Potential Of Biotech Crops As Livestock Feed

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Genetic engineering has been performed for centuries in plants and animals beginning with the selection of seed with desirable traits from superior plants and livestock and reproducing these through breeding. These methods have significantly increased productivity, with corn and wheat yields approximately doubling over the past 40 to 50 years, substantial improvements in milk yield per cow, more efficient use of feed and leaner pig meat, just to name a few. However, the rate of these gains (which is critically needed to help address the rapidly growing world population) will decrease without continued innovation. The projected doubling of the global population will require at least a doubling of the amount of food that will be needed in the next 40 to 50 years.

The ability to introduce DNA directly into crop plants enables a selective plant improvement process that promises to continue to enhance agricultural productivity as well as being environmentally sustainable. Numerous traits are being evaluated for their potential to: (a) protect plants against insect damage, fungal, viral or bacterial diseases; (b) provide selectivity to more desirable herbicides for improved weed control; (c) directly enhance crop yields; (d) increase nutritional value to animals and humans; (e) reduce naturally occurring toxicants or allergens; (f) modify the ripening process and provide superior flavor; (g) use plants as factories to make such products as biodegradable polymers or pharmaceutical products; (h) modify food composition for disease prevention; and many others. While biotechnology provides an important tool to help address many of these challenges, this tool must be effectively integrated with the best current agricultural practices that encompass the most productive and environmentally appropriate technologies around the world.

▪ Biotech Crops: Value to the Grower

Overall, the value of transgenic crops to the grower is demonstrated by the rapid increase in acres of land planted with biotech crops. In 2000, the global area of biotech crops increased to 109.2 million acres from 4.3 acres in 1996. of which 68%, 23%, 7% and 1% of the global acres were in the United States, Argentina, Canada and China, respectively, with some acreage in Australia, South Africa, Mexico, Spain, France, Bulgaria, Romania and Uruguay (James, 2000).

Insect-Protected Crops

- **The use of *B.t.* gene in crops results in improved quality, less pesticidal use, improved yields, improved profits, reduced mycotoxins and an increased number of beneficial insects.**

Insecticides and associated management practices that have been used traditionally to control insect pests cost approximately $10 billion annually worldwide. Yet 20 to 30% of total crop product is still lost due to insect pests. Insect-protected plants were among the first genetically modified plants to be field tested and marketed because of their importance, the value associated with effective insect control and the availability of microbial genes with insecticidal activity. Use of these products reduces chemical insecticide use, reduces energy and labor costs and improves the quality and quantity of the plant product . Recently Gianessi and Carpenter (1999) described and quantified the insect control benefits on the *B.t.* corn, *B.t.* cotton and *B.t.* potato acreage planted in 1997 and 1998. The effectiveness of this technology is demonstrated by successful launches of insect-protected potato, cotton and corn products. In 2000, about 27.5 million acres were planted in insect-protected or a combined insect-protected/herbicide tolerant crop globally (James, 2000).

Genetically modified *B.t.* corn plants have provided significant increases in yield and enhanced grain quality with reduced mycotoxin contamination. Research from Iowa State University and the U.S. Department of Agriculture (USDA) (Munkvold *et al.* 1997) showed a 96, 54 and 64% reduction in the severity of insect damaged ears with the *B.t*. gene in studies conducted in 1994, 1995, and 1996, respectively. These same researchers (Munkvold *et al.* 1999) reported a 78% and 87% reduction in mean total fumonisin concentrations (fumonisin B_1 + B_2 + B_3) in kernels where the hybrids were manually infested with neonatal European corn borer larvae in 1996 and 1997, respectively.

Herbicide-Tolerant Crops

- **The use of herbicide-tolerant crops results directly in weed control systems which provide improved seed quality, less herbicide use, improved yields, more efficient use of fertilizers, improved profits and reduced foreign matter in grain. Indirect benefits through the adoption of direct drilling include improved soil quality and conservation, increased carbon retention in the soil, reduced fuel use and emissions and improved wildlife habitat.**

Biotechnology provides an opportunity to modify crops to tolerate selected herbicides with desirable environmental properties, such as glyphosate, the active ingredient in Roundup® herbicide, and glufosinate, the active ingredient in Liberty® herbicide. These herbicide-tolerant crops allow the farmer to apply herbicide to planted fields, killing weeds but leaving the planted crop unaffected, providing increased flexibility and value to growers. In addition, farmers can move from using pre-emergent, soil incorporated herbicides to post-emergent herbicides that are applied on an "as needed" basis. This strategy can reduce the number and total amount of herbicides used and enable the application of herbicides that bind tightly to the soil and are rapidly degraded so that they are less likely to enter the ground water. These products also make it easier for farmers to move to no-till farming methods that provide significant environmental benefits.

Plants Engineered For Disease Resistance, Improved Nitrogen Assimilation and Tolerance to Environmental Extremes

- **The use of disease resistance, tolerance to environmental extremes, and improved nitrogen assimilation in crops are expected to result in improved quality, improved yields, more efficient use of fertilizers, improved profits and access to land now unusable for crop production.**

Disease can have a major economic impact on the food supply. For example, wheat head scab caused by the fungus *Fusarium graminearum* has caused a loss of over one billion dollars in the Northern Great Plains and the Eastern U.S. three times in the 90's. As a result of the potential impact of disease on yield, fungal disease resistance is being introduced into corn and wheat. Virus (potato leaf roll virus) and disease control for late blight and Vetricillium are new product improvements for potatoes. Viral resistance, bacterial leaf blight and fungal disease control for Blast and Sheath Blight are being developed for rice.

Improved nitrogen assimilation will provide value to the grower as well as the environment. The grower will be able to optimize the crop's response to fertilizer, leading to increased yield potential. Plants will have the capacity to more efficiently use the nitrogen applied. In addition, the quality of the crop may be improved through increased protein content in seed and leaves. The environment benefits as a result of decreased nitrogen leaching into the ground water.

There are many environmental situations that limit the ability of the current crops to grow and produce yields of economic value in many areas of the world. Active research programs are in place to develop crops that are cold tolerant, drought tolerant, salt tolerant, can withstand flooding, tolerant to high aluminum levels, to name a few. Crops with these traits will open up new areas of land that are unusable for crop production today.

■ Biotech Crops: Value to the Livestock Producer

- **Biotech crops of the future will help improve profitability, feed utilization, performance, meat and milk quality and health of livestock as well as providing important environmental benefits.**

The initial genetic modifications of plants have focused on improved agronomic traits such as insect-protected, herbicide-tolerant and virus-resistant traits which primarily benefit the grower. Since these crops and their co-products are substantially equivalent to their conventional counterparts, one would expect animals fed these crops to perform in a similar manner. In fact, published research has shown that livestock fed crops containing herbicide-tolerant or insect-protected traits indeed perform in a similar fashion with no adverse effects as compared to animals fed the nontransgenic conventional products (Table 1).

Table 1. Comparison of Livestock Performance When Fed Biotech Crops Versus Their Conventional Controls.

Crop	Animal	Description	Results	Ref. *
Trait: Insect-Protection (B.t.)				
Corn grain	Chicken: broiler	35 to 42 d performance	No difference in intake, gain or feed efficiency	1,2 3
Corn grain	Chicken: laying hens	Digestibility	No differences in dig. OM, CP or metabolizable energy	4
Corn grain	Pigs	Performance	No difference in intake, gain, feed efficiency or carcass quality	5
Corn silage	Sheep	Digestibility	No differences in dig. OM, fat, fiber or NFE	6
Corn silage	Growing beef	Performance	No differences in gain, intake, feed efficiency or carcass quality	7,8 9
Corn stover	Beef cows & steers	Grazing	No difference in preference or body weight	8,9 10 11
Corn plant	Dairy cows	Performance	No difference in milk yield , composition, intake	12
Corn silage & grain	Dairy cows	Performance	No difference in milk yield, composition, feed intake or rumen parameters	13
Corn silage	Dairy cows	Digestibility	No differences	14
Trait: Herbicide-tolerance				
Corn	Pigs	Digestibility	No differences	15
Corn	Dairy cows	Performance	No difference in milk yield, composition or feed intake	16
Corn	Chicken: broiler	38-40d performance	No differences in feed intake, gain, feed efficiency	17
Sugar beets	Pigs	Digestibility	No differences	15
Soybeans	Dairy cows	Digestibility & performance	No differences in milk yield, composition, feed intake, digestibility or rumen parameters	18
Soybean meal	Chicken: broiler	Performance	No differences in feed intake, gain, feed efficiency	18

***** 1 - Brake and Vlachos, 1998; 2 - Halle *et al.,* 1998; 3 - Mireles, *et al*., 2000; 4 - Aulrich *et al.,* 1998; 5 - Weber *et al.,* 2000; 6 - Daenicke *et al.,* 1999; 7 - Hendrix *et al.,* 2000; 8 - Folmer *et al.,* 2000a; 9 - Russell and Peterson, 1999; 10 - Russell *et al.,* 2000a; 11 - Russell *et al.,* 2000b; 12 - Faust and Miller, 1997; 13 - Folmer *et al.,* 2000b; 14 - Mayer and Rutzmoser, 1999; 15 - Böhme and Aulrich, 1999; 16 - Donkin *et al*., 2000; 17 - Sidhu *et al*., 2000; 18 - Hammond *et al*., 1996.

Attention is turning quickly to value-added traits that directly benefit the livestock producer (Araba, 1997; Owens and Sonderlund, 2000; Sauber, 2000). Efforts are underway to genetically modify plants to enhance protein quality of cereals, increase protein content, modify amino acid composition (emphasis on lysine and methionine), modify starch and oil compositions, increase the oil content, reduce protease inhibitors, decrease lectin content in soybeans, reduce oligosaccharide (Parsons *et al.* 2000), increase levels of oligofructans, enhance vitamin content and produce compounds that result in increased feed efficiency and performance (Bajjalieh, 1996). High oleic acid soybean will provide high energy concentrations. Grains with oligofructans may reduce the need for antibiotics. The transformation of active components found in botanicals into crops may offer a future substitute for antimicrobials. Holden *et al.* (1999) summarized three trials that examined the use of garlic, echinacea and peppermint on growth promotion and meat quality in swine. Garlic has shown antimicrobial, antiviral and possesses activity against common intestinal roundworms and hookworms. Echinacea is stated to possess antibacterial activity in some cases and immuno-enhancing properties. Peppermint has demonstrated antiviral, and antimicrobial activity. The feeding of garlic at 0.5, 2.5 and 5.0% of the diet to nursery pigs for five weeks resulted in poorer performance and objectionable odor in the meat as compared to the control. However, in studies with chickens, feeding a 2 to 4% inclusion rate of garlic had a protective effect when chickens were subjected to candidases and feeding 5% eliminated the candida infection. Feeding nursery pigs 0.1, 0.5 and 2.0% echinacea in the diet or 0.5, 2.5 and 5.0% peppermint in the diet resulted in no benefit in performance. Through biotechnology a more precise selection of specific active agents may help in overcoming the negative or lack of effects observed in these studies.

Grains with an increased amino acid content may reduce or eliminate the need for amino acid supplementation. Douglas *et al.* (2000) evaluated Nutri-Dense® (genetically modified corn from Exseed Genetics, Decatur, IL) using the precision-fed cecectomized rooster assay. The Nutri-Dense® corn averaged 13.1% CP, 0.42% lysine, 0.24% methionine and 0.26% cystine. The true digestibility coefficients of amino acids were similar (88.6%) as compared to conventional corn (88.5%). Thus, the protein enhanced corn contained substantially higher amounts of digestible amino acids than the conventional corn. Edwards *et al.* (2000) evaluated soybean meal from conventional and two genetically modified soybeans. The crude protein levels of the soybean meal samples were 52.5%, 53.4%, 62.7% and 42.7% for pilot plant processed conventional, genetically modified, high protein genetically modified, and commercially produced soybean meal, respectively. Digestible lysine, methionine, cystine, threonine and valine as well as TME_n were higher for the high protein biotech soybean meal as compared to the other meals using the cecectomized cockerel assay. Parsons *et al.* (1997) also reported similar digestibility of amino acids in properly processed high lysine soybean meal. They did indicate the high lysine soybean meal may be more sensitive to overprocessing.

Producers may have the ability to select specific grains or protein sources that were designed for optimizing performance and profitability of their particular livestock enterprise. White and Higgins (2000) reported an eight percent increase in wool growth and seven percent increase in live weight gain in sheep fed modified lupin. Lupin was genetically modified to contain a sunflower gene that produces a protein that is both rich in sulfur amino acids and stable in the sheep's rumen. Dado (1999) reviewed the nutritional value of different corn hybrids (high lysine, high oil, high protein) and their economic value for lactating dairy cows. Table 2 contains the results from the economic evaluation. All specialty corns reduced total feed costs compared to regular corn when the price was the same. High protein corn is the most economical with herd lactation averages of 9520 kg and less whereas high lysine corn is the most economical for herds with greater than 9520 kg production. Dado (1999) concluded that both ruminally undegraded lysine and oil will become more valuable selection criteria as milk production of US herds continues to increase.

Table 2. Total feed ingredient costs of diets using a specialty corn grain across an entire lactation for cows with different milk production.[1]

	Milk Production[2] ($ per cow per lactation)			
Corn type	**7705 kg**	**9520 kg**	**11,335 kg**	**13,150 kg**
Regular	939	1087	1230	1323
Enhanced high lysine[3]	935	1072	1206	1293
High oil	933	1076	1212	1300
High protein[4]	923	1071	1215	1310

[1] Ingredient costs: corn = $118/tonne, alfalfa = $132/tonne (hay equivalent), soybean meal = $248/tonne, and tallow = $385/tonne. Diets were overformulated by 4.5 kg/d of milk.
[2] Kilograms per lactation.
[3] Reflects nutrient value of possible future hybrids containing high amounts of ruminally undegradable lysine.
[4] Possible future hybrid containing 3% units more protein than regular corn.
Source: Dado (1999)

Stock (1999) reviewed the effects of nutritional changes in cereal grains from genetic modification in beef feedlot diets. One of the earliest examples of genetic manipulation was the introduction of tannins into grain sorghum hybrids to decrease losses from birds and preharvest mold. The beneficial change also resulted in decreased digestibility of the grain. Efforts continue to improve digestibility without sacrificing grain yield, drought or heat tolerance. Data on the evaluation of waxy corn, high lysine corn, high oil corn and other grains in beef feedlot diets is limited. Results to date are variable.

Stilborn (1999) recently examined the future of designer grains for nonruminants. Benefits from feeding high oil corn (HOC) to broilers may include a reduction in abdominal fat and increased breast meat yield when diets contain similar nutrient to energy ratios as the yellow corn control diets. HOC may be used to increase the energy intake of the laying hen during peak production. In swine diets, HOC can be used to either increase dietary energy density or replace yellow dent corn and supplemental fat. Nutritional inputs to consider include high lysine and/or high methionine high oil corn, high lysine, methionine or protein in corn and soybean meal with high lysine or methionine concentrations. High oleic acid high oil corn will offer livestock producers the ability to modify the fatty acid profile of lipid deposited in the carcass resulting in improved processing, storage and consumer preference properties.

Nutritional value of genetically improved high lysine, high oil corn was evaluated in young pigs (O'Quinn *et al.* 2000). Researchers reported the lysine in the high lysine, high corn was as available as that in the high oil corn based on results of a pig digestibility and a performance trial. High lysine, high oil corn offers the potential to reduce the amount of supplemental protein and/or lysine and energy needed in swine diets.

Baumel *et al.* (1999) evaluated the impact of six corn modifications used in least-cost swine and poultry feed rations. The six corn modifications were 1) increased protein by 8 percentage points (from 8.7 to 16.7% dry matter basis); 2) enlarged germ size (from 11.1 to 27.1% of kernel size); 3) increased starch digestibility by 8 percentage points in poultry diets; 4) doubled methionine content (from 0.207 to 0.414% dry matter basis); 5) doubled lysine content (from 0.30 to 0.60% dry matter basis); and 6) doubled available phosphorus (from 0.068 to 0.12% dry matter basis). Their analysis estimated the impact of each modification on increased corn consumption, changed consumption of traditional ingredients, net value of the modified corns and range of possible price responses for traditional feed ingredients. Price of the modified corn was the same as the price used for the conventional corn.

The increase in protein percentage had the highest savings per ton of feed ($11.75) and the greatest impact on the consumption of corn and soybean meal. Increasing starch digestibility followed by increasing germ size had the next largest effect on cost per ton of feed and the largest impact on feed fat consumption. The small economic impact of available phosphorus would indicate that it would be used when environmental policies dictate.

The per bushel added values of the six modifications in swine and poultry diets are summarized in Table 3. These are gross values since the added costs of providing these modifications were not subtracted from the added values. The added value of each of the six genetic modifications of corn was obtained by dividing the feed savings by the quantity of modified corn used in the feed. Estimates of added value were calculated only for diets in which each modification would likely add value. In swine rations, high protein had the largest benefit with 15.6 to 29.4 cents per bushel of corn. Modifying corn to contain high protein, enlarged germ or high starch digestibility significantly benefited the poultry producer ranging 27.1 to 57.4 cents per bushel of corn.

Table 3. Added values for six genetic modifications of corn in swine and poultry rations, in cents per bushel.

	------------Swine------------		----------------Poultry--------------------		
Modification	**8-13 lb. piglets**	**233-283 lb. finishers**	**Broilers**	**Tom Turkeys**	**Layers**
High protein	29.4	15.6	57.4	45.0	27.1
Enlarged-germ	0.0	10.3	48.0	44.2	36.3
High starch digestibility	---	---	39.8	33.4	31.1
High methionine	---	---	7.4	4.1	5.7
High lysine	0.0	5.2	---	---	---
High available phosphorus	1.7	1.7	---	---	---

--- Indicates that estimates were not calculated in these diets.
Source: Baumel *et al.* (1999)

In summary, the estimated least-cost feed ration data by Baumel *et al.* (1999) show that modified corn with enhanced nutrient content would decrease the cost of swine and poultry diets and decrease the consumption of other major feed ingredients. The greatest value in nutrient modification is increased protein and oil content in swine and poultry rations and increased starch digestibility in poultry rations.

One of the current agronomic traits (incorporation of the *B.t.* gene) has already proven beneficial in the reduction of mycotoxins in corn (Munkvold *et al.* 1999). This trait in itself is very valuable since it helps reduce the incidence of mycotoxicosis in livestock and increases the likelihood of the producer selling this grain. Genetically enhancing the mannanoligosaccharide level in grain may also be beneficial in counteracting the effects of mycotoxins. Recent research has shown the supplementation of the diet with modified mannanoligosaccharide to be beneficial in counteracting the adverse effects of dietary mycotoxins on the immunological status of broiler breeder hens (Afzali and Devegowda, 1999) and significantly improving body weight, feed consumption and antibody titers in broilers (Raju and Devegowda, 1999).

Plant breeders have made great strides in reducing or eliminating some undesirable constituents of feeds such as erucic acid and glucosinolates. However, with the use of biotechnology, in conjunction with plant breeding, a greater number of anti-nutritionals can be addressed in a shorter time period. For example, in legumes there are protease inhibitors, tannins, phytohemagglutinins and cyanogens. Anti-nutritionals in oil seed rape include thioglucosides, also known as glucosinolates, whose degradation products are goitrogenic and heptatoxic, tannins and sinapine (affects palatability and can result in a fishy taint in eggs of certain strains of laying hens) (Armstrong and Gilbert, 1989). Soybean contains lectin, proteins that bind carbohydrate containing molecules (Sauber, 2000). Barley grain contains significant amounts of β-1,4 glucan which results in increased viscosity and poor performance in monogastrics. Currently, β-glucanases and xylanases are being added to barley-based diets to overcome this problem for poultry and swine. Fungi and plants are now being bioengineered to produce these specific enzymes. In the future, low β-1,4 glucan barley and/or barley already containing the glucanase and xylanase enzymes in the seed may be bioengineered.

Nutritive value of roughages and forages will be enhanced through improved fiber digestibility (Armstrong and Gilbert, 1989). The plant may contain lignin, cellulose and hemicellulose that are more easily degraded or cellulase, hemicellulase and lignase enzymes may be bioengineered into plants or rumen microbes that enhance the utilization of these energy sources. Low lignin corn is already here via plant breeding. The brown mid rib mutant gene was identified and bred into certain lines of corn. This product contains about 40% less lignin than its parental variety. Enzymes could be genetically engineered to convert roughages to substrates now utilizable by monogastrics. Microbes (silage microbial innoculants) could be genetically modified to enhance the fermentation process of forages in silos.

Mineral bioavailability will be improved to make more efficient use of the minerals in plants and reduce the contribution to the environment where leaching can occur in streams and lakes. Phosphorus is the main mineral of concern at this time. Phosphorus is locked up in the plant as phytate phosphorus. Monogastric animals do not have the necessary enzyme machinery to access the phosphorus so it ends up in animal waste. The waste is applied to the fields where leaching and run-off can occur. To prevent this problem phytase enzyme is added to poultry and swine feed to unlock this valuable mineral (Stilborn, 1999). Through biotechnology, plants will contain low phytate (high available phosphorus) or phytase activity thus allowing for more efficient use of phosphorus with reduced supplementation of inorganic sources and (Douglas *et al.*, 2000; Stilborn, 1999).

Efforts are underway to bioengineer plants to produce proteins that illicit positive health effects in animals. In particular, the chicken interferon gene is being incorporated into corn so a particular protein can be produced in the seed as a vaccine to help combat avian influenza and help keep chickens healthy. The market (estimated $1.7 billion market for chicken vaccines) is high because farmers who raise the world's 18 billion chickens live in fear of the outbreak of virulent avian influenza strains. Recently ProdiGene (College Station, Texas) received a patent covering viral disease vaccines produced in genetically enhanced plants (Feedstuffs, Vol. 71, 1999). The vaccines produced via this technology can be marketed either in edible form, made from parts of the fruit, vegetable or grain plant or in injectable form. Hepatitis B in humans and transmissible gastroenteritis virus (TGV) in swine are two diseases being targeted. Clinical trials for the TGV vaccines are underway. Other oral vaccines under development for swine include vaccines against porcine reproductive and respiratory syndrome (PRRS) and diseases like parvovirus (http://agbio.cabweb.org/news/research.htm).

▪ Biotech Crops: Value to the Feed Manufacturer

With the rapid change in the genetic make-up of crops, corn will no longer mean traditional corn, soybean will no longer mean traditional soybean. The livestock producers will need increased technical expertise to advise them as to what are the best products and combinations to optimize the profitability of his/her livestock enterprise. There will be many different varieties of corn, soybean meal and other crops with different oil, fatty acid compositions, protein, amino acid combinations, vitamin and available mineral levels. The feed manufacturer will have to assess the needs of their market and provide the best possible products for their customers. These products will provide greater flexibility by providing alternatives to optimize feed formulations.

Crops utilized by the feed manufacturer may be engineered to reduce the energy required to grind, improve feed mixing efficiency and contain compounds that enhance the durability of pellets while using less energy in the production process. Manufacturing costs may be improved by increasing flow through using less energy. As a result of improved and more consistent quality of feed ingredients (less foreign material), the variability of the nutrient content may be decreased thus allowing for the formulator to reduce the amount of overages needed to meet label guarantees for proteins, fat, amino acids and minerals. In addition, grain and protein sources containing more balanced nutrients may reduce the need for additional vitamins, fat sources, enzymes and synthetic amino acids. This allows more flexibility for the formulator and more flexibility for use of bin space at the manufacturing facility.

▪ Conclusion

The benefits of biotech plant products are becoming well accepted as the first products are established in the market place. Initial benefits are realized primarily by farmers who produce crops with increased yields and quality while requiring less chemical inputs and the use of more environmentally compatible practices. Indirectly, livestock producers are benefiting through an even safer feed source as a result of the reduction in fumonisin observed with insected-protected corn and the reduced use of pesticides and herbicides. Future generations of genetically modified plant products will include products with enhanced nutritional qualities that will directly benefit livestock producers and improve the diets of people globally. These innovations will be key to feeding the increasing world's population.

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