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Modifications in Soybean Seed Composition to Enhance Animal Feed Use and Value: Moving From a Dietary Ingredient to a Functional Dietary Component

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Animal feed is the primary user of the nonoil component of soybeans. Breeding and gene modification strategies have been successfully employed to alter the seed composition of soybeans in a manner that enhances their use in animal feeds. Examples include altering amino acid profiles, fatty acid composition, oligosaccharide removal, and most notably phytic acid reduction. Such enhancements are required if soybeans are to maintain their use level in animal feeding applications. As advancements in genetic modification continue, an even greater level of animal feed applications will ensue through development of soybeans that have antimicrobial, health, and biogenic properties. Thus, soybeans in the future may not be produced as much for use as a protein feedstuff or as a source of oil, but rather for their ability to promote beneficial physiological properties or to enhance food safety.

Key words: soybean, feed, genetic modification.

Introduction

Soybeans represented 30.2 million hectares of crop production in the United States in 2000, with a value of over $12 billion (American Soybean Association, 2003). Soybeans accounted for 56% of the world oilseed production, with US soybean production accounting for 25% of the world production. The animal feed industry uses 77% of the soybean meal produced primarily as an amino acid and protein source in diets. Consequently, soybeans are an integral component of the US agriculture industry, and use of the soybean in animal feed formulations is important to the viability of the agriculture industry. The continued dominance of soybean use in animal feed applications is dependent upon designing soybean seed compositions that will benefit animal production. These benefits will be in areas that are apparent from our understanding of limitations to soybean meal use (primary protein structure, phosphorus unavailability, etc.) and in areas that arise from our understanding of how animal physiology and food products can be improved (reproductive efficiency, body composition, pathogen reduction, etc.).

One of the greatest challenges facing animal production in many regions of the world is the prevention of environmental pollution from animal production facilities. Environmental pollution concerns to date have focused primarily upon phosphorus, nitrogen, and malodor. However, other nutrients, such as copper and zinc, are also becoming a concern. In the United States, the Environmental Protection Agency, as well as state natural resources and conservation agencies, have enacted (or are in the process of drawing) regulations for the application of animal waste to land. Most of these applications concern the loading rate of phosphorus and nitrogen onto soil. In many cases, the loading rates are economically challenging, if not prohibitive, to sustainable animal production. Many animal production facilities have been impacted by nuisance suits seeking malodor abatement. Land values surrounding animal production facilities have also been impacted due to malodor emanating from animal production facilities. Failure to address these issues will drastically alter, if not prohibit, animal production in the United States and other countries of the world. The connectivity between soybean value and use in animal feed applications is such that deterrent effects on animal production will reverberate to reduced soybean value.

There are a myriad of opportunities for soybean manipulation to enhance animal production—and hence soybean use and value. Pressure to remove antibiotics from animal diets is almost globally unified. Concern for food safety, primarily directed toward prevention of food-born pathogens, has been elevated to the point that several countries now regulate animal product inspections and pathogen contamination guidelines. Our knowledge base concerning the role that fatty acid structure plays in body composition and function is increasing greatly. Fatty acids have been shown to influence body composition (reduced body fat), prevent cardiovascular disease and certain cancers, enhance reproduction, effect immune function, and so forth.

Genetic modification technologies and identity preservation capabilities now in place allow the potential to develop a soybean that can improve animal growth efficiency, reduce phosphorus and nitrogen release into the environment to less than half of its present level, alleviate high levels of zinc and copper excretion, reduce malodor to nonobjectionable levels, allow removal of antibiotics from animal diets, reduce human pathogen loads in animal-produced food products, and create foods for human consumption that promote weight loss, cardiovascular health, cancer prevention, and immune function. Although we obviously take some license in listing expectations of the beneficial outcomes that will occur, our expectations are not without basis. Moreover, although it is impossible to reformulate manna via soybean selection and modification, it is unarguable that such modifications would enhance the demand and value of soybeans.

Future Modifications (Within Range)

The majority of soybean meal is used to provide amino acids to poultry and swine. Typically, soybean meal is used to meet the animal's requirement for limiting amino acids, because soybean meal is usually the most cost-effective source of amino acids. Soybean meal is also one of the best protein sources for complementing the limiting amino acid profile of corn protein. However, the use of soybean meal in a corn-based diet to meet the animal's requirement for the most limiting amino acid results in the overfeeding of nonlimiting amino acids. The amino acids overfed are metabolized by the animal to carbon dioxide and urea, with the urea contributing to nitrogen excretion. Further, the protein is not completely digested by the animal, with the undigested protein being eliminated in the feces and contributing to nitrogen waste. The incomplete digestion of protein by the small intestine renders the protein susceptible to fermentation by the colonic microflora. Fermentation, in turn, plays an important role in malodor of animal waste. The regulatory pressures of nitrogen excretion and malodor abatement present a cost associated with feed ingredients that contribute to excess nitrogen excretion or malodor production. Thus, the economics of soybean meal use in animal diets has changed from the original requirement of the lowest cost source of amino acid. To adjust to market economics, the primary structure of soybean protein needs to be altered and its digestibility needs to be improved.

The amino acid requirements for poultry and swine are reasonably well elucidated. Using this information and the digestible amino acid profile of corn (the major energy feedstuff used in poultry and swine diets), the ideal amino acid profile of soybean protein can be targeted. When designing the optimum amino acid profile for soybean meal, consideration should also be given to market dynamics of alternative amino acid sources. In other words, there is more value in targeting increased concentrations of amino acids that are priced over $30/kg than amino acids priced at less than $1/kg. Specific amino acids that should be targeted are tryptophan, isoleucine, and valine for the pig, and the additional amino acid arginine for the chick. Improvement in protein digestibility would also enhance the value of soybean meal. Soybean meal protein digestibility is approximately 85% (Woodworth et al., 2001), ranging between 82% and 94% for individual amino acid digestibility. Improving intestinal availability of the amino acids to 95% or greater concomitantly with modifications of the amino acid profile would substantially improve the value of soybean meal protein for animal feed use.

The availability of phosphorus from soybean meal and other grains is compromised by the presence of phytic acid. The phytic acid binds the phosphorus, preventing its absorption by the animal's intestinal tract. The failure of phytic acid phosphorus to be available to the animal results in supplemental phosphorus required in the diet and substantial quantities of phosphorus excreted into the environment. If phytic acid were removed, as is accomplished by phytase addition to the diet, phosphorus retention is increased by 50% and excretion is reduced by 42% (Lei, Ku, Miller, & Yokoyama, 1993). Modifying soybeans to prevent the synthesis of phytic acid would have substantial value for animal feed applications.

Digestible and metabolizable energy value of soybean meal could be improved by alleviating carbohydrates in the meal. Removal of raffinose and stachyose improved metabolizable energy content 12% (Graham, Kerley, Firman, & Allee, 2002). Other oligosaccharides, as well as structural carbohydrates, are contained in soybean meal. These carbohydrates are incompletely digested by colonic microbiota of the chick. Reduction of these carbohydrates could improve energy density of the soybean meal and reduce hydroscopic nature of the litter.

Future Modifications (On the Horizon)

The advancements that will be made in soybean seed composition in the future are obviously only limited by our ability to imagine. Our discussion is limited to some seed components that have been shown to be subject to modification or have significant potential in animal feed applications.

Modification of the fatty acid profile of soybeans has substantial potential to improve animal production. Supplementing specific fatty acids has been shown to positively affect conception rates and semen quality. The exact mechanism has not been elucidated, but the current best hypothesis is that the fatty acids are influencing hormonal physiology of the animal. There has been much interest in the conjugated fatty acids due to their apparent ability to have positive health benefits to humans. Likewise, there is interest in creating a "heart healthy" fatty acid profile in meat and milk. This would include higher contents of conjugated linoleic acid and oleic acid and lower contents of saturated and fatty acids susceptible to developing a trans configuration. More recent research has led to the suggestion that some fatty acid structures can even promote weight loss in humans and increase the lean-to-fat ratio in animals (and therefore the associated meat products). Although research in these areas is ongoing, the importance of feeding animals a diet that would convey cardiovascular health, cancer prevention, and weight control to humans consuming the food products is obvious.

Modifications in the soybean seed composition could also result in promoting antimicrobial activities. Antimicrobial activity could be accomplished by promoting oligosaccharide and/or protein synthesis in the soybean seed. Oligosaccharides have been shown to promote growth of beneficial indigenous bacteria in the digestive tract. The indigenous fauna in turn produce antimicrobials against pathogenic bacteria, such as *E. coli* and *Salmonella*. Casein proteins, contained in milk, have been shown to have both prebiotic and antimicrobial activities. Using casein as an example protein, there are proteins or protein hydrolysate products that could be used, directly or indirectly, as antimicrobials. This would have value in preventing food-borne pathogen contamination of human food products and intestinal infections in animals and would provide an alternative to the current growth-promoting practice of including subtherapeutic levels of antibiotics into animal diets.

There is a plethora of biogenic peptides and amino acids that influence animal production. These effects range from influencing gut motility and function to regulation of endocrine hormone profiles in the body. Gut motility and function is central to postnatal or post-hatching development of the animal. Successful maturation of the gut tissue is central to survival and productivity of the animal throughout its productive life. Modulation of the immune system has tremendous influence on growth and development capability of the animal. Peptides and amino acids can influence endocrine signals (such as growth hormone and insulin-like growth factors) that affect the growth rate and efficiency of growth. It is well within the realm of possibility to design soybean proteins that yield peptide structures that elicit a specific metabolic response in an animal, resulting in a production advantage to that animal. This would not be dissimilar from the strategy of using a mineral or nutrient as a promoter signal for a metabolic function in plants.

Modifications in soybean protein that prevent immune hypersensitivity in young pigs would enhance the value and potential inclusion rate in diets of early-weaned pigs. The soybean protein can cause an immune response at the intestine, which impairs digestion, absorption, and ultimately productivity of the pig. The protein structure of soybean needs to be modified to alleviate the allergenicity of soybean meal to the pig. Such a modification would allow greater levels of soybean meal to be included into swine diets.

Isoflavones, contained within soybean seeds, have been shown to have various positive health benefits to humans. It is possible that similar types of health benefits would occur in animals as well—particularly in species where longevity was a parameter of importance, such as companion animals, horses, breeding livestock, and so forth. The isoflavones, being classified as phytoestrogens, induce their effect via estrogenic activities. The isoflavones are an example of how compounds either present in the soybean seed or capable of being placed into the soybean seed could have physiologic or metabolic effects that would enhance the productivity or longevity of an animal. The potential to formulate a diet that would offer a better quality of life and an extended life of a beloved pet would obviously have tremendous value.

Use of Soybeans in Animal Diets

Soybeans have historically enjoyed a prominent role in the formulation of animal diets. This presents soybean with a significant advantage in the marketplace. However, the animal feed market share currently held by soybean meal will not be maintained without modifications in soybean seed composition. There are two avenues that soybean can follow to enhance its position in animal feed markets. One is to identify new uses in animal feeds and the second is to select or engineer nutritionally important traits such as those identified above.

The use of fiber-rich soybean hulls has largely been focused upon ruminant feeding applications. However, the digestibility characteristics of this fiber greatly widen its potential use across various animal species. The benefits of fiber in companion animal diets are now becoming known, and there is little reason that soy hulls could not be strategically used for this purpose. We conducted research replacing the sucrose and starch in ape diets with soy hulls and found nutritional benefits to the high levels of digestible fiber. Horses also would be well adapted to high levels of dietary fiber, such as soybean hulls. The research needed is not so much characterization of the soybean hull (which in large part we already know) but rather emphasis on the nutritional quality of the soybean hull fiber across various animal species.

Research is also needed to expand the uses of soybean processing wastes (or by-products) in animal feeds. We have fed oil-refining wastes to reproducing cattle and demonstrated improvements of over 20% in first conception rates (believed to be due to the consumption of fatty acids in the waste). There is a myriad of waste streams coming from the crushing, extraction, and value-added processing of soybeans that have nutritional value, which would greatly benefit the profitability of soybean production and processing.

Conclusion

Demands on animal production exerted by environmental regulations, food safety, and production economics implore us to develop soybean seed compositions that not only allow animal production systems to meet these demands but also to gain productivity advantages. Such modifications are a prerequisite to maintaining and growing the market presence of soybeans in the animal feed market. Such accomplishment will require the coordination of breeding and genetic modification technologies with an understanding of the advancements needed to enhance food animal production.

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