., 2002), and micronization (Marty et al., 1994; Subuh et al., 2002). These methods lead to variations in nutrient composition of the final product (s). In addition to the various methods used in the production of soybean products, there are also variations in the

parameters used in the production of soybean meal and soybean protein concentrates, which is reflected in the nutrient composition of the final products. These include the combinations of heat, timing, moisture and the quality of the soybean. These variations can be minimized through implementation of good quality control mechanisms during processing. A schematic presentation of the commercial production of the soybean products, soybean meal and soy protein concentrate is presented in Fig. 1.

Nutrient	Soybean Meal ²	Soybean Meal ³	Cottonseed Meal ⁴	Canola ^a Meal ⁴	Safflower Meal ³	Peanut Meal ⁵	Sunflower Meal ²
IFN ⁶	5-04-604	5-04-612	5-07-872	5-06-145	5-07-959	5-03-650	5-09-340
	------(%)-----						
Arginine	3.14	3.48	4.59	2.08	3.65	5.33	2.30
Lysine	2.69	2.96	1.71	1.94	1.27	1.54	1.00
Methionine	0.62	0.67	0.52	0.71	0.68	0.54	0.50
Cystine	0.66	0.72	0.64	0.87	0.70	0.64	0.50
Tryptophan	0.74	0.74	0.47	0.44	0.59	0.48	0.41
Histidine	1.17	1.28	1.10	0.93	1.07	1.07	0.55
Leucine	3.39	3.74	2.43	2.47	2.46	2.97	1.60
Isoleucine	1.96	2.12	1.33	1.37	1.56	1.55	1.00
Phenylalanine	2.16	2.34	2.22	1.44	1.75	2.41	1.15
Threonine	1.72	1.87	1.32	1.53	1.30	1.24	1.29
Valine	2.07	2.22	1.88	1.76	2.33	1.87	1.74
Glycine	1.90	2.05	1.70	1.82	2.32	2.67	2.03
Serine	2.29	2.48	1.74	1.53	-	2.25	1.00
Tyrosine	1.91	1.95	1.13	1.09	1.07	1.80	0.91

¹National Research Council, 1994.
² Seeds, meal solvent extracted.
³ Seeds without hulls, meal solvent extracted.
⁴ Seeds, meal pressed solvent extracted.
⁵ Kernels, meal solvent extracted.
⁶ International feed number.
^a Low erucic acid and low glucosinolates rapeseed cultivars.

Table 2. Comparison of selected amino acid composition of soybean and other oilseed meals¹

The two major products of soybean processing are soybean meal which is used extensively in livestock feeding and the soy protein concentrate which is used in production of specialty soy proteins after removal of soluble carbohydrates (oligosaccharides) from solvent extracted soybean flakes using aqueous alcohol leaching. The alcohol treatment of soybean flakes also removes other anti-nutritional factors which include estrogens and antigenic factors such as glycinin and β -conglycinin (Peisker, 2001). Hence, the soy protein concentrate differs from soybean meal in that it contains less oligosaccharides and antigenic substances when compared to soybean meal. The composition of oligosaccharides, lectins, β -conglycinin and saponins in soy protein concentrate and soybean meal are 1%, <1%, <10% and 0%, and 15%, 10-200 ppm, 16 and 0.6%, respectively (Peisker, 2001). The soy protein concentrate is produced by extraction of soluble carbohydrates from alcohol leached solvent

extracted soybean meal. The soy protein concentrate is of lesser significance in animal feeding but a favorable protein source for monogastric animals. The estrogens can also be extracted from solubilized carbohydrates to produce isoflavones rich nutraceuticals for human consumption.

Feed ingredient	CP content (%)	Minimum price (\$)/ton	maximum price (\$)/ton
Soybean meal	48	348	388
Cotton seed meal	41	310	360
Canola meal	38	202	202
Sunflower meal	32	240	240
Linseed meal	34	265	360
Ruminant blood meal	81	800	850
Fish meal	61	1,395	1,455

¹Dairy and beef nutrition extension program of The University of Missouri Division of Animal Sciences and Extension Commercial Agriculture, Columbia, Missouri (March 24, 2011) and Feedstuffs (March 28, 2011 | Issue 13 | Volume 83).

Table 3. Comparison of prices of soybean meal and other protein sources¹

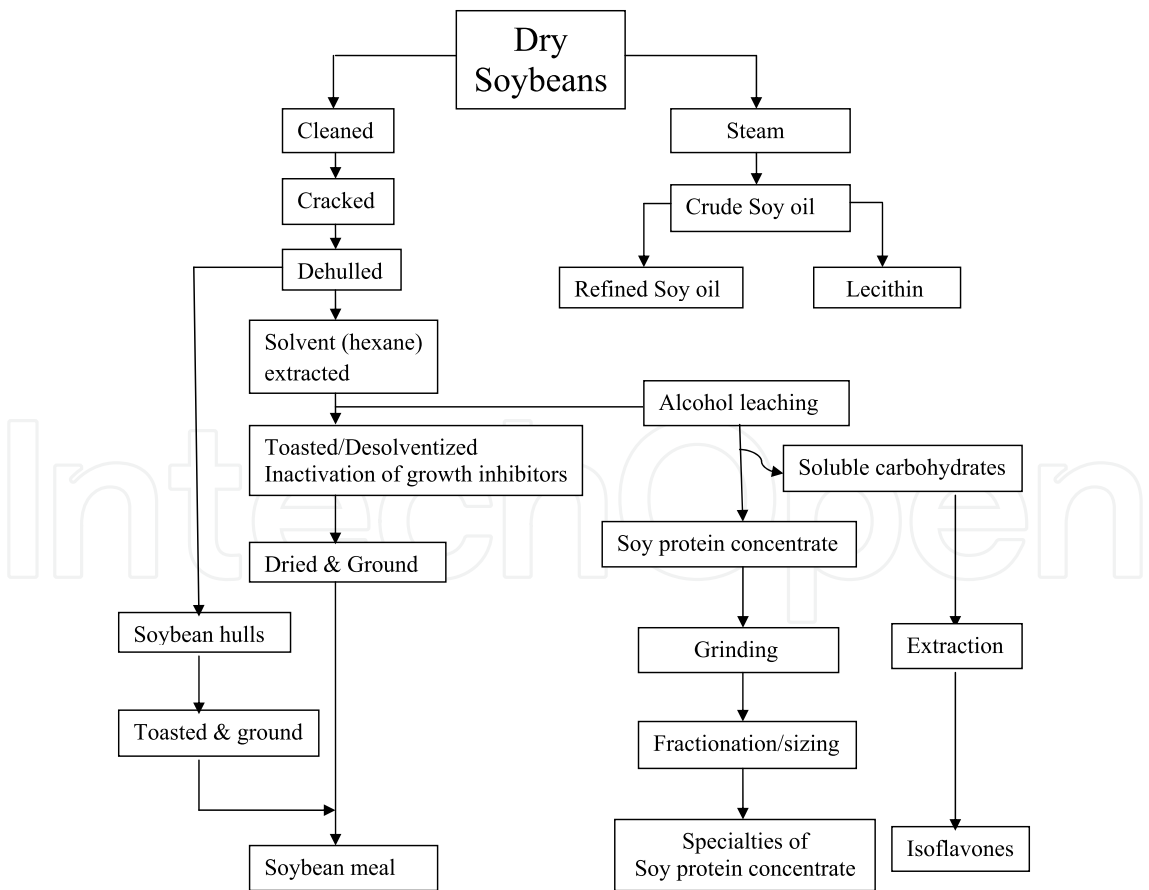


Fig. 1. Schematic presentations of the commercial production of the soybean products, soybean meal and soy protein concentrate.

3. Challenges and opportunities in enhancing quality and nutritive value of soybean

3.1 Challenges of soybean as a protein source

3.1.1 Variations in nutritional composition based on geographic locations

According to the American Soybean Association (2010), in 2009, soybean meal accounted for about 67% of the proteinaceous feed ingredients used in diets of all food-producing animals. The world soybean production totaled 80.7 million metric tons and the largest share of the crop was produced in the United States of America (38%). Other significant producers of soybean in 2009 were Brazil (27%), Argentina (15%), China (7%) and India (4%). Soybean meal is also widely consumed in animal production systems worldwide than any other meal ranging from cotton seed meal to fish meal (American Soybean Association, 2010). Soybean meal (SBM) remains the primary protein source in diets of poultry and swine.

Growing conditions in addition to location where soybean is grown can also affect the nutritional value and quality of soybean and soybean products. Karr-Lilienthal et al. (2004) imported soybean from Argentina, Brazil, China and India, other leading soybean producing countries after the United States and processed it to soybean meal. They reported that SBM produced in the U.S. exhibited a higher crude protein than the SBM produced in the other countries. There were also variations in amino acid and mineral concentration of the soybean meal from the various geographical regions. For instance, consistent with the crude protein levels, soybean from China had the highest levels of most amino acids including lysine, methionine, and arginine and the total essential and non-essential amino acids (Karr-Lilienthal et al. 2004). The content of iron and potassium seemed to be higher in soybean from Argentina when compared to the other countries (Karr-Lilienthal et al. 2004).

In more recent reports, evaluation and comparison of the quality of soybean and soybean meals (SBM) from US, Asia and South America, Thakur and Hurburgh (2007) reported that SBM from Brazil had the highest protein content whereas SBM originating from US and China had the highest percentage of total digestible amino acids. They also reported that US SBM had the highest content of total of five essential amino acids (threonine, methionine, tryptophan, cysteine and lysine) for poultry and swine nutrition. These amino acids also exhibited higher digestibility and overall amino acid balance. Many of these differences in nutrient composition and digestibility among SBM from various geographical regions may be due to variations in environmental conditions in which soybeans are grown. These include soils, water, climate etc. Differences in varieties of soybean and agricultural practices also contribute to the many of the variations in nutrient content of the SBM based on geographic location. In earlier studies, Grieshop and Fahey (2001) reported that soybeans from China had a higher crude protein and lower lipid content (42.14 and 17.25%, respectively) than those from Brazil (40.86% and 18.88%, respectively) and US (41.58 and 18.70%, respectively).

In the report of Thakur and Hurburgh (2007) the highest crude protein SBM was from Argentina, China and India. It has also been demonstrated that the quality of protein and digestibility of individual amino acids varies by geographical regions. Moizuddin (2003) reported that the lysine content of SBM from the US and EU were higher than those of other origins. The true digestibility of SMB from Argentina (87%) and Brazil (82%) were lower than that of the US SBM at 91% (Moizuddin, 2003). Other reports (Baize et al. 1997; Grieshop et al., 2003) have consistently shown differences in nutrient composition of soybean and SBM within and among geographical regions of the world.

Within individual countries there have been reported variations in nutrient concentrations of soybean and SBM from region to region. This is in most part attributed to variations in environmental conditions in which soybeans are grown. Different varieties of soybean thrive better in certain areas than others and since genetic differences are also associated with differences in various characteristics including nutrient composition, they also contribute to the variations in nutrient composition. Karr-Lilienthal et al. (2005) demonstrated that soybeans collected from seven different geographic regions within the US had variations in total amino acid and oligosaccharide concentrations. Therefore, it is essential to always quantify nutrient composition of soybean acquired from new sources and geographical locations outside of the common source to ensure formulation of balanced diets for monogastric animals or the development of proteinaceous products of soybean origin.

3.1.2 Nutrient deficiencies and anti-nutritional factors in soybean based diets

Soybean meal has an excellent balance of highly digestible amino acids with the exception of methionine which tends to be low. Soybean meal is however rich in the amino acids lysine, tryptophan, threonine, isoleucine, and valine which are deficient in cereal grains such as corn and sorghum most utilized in poultry and swine diets. However, similar to other oilseeds meals, soybean meal contains anti-nutritional factors (ANFs) which depress growth performance when fed to monogastric animals (Liener and Kakade, 1980). These ANFs, according Rackis et al. (1986), inhibit the proteolytic action of the pancreatic enzyme trypsin and they may limit the usage of soy products in feeds of young animals with undeveloped digestive tracts. Since the anti-nutritional factors of soybean are known, they are inactivated by optimized heat treatment without compromising the nutritional value of the meal. Herkelman et al. (1991) reported maximum performance when chicks were fed full-fat soybean heated at 120°C for 40 minutes and that sodium metabisulfite decreased the time required to inactivate the trypsin inhibitors by one-half. Therefore soybean meal has no ANFs when properly processed, has the highest nutrient content, excellent amino acid balance, low in fiber and highest in energy content when compared with other oilseed (NRC 1994). Earlier reports indicate that soybean genotype (Palacios et al., 2004) as well as the geographical location and environment in which the soybeans were grown were contributing factors to variations in the SBM nutrient content, digestibility and availability to animals of the SBM (van Kempen et al., 2002; Goldflus et al., 2006). These factors would also influence the level of anti-nutritional factors in soybeans.

There are other oil seed meals such as safflower (Table 1 and 2) which display richness of major nutrients and balanced amino acids almost comparable or better than soybean in some cases, but they also contain ANFs which have not been determined or characterized. The digestibility values of safflower and its constituent amino acids have not been determined yet (Galacia-Gonzalez et al., 2010). Although soybean contains ANFs, these factors are known and can be reduced significantly during the meal processing to a level that will not interfere with animal performance. These include heat processing (Perilla et al. 1997) in order to denature inhibitory enzymes like urease and haemagglutinins.

Unlike heat pressed or processed soybean and soybean byproducts, raw soybean contain compounds that inhibit the activity of the proteolytic enzyme trypsin. Supplementation of the amino acids lysine, threonine and tryptophan in raw soybean diets improved pig performance (Southern et al., 1990).

The ANFs in soybean are either heat labile or heat stable. The heat labile ANFs are usually inactivated by heat treatment.

Heat labile ANFs

Soyin

The isolation and purification of a toxic protein “glicin” from defatted soybean flour were described by Liener and Pallansch (1952). The toxic protein was later identified as “Soyin” and Liener, (1953) reported that the protein was an albumin-like fraction derived from raw soy beans and was toxic when injected into guinea pigs. This preparation was also reported to possess hemagglutinating properties and was later reported to possess urease activity. Liener, (1953) also observed poor performance of rats fed raw soybean and suggested that the destruction of the heat-labile substance (soyin) was necessary in ensuring optimum performance.

Protease inhibitors

Protease inhibitors have been reported to hinder the activity of the proteolytic enzymes trypsin and chymotrypsin in monogastric animals which in turn lowers protein digestibility. The reports of Liener and Kakade, (1969) and Rackis, (1972) confirmed that trypsin inhibitors were key substances in soybean that affected its utilization by chicks, rats and mice. Earlier reports had shown that trypsin inhibitor which was isolated from raw soybeans (Kunitz, 1946) was for growth inhibition. The protease inhibitors were also reported to inhibit Vitamin B12 availability (Baliga et al., 1954). Later studies have also shown that the presence of dietary soybean trypsin inhibitors caused a significant increase in pancreatic proteases (Temler et al., 1984). Hwang et al. (1978) suggested that these plant source protease inhibitors may serve various purposes which include storage of proteins in seeds, regulation of endogenous proteinases, and also as protective agents against insect and/or microbial proteinases. These protease inhibitors contain about 20% of S-containing amino acids, especially methionine, the most limiting essential amino acid in soybean seeds and cysteine (Hwang et al., 1978).

The effect of soybean trypsin inhibitor on monogastric animal performance has been evaluated extensively. Birth et al. (1993) cited evidence that ingestion of food containing trypsin inhibitor by pigs increased endogenous nitrogen losses hence the effect of the trypsin inhibitors affected nitrogen balance more by losses of amino acids of endogenous secretion than by losses of dietary amino acids. This may be due to compromised integrity of the gastrointestinal lining leading to reduction of absorptive surface. Gertler et al. (1967) attributed the depression of protein digestibility to reduced proteolysis and absorption of the exogenous or dietary protein which was caused by inhibition of pancreatic proteases.

More recent reports (Dilger et al., 2004; Opapeju et al., 2006; Coca-Sinova et al., 2008) indicate that the nutritional value of soybean meal for monogastric animals is limited by anti-nutritional factors which interfere with feed intake and nutrient metabolism. They reported that soybeans with high content protease inhibitors, especially trypsin inhibitors adversely affect protein digestibility and amino acid availability. However, heat processing inactivates these protease inhibitors, although there has to be a balance in conditions of heat inactivation since excessive heating could also destroy other essential nutrients. Qin et al. (1998) demonstrated that excess heat in the inactivation of protease inhibitors of soybean may increase Maillard reactions between the amino group of amino acids and reducing

sugars and as a result decrease the digestibility of energy and amino acids by monogastric animals.

Hemagglutinins or lectins

Hemagglutinins or lectins are a component of soybeans that were characterized as anti-nutritional factor by Schulze et al., (1995). Oliveira et al., (1989) reported that lectins are glycoproteins which bind to cellular surfaces via specific oligosaccharides or glycopeptides. They exhibit high binding affinity to small intestinal epithelium (Pusztai, 1991) which impairs the brush border and interfere with nutrient absorption. Hemagglutinins have also been implicated in producing structural changes in the intestinal epithelium and resisting gut proteolysis (Pusztai et al., 1990), changes which in most cases result in impairment of the brush border and ulceration of villi (Oliveira et al., 1989). This occurrence result in significant decrease in the absorptive surface and increased endogenous nitrogen losses as reported by Oliveira and Sgarbierri (1986) and Schulze et al. (1995). Pusztai et al. (1990) observed that hemagglutinins depressed growth rate in young animals.

Goitrogens

The possible goitrogenic effect of soybean in animals has not been researched. However, certain soy components may present some antithyroid actions, endocrine disruption, and carcinogenesis in animal and human. For example, Soybean contains flavonoids that may impair the enzymes thyroperoxidase activity (Messina, 2006). Reports have also shown that use of soy-based formula without added iodine can produce goiter and hypothyroidism in infants, but in healthy adults, soy-based products appear to have negligible adverse effects on thyroid function (Messina, 2006; Xiao, 2008; Zimmermann, 2009). In earlier reports (Fort, 1990) concentrations of soy isoflavones resulting from consumption of soy-based formulas were shown to inhibit thyroxine synthesis inducing goiter and hypothyroidism and autoimmune thyroid disease in infants. Still many questions linger on the full Impacts of soy products on thyroid function, reproduction and carcinogenesis, hence the need for further research in this context.

Heat stable ANFs

With the exception of oligosaccharides and antigenic factors, there is less likelihood that the other heat stable anti-nutritional factors would cause problems to monogastric animals consuming soybean-based feeds.

Cyanogens

Legumes such as soybean have long been recognized to contain cyanogenic compounds (Montgomery, 1980). Soybean is a major food ingredient in monogastric nutrition, therefore, any level of cyanogens is considered to be important. The content of cyanide in soybean meal protein was reported at 0.07-0.3 pg of hydrogen cyanide/g of sample in soy protein products and 1.24 pg/g in soybean hulls when browning was kept to a minimum. These values are relatively small when compared with the cyanide content of cassava which ranges from 1 to 3 mg/g (Honig et al. 1983). Cyanide is considered toxic even in small amounts, hence where soy is a major constituent of a diet, there are concerns of cyanide content from a toxicological point of view.

Saponins

Saponins are unabsorbable glucosides of steroids, steroid alkaloids or triterpenes found in many plants including soybeans. They form lather in aqueous solutions and impart a bitter

test or flavor in feed, resulting in reduction of feed consumption. In severe cases they cause haemolysis of red blood cells and diarrhea (Oakwundull, 1981). While raw soybeans have been reported to contain between 2 and 5 g saponins per 100 g, soy products, except those extracted with alcohol, contain high levels of saponins. Soy saponins are divided into groups A and B whereas group A saponins have undesirable astringent taste and are found in soybean germ. Group B saponins are found in both the soybean germ and cotyledons. Although soybean saponins possess anti-nutritional properties, some are edible and have been reported to possess some health benefits. They have been shown to stimulate the immune system, bind to cholesterol and make it unavailable for absorption and allowing its clearance into the colon and eventual excretion (Elias et al., 1990).

Estrogens

Environmental estrogens are classified into two main categories namely phytoestrogens which are of plant origin and xenoestrogens which are synthetic (Dubey et al., 2000). Soybeans contain phytoestrogens which can cause enlargement of the reproductive tract disrupting reproductive efficiency in various species, including humans (Rosselli et al., 2000), and rats (Medlock et al., 1995). In some cases these estrogens are hydrolyzed in the digestive tract to form poisonous compounds such as hydrogen cyanide. Woclawek-potocka et al. (2004) reported that phytoestrogens acting as endocrine disruptors may induce various pathologies in the female reproductive tract. Studies have shown that soy-derived phytoestrogens and their metabolites disrupt reproductive efficiency and uterus function by modulating the ratio of prostaglandins PGF2a to PGE2. Because of the structural and functional similarities of phytoestrogens and endogenous estrogens, there is the likelihood that the plant-derived substances modulate prostaglandin synthesis in the bovine endometrium, impairing reproduction. Previous research has shown that phytoestrogens may act like antagonists or agonists of endogenous estrogens (Rosselli et al., 2000; Nejaty and Lacey, 2001).

Antigens

Antigenic factors glycinin and β -conglycinin removal increases animal performance. A study was conducted to determine the relationship between adverse health outcomes and occupational risk factors among workers at a soy processing plant (Cummings et al., 2010). They reported that asthma and symptoms of asthma were associated with immune reactivity to soy dust. Further discussion of this topic is in the soybean and food safety issues.

Phytates

Phytic acid (inositol hexakisphosphate, IP6), which is considered an anti-nutritional factor, is the storage form of phosphorus in seeds such as those of soybean (Asada et al., 1969). The presence of phytic acid (Fig. 2) in seeds is even more critical in leguminous plants such as soybean which are commonly used in animal feeds because it not only makes phosphorus unavailable, but also reduces the bioavailability of other trace elements such as zinc. The composition of phytic acid in various by-products of oilseeds is presented in Table 4. Raboy and Dickinson (1984) timed the rate of accumulation of phytic acid in seeds of developing soybean and they reported a linear accumulation of phytic acid with the age of the plants. Studies have also shown that the accumulation of phytic acid is also associated with a decline in free phosphorus suggesting that phytic acid synthesis is involved in phosphorus homeostasis of growing soybean plants. This has an effect on the availability of phosphorus from soybean by monogastric animals.

Heaney et al. (1991) reported that the absorption of calcium from soybean-based diets was higher in low-phytate soybean when compared with high phytate-soybean. This supports the assertion that soybean has the potential to form phytate-mineral-complex which inhibits the availability of the minerals to monogastric animals. Phytate is usually a mixture of calcium/magnesium/potassium salts of inositol hexaphosphoric acid in soybean and is shown to adversely impact mineral bioavailability and protein solubility when present in animal feeds (Liener, 1994). Raboy and Dickinson (1984) observed that phytic acid levels and the available (free) phosphorus in mature soybean seeds are responsive to altered concentrations of nutrient phosphorus. However, they observed little or no significant change in content of protein and zinc in the soybean seeds.

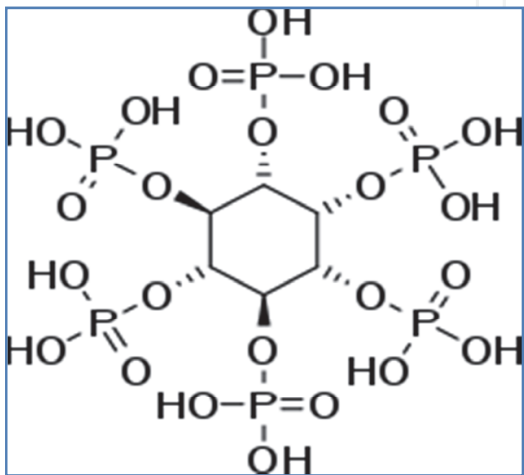


Fig. 2. Molecular structure of Phytic acid

According to Raboy et al. (1984) phytic acid accounts for 67-78% of the total phosphorus in mature soybean seeds and these seeds contain about 1.4-2.3% phytic acid which varies with soybean cultivars. In plants phytic acid is the principal store of phosphate and also serves as natural plant antioxidant. Reports of Vucenik and Shamsuddin (2003) point that inositol bears biological significance as antioxidant in mammalian cells. However, it interferes with mineral utilization and is the primary cause of low phosphorus utilization in soy-based poultry and swine diets. Phytin also chelates other minerals such as Calcium, Zinc, iron, Manganese and Copper, rendering them unavailable to the animals.

Foodstuffs	Minimum, %	Maximum, %
Soybeans	1	2.22
Soybean protein concentrate	1.24	2.17
Peanuts	1.05	1.76
Linseed	2.15	2.78
Sesame seed	5.36	5.36

Adopted from: Reddy, N. R. and Sathe, Shridhar K. (2001).

Table 4. Percent composition of phytic acid in various by-products of oilseeds

The anti-nutritional effects of phytate in soybean-based diets are primarily due to the chelation of calcium (Cheryan, 1980), amino acids (De Rham and Jost, 1979), and starch (Ravindran et al., 1999) by phytate. Ravindran et al., (2006) demonstrated this anti-

nutritional effect in broiler chickens where the digestibility of energy and amino acids declined with an increase in dietary phytate.

Non-starch polyssacharides and soy oligosaccharides

Soybean oligosaccharides (OS) such as raffinose and stachyose are carbohydrates consisting of relatively small number of monosaccharides and they have been reported to influence ileal nutrient digestibility and fecal consistency in monogastric animals (Smiricky et al. 2002). In soybean the OS raffinose and stachyose represent about 4 to 6% of soybean dry matter (Leske et al., 1993). The digestion of OS in the small intestine is limited because mammals lack α -galactosidase necessary to hydrolyze the α 1,6 linkages present in OS (Slominski, 1994). However, according to reports of Rackis, (1975), fermentation of OS occurs in the small intestine, to a limited extent, due the action of small intestinal microflora. The majority of digestion occurs in the large intestine, where OS function as selective growth factors for beneficial bacteria (Hayakawa et al., 1990). The OS in soybean, raffinose and stachyose, are not eliminated by heat treatment during processing (Leske et al., 1993). Coon et al. (1990) observed that removal of the OS from SBM in poultry diets increased the true metabolizable energy value of the diet by 20 percent. Previous research has demonstrated that soy OS are responsible for increasing intestinal viscosity of digesta and as a result interfere with digestion of nutrients by decreasing their interaction with digestive enzymes (Smits and Annison, 1996). Irish and Balnave (1993) demonstrated that stachyose derived from the oligosaccharides of soyabean meals exert anti-nutritive effects in broilers fed high concentrations soyabean meal as the sole protein concentrate. Certain oligosaccharides, however, are considered to be prebiotic compounds because they are not hydrolyzed in the upper gastrointestinal tract and are able to favorably alter the colonic microflora. Feeding a higher level of an oligosaccharide (8 g/kg) to chicks, however, may depress metabolizable energy and amino acid digestibility (Biggs et al., 2007). Smiricky-Tjardes et al. (2003) reported the presence of significant quantities of galactooligosaccharides in soy-based swine diets. These soy oligosaccharides are partially fermented by gut microflora functioning as prebiotics which promote selective growth of beneficial bacteria.

3.2 Enhancement of nutritive value of soybean in monogastric diets

3.2.1 Mechanisms of adding value to soybean

i. Direct-fed microbials and fructose oligosaccharides

In the recent past beneficial microorganisms (probiotics) and non-digestible ingredients (prebiotics) have been utilized to improve nutrient utilization in soybean-based diets and to enhance health and growth performance of monogastric animals. Probiotics, which is synonymous to direct-fed microbials, are defined as live microbial feed supplements which beneficially affect the host animal by improving its intestinal microbial balance (Fuller, 1989). They improve feed acceptance, feed efficiency, health and metabolism of the host animal (Cheeke, 1991). Other proposed modes of action of probiotics in monogastric animals are: (1) maintaining a beneficial microbial population by competitive exclusion and antagonism (Fuller, 1989), (2) improving feed intake and digestion and production performance (Nahashon et al., 1994a, 1994b, 1994c, 1996), and (3) altering bacterial metabolism (Cole et al., 1987; Jin et al., 1997).

Nahashon et al (1994a) evaluated the phytase activity in lactobacilli probiotics and the role in the retention of phosphorus and calcium as well as egg production performance of Single Comb White Leghorn laying chickens. They reported phytase activity in the direct-fed microbial and that supplementation of the corn-soy based diets with the probiotics (lactobacilli) to a 0.25% available phosphorus diet improved phosphorus retention and layer performance.

Prebiotics, on the other hand, are defined as non-digestible food ingredients that beneficially affect the host, selectively stimulating their growth or activity, or both of one or a limited number of bacteria in the colon and thus improve gut health (Gibson and Roberfroid, 1995). They are short-chain-fructo-oligosaccharides (sc-FOS) which consist of glucose linked to two, three or four fructose units. They are not absorbed in the small intestine but they undergo complete fermentation in the colon by colonic flora (Gibson and Roberfroid, 1995). Three events take place: (1) release of volatile fatty acids which are absorbed in the large intestine and contribute to the animal's energy supply; (2) although not conclusive, they have been reported to enhance intestinal absorption of nitrogen, calcium, magnesium, iron, zinc and copper in rats (Ducros et al., 2005); and (3) increase the number and/or activity of bifidobacteria and lactic acid bacteria (Hedin et al., 2007).

Many oligosaccharides are considered to be prebiotics compounds that can directly or indirectly improve intestinal health and as a result improve animal performance (Biggs et al. 2007), although the mode of action of several of these prebiotics are still obscure. It was reported that even low concentrations (4 g/kg) of an indigestible, prebiotic oligosaccharide can be fed with no deleterious effects on metabolizable energy and amino acid digestibility (Biggs et al., 2007). Fructooligosaccharides such as inulin, oligofructose, and other short-chain fructooligosaccharides can be fermented by beneficial bacteria such as bifidobacteria and lactobacilli (Bouhnik et al., 1994; Gibson and Roberfroid, 1995) which control or reduce the growth of harmful bacteria such as *Clostridium perfringens* through competitive exclusion. The bifidobacteria and lactobacilli are generally classified as beneficial bacteria (Gibson and Wang, 1994; Flickinger et al., 2003).

The benefit of utilizing oligosaccharides in soy-based diets of monogastric animals are due to the ability of these oligosaccharide to pass through to the hindgut of the monogastric animals intact and to be fermented by beneficial bacteria that are stimulated to grow and produce compounds that are beneficial to the host. These beneficial bacteria are also able to prevent the growth of bacteria such as *Escherichia coli* and *lostridiumperfringens* that can be harmful to the host through competitive exclusion (Gibson and Roberfroid, 1995). The digestibility of a few amino acids was increased by some oligosaccharides in cecectomized roosters (Biggs and Parsons, 2007).

ii. Enzymes-Phytases, carbohydrases and proteases

Phytase (myo-inositol-hexakisphosphate phosphohydrolase) is an enzyme that catalyzes the hydrolysis of phytic acid, an indigestible inorganic form of phosphorus in oil seeds and as a result increases the digestion of phosphorus, consequently increasing its utilization and reducing its excretion by monogastric animals. The phytase enzymes are derived from yeast or fungi and bacteria. Nahashon et al. (1994a) reported that P retention was improved in layers when the diet was supplemented with *Lactobacillus* bearing phytase activity. The use of phytase to hydrolyze phosphorus and possibly other mineral elements that may be bound onto phytate has been extensively researched (Selle and Ravindran, 2007; Powell et al. 2011). The ability of phytase to improve performance and the digestibility of Calcium and

phosphorus in layers fed a corn- and soybean-based diet is also well documented (Lim et al., 2003; Panda et al., 2005; Wu et al., 2006).

Recently, Liu et al. (2007) demonstrated that phytase supplementation in corn-soybean diets significantly improved the digestibility of phosphorus and calcium by 11.08 and 9.81%, respectively. A 2-8% improvement of the digestibility of amino acids was also noted. Phytase supplementation in corn-soybean layer diets also improved egg mass, the rate of lay and egg shell quality of laying birds. These findings suggest that phytase supplementation in soybean; corn-based diets of layers can improve the digestibility of calcium, phosphorus and amino acids.

These results demonstrate that high dietary levels of efficacious phytase enzymes can release most of the phosphorus from phytate, but they do not improve protein utilization (Augspurger and Baker, 2004). Supplemental phytase has also been reported to improving dietary phosphorus utilization by pigs (Sands et al., 2001; Traylor et al., 2001). Recent reports have suggested that the presence of calcium negatively affects the activity of phytase enzymes. Applegate et al. (2003) reported that 0.90% dietary calcium reduced intestinal phytase activity of turkey poults by 9% and phytate phosphorus hydrolysis by 11.9% compared with 0.40% calcium. However, recent report of Powell et al. (2011) indicate that dietary calcium level, within the ranges of 0.67-1.33% did not negatively affect the efficacy of phytase. Other reports (Pillai et al., 2006) demonstrated that addition of *E. coli* phytase to phosphorus deficient broiler diets improved growth, bone, and carcass performance.

Carbohydrases such as xylanase and amylase are enzymes that catalyze the hydrolysis of carbohydrates into sugars which are readily available or metabolizable by monogastric animals. Proteases on the other hand break down long protein chains into short peptides. Most enzyme complexes in monogastric feeding comprise carbohydrases, proteases and phytases. In the animal feed industry these enzymes are produced commercially and used to hydrolyze soluble nonstarch polysaccharides (NSP) of viscous cereals such as rye, triticale, wheat, barley, and oats. Soybean meal contains approximately 3% of soluble NSP and 16% of insoluble NSP (Irish and Balnave, 1993) whereas corn contains approximately 8% of insoluble NSP, mainly arabinoxylans (Choct, 2006). Both corn and soybean contains negligible amounts of soluble NSP, not yielding digesta viscosity problems. Therefore, corn-soy based diets of monogastric animals are considered highly digestible, hence requiring less use of carbohydrases. Previous reports have, however, pointed out that since these cereal grains contain some soluble NSP, there is need to supplement corn-soy based diets with these enzymes to further improve their nutritional value (Maisonnier-Grenier et al., 2004).

Studies to determine the effect of supplementing a corn-soybean meal-based diet with a combination of multicarbohydrase, a preparation containing nonstarch polysaccharide-degrading enzymes, phytases and proteases revealed that these enzymes improved nutrient utilization and growth performance of broiler Chickens (Woyengo et al., 2010). Feeding a combination of xylanase, protease, and amylase resulted in significant improvements in feed conversion and body weight gain of broilers (Cowieson, 2005). When these enzyme combinations were fed in broiler diets with both adequate and reduced energy and amino acid content, a 3% and 11% increase in apparent metabolizable energy and nitrogen retention, respectively, were observed (Cowieson and Ravindran, 2008).

Although the enhancement of monogastric animal performance using enzyme supplements in feed have been extensively researched and documented, the benefits of phytases in soy-

based diets of monogastric animals have not been fully explored and require further research. There is still a great deal of uncertainty regarding the mode of action of phytases, carbohydrases and proteases and their combination thereof in corn-soy based diets of monogastric animals.

iii. Genetic modifications

Increasing demand for soybean has necessitated genetic modifications to improve yield, develop disease resistant varieties and varieties with enhanced nutritional value. Drought tolerant varieties of soybean have also been developed through genetic engineering. The Roundup Ready soybean, also known as soybean 40-3-2, is a transgenic soybean that has been immunized to the Roundup herbicide. Although soybean's natural trypsin inhibitors provide protection against pests, weeds still remain a major challenge in soy farming (Wenzel, 2008). A herbicide used to control weeds in soybean farming contains glyphosate which inhibits the expression of the soybean plant's enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene. According to Wenzel, (2008), the gene is involved in the maintenance of the "biosynthesis of aromatic metabolites," and would kill the plant along with the weeds for which the herbicide was meant. Consequently, the soybean was genetically engineered by transferring a plasmid which provided immunity to glyphosate-containing herbicides into the soybean cells through the cauliflower mosaic virus, perfecting the Roundup Ready soybean.

Since drought stress is a major constraint to the production and yield stability of soybean, integrated approaches using molecular breeding and genetic engineering have provided new opportunities for developing high yield and drought resistance in soybeans (Manavalan et al., 2009). Recently, Yang et al. (2010) pointed out that genetic engineering must be employed to exploit yield potential and maintaining yield stability of soybean production in water-limited environments in order to guarantee the supply of food for the growing human population and for food animals.

There are efforts to also develop new soybean varieties that are resistant to diseases and pests. Hoffman et al. (1999) observed that plants commonly respond to pathogen infection by increasing ethylene production. They suggested that ethylene production and/or responsiveness can be altered by genetic manipulation and as a result they used mutagenesis to identify soybean lines with reduced sensitivity to ethylene. Two new genetic loci were identified, *Etr1* and *Etr2* and plant lines with reduced ethylene sensitivity developed similar or less-severe disease symptoms in response to virulent *Pseudomonas syringae*. Other reports (Yi et al., 2004) indicate that *CaPP1*, a ERF/AP2 transcription factor in hot pepper plants may play dual roles in response to biotic and abiotic stress in plants and that through genetic engineering this factor could be modified to improve soybean disease resistance as well.

Enhancement of the nutritional value of soybean through genetic engineering has been reported. According to Wenzel (2008), the soybean is a crop with the best amino acid composition within all cultivated protein crops. He pointed out that since amino acids are directly used in the genetic formation of proteins and fatty acids, this makes the soybean invaluable in oil production. One of the main goals in genetic modification of the soybean have essentially been to improve its oxidative stability by changing the mass percentage of certain fatty acids, which would provide a more useful oil, and to increase the overall amount of oil produced. The enhancement of soybean oil content was achieved by the

introduction of a seed-specific transgene for diacylglycerol acyltransferase (DGAT2)-type enzyme from the oil-accumulating fungus *Umbelopsis ramanniana* (Clemente et al., 2009). Without disrupting the protein content, the oil content was increased from approximately 20% of the seed weight to approximately 21.5%.

Attempts were also made to increasing the oxidative stability of soybean oil. The primary objective was to increase the composition in soybean of the fatty acids oleic and stearic and decrease linoleic acid content of the soybean without creating *trans* or polyunsaturated fatty acids (Clemente, 2009). Recently, DuPont has announced the creation of a high oleic fatty acid soybean, with levels of oleic acid greater than 80%, (Clemente, 2009; Clemente and Cahoon, 2009). Soybean mutants with elevated and reduced palmitate have also been developed (Rahman et al. 1999). While the palmitate content of commercial soybean cultivars is approximately 11%, elevated palmitate content in soybean oil may be important for the production of some food and industrial products.

Low phosphorus (P) availability is also a major constraint to soybean production, therefore, developing soybean varieties that can efficiently utilize phosphorus in the soils would be a sustainable and economical approach to soybean production. Wang et al. (2010) demonstrated the needed to develop more soybean varieties with enhanced P efficiency through root modification, which might contribute to reduced use of P fertilizers, expanding agriculture on low-P soils, and achieving more sustainable agriculture.

Soybeans, like many plants have also been reported to possess intrinsic allergens that present problems for people with food allergies. However, genetically modified soybean has not been shown to add any additional allergenic risk beyond the intrinsic risks already present (Herman, 2003a). Through genetic engineering, major allergens in soybean have been removed providing a very rich protein to both humans and food animals. According to Herman (2003a), the sensitivity to soybean proteins in humans is estimated to occur in $5 \pm 8\%$ of children and $1 \pm 2\%$ of adults. These allergenic reactions are only rarely life-threatening with the primary adverse reactions to consumption being atopic (skin) reactions and gastric distress. After eliminating a dominant allergen in soybean seeds through genetic engineering, Herman et al. (2003b) reported that there were no significant differences in composition of transgenic and non-transgenic seeds. They pointed out that the lack of a collateral alteration of any other seed protein in the Gly m Bd 30 K-silenced seeds supports the presumption that the protein does not have a role in seed protein processing and maturation.

iv. Synergistic value of soybean and other protein sources-supplementation/substitution

Protein for poultry diets may be derived from both animal and plant sources, with those from animal sources being considered "good-quality". They receive this designation because of their relatively high level of crude protein and their good balance of essential amino acids but they are much more expensive than their plant source counter-parts. Specific animal sources of protein include blood meal (80-88% CP), meat and bone meal (45-50% CP), fish meal (60-70% CP), and poultry by-product (50-55% CP). Common plant sources used in poultry production include soybean meal (41-50% CP), cottonseed meal (41-50% CP), canola meal (45-50% CP), peanut meal (40-45% CP), and alfalfa meal (15-20% CP). It should be noted that, because of the relative low cost and high CP levels, soybean meal is used by nearly all US poultry producers (Kilburn and Edwards, 2004).

In a study performed by Odunsi (2003), bovine blood was evaluated for its efficacy in layer diets. Results from that experiment suggest that full productive performance could not be

achieved without the supplementation of another protein source, in this case fish meal. This conclusion is supported by earlier work done by Onwudike (1981), where birds fed diets containing blood meal as the sole protein source had average hen-day egg production percentages far less than those given other feed ingredients. In that experiment, the average amount of feed required to produce one dozen eggs was also significantly higher for birds on blood meal than in any other test group. It has been suggested that lowered production observed in birds given blood-type protein products could be a result of nutrient imbalance. Blood meal, as a feedstuff, is used primarily to supplement protein requirements of livestock. In general, it has a crude protein content of 80 to 88% (Knaus et al., 1998) with varying digestibility and bioavailability depending on factors that include species, breed, feeding regimen, and climate. The low palatability of blood meal has been an issue and concern for producers (Lim, 2004; DeRouchey, 2002). For this reason, it is recommended that the use of blood meal in rations is restricted to no more than about 5 to 10% of the total ration. The specific amino acid content is generally good, but unbalanced. Isoleucine, for example, is the primary limiting amino acid, and can be found in only trace amounts (often less than 1% of total volume). In one study, isoleucine availability was found to be only 39%, compared to 59% or better for all other essential amino acids (Gaylord and Rawles, 2003). Researchers have studied blood meal as a viable protein supplement in many species including beef cattle (Rangngang et al., 1997), dairy cattle (Schor and Gagliostro, 2001), nursing swine (DeRouchey et al., 2002), sheep (Hoaglund et al., 1992) and poultry (Tyus et al., 2009).

Blood meal contains about 80 to 88 percent CP compared to about 48 percent CP in soybean meal. It has a minimum biological availability of 80 percent based on the species studied, feeding regimen, housing conditions and other environmental factors. (Hoaglund et al., 1992; Sindt et al., 1993; and Kats et al., 1994). The National Research Council (1994) reports methionine and lysine digestibility coefficients of about 90 percent while cysteine and isoleucine figures were both below 80 percent. Blood meal is considered to be deficient in isoleucine, containing less than one percent on a dry-matter basis. When deficient, isoleucine, a limiting amino acid in blood meal, has been shown to cause fatal blood clots and reduced egg production in layers (Peganova and Eder, 2002).

The suitability of blood meal supplemented with isoleucine as protein source for Single Comb White Leghorn (SCWL) chicks was evaluated (Tyus et al. 2009). Based on this study, substitution of up to 50 percent of soybean meal with blood meal supplemented with isoleucine in corn-soy based diets did not adversely affect growth performance of SCWL chicks from day-old to 10 weeks of age. Laying performance of chicks fed diets containing blood meal supplemented with isoleucine from hatch to ten weeks of age was also evaluated (Tyus et al., 2008). They reported that feeding corn-soy diets containing blood meal and supplemented with isoleucine to SCWL chicks at 0-10 WOA significantly improved their subsequent egg production performance, but depressed their internal egg quality and egg shell thickness.

Soybean meal is also a suitable partial substitute for fishmeal in efforts to reduce cost of feeding and environmental pollution resulting from nutrient (phosphorus and nitrogen) overload in aquaculture. Fish meal which is traditionally the protein source of choice in aquaculture is expensive. There are reports indicating that soybean meal can replace up to 60% fish meal in fish diets without adversely affecting performance. Soybean meal can also replace 25% fish meal in diets of red snapper without adversely affecting performance. However, higher substitutions require phosphorus supplementation.

Soybean meal has also been used as partial substitute for groundnut meal in diets of broiler chickens. This has been attributed in part to the seasonal failure of the groundnut crop and the susceptibility of the groundnut cake to aflatoxins. Fishmeal could be a viable substitute but the variations in quality because of adulterations and the cost of the meal has led to the search for other potential protein sources as substitutes. Ghadge et al. (2009) suggested that soybean meal can adequately serve as economical substitute for groundnut cake at 75-100 percent substitution.

A recent study was also conducted to evaluate the replacement of rapeseed meal with soybean meal in diets of broilers because rapeseed meal contains anti-nutritional factors. These include goitrogens or progoitrogens and glucosinolates which reduce growth and egg production when fed to poultry at high concentrations (NRC 1994). Leeson et al. (1987) reported that inclusion of rapeseed as protein source in poultry feeds causes an imbalance between lysine and arginine. They also reported that leucine and isoleucine of rapeseed or canola would be limiting in poultry diets. The rapeseed contains about 42% of oil while its seed meal has an average of 38% crude protein (Montazer-Sadegh et al., 2008).

4. Soybean in monogastric animal nutrition and health

Soybean meal is the most widely used protein source in livestock diets around the globe and according to Kohl-Meier, (1990) it accounts for more than 50% of the world's protein meal. It is also a source of isoflavones which are known to improve growth, promote tissue growth in pigs, and prevent diseases. Isoflavones are a class of phytoestrogens, a group of nonsteroidal plant chemicals with estrogen-like activity. Recent report of Sherrill et al. (2010) indicated that perinatal exposures of male rats to isoflavones affected Leydig cell differentiation, and they imply that including soy products in the diets of neonates has potential implications for testis function. On the other hand, soy isoflavones supplements, which are phyto-oestrogens widely used as alternatives to alleviate menopausal syndromes or prevent chronic diseases, may exert oestrogenic and anti-oestrogenic activities. Hong et al. (2008) reported a significant increase in the oestrogenic activity of the methanol extracts of soy isoflavones for oestrogen receptor (ER) β , but not (ER) α , suggesting that soy isoflavones have a selective modulation of ER activation. The soy isoflavone supplementation did not aggravate murine lupus, but apparently ameliorated the disease.

Human health benefits of soy isoflavones have been reported and they are thought to be due, in part, to their estrogenic activity (Dixon, 2004; McCue and Shetty, 2004). Genistein and daidzein are the two principle isoflavones in soybeans and they are known to bind to estrogen receptors. As a result and as suggested by Wilhelms et al. (2006), isoflavones may exert modest endocrine disruptor-like effects on reproduction in male, but not female, quail. Studies were conducted to determine the effect of soy isoflavones on growth and carcass traits of commercial broilers (Payne et al., 2001). They observed a decrease in average daily weight gain and feed intake of broilers fed diets containing isoflavones. Isoflavones may also affect carcass traits in broilers. Earlier work (Cook, 1998) indicated that supplementation of broiler diets with isoflavones at 1,585 mg/kg diet significantly increased growth rate and carcass muscling in pigs from 6-32 kg body weight. Payne et al. (2001) also reported that addition of isoflavones to a corn-soy protein concentrate increases carcass leanness and decreases carcass fat in broiler chickens.

Processed soybean products which are of lesser significance in monogastric animal feeding have been cited as possessing functional properties to human health such as cancer

prevention (Linz et al., 2004) and liver disease (Gudbrandsen et al., 2006). Partial replacement of soybean meal with extruded soy protein concentrate improved pig performance significantly (Lenehan et al., 2007).

As demonstrated by the supplementation of diets of monogastric animals with isoflavones and soy protein concentrates, there are significant differences among the monogastric animals in response to the inclusion of soybean in their diets.

a. Soybean in Poultry feeding

Soybean meal (SBM) is the primary protein source in corn-soy based poultry rations. It is fed to poultry as soybean meal and is primarily the by-product of soybean oil extraction; it's the ground defatted flakes. Various studies have been conducted to evaluate methods of enhancing the acceptability of soybean and the enhancement of its nutritional value in poultry feeding. For instance, a study was conducted to evaluate the effect of extruding or expander processing prior to solvent extraction on the nutritional value of soybean meal for broiler chicks. The results of this study indicate that pre-solvent processing method (expander or non-expander) had no significant effect on the nutritional value of SBM for Broiler chicks. However, both Methionine and Lysine supplementation increased feed efficiency (Douglas and Persons, 2000). Several other studies (Coca-Sinova et al., 2008; Dilger et al., 2004; Opapeju et al., 2006) have evaluated various methods of enhancing the digestibility of individual amino acids and protein of soybean meal.

b. Soybean in Swine feeding

Soybean meal and soybean products have also been used extensively in swine production because of its relatively high concentration of protein (44 to 48%) and its excellent profile of highly digestible amino acids. Soy protein contains most amino acids that are deficient in most cereal grains commonly fed as energy sources in swine production. Due to the high cost of feeding, attempts to minimize the amount of soybean in swine rations and also to improve its digestibility have taken center stage. Bruce et al. (2006) evaluated the inclusion of soybean processing byproducts such as gums, oil, and soapstock into soybean meal. Addition of these processing by-products significantly reduced the nutritive value of the resultant meal. Several other approaches to enhance and expand the utilization of soybean in swine production include the use of oligosaccharides as reported by Smiricky-Tjardes et al. (2003). They evaluated the effect of galactooligosaccharides on ileal nutrient digestibility of nutrients in pigs fed soy-based diets. The digestibility of soy amino acids by swine have also been researched quite extensively (Smiricky-Tjardes et al. 2002; Sohn et al. 1994; Grala et al. 1998; Liener, 1981; NRC 1998; Sohn et al. 1994).

c. Soybean in aquatic feeding

The feeding value of soybean as a rich protein source has also been extended to aquaculture. Soybean meal and genetically modified soybean products have also been employed in aquaculture (Hammond et al., 1995). Naylora et al. (2009) points to the importance of fish oils and fishmeal as a protein source in food animal production and also the extensive use of soybean and soybean products as protein supplements in aquaculture feeds.

d. Soybean Food safety issues

This section is discussed in three parts: 1) bacterial contamination of soybean meal and its relation to human foodborne illness; 2) bacterial contamination of soy products; and 3) soy allergies.

Bacterial contamination of soybean meal and its relation to human foodborne illness

Soybean crop fertilized with animal manure has potential for higher yields when compared to soybeans fertilized with commercial fertilizer (McAndrews et al., 2006; Barbazan, 2004).

However, application of contaminated manure to the growing crop may contaminate soybeans with foodborne pathogens such as *Salmonella* spp, and *E. coli* O157:H7. Foodborne pathogens present in the intestinal tracts of animals may contaminate soybean crop via field application of animal manure. Since many animal producers use soybean meal as a major constituent of animal feeds, contamination of these feeds with zoonotic foodborne pathogens has increasingly become a global concern. Animal feeds are frequently tainted with vital human foodborne bacterial pathogens such as *Salmonella* spp. and *E. coli* O157:H7 (Crump et al., 2002; Davis et al., 2003). Use of contaminated soybean meal as ingredients in animal feeds affects the quality and safety of foods of animal origin. Food animals may get infected with foodborne pathogens via contaminated animal feed. Bacteria from the animal's gastrointestinal tract has the potential to contaminate raw meats during evisceration and processing stages (Madden et al., 2004). Raw retail meats have been reported as a major source of zoonotic foodborne pathogens (Foley et al., 2006; NARMS, 2006). *Salmonella* is the leading cause of foodborne illness in the United States and poultry has been identified as the primary source of infection (Braden, C.R. 2006).

Previously, *Salmonella* has been detected in poultry feed (Williams, J.E., 1981) and can be transmitted to human through animals infected by consuming the contaminated feed (Hinton, 1998). Contaminated feed is therefore a potential path for transmission of foodborne illnesses to humans.

Several environmental sources may be contributing to *Salmonella* contamination in monogastric animals, but feed is alleged to be the leading source. Implementation of food safety plans on the growing, harvesting, and packing of soybean has the potential to minimize contamination of soybean as a primary feed ingredient. Heat treatment (Stott et al. 1975) and ionizing radiation should be applied to eliminate or limit microbial contamination in animal feed (Macirowski et al., 2004). Soybean crop growers should constantly practice Good Agricultural Practices (GAPs) in their farms. Implementation of food safety plans on the growing, harvesting, and packing of soybean has the potential to minimize contamination of soybean as a primary feed ingredient. Detecting *Salmonella* in feed can be difficult as low levels of the pathogen may not be recovered using traditional culturing methods. Rapid and reliable methods for the detection of foodborne pathogens in soybean meal, and monitoring of soybean as a raw feed ingredient have been crucial in mitigation efforts in prevention of zoonotic pathogens entering the animal feed processing. Since animal feed is the first step of the farm to fork continuum for food safety, it is crucial to test for foodborne pathogens in the feed ingredients such as soybean meal for control of *Salmonella* and other foodborne pathogens.

Bacterial contamination of soy products

Various products are derived from soybeans including milk, infant formula, meal, flour, tofu, cereals, meat analogs and meat products. Consumers should follow manufactures instructions for ideal storage and shelf life of soy products. Recently, consumption of soymilk products has been increasing for the reason that these foods contain proteins which are lactose and cholesterol free. According to Liu and Tser-KeShun (2008), *Listeria monocytogenes* has the ability to survive and multiply in soymilk products and cannot be prevented by refrigeration. *Listeria monocytogenes* has the ability to grow at low temperatures and therefore permits multiplication at refrigeration temperatures. Consumer's improper handling and storage, especially of soy milk or yogurt is a food safety threat in regard to post-production contamination with foodborne pathogens. As with

soymilk and soymilk based products, post-production contamination of soybean products is a potential health hazard. Ikuomola and Eniola (2010) found high bacterial counts in samples of a popular non-fermented Nigerian fried soybean snack, Beske collected from various markets and Hawkers in Ikeji-Arakeji, Nigeria. *Staphylococcus aureus*, *Micrococcus luteus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa* and *Proteus vulgaris* along with four fungi, *Penicillium* spp, *Rhizopus stolonifer* and *Mucor mucedo* were some of the microorganisms isolated and identified from the Beske.

Recently, consumption of fresh green sprouts has increased, all over the world, in part due to health benefits. Sprouts have a risk of being contaminated with pathogenic bacteria such as *Salmonella*, *Escherichia coli* O157:H7, and *Listeria monocytogenes*. The consumption of sprouts has resulted to a number of outbreaks of foodborne illness in several countries. Seed sprouts are regularly linked to foodborne illness, especially those caused by *enterobacteriaceae* (2002; Harris et al., 2003; DuPont, 2007). Water used for soy sprouts should be potable and free of foodborne pathogens. The most significant factor in germination and sprouting of soy is clean water supply. Food-borne pathogens in the water supply have the potential to proliferate in the warm, moist environment that trays of sprouts provide. Soy sprouts are grown from seeds placed in warm, moist, nutrient-rich conditions, which are perfect environments for bacteria growth.

Soy allergy

Food allergies have become a common serious health threat and food safety concern globally. Food allergies can often turn into a lifelong concern. Eight types of foods which include milk, eggs, peanuts, tree nuts, fish, shellfish, soy and wheat account for 90 % of food allergies (Sicherer and Simpson, 2010). Allergy to soy is major allergy and one of the more frequent food allergies. Soybean (*Glycine max* L. Merr.) is described as one of the main allergenic food crops in the labeling regulation in many continents. The severity of the soy allergy reaction ranges from mild rashes up to anaphylaxis. Allergic reactions to soybean can be systemic, but typically have more localized effects including the skin, the gastrointestinal tract, or the respiratory tract (Savage et al., 2010). The prevalence of soybean allergy is estimated at 0.4% in children and 0.3% of adults in North America (Sicherer and Sampson, 2010).

Soy products are widely used as a major ingredient in most manufactured products and fast food restaurants such as McDonalds and Wendy's (http://www.allergicchild.com/soy_allergies.htm). There have been recalls by the Food and Drug Administration (FDA Enforcement Reports) of several products containing soy proteins, paste, oils and flour due to improper labeling. Consumers who have allergies to soy are often at a risk of serious or life threatening allergic reaction if they consume these products. Unlisted soy protein on product labels is considered a potential hazard for people who may be allergic to soy. Recently, Pasta Mia Veal Ravioli Gastronomica and Mooney's Kentucky Bourbon Cheese by Nina Mia, Inc and Shuckman's Fish Co, respectively, were recalled due to undeclared soy labelling (<http://www.foodsafety.gov/>). Therefore, failing to list soy proteins on the label places consumers with allergies at risk. Companies often supply soy substrates to other food processors and use as fillers, consequently recalls due to soy ingredients may include a wide range of prepared or processed foods: frozen pizza, cereals, granola bars and meat products. Consumer, particularly with food allergy concerns, must take time and read food labels while purchasing their foods.

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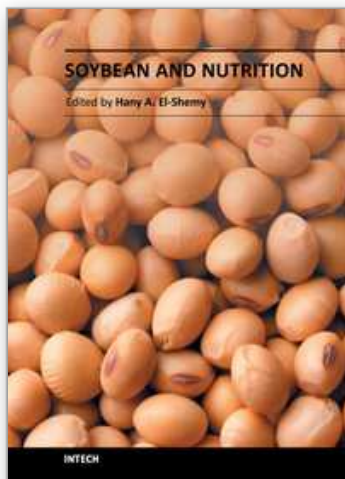
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Worldwide, soybean seed proteins represent a major source of amino acids for human and animal nutrition. Soybean seeds are an important and economical source of protein in the diet of many developed and developing countries. Soy is a complete protein and soy-foods are rich in vitamins and minerals. Soybean protein provides all the essential amino acids in the amounts needed for human health. Recent research suggests that soy may also lower risk of prostate, colon and breast cancers as well as osteoporosis and other bone health problems and alleviate hot flashes associated with menopause. This volume is expected to be useful for student, researchers and public who are interested in soybean.

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