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Feeding animals with GM crops: Boon or bane?

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Genetically modified (GM) crops with higher yields and better quality are currently being used in the feeds of livestock and fishes. Despite the advantages, there are concerns about GM-feeds including their effect on animal health, performance and safety of the consumers of animal products like milk, meat, egg and fish. Studies are conducted to assess the feeding efficiency of GM-crops in livestock feeds. The safety aspects of these feeds are also examined in considerable number of experiments. Results from some of the feeding trials indicate that GM-crops are substantially equivalent in terms of composition, digestibility and feeding value. Transfer of transgenic DNA and protein from GM-crops to animal products is a critical safety concern that is also being examined. In the present article, efforts have been made to review different safety concerns of GM-feeds in livestock and fishes.

Keywords: Genetically modified (GM) crops, livestock, safety assessment

Introduction

Agriculture and livestock being the main stay of developing countries, the demand for livestock products increases dramatically as population increases. Moreover, with increasing urbanization and rising income in many parts of the developing world, per capita consumption of meat, milk, and eggs is expected to rise by about 2%[1]. Global demand for meat is also forecasted to increase by more than 55% of current consumption by 2020, with most of the increase occurring in developing countries[2]. Huge proportions of crop harvest are used as animal feed. The compound feed of pigs, poultry, dairy cows and other livestock is prepared using a range of raw materials, including soya, maize, oilseed rape, cotton seed, canola and other grains. World's 90% of soya produced is used in animal feed[3]. Thus the demand for feed grain is expected to increase by 3% per year in developing countries and 0.5% in developed countries. On an average, less than 3 kg of feed grain are required to produce 1 kg of livestock meat and less than 1 kg of feed grain per kg of milk[4].

Genetically modified (GM) crops are the plants whose genomic DNA is modified using genetic engineering techniques[5,6]. In most cases, the aim is to introduce a new trait to the plant which does not occur naturally in this species. The new traits may include resistance to certain pests, diseases or environmental conditions, or the production of a certain nutrient or pharmaceutical agent. Livestock have been fed with GM crops since these crops were introduced in 1996. GM crops have indirectly benefited the livestock sector as they have increased yield of feed ingredient and have better quality traits. These crops are principally used in livestock feed rations either as an energy and/or protein source. The conventional crops like rapseed and mustard oil cake can be readily used as a protein supplement for ruminants but presence of glucosinolate may lead to pungent smell and bitter taste of the feeds after producing substances on hydrolysis by endogenous enzymes[7,8]. Thus considering the quality concern of the feed as well as other aspects like pest control, disease as well as herbicide resistant, GM crops for feeding trails have upper hand.

In spite of these apparent advantages of GM crops on animal production, there are real concerns expressed by the consumers of animal origin food. Since supermarkets make every effort to remove GM ingredients from human food but GM crops and grains are continuously being fed to farm animal at large scale. GM products especially those fed to

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animals, such as, pig, cattle and poultry have been targeted by anti-GM campaigners. There are considerable number of studies examining the effect of these GM crops fed to animals on animals themselves and also on the human health *via* animal products, such as, meat, milk and eggs. The studies are designed to address three questions: 1) Whether foreign DNA inserted/modified in the GM crops affects the farm animal health on feeding; 2) whether foreign DNA gets accumulated in the animal products (milk, meat & egg); and 3) whether consumption of such products in anyway affects human health? Environmental protection agency, the Department of Agriculture and the Food and Drug Administration, reviews observed no risk to mammals when fed with approved GM crops. But there are other safety issues including high anti-nutritional factors, adverse effect on animal health and broader environmental concerns for growing GM crops like imbalanced biodiversity, cross pollination of GM and native crops. The studies should bring consensus among the scientific community and general public regarding relative benefits and adverse effects of animal products obtained by feeding GM crops.

Global Scenario of GM Crops Used for Feeding Livestock

The total global area sown with GM crops in 2010 was estimated as 148 million hectares in 29 countries (up from 134 million hectares in 25 countries in 2009). This was the 15th consecutive year of increase in the area devoted to GM crops, with much of the increase being in developing countries. These were responsible for 48% of the world's GM crop production. It is estimated that 90% of the 15.4 million farmers grow GM crops are located in developing countries, such as, China, India, the Philippines and South Africa, and that most of these farmers are producing on a smaller scale than their industrial-scale equivalents in USA. USA is the largest producer of GM commodity crops. In 2010, it grew 66.8 million hectares, followed by Brazil in second place with 25.4 million hectares and Argentina in third place with 22.9 million hectares. The other top 10 GM commodity crop producing countries, each with more than 1 million hectares in production, are (in order) India, Canada, China, Paraguay, Pakistan, South Africa and Uruguay. The leading GM crop in the America is soybean, which (by volume) accounts for more than ½ of all the GM crops grown worldwide. GM maize is the second most common crop, accounting for ⅓ of global GM production, again mostly from the America. Canada is the leading producer of GM oilseed rape. Brazil, India and China account for the bulk of GM cotton production (http://www.food.gov.uk/businessindustry/farmingfood/animalfeed/animalfeedlegislation/). Although numerical estimates for 2010 are not available, estimates for previous years have indicated that GM varieties now constitute a high proportion of crops grown in countries that are net exporters to the world market. For example, it was reported in 2009 that, in USA, GM accounted for 85% of maize plantings, 88% of cotton plantings, 91% of soybean plantings and 95% of sugar beet plantings. In Argentina, in the same year, GM varieties accounted for almost all of the soya plantings and 65% of maize plantings; in Canada, GM varieties formed 93% of the oilseed rape crop; and GM cotton accounted for 40% of Brazil's cotton production, 87% of Indian cotton output and 68% of Chinese cotton (http://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us.aspx).

The principal GM crops modified for agronomic input traits are soybean (36.5 million ha), maize (12.4 million ha), cotton (6.8 million ha) and canola (3.0 million ha)[9]. With a few exceptions, these crops have been modified for herbicide tolerance and/or insect resistance. These crops are all used in livestock production rations as either energy and/or protein feed resources. They are included either in the form of whole crop (maize silage), from a specific component of the crop (maize grain) or as co-products, such as, oilseed meals. The largest use made of first-generation GM crops in livestock production is that of oilseed meals. For example, since it is estimated that over 150 million tonnes of soybean were produced in 2002 and that approx 50% of the global area was planted to GM soybean, then approx 35 million tonnes of GM soybean meal was used by the livestock industry. In addition, significant quantities of maize grain, canola and cottonseed meal and maize silage have been incorporated into livestock rations.

GM Crops as Feed Ingredients for Farm Animals

Livestock digest and absorb nutrients from GM crops in the same way as conventional feeds. The digestive process in all farm animals breaks down the nutritional components in feeds and uses these nutrients for the growth and development. Livestock producers in many parts of the world prefer corn grain and soybean meal for energy and/or protein source in both monogastric and ruminant diets. About 90 million metric tons of GM corn grains are produced worldwide, of which 65 million metric tons of grains are used in livestock diets annually (~70%)[10]. In case of soybean, about 70 million metric tons of soybean meals derived from GM soybean are fed to livestock per annum[11]. Most crops developed through biotechnology that are on the market today provide farmers with increased convenience and product quality while requiring fewer chemical inputs. According to the USDA, livestock require approx 70 per cent of the soybean and consume 80 per cent of the corn grain and silage grown in the USA making the livestock industry a major user of biotech crops (http://www.ers.usda.gov/data/biotechcrops). Plant breeders are concentrating on enhancing grains or protein sources to produce feedstuff that will improve feed utilization, performance, product quality and health of livestock, while reducing production costs and environmental impacts. It is likely that biotech crops of the future will play an important role in this arena.

Risks and Concerns of GM Crops

Many public organizations, environmental activists, professionals and some governmental officials criticize the use of GM foods. GM foods are blamed for bringing only economic benefits without concerns for potential hazards emanating from them. Broadly the concerns against GM foods fall into three categories: Health risks, environmental hazards and economic concerns.

Human and Animal Health Risks

Unexpected mutations can increase the toxicity level in the GM crops[12] and genetic modification may provoke allergic reactions to the GM feeds. Introduction of genes into the crops from known allergenic plant is always avoided for the fear of causing unexpected allergic reactions. One such case of allergenicity was assessed in GM soybean, which has come from Brazilian nut[13]. Extensive testing of GM crops is essential to avoid potential food allergy cases in animals and human beings. Inserting a foreign gene can also be a source of unwanted negative effect on animal health. The study conducted in rats fed with GM potato showed harmful effects on their intestine compared to the conventional potato fed rats[14]. But the GM potato used in this study was not intended for human or animal consumption as the gene (snow drop lectin) introduced in the experiment was known to be toxic for mammals. A 90 days safety study for GM rice conducted in rats found no significant adverse effects on their health[15]. However, there is a growing debate over the adverse effects of GM food on health with controversial interpretation of biological data and divergent opinions[16]. The recent among them is the raging controversy associated with the Bt brinjal in India (http://www. sciencebeing. com/2013/02/bt-brinjal-and-its-controversy-in-india/). Although it has beneficial impact on small farmers because of its insect resistant potentiality, high yielding power, cost-effectiveness and most importantly the minimal environmental impact, but there are also many disadvantages associated with the production and use of Bt brinjal, such as, it's possible adverse impact on human health as well as biosafety, livelihood and biodiversity. This clearly shows the need of sound experimental set up, followed by valid data collection and interpretation.

Environmental Hazards

GM crops pose many environmental and biodiversity related concerns[17]. The effect of GM crops on nontarget organisms (insects) is well documented. Bt insect toxin of GM crops can kill insects other than crop damaging pests. Monarch caterpillars consume milkweed plants instead of corn, but the pollen from Bt corn blown by the wind onto milkweed plants kills the caterpillars[18]. Such effect on other beneficial insects is detrimental to the biodiversity. There is also growing concern of faster induction of resistance to Bt in insects. In the view of the coexistence of GM and non-GM crops, there is a concern that weeds can acquire herbicide resistance genes by cross pollination leading to a condition like superweeds. Herbicide resistant GM crops encourage farmers to use more herbicides resistance crops, bringing the problem of herbicide residues, altering the plant and wild life biodiversity and a decreased use of the important practice of crop rotation in certain local situations. GM crops detrimental effect on the environment and their assessment criteria are being increasingly studied[19]. Recently, for the first time, the presence of GM maize in Turkish food and feed products has been demonstrated qualitatively after screening the presence of CaMV 35S promoter, *nos* terminator and Bt11 maize[20].

Economic Concerns

Companies always patent GM plants for economic returns. Corporates sell GM seeds at premium prices that the small and marginal farmers cannot afford to purchase. This has widened the gap between rich and poor farmers and resulted in the decline and destruction of the self sufficient family farms.

Safety Assessment of GM Feeds of Livestock

Extensive testing and a long approval process accompany with the every introduction of GM crop[21]. The approval process includes comprehensive analyses to ensure food, feed, and environmental safety before a GM crop enters into the market place. The livestock feed of GM origin always assessed for its nutritional composition and digestibility by comparing it with the conventional crop[22]. OECD (Organisation for Economic Co-operation and Development) formulated the concept of a substantial equivalence as a starting point for the safety assessment of GM crops[23-25]. The concept is based on comparison of GM crop with the nearest non-GM crop, which has the long history of safe consumption. The only difference between them is the composition with respect to the presence or absence of target protein in GM crop, giving it a desired trait[26]. Agronomic, phenotypic and compositional analysis of key nutritional components is the basis for establishing substantial equivalence. This comparison is not a safety assessment *per se* but helps to identify similarities and differences between conventional and GM crops. Other critical safety assessment tests include examination of properties of protein produced by the introduced gene in the GM crop, especially its possible toxicity and allergenicity in animals when used as feed [27]. The studies are also necessary to examine the effect of feeding GM crops on animals themselves and also the effect of these crops on animal products, such as, meat, milk and eggs. The foreign DNA in transgenic crop is being viewed as one of critical component. Studies were conducted to detect the presence of recombinant DNA of the GM crops in the animal tissues and products derived from the animals,, such as, milk, meat and egg. According to Faust[28] and Flachowsky and Aulrich[29], transgenic DNA had not been found in milk, meat or eggs derived from animals receiving GM feed ingredients in their diets. Similarly no GM DNA could be detected in any of the milk samples where the detection limit for the test was established at 7.5 µg/L of milk. When DNA was extracted from the diet, the yield obtained was equivalent to 0.16 g/20 kg DM, which was the average daily feed intake/cow/day. And even if fragments of transgenic DNA have been detected in the study, it should be noted here that the World Health Organization[30] has reached to the conclusion that there is no inherent risk in consuming DNA, including that from GM crops. The basis of the conclusion has been the fact that mammals have always consumed significant quantities of DNA from a wide variety of sources, including plants, animals, bacteria, parasites and viruses. This is also not considered as a safety issue by regulatory agencies in US, Canada, Japan or the EU. Scientific studies have also demonstrated that transgenic DNA and/or protein expressed in GM crops are not detectable in the raw food products derived from animals fed with transgenic crops[31,32]. Animal digestive system rapidly degrades DNA and proteins. Moreover, studies have shown that ensiling and feed processing resulted in DNA fragmentation[11]. Based on the safety analyses required for GM crops, consumption of milk, meat, and eggs derived from farm animals fed with transgenic crops could be considered as safe as traditional counterparts. Numerous scientific studies evaluating animal performance on GM feed have also been performed on beef cattle, swine, sheep, fish, lactating dairy cows, and chickens[33].

Feeding GM Crops in Large Animal

GM crops are being increasingly utilized to feed cattle and buffaloes[34,35]. Several studies were carried out to evaluate these GM crops on performance of dairy and beef cattle including their safety aspects. According to Singhal *et al*[36], no statistically significant variations in terms of fat, protein, lactose, SNF and total solids content existed in milk composition of dairy cows receiving GM and non-GM feeds. Further, Bt protein (Cry1Ac) was not detected in the milk samples, collected at various intervals, after incorporation of Bt cotton seed in the ration of cows[37]. Similar results were reported while feeding Bt cottonseed, BG-II cottonseed and Bt corn silage[38,39]. These results suggest that the Cry1Ac protein consumed by cows through Bt cotton seed either got degraded in the rumen or not absorbed across the intestinal mucosa into the blood circulation. Similarly, Lutz *et al*[27] used ELISA and immunoblotting methods to prove that Cry1Ab protein from genetically modified maize were degraded in the digestive tract. Bohme *et al*[40] reported that feeding ruminants as well as pigs with transgenic maize and sugar beet, where glufosinate-tolerant (*Pat*) gene is inserted, did not show any influence on the feeding value. Similarly, Donkin *et al*[41] reported that feeding of lactating dairy cows with European corn borer (*Ostrinia nubilalis*) infestation resistance Roundup Ready (RR) corn (Bt-MON810) did not interfere with dry matter (DM) intake, milk production and composition. Grant *et al*[42] and Chowdhury *et al*[43] demonstrated that GM-corn line resistant to root worm and glyphosite had no significant affect on DM intake (DMI), crude protein (CP), acid and neutral detergent fiber, and non-fiber carbohydrates for lactating dairy cows. It has been noticed that feeding of bovine with transgenic Bt-176 maize had no significant influence on the composition of the ruminal microbial population[44]. It has also been demonstrated that Bollgard-II cotton seed (producing the Cry1Ac and Cry2Ab2) was compositionally and nutritionally equivalent to conventional cotton varieties for food and feed in ruminants[45]. Phipps *et al*[11] showed that feeding of cows with herbicide-tolerant corn silage did not affect milk yield, milk composition, dry matter (DM) intake. Further, Russell *et al*[46] reported that feeding of beef cattle with Bt-corn hybrids (Pioneer 34RO7, Novartis NX6236 and Novartis N64-Z4) did not have any effect on beef yields. Several feeding trials have been conducted to examine the safety and efficacy of GM feeds in ruminants[40,47-58] (Table 1). Most of these studies have shown no significant difference in terms of digestibility, milk production, milk composition and feed efficiency between those fed either GM or non-GM crops. Thus, these studies support the view that GM feed ingredients are nutritionally equivalent to their isogenic non-GM counterparts.

Feeding GM Crops in Small Animals

GM crops are utilized to feed pigs and small ruminants including sheep and goats similar to large animals. Different feeding trials were conducted to assess nutritional and safety concerns of GM crops. Piva *et al*[15] reported that the performance of the pigs was significantly higher when offered the GM based diet. This was attributed to the fact that GM crops were insect protected and hence were not affected by fungal damage and had lower mycotoxin content as compared with the conventional maize grain. Reuter *et al*[59] confirmed that the performance of grower-finisher of pigs remained unaltered after feeding genetically modified (GM) Bt-maize (NX6262). Questions regarding the digestive fate of DNA and protein from GM crops fed to animals have been raised. Using highly sensitive and well-characterized analytical methods, pork loin samples were analyzed for the prence of transgenic DNA

Table 1—Large animal feeding trials for nutritional and safety assessment of feeds from GM crops

GM crop	Experimental animals	Remarks	References
GM corn (insect tolerant)	Dairy cattle	No difference was observed in carcass characteristics; performance not negatively affected, suggesting that rootworm-protected hybrid corn grain is similar to conventional, non-transgenic corn grain.	47
Glufosinate-tolerant sugar beets & maize	Ruminants	No differences were observed in the digestibility and metabolic energy of macronutrients.	40
Bt corn	Beef cattle lactating cows	No grazing preference and feeding effinciency were observed between Bt and non-Bt corn residue in steers. No effect of the Bt trait was observed on efficiency of milk production, ruminal pH and acetate:propionate ratio.	48-50
GM corn silage	Dairy cows	Transgenes did not affect nutrient composition of the silages and had no effect on animal performance and milk composition. No transgenic DNA and Cry1Ab protein were detected in milk.	51,52
Glyphosate-tolerant corn hybrids	Lactating cows	No differences were observed for dry matter intake, rumen degradability and milk composition.	53
Bt cotton seed	Water buffaloes	Transgenic cottonseed and non-transgenic cottonseed had similar nutritional value without any adverse effect on health status of buffaloes as assessed from haemato-biochemical constituents.	54
Bt cotton seed	Water buffaloes (Murrah)	No differences were observed in gross energy value for milk production and feed utilization. Bt protein was not detected in the milk of buffaloes.	55
Glyphosate-tolerant alfa-alfa	Dairy cattle	No effect was observed on feed intake, milk composition or milk production.	56
Transgenic Bt cotton seeds	Lactating cows	No significant difference was observed in intake of nutrients, digestibility, milk production and body condition score (BCS). Transgenic protein (Cry1C) was not detected in the weekly milk samples or in blood plasma at the end of the experiment.	57
Bt maize	Dairy cows	By immunoblotting assay, transgenic Cry 1A protein was found to be degraded during digestion in GI tract.	58

and protein from pigs fed with glyphosate-tolerant RR soybean. The study confirmed that neither small fragments of transgenic DNA nor immunoreactive fragments of transgenic protein were detectable in loin muscle samples[60]. Similarly, Reuter and Aulrich[59] also reported that although plant DNA fragments could be detected in the tissues of pigs at 48 h post-feed with transgenic maize, but no recombinant DNA was detected. Hyun *et al*[61] demonstrated that feeding of growing pigs with glyphosate-tolerant RR (event nk603) corn gave equivalent animal performance as conventional corn. Broll *et al*[62] used silage from a GM potato in a feeding experiment with pigs. After a feeding period of 42 d, they collected samples from various organs and digesta and investigated the fate of the foreign DNA with 4 different real-time PCR systems. No plant specific DNA or foreign recombinant DNA of the transgenic potato were detected. In contrast, chloroplast specific DNA was detected in the digesta of duodenum, jejunum, colon and rectum. In another study, the single-copy of metallo-carboxypeptidase inhibitor gene sequence was detected in samples from the stomach content of pigs fed with isogenic potato and animals fed the transgenic potato. No evidence for the integration of the foreign DNA into the host genome was observed. The sheep fed with silage sources of Rh208 (conventional isogenic Bt hybrid) and Rh208Bt (GM Bt176 corn hybrid) for 1 wk, when assayed biochemically, did not show any significant difference in organic matter digestibility and crude fiber digestibility[63]. The stability of transgenic DNA, encoding the synthetic cp4 epsps protein, present in a diet containing RR® canola meal was determined in duodenal fluid (DF) batch cultures from sheep by real-time TaqMan® PCR assay. The study revealed that digestion of plant material and release of transgenic DNA could occur in the ovine small intestine, but free DNA was rapidly degraded at neutral pH in DF. This had reduced the likelihood that intact transgenic DNA would be available for absorption through the Peyer's Patches in the distal ileum[64]. The findings of some of the feeding trials for neutritional and safety studies for small animals (pig, sheep, goat and rabbit)[60-63,65-76] are presented in Table 2.

GM Feeds in Poultry

The main conscious effort of plant breeders are to enhance the grain yield, while reduce the production cost. In this regard, GM crops could play an important role. Poultry feeds can utilize GM crops, especially, corn, soybean, wheat, canola and other ingredients to keep the industry economically viable. However, there are apprehensions regarding the use of GM crops in poultry nutrition, especially the unknown effects of foreign DNA and protein from these GM feeds. To this context, several feeding trials were done to analyse the effect of GM grains on productivity and safety concerns. In one of the early studies, a control parental line (DK580), a glyphosate-tolerant line (GA21/DK580) and five commercial varieties of corn were evaluated with 560 growing broiler chickens in a 39 d growth trial[77]. Growth and feed efficiency were not found different for chickens fed with the control, glyphosate-tolerant corn or five commercial corn varieties. Similarly, in another study, a genetically modified Bt176 corn hybrid, containing an insecticidal protein against the European corn borer, and its conventional, non-modified counterpart were evaluated in four separate trials to verify substantial equivalence in feeding value and performance of broilers[78]. The results revealed no significant differences in the performance between the birds that received the conventional non-modified corn and those that received GM-corn. It was also observed that no recombinant plant DNA, such as, recombinant bla or cry1 A(b) fragments, could be found in organs, meat or eggs of poultry. In order to assess safety of GM crop, Scheideler *et al*[79] studied the fate of the Cry3Bb1 protein from YieldGard Rootworm corn (MON 863) when fed to laying hens. The results showed no significant effect on feed intake, egg production and body wt. The Cry3Bb1 protein was extensively digested, similar to that of other dietary proteins and, therefore, it was not detected in hepatic or muscle tissue. This study clearly shows that the intact foreign protein from the GM-crop would not get into the tissues of the food animals. Recently, Mejia *et al*[80] reported the performance of hens after feeding with diets containing GM transgenic soybean containing the *gm-fad2-1* gene fragment and the *gm-hra* gene for high level oleic acid. The results indicated that body weight, egg production, egg mass, feed consumption and feed efficiency for hens fed GM soybean meal were not significantly different from hens fed with control soybean meal. Different feeding trails for GM feeds conducted in chicken and quails were listed in the Table 3[79-85]. Over all, it can be inferred that the

Table 2—Small animal feeding trials for nutritional and safety assessment of feeds from GM crops

GM crop	Experimental animals	Remarks	References
GM potatoes (inulin synthesizing)	Pig	No plant specific DNA or foreign DNA of GM potato as detected in any organ. No evidence for the integration of the foreign DNA into the host genome was observed.	62
RR corn (event nk603)	Pig	Equivalent animal performance to conventional corn for growing pigs (growth and carcass traits).	61
RR soybean meal	Pig	Neither small fragments of transgenic DNA nor immunoreactive fragments of transgenic protein were detected in loin muscle samples from pigs fed a diet containing Roundup Ready soybean meal.	60,65
Bt maize	Pig	Recombinant DNA was not detectable in tissue samples of pigs. In contrast, plant DNA fragments were detectable in the investigated pig tissues.	66,67
Bt corn (DAS-59122-7)	Finishing pigs	No differences observed in dressing percentage.	68
Bt maize (MON 810)	Weaning piglets	No adverse effect was observed on intestinal morphology. No changes were observed in culturable GI microbial population. Lack of systemic immune stimulation was observed in GM fed piglets.	69
RR wheat	Finishing pigs	Similar feed intake, live wt gain, feed conversion ratio and backfat thickness were observed compared to conventional wheat.	70
Bt maize (E176)	Goats	Milk samples were negative for chromosomally located zein gene and transgene Cry 1Ab gene. No bacterial transformants were able to form on exposure to DNA of Bt maize or milk of goat fed with Bt maize	71
Bt maize (E176)	Sheep	No significant effect was observed in the feeding value.	63
Bt176 maize (insect-resistant)	Sheep	No transgenic DNA was detected in tissues, blood and ruminal fluid, or ruminal bacteria.	72
RR sugar beet (glyphosate-tolerant)	Sheep	Digestibilities and feeding values of Roundup Ready fodder beet, sugar beet, and beet pulp produced from Roundup Ready sugar beet varieties were not influenced by the introduction of the Roundup Ready trait compared with conventional varieties.	73
RR rapeseed	Sheep	PCR and Real time PCR was unable to detect transgenic DNA in faeces or blood, or in microbial DNA.	63
Bt cotton	Sheep	Sero-biochemical studies and histological examination of liver and kidney did not reveal any significant changes in Bt and non-Bt cotton-fed groups.	74
Bt cotton	Lambs	Growth, haemato-biochemical and histopathology did not change by Bt cotton eed feeding.	75
GM soybean	Rabbit	GM soybean specific DNA fragments in tissues from rabbits were not detected by PCR. No differences in enzyme levels were detected in serum. No significant differences were detected concerning body wt, fresh organ wt and sexual differences were detected.	76

Table 3—Feeding trials in poultry for nutritional and safety assessment of GM feeds

Transgenic crops	Poultry birds	Remarks	References
Bt176 corn	Chicken (broiler)	Recombinant plant DNA fragments, such as, recombinant bla or cry1A(b) were not detected in any of the poultry samples like organs, meat or eggs.	79
DAS-59122-7 Bt corn	Chicken (hen)	No significant difference in performance of egg production and egg quality was observed.	81
Glyphosate-tolerant soybeans	Chicken (broiler)	No significant effect in the concentrations of nutrients and antinutrients was observed.	82,80
5307 transgenic corn	Chicken (broiler)	No significant effects in the performance were observed.	83
MON 863 transgenic corn	Chicken (hen)	Whole egg, egg albumen, liver, and feces were all negative for Cry3Bb1 protein.	85
GM Bt maize	Quail	No transgene was identified.	84
GM Bt maize	Quail	No significant difference in immunity was identified among transgenic and nontransgenic birds.	85

composition of GM crops, engineered for insect resistance (Bt-maize) or herbicide tolerance (glyphosate), have been essentially indistinguishable from their conventional counterparts, even though their safety aspects require more number of long term studies.

GM Feeds in Fishery

Most prepared fish feeds utilize soybean and maize meals[86]. GM soybean and GM corn are increasingly being used as a feed ingredient in fish feeds. Hence, the safety and quality needs to be investigated. Similar to GM-feeds of other livestock, two important issues are considered in the safety assessment of GM crops used as fish feed ingredients. First, the fish safety, which is assessed through feed studies to evaluate the equivalence of nutritional performance. Second, the food safety, which is determined by the digestibility of the transgenic protein and its incorporation within the fish[87,88]. Some of the feeding trials of GM crops in fishes are presented in Table 4[89-94]. These studies on feeding trails showed that GM crops did not interfere the economical traits of the fishes.

Conclusion and Future Prospective

The use of GM feed ingredients in feedstocks will going to benefit livestocks in near future with improved feed qualities and higher crop production per hectare. Further, GM crops will have enhanced nutritional characteristics as they are aimed to manipulate the levels of proteins, amino acids, oil and carbohydrates in major feed crops. GM crops have already been developed with improved nutritional characteristics, such as, higher concentration of methionine content in maize, increased lysine content in canola and soybean, increased levels of free and protein-bound threonine in lucern, and reduced phytate content in corn. Researchers are also looking for ways to improve digestibility of wheat, barley, corn, soybean and rape seed. Many of these biotech crops are already under field evaluation. The use of insect protected corn is already improving feed quality by decreasing mycotoxin contaminations. The presence of mycotoxins in feed grains or ingredients makes them unfit for animal (or human) consumption and can cause serious health risks. Recently, GM crops expressing antigens from various pathogens are also being developed. Such GM feeds can act as viable means of oral immunization called edible vaccines. Edible vaccines have many advantages over the conventional vaccines like cost-effectiveness, easy-to-administer, easy-to-store, and have acceptable vaccine delivery systems. The genes of viruses of animal diseases, such as, foot and mouth diseases virus (FMDV), bovine rhino-treachitis virus (BRV) and bovine viral diarrhea virus (BVDV), were expressed in various plants including *Arabidopsis thaliana*, alfalfa and potato. These edible vaccines delivered *via* feeds have the potential to control economically many important diseases in livestock.

With the increasing population and shrinking land cover under food crops, agricultural production systems cannot be continued in their present form. There is a dire need for new technology that can produce more food of improved nutritional value, and can reduce crop losses encountered by pest attacks

Table 4—List of GM-feeds and their effect on different kinds of fishes

GM crops	Fishes	Remarks	References
GM cotton seeds	Channel catfish (*Ictalurus punctatus*)	Weight gain, feed conversion, survival and fillet composition of catfish fed GM cottonseed meals appeared similar to that of either the control or the commercial cottonseed meals.	89
GM soyabean meal	Rainbow trout (*Oncorhynchus mykiss*)	Foreign DNA fragment was not detected .	90
GM lupin	Marine fish, *Pagrus auratus*	Digestible value of the protein and energy content of the GM feed were not different. A significant benefit of the enhanced methionine level in the transgenic lupin was observed.	91
GM soyabean meal	Atlantic salmon (*Salmo salar* L.)	The incidence of moderate inflammation was higher in the GM soy group compared with the non-GM soy group. Differences were not observed in the activities of digestive enzymes. No significant differences were found in the number of MHC II cells and in total IgM of the distal intestine.	92,93
Bt maize (Mon810)	Atlantic salmon (*S. salar* L.)	Protein similar to proton-dependent high-affinity oligopeptide transporter was significantly up regulated in the distal intestine of fish fed with GM maize compared with fish fed with non-GM maize.	94

and diseases. Genetic engineering can stand up to our present need by producing GM crops with many advantages. However, on the other hand, safety assurance of GM crops is mandatory to introduce them as food for human beings and feed for livestock. Hence, safety assessments are necessary with plant biotech products to provide equal or greater assurance to the society. The GM crops can directly benefit livestock production through safer and more abundant feed source. Further, GM crops like soya and corn with enhanced output traits have the profound effect on improving animal productivity and performance. However, genetic modification is not a panacea for improvement in agriculture as it brings enormous safety issues, which should be studied critically to bring consensus in the society and convince the general public. From the ongoing literature, it is apparent that GM crops are equally or more beneficial to livestock as compared to normal crops. However, long term safety studies are required from envioronmental point of view.

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