Effect of Genetically Modified Corn on Swine Production

R.L. Aguilera[1], L. Purnamasari[2,3], J.F. dela Cruz[1*]

[1]Department of Basic Veterinary Sciences, College of Veterinary Medicine, University of the Philippines Los Baños, 4031, Laguna, Philippines; [2]Department of Animal Husbandry, Faculty of Agriculture, University of Jember, Jember 68121, Indonesia; [3]School of Animal Life and Convergence Science, Hankyong National University, Anseong, Republic of Korea
*Corresponding author e-mail: jfdelacruz@up.edu.ph

Journal of Livestock Science (ISSN online 2277-6214) 15: 232-241
Received on 16/4/24; Accepted on 4/6/24; Published on 15/6/24
doi. 10.33259/JLivestSci.2024.232-241

Abstract

Corn is widely acknowledged as the primary energy source in commercial animal diets worldwide, primarily due to its consistent and high nutritional value for livestock. However, concerns arise regarding the potential effects of various factors such as genetics, agronomic conditions, composition, and processing on nutrient variability. Agricultural biotechnology has paved the way for developing new crop varieties with improved characteristics, including resistance to pests, tolerance to herbicides, and enhanced quality traits. This study aimed to assess the performance, carcass yield, characteristics, and health parameters of pigs fed with corn hybrids. The review findings indicate no significant differences observed in these parameters between pigs fed with genetically modified (GM) or non-GM corn, as reported in various studies. In conclusion, the research suggests that the specific type of corn utilized in pig diets does not significantly affect pig health or performance, including growth and feed efficiency. Therefore, it assures that incorporating genetically modified maize into pig diets does not lead to noticeable clinical symptoms.

Keywords: Corn hybrid; Carcass quality; Feed; Growth; Maize, Pig

Introduction

Swine farmers across the globe aims to get sustainable income (Das et al,. 2021). Low cost feed but yielding high productivity is the need of hour for making swine husbandry profitable (Niyazov et al 2020). Maize, widely acknowledged as a valuable source of nutrition for humans and animals worldwide (FAO, 2012), is the second most significant biotech crop, surpassing glyphosate-tolerant soybeans in terms of genetic alterations (James, 2010). As such, the development and enhancement of economically viable varieties of genetically modified (GM) maize hold substantial importance across various domains. The utilization of GM insect-resistant maize, for instance, experienced a remarkable surge over the past 15 years, accounting for 24.6% of global maize output in 2010 (James, 2010). The prevalence of insect-resistant GM maize, predominantly achieved through the expression of the Cry1Ab transgenic protein derived from *Bacillus thuringiensis* (commonly referred to as Bt maize), has played a pivotal role in safeguarding crops against insect damage.

Moreover, the cultivation area dedicated to GM crops has expanded exponentially, reaching 148 million hectares globally in 2010, a staggering 87-fold increase (Walsh *et al*., 2011). Consequently, the acquisition of entirely non-GM commodities has become increasingly challenging and costly. This predicament has led numerous farmers to convert their conventional corn farms into transgenic corn farms, driven by the desire to improve crop yield and productivity.

Genetic engineering has introduced several prominent agronomic features, namely herbicide tolerance, insect resistance (Bt), and the combination of both traits (James, 2010, Walsh *et al*., 2011). These genetic modifications hold the potential to enhance agronomic production, especially during insect infestations, by obviating the need for extensive insecticide application and by employing cost-effective broad-spectrum herbicides for weed management (Bertoni, 2005). Consequently, these advancements contribute to reducing production costs and increasing efficiency.

However, the escalating utilization of GM crops in human consumption and as feed for livestock, particularly meat and milk- producing animals, has sparked public concerns (Paparini and Romano- Spica, 2004). These concerns primarily revolve around potential risks associated with health, such as perceived threats to human well-being, the development of toxicity, allergic reactions to transgenic proteins, and the transfer of antibiotic resistance from plants to bacteria within the human gastrointestinal system (Bertoni and Marsan, 2005). Additionally, environmental apprehensions encompass issues such as gene transfer from GM crops to native plant species, biodiversity loss, and the impact of GM crops on non-target organisms (Moses, 1999, Malarkey, 2003, Hug, 2008). In the Philippines, several corn hybrids are currently cultivated, including Bt MON 810, nk603, Bt 11, DAS 59122-7, DAS-Ø15Ø7-1

(TC1507), and MON 863. These hybrids have been developed with specific genetic modifications to confer traits such as insect resistance or herbicide tolerance. Bt MON 810, for example, contains a gene from the bacterium *Bacillus thuringiensis* (Bt) that produces a toxin lethal to certain pests. nk603, on the other hand, is engineered for herbicide tolerance, allowing farmers to control weeds effectively. Bt 11, DAS 59122-7, DAS-Ø15Ø7-1 (TC1507), and MON 863 also possess insect resistance traits. These corn hybrids have been adopted by farmers in the Philippines to improve crop yields and manage agricultural challenges (GM Crop Events List - GM Approval Database | ISAAA.Org, 2023).

The objective of this review is to comprehensively examine the variations in growth performance, carcass yield, and health parameters observed in pigs when exposed to different types of corn hybrids.

This literature review is from different academic research papers. After collecting the articles, analyze each one by breaking it down and identifying the important information and then synthesize and identify the conclusions that can be drawn.

Genetically Modified (GM) or hybrid crops have been authorized for use as food and/or feed in many countries based on those countries' criteria for safety assessment. GM corn is one of the most extensively cultivated GM plants. Thirty varieties, including 14 stacked GM corn, have been authorized by the European Commission (EC). These varieties and countries that are allowed to consume GM crops for livestock are shown in Table 1.

Effect of different corn hybrids on the growth performance of swine

Live Weight

Live weight is an essential pig index, and measuring the weight of pigs quickly and precisely can immediately evaluate the development and health state of pigs and identify the feed absorption rate of pigs. It can also assist in individually rearing pigs with varied nutritional statuses to get the highest feed utilization rate and the greatest growth management (Chen *et al*., 2023). The entire procedure is time-consuming and arduous, and the inaccuracy of manual measurement is significant, necessitating human and animal interaction, which readily leads to disease transmission. Because of this, it is necessary to follow safety protocols to prevent these consequences. Moreover, it is often essential to use sedatives and other pharmaceuticals to assist, which put pigs under a lot of stress, interferes with everyday routines like feeding and mating, and even causes pigs to die suddenly, resulting in huge economic losses (Alsahaf *et al*., 2018, NRC, 1998).

Bt MON810 maize, a genetically modified corn developed by Monsanto Company, incorporates a modified form of the Cry1Ab toxin from *Bacillus thuringiensis* (Schnepf *et al*., 1998; Crickmore, 2005, Broderick *et al*., 2009). This alteration enables the maize plant to resist damage caused by the European maize borer. The Cry1Ab toxin affects the intestinal cells of the borer larvae, leading to disruptions in their intestinal lining and eventual mortality. Importantly, research suggests that this toxin does not pose a threat to mammals, birds, reptiles, and amphibians due to the absence of specific receptors in their intestinal tracts that would interact with the toxin and cause toxicity (Schnepf *et al*., 1998). Furthermore, the Cry1Ab protein lacks similarities with allergenic proteins and is effectively broken down in simulated gastric conditions (EFSA, 2008). Alongside these modifications, Bt MON810 GMO corn encompasses various genetic traits, including glyphosate herbicide tolerance, lepidopteran insect resistance, and antibiotic resistance, each accomplished through distinct genes (GM Crop Events List - GM Approval Database | ISAAA.Org, 2023). These modifications allow the corn to combat lepidopteran insects, resist glyphosate herbicides, and metabolize antibiotics, providing enhanced crop protection and management options.

These findings are particularly significant considering the increasing use of genetically modified crops in animal feed formulations. The ability to assess and understand the potential impacts of such crops on livestock performance is crucial for farmers, animal nutritionists, and industry professionals. Bt MON810 GMO corn is engineered to resist damage from the European maize borer, an insect pest that can cause significant harm to maize crops. On the other hand, nk603 GMO corn has been developed to possess glyphosate herbicide tolerance through the incorporation of a modified protein called modified maize enzyme 5-enolpyruvylshikimate-3-phosphate synthase (mEPSPS). This modification allows the corn plants to withstand glyphosate-based herbicides, which are commonly used for weed control in agricultural settings.

Additionally, the broader approval of nk603 GMO corn as a feed ingredient in various countries compared to Bt MON810 GMO corn reflects a higher level of acceptance and regulatory authorization for nk603. This indicates that nk603 has undergone rigorous testing and evaluation, ensuring its safety for use in animal feed. These regulatory considerations further contribute to the understanding and acceptance of genetically modified crops in livestock production (Fischer *et al*., 2002).

The Bt 11 corn variety was genetically modified to possess insect resistance and herbicide tolerance traits. It was achieved by introducing the cry1Ab gene from *Bacillus thuringiensis* and the pat gene from Streptomyces viridochromogenes through direct DNA transfer (Agbios, 2003; Koziel *et al*., 1993). The cry1Ab gene produces the cry1Ab protein, which controls the European corn borer, while the pat gene regulates the production of phosphinothricin N-acetyltransferase (PAT), an enzyme that breaks down the herbicide glufosinate (Agbios, 2003). Studies have shown the presence of cry1Ab proteins in various parts of the corn plant, including leaves, roots, pollen, and kernels (US EPA, 2000). Bt 11 corn is a genetically modified corn developed by Syngenta, providing resistance to Glufosinate herbicide and Lepidopteran insects through the expression of the bacterial Bt toxin (GM Crop Events List - GM Approval Database | ISAAA.Org, 2023).

Regarding their resistance to the European corn borer, 39WM27 corn, and 39W54 corn are genetically modified corn varieties. They have been genetically engineered to incorporate the Cry 3Bbl protein derived from *Bacillus thuringiensis*, a bacterium. This protein exhibits toxicity against the European corn borer, potentially offering a means to reduce the reliance on insecticides for controlling this pest (MAFRI, 2004; Hyun *et al*., 2005).

The 59122 variety of corn, known as DAS59122-7, possesses resistance to corn rootworms. It was developed through genetic modification, incorporating the cry34Ab1 and cry35Ab1 genes from *Bacillus thuringiensis* (Bt) Berliner strain PS149B1 and the phosphinothricin acetyltransferase (pat) gene from Streptomyces viridochromogenes. The expression of Cry34Ab1 and Cry35Ab1 proteins within the plant provides protection against coleopteran pests, specifically corn rootworms. Additionally, the presence of the PAT protein in DAS59122-7 corn enables the plant to tolerate herbicides containing glufosinate-ammonium as the active ingredient. This genetically modified corn, developed by Monsanto Company, exhibits traits of Glufosinate herbicide tolerance and Coleopteran insect resistance. The various genes present in this GMO maize function differently, with cry34Ab1 targeting and destroying the midgut lining of coleopteran insects, particularly maize rootworms, and counteracting the herbicidal effect of glufosinate (phosphinothricin) herbicides (GM Crop Events List - GM Approval Database | ISAAA.Org, 2023).

Victor Raboy, a plant breeder at Montana State University, made a significant discovery of low-phytate genes that can suppress the production of phytic acid in corn kernels while maintaining phosphorus levels (Low-Phytate Corn Works for Finishing, 2011). This breakthrough led to Pioneer Hi-Bred International, a prominent seed company, incorporating these genes into their hybrid corn varieties. Phytic acid, or phytate, constitutes a substantial portion (around 60-80%) of the phosphorus in corn. However, pigs and poultry lack the necessary digestive enzyme, phytase, to effectively break down phytate. Consequently, the unutilized phosphorus passes through their digestive systems and is excreted in manure, posing potential environmental concerns.

Including low-phytate corn in animal diets addresses this issue by reducing the need for additional phosphorus supplementation. Research conducted at the University of Kentucky involving growing and finishing pigs demonstrated that diets containing low-phytate corn and soybean meal, with a slight reduction in total phosphorus compared to regular diets, yielded comparable performance and bone mineralization to pigs fed standard corn-soybean meal diets (Low-Phytate Corn Works for Finishing, 2011).

The genetically modified corn variety known as DAS-Ø15Ø7-1 (TC1507) contains the cry1F gene derived from *Bacillus thuringiensis* var. aizawai and the phosphinothricin acetyltransferase (pat) gene from Streptomyces viridochromogenes. This corn variety was developed by collaborating with Pioneer Hi-Bred International Inc. (Johnston, IA) and Dow AgroSciences LLC (Indianapolis, IN). The cry1F gene produces the Cry1F protein, which exhibits insecticidal properties against various pests such as European corn borer, southwestern corn borer, fall armyworm, black cutworm, corn earworm, and western bean cutworm (Catangui and Berg, 2006). The expressed PAT protein also provides tolerance to glufosinate-ammonium herbicides, such as Liberty (Bayer AG, Leverkusen, Germany), within the plant. The commercial name for the TC1507 corn with these traits is Herculex I. The effect of providing genetically modified (GM) crops to pigs on growth performance is shown in Table 2.

In general, the lack of significant differences in the body weights of pigs fed with various genetically modified corn varieties, including Bt MON810, nk603, 39WM27, 39W54, Bt 11, DAS-59122-7, Low-phytate, DAS-Ø15Ø7-1 (TC1507), and conventional corn, indicates that these corns can be safely incorporated into animal feed without negatively impacting pig growth. These findings contribute to a wider understanding of the safety and suitability of genetically modified crops in animal farming. They enable informed decision-making and promote sustainable practices in livestock production.

Average Daily Gain, Average Daily Feed Intake, Gain to Feed Ratio

Pigs are omnivorous creatures, and consuming feed is crucial to their growth, development, and general health. Pigs must get the proper diet to suit their needs for growth, reproductive efficiency, and illness resistance (Stein & Shurson, 2009). Additionally, pigs' intake of feed is affected by several variables, including age, sex, genetics, environment, and management techniques. Younger piglets consume more feed per unit of body weight than older pigs do. Similarly, male pigs often eat more feed than female pigs do, especially while they are growing. As certain breeds of pigs have a larger capacity for feed intake than others, the genetics of the animal can have a significant impact on feed intake (Fang *et al*., 2019). The environment in which pigs are kept has an impact on how much feed they consume. A pig's appetite can be influenced by conditions including temperature, humidity, ventilation, and illumination. Feed intake is significantly influenced by good management techniques, including feed availability and quality, feeding schedules, and feeding systems (Patience *et al*., 2015).

Numerous factors, including genetic traits and environmental factors, can impact the nutritional composition of corn. Genetic selection can have varying effects on important heritable parameters such as kernel weight, volume, endosperm type, degree of damage, density, and kernel breakage (Melo-Durán *et al*., 2021). Genetic diversity can also lead to variations in the nutritional and anti-nutritional components of corn (Reynolds *et al*., 2005). The presence of anti-nutritional factors in corn, such as non-starch polysaccharides (NSP), can have an impact on the availability of vital nutrients, thereby reducing their digestibility and subsequently affecting the performance and digestibility of pigs. The effect of providing genetically modified (GM) crops to pigs on average daily gain, average daily feed intake, gain to feed ratio are shown in Table 3.

MON 863, developed by Monsanto Company, possesses traits of Coleopteran insect resistance and antibiotic resistance. Overall, several studies consistently demonstrate that the type of corn used in pig diets does not have a significant impact on average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G: F). While there may be some minor variations in specific phases or interactions with gender, overall there were no significant performance differences observed between pigs fed different corn varieties, including transgenic and non-transgenic hybrids. These findings provide reassurance that pigs can be fed a variety of corn types without compromising their growth and feed conversion efficiency.

Carcass yield

The carcass weight and characteristics of pigs are important factors in determining the quality and value of pork products. The weight of pig carcasses at slaughter can vary based on factors such as breed, genetics, age, and management practices. Conformation, referring to the overall shape and muscling, plays a crucial role, with well-developed muscling indicating better meat yield and quality. Fatness is another important characteristic, that impacts the flavor, juiciness, and tenderness of pork. Evaluating fatness involves measuring back fat thickness and assessing fat distribution. Additionally, the overall meat quality of pork, including tenderness, juiciness, color, and flavor, is assessed through sensory attributes and objective measurements. Understanding the carcass weight and characteristics of pigs is essential for pork producers to ensure desirable meat quality and profitability (Nielsen et al., 2020). The effects of providing modified (GM) crops to pigs on carcass yield are shown in Table 4.

Table 1. Varieties of GM Corn and consuming countries for feed

GM Corn varieties	Livestock	Country	Reference
Bt and BtHT corn	Pigs, quail & chicken	Philippines	Afidchao *et al*, 2014; Torres *et al*, 2022; Gatdula *et al,* 2023
Bt 176 corn	Chicken	European countries	Aeschbacher *et al*, 2005
Bt11 Hybrid Corn (N7070Bt, e NC2000 corn)	Chicken	United States countries	Brake *et al*, 2003
GM soy and GM corn (NK603, MON863 and MON810)	Pigs	USA	Carman *et al,* 2013
Bt MON810	Pigs	Ireland	Buzoianu *et al,* 2020

Table 2. The effect of providing genetically modified (GM) crops to pigs on growth performance

GM Crop	Production Stage	Studied health parameters	Results	References
Bt 11 corn and conventional corn	pigs	live b wt	no significant differences between the two groups	Custodio *et al*. (2006)
39WM27 corn and 39W54 corn	growing pigs	live b wt	no significant disparities between the two groups of pigs.	Opapeju *et al*. (2006)
Bt MON810 GMO corn and conventional corn	pigs	pig b wt	no significant differences in body weights between the two groups	Walsh *et al*. (2011)
Bt MON810 GMO corn, nk603 GMO corn, and conventional corn	pigs	pig body weights	does not adversely affect pigs	Hyun *et al*. (2004)
DAS-59122-7	pigs	live b wt	no significant differences	Stein *et al*. (2009)
transgenic maize with different levels of fumonisin B1 (a mycotoxin) and deoxynivalenol	piglets	live b wt	higher ultimate live weight	Piva *et al*. (2001)
different hybrid known as low-phytate corn	pigs	final body weight	did not experience any negative effects on their final body weight	Spencer *et al*. (2000)
DAS-Ø15Ø7-1 (TC1507), and conventional corn	pigs	final body weight	No differences among treatment groups	Stein *et al*. (2009)

Table 3. The effect of providing genetically modified (GM) crops to pigs on average daily gain, average daily feed intake, gain to feed ratio

GM Crop	Production Stage	Results	References
DK647, nk603 and RX740 corn.	Piglets, growing periods and finishing periods	did not have a significant impact on the average daily gain (ADG), average daily feed intake (ADFI), or gain-to-feed ratio (G: F).	Hyun *et al*. (2004)
DK647, RX670, and RX740	Piglets, growing periods and finishing periods	no significant effect of the corn type on the G: F ratio during the overall growth period.	Bressner *et al*., 2002
MON 863, DK647, RX670, and RX740	four growth phases.	no significant interaction between diet and gender in terms of growth performance measurements (ADG, ADFI, or G: F)	Hyun *et al*. (2005)
Bt 11 corn and conventional corn	pigs	did not have a significant impact on the average daily feed intake (ADFI) or average daily gain (ADG) of the pigs.	Custodio *et al*. (2006)
GM maize and non-GM maize	pigs	no significant differences in food consumption, average daily weight gain, or feed conversion efficiency among different groups of animals during the initial 14 days of the experiment. However, from days 14 to 30, pigs fed a diet containing genetically modified (GM) maize consumed slightly more food and had a slightly less efficient feed conversion compared to those fed a non-GM maize diet.	Walsh *et al*. (2011)
DAS-Ø15Ø7-1 (TC1507	pigs	no significant differences were observed in ADG, ADFI, and G: F between pigs fed diets based on barley and those fed diets based on either of the two corn hybrids.	Opapeju *et al*. (2006); Spencer *et al*. (2000)

Table 4. The effects of providing modified (GM) crops to pigs on carcass yield

GM Crop	Carcass part	Results	References
DK647, nk603 and RX740 corn.	carcass	The first study, Study 1, revealed that the type of corn had no significant impact on any of the carcass measurements. Furthermore, there were no significant differences observed among the corn types in terms of TOBEC (Total Body Electrical Conductivity) measurements, which is a technique used to estimate body composition in pigs.	Hyun *et al.* (2004)
type of corn and gender (DK647, nk603, and RX740 corns)	longissimus muscle area	Specifically, barrows fed the DK647 corn exhibited a smaller longissimus muscle area compared to those fed the nk603 hybrid corn. Conversely, gilts fed the DK647 corn had a larger longissimus muscle area compared to those fed the nk603 and RX740 corns. However, when measuring the longissimus muscle area on the carcass itself, there was no interaction between corn type and gender	(Rentfrow *et al.*, 2003)
DK647 corn	cold carcass	no effect on the cold carcass weight of barrows	(Reuter *et al.*, 2002)
MON 863 corn	carcass weight and characteristics	no significant interactions were found between diet and gender, and no significant differences in carcass measurements were observed among the different corn varieties. The only minor difference observed was in the color of the longissimus muscle, where there was a slight variation between the corn types, albeit within the acceptable range.	Hyun *et al.* (2005)
Bt 11 corn	carcass weight and characteristics	no significant differences in carcass characteristics were observed except for a slight difference in longissimus muscle color.	Custodio *et al.* (2006)
barley and 39WM27 diets	carcass weight and characteristics	found no significant differences in carcass characteristics between pigs	Opapeju *et al*. (2006); Carr *et al*. (2005)
GM barley and corn diets	carcass wt. & characteristics	found no significant differences in carcass characteristics between pigs	Carr *et al.* (2005)
DAS-Ø15Ø7-1 (TC1507) corn	carcass measurements were observed between sex	Barrows had higher back fat thickness compared to gilts, which aligns with the findings from previous studies. Conversely, gilts had larger loins, a higher proportion of fat-free lean, and a greater percentage of lean meat compared to barrows. These results highlight the substantial gender differences in carcass characteristics, with gilts generally exhibiting more desirable traits in terms of lean meat yield.	Stein *et al.* (2009)

Study by Hyun *et al*. (2004) there is interesting observations regarding gender differences. It was found that barrows, which are castrated male pigs, had higher TOBEC measurements for hot carcass weight, shoulder weight, and total lean weight compared to gilts, which are female pigs. On the other hand, gilts exhibited a higher percentage of primal cuts and fat-free lean compared to barrows. These findings were consistent with previous studies reported by Gu *et al*. (1992), Cisneros *et al*. (1996), and Unruh *et al*. (1996), which also showed that gilts tend to have a higher percentage of primal cuts compared to barrows. The higher shoulder weight observed in barrows in the current study was attributed to their higher slaughter weight compared to gilts. Additionally, previous research by Cromwell *et al*. (1993), and Unruh *et al*. (1996) indicated that gilts tend to have a higher percentage of lean in their carcasses compared to barrows when they reach a similar slaughter weight.

Interestingly, the fat-free lean gain, as determined using TOBEC measurements, was not influenced by either the gender of the pigs or the type of corn used. Moreover, most studies have found comparable rates of lean growth between barrows and gilts, further supporting the notion that carcass characteristics are more closely related to gender differences rather than the type of corn in the diet.

In both studies, it was consistently observed that barrows had a higher back fat thickness compared to gilts. These findings align with the results of previous studies conducted by Cromwell *et al*. (1993), and Hahn *et al*. (1995). However, interestingly, in those experiments, gilts exhibited a larger longissimus muscle area than barrows, which contrasts with the results of the present studies. The absence of a gender effect on the longissimus muscle area could be partially attributed to differences in the live weight at the time of slaughter between barrows and gilts. However, when the live weight at slaughter was included as a covariate in the analysis, it eliminated the gender difference in carcass yield and longissimus muscle area, suggesting that gender-related differences in growth rate and body composition play a significant role.

Table 5. The effects of providing modified (GM) crops to pigs on health parameters

GM Crop	GM Traits*	Production Stage	Studied health parameters	Results	References
Bt maize (Nk603, MON 863, MON810) and RR soybean	GP, L, A	Weaned piglets	Serum biochemistry, histopathology,organ weight	Higher level of severe inflammation in the stomach andhigher uterus weight in GM fed animals	Carman *et al.*, 2013
Bt maize (810)	GP, L, A	28-day old piglets	Serum biochemistry, histopathology,organ weight, gastrointestinal microbiota	Lower spleen wt, greater duodenal crypt depths, lower villus height/crypt depth ratios, higher urea conc on d 0, lowercreatinine conc. on d 30, and higher aspartate aminotransferase conc ond 115, higher faecal Enterobacteriaceae and faecal total anaerobe counts in piglets born to GM-fed sows; higher ileal total anaerobe counts in GM-fed piglets;differences in relative abundance offaecal microbiota between piglets born to GM-fed sows and piglets born to control sows, as well as between GM-fed piglets and pigletsfed isogenic maize	Buzoianu *et al.*, 2013a;Buzoianu *et al.*, 2013b
Bt maize (MON810)	GP, L, A	35-day-old malepigs	Immune response, histopathology, serum biochemistry, organ weight	Lower IFNγ production fromPBMC in GM-fed animals	Walsh *et al.*, 2011;Walsh *et al.*, 2012a
Bt maize (MON810)	GP, L, A	35-day old pigs	Immune response	Higher IL-4 and IL-6 production from isolated splenocytes in GM- fed animals; higher IL-4 productionfrom isolated intraepithelial and lamina propria lymphocytes in GMfed animals; lower proportion of B cells and macrophages in ileum of GM-fed pigs; higher proportion of CD4+ T-cells in ileum of GM-fed pigs	Walsh *et al.*, 2011
Bt maize (MON810)	GP, L, A	40-day old malepigs	Haematology, immune response, histopathology, serum biochemistry, organ weight, gastrointestinal microbiota	Differences observed in leukocyte,lymphocyte, and monocyte counts,and serum and urine biochemistry, but not consistently differentiatingbetween GM-fed and control animals	Buzoianu *et al.*, 2012a;Buzoianu *et al.*, 2012b; Walsh *et al.*, 2012b
Bt maize (CBH 351Starlink)	GF, L, A	3-month old pigs	Haematology, serum biochemistry, histopathology	Higher blood urea nitrogen in GM- fed animals; lower glucose levels inGM-fed animals	Yonemochi *et al.*, 2010
Bt maize (MON810)&RR soybean (MON-40- 30-2)	GP, L, A	Fattening pigs	Haematology Histopathology	No effect of GM feed observed	Bednarek *et al.*, 2013 Reichert *et al.*, 2012
Bt maize (MON810)and RR soybean (MON-40- 30-2)	GP, L, A	Pregnant sowsand offspring	Haematology	No effect of GM feed observed	Swiatkiewicz *et al.*,2013
Bt maize (MON810)and RR soybean (MON-40-30-2)	GP, L, A	Sows	Haematology	No effect of GM feed observed	Bednarek *et al.*, 2013
Bt maize (MON810)	GP, L, A	Nulliparous sowsand offspring	Haematology, immune response, serum biochemistry, gastrointestinal microbiota, organ wt (offspring only)	Higher blood monocyte count and percentage, and lower granulocytepercentage on day 110 of gestationin GM fed animals; lower percentage CD4+CD8+ T lymphocytes in GM-fed animals; lower granulocyte count and percentage at birth in offspring from GM-fed animals.	Buzoianu *et al.*, 2013b; Walsh *et al.*, 2013

GM Traits: GP: Glyphosate herbicide tolerance; L: Lepidopteran insect resistance; A: Antibiotic resistance; GL: Glufosinate herbicide tolerance

In summary, the type of corn used in pig diets does not appear to have a significant impact on carcass weight, yield, back fat thickness, and most muscle characteristics. Gender differences, on the other hand, play a more substantial role in determining carcass traits, such as primal cuts, fat- free lean, longissimus muscle area, and back fat thickness. While slight variations in muscle color and longissimus muscle area were observed among different corn types, these differences were relatively small and unlikely to have practical implications in terms of carcass quality and composition.

Health Parameters

Significant differences in health parameters were observed between animals fed genetically modified (GM) diets and control animals. The most pronounced effects were seen in animals, particularly pigs, that were fed GM maize. However, when animals were fed a diet containing both GM maize and GM soybean, fewer health effects were observed compared to a diet consisting of GM maize alone. In combined diets, effects were noted in organ weight, histopathology, and the immune response. Conversely, GM maize-only diets exhibited effects in all health parameters except clinical examination. These findings suggest that GM maize may have a greater impact on health parameters compared to GM soybean, and that the combination of GM crops in the diet may mitigate some of the observed effects (De Vos and Swanenburg, 2017). The effects of providing modified (GM) crops to pigs on health parameters are shown in Table 5.

Conclusion

The research indicates that feeding genetically modified (GM) corn varieties to pigs, including Bt MON810, nk603, 39WM27, 39W54, Bt 11, DAS-59122-7, Low-phytate, and DAS-Ø15Ø7-1 (TC1507), does not harm pig growth parameters. These findings support the safe incorporation of GM corn into animal feed, allowing informed decision-making and promoting sustainable practices in livestock production. The absence of significant differences in growth, feed efficiency, and carcass traits between pigs fed different corn varieties, including transgenic hybrids, suggests that the type of corn used does not significantly affect pig health or performance. Overall, the research assures that feeding GM maize to pigs does not result in noticeable clinical symptoms.

References

1) Aeschbacher K, Messikommer R, Meile L, Wenk C. 2005. Bt176 Corn in Poultry Nutrition: Physiological Characteristics and Fate of Recombinant Plant DNA in Chickens. Poultry Science 84:385-394.
2) Afidchao MM, Musters CJM, Wossink A, Balderama OF, de Snoo G. 2014. Analysing the farm level economic impact of GM corn in the Philippines. NJAS - Wageningen Journal of Life Sciences. 70–71: 113-121
3) Agbios 2003. GM crops used in animal feeds. Agriculture and Biotechnology Strategies, Merrickville, ON.
4) Alsahaf A, Azzopardi G, Ducro B, Hanenberg E, Veerkamp RF, and Petkov N. 2018. Prediction of slaughter age in pigs and assessment of the predictive value of phenotypic and genetic information using random forest. Journal of Animal Science, 96(12), 4935-4943
5) Bednarek D, Dudek K, Kwiatek K, Swiatkiewicz M, Swiatkiewicz S, and Strzetelski J, 2013. Effect of a diet composed of genetically modified feed components on the selected immune parameters in pigs, cattle, and poultry. Bulletin of the Veterinary Institute in Pulawy. 57, 209- 217
6) Bertoni G, and Marsan PA. 2005. Safety risks for animals fed genetic modified (GM) plants. Veterinary Research Community 29, Suppl. 2, 13–18.
7) Brake J, Faust MA, Stein J. 2003. Evaluation of Transgenic Event Bt11 Hybrid Corn in Broiler Chickens. Poultry Science. 82:551-559.
8) Bressner G, Hyun Y, Stanisiewski E, Hartnell G, and Ellis, M. 2002. A comparison of swine performance when fed diets containing Roundup Ready® (event NK603) or conventional corn lines. Journal of Animal Science 80 (Suppl. 2): 128.
9) Broderick NA, Robinson CJ, McMahon MD, Holt J, Handelsman J, and Raffa K. 2009. Contributions of gut bacteria to Bacillus thuringiensis-induced mortality varies across a range of Lepidoptera. BMC Biology 7, 11.
10) Buzoianu SG, Walsh MC, Rea MC, O'Sullivan O, Crispie F, Cotter PD, Ross RP, Gardiner GE, and Lawlor PG. 2012a. The effect of feedingBt MON810 maize to pigs for 110 days on intestinal microbiota. PLoSONE 7, e33668.
11) Buzoianu SG, Walsh MC, Rea MC, O'Donovan O, Gelencsér E, Ujhelyi G, Szabó E, Nagy A, Ross RP, Gardiner GE, and Lawlor PG. 2012b. Effects of feeding Bt maize to sows during gestation and lactation on maternal and offspring immunity and fate of transgenic material. PLoS ONE 7, e47851.
12) Buzoianu SG, Walsh MC, Rea MC, Cassidy JP, Ryan TP, Ross RP, Gardiner GE, and Lawlor PG. 2013a. Transgenerational effects of feeding genetically modified maize to nulliparous sows and offspring on offspring growth and health. Journal of Animal Science 91, 318- 330.
13) Buzoianu SG, Walsh MC, Rea MC, Quigley L, O' Sullivan O, Cotter, PD, Ross RP, Gardiner GE, and Lawlor PG. 2013b. Sequence-based analysis of the intestinal microbiota of sows and their offspring fed genetically modified maize expressing a truncated form of Bacillus thuringiensis Cry1Ab protein (Bt maize). Applied and Environmental Microbiology.79, 7735-7744.
14) Buzoianu SG, Walsh MC, Rea MC, Cassidy JP, Ross RP, Gardiner GE, and Lawlor PG. 2020. Effect of feeding genetically modified Bt MON810 maize to ∼40-day-old pigs for 110 days on growth and health indicators. Animal, 6(10): 1609-1619.
15) Carman JA, Vlieger HR, Ver Steeg LJ, Sneller VE, Robinson GW, Clinch-Jones CA, Haynes JI, and Edwards JW. 2013. A long-term toxicology study on pigs fed a combined genetically modified (GM) soy and GM maize diet. Journal of Organic Systems 8, 38-54.
16) Carr SN, Rincker PJ, Killefer J, Baker DH, Ellis M, and McKeith FK. 2005. Effects of different cereal grains and ractopamine hydrochloride on performance, carcass characteristics, and fat quality in late-finishing pigs. Journal of Animal Science. 83:223–230
17) Catangui MA, and Berg RK. 2006. Western bean cutworm, Striacosta albicosta (Smith)(Lepidoptera: Noctuidae), as a potential pest of transgenic Cry1Ab Bacillus thuringiensis corn hybrids in South Dakota. Environmental Entomology, 35(5), 1439-1452.

18) Chen H, Liang Y, Huang H, Huang Q, Gu W, and Liang H. 2023. Live Pig- Weight Learning and Prediction Method Based on a Multilayer RBF Network. Agriculture, 13(2), 253. https://doi.org/10.3390/agriculture13020253
19) Cisneros F, Ellis M, McKeith FK, McCaw J, and Fernando RL. 1996. Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genotypes. Journal of Animal Science. 74:925–933.
20) Crickmore N. 2005. Using worms to better understand how Bacillus thuringiensis kills insects. Microbiology 13, 347–350.
21) Cromwell GL, Cline TR, Crenshaw JD, Crenshaw TD, Ewan RC, Hamilton CR, Lewis AJ, Mahan DC, Miller ER, Pettigrew JE, Tribble LF, and Veum TL. 1993. The dietary protein and(or) lysine requirement of barrows and gilts. Journal of Animal Science. 71:1510–1519.
22) Custodio MG, Powers WJ, Huff-Lonergan E, Faust MA, and Stein J. 2006. Growth, pork quality, and excretion characteristics of pigs fed Bt cornor non-transgenic corn. Canadian Journal of Animal Science, 86(4), 462-469.
23) Das, G., Hajra, D.K., Mukherjee, R.D., Hembram, S., Roy B. 2021. Sustainable income generation of the farmers through pig farming: A case study in Terai region of West Bengal. Journal of Livestock Science 12: 241-245 doi. 10.33259/JLivestSci.2021.241-245
24) EFSA. 2008. Safety and nutritional assessment of GM plants and derived food and feed: the role of animal feeding trials. Food and Chemical Toxicology 46, S2–S70.
25) Fang LH, Jin YH, Do, SH, Hong JS, Kim BO, Han TH, and Kim YY. 2019. Effects of dietary energy and crude protein levels on growth performance, blood profiles, and carcass traits in growing-finishing pigs. Journal of Animal Science and Technology, 61(4), 204.
26) FAO. 2012. FAOSTAT. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID567#ancor.
27) Fischer RL, Lewis AJ, Miller PS, Stanisiewski EP, and Hartnell GF. 2002. Comparison of swine performance when fed diets containing Roundup Ready® Corn (event NK603), control, or conventional corn grown during 2000 in Nebraska. Journal of Animal Science 80 (1): 894.
28) Gatdula NVGF, Purnamasari L, dela Cruz JF. 2023. Effect of different corn hybrids on the growth performance, survival and carcass yield of broilers - a review. Journal of Livestock Science, 14: 224-232.
29) Gu Y, Schinckel AP, and Martin TG. 1992. Growth, development, and carcass composition in five genotypes of swine. Journal of Animal Science 70:1719–1729.
30) Hahn JD, Biehl RR, Baker DH. 1995. Ideal digestible lysine level for early- and late-finishing swine. Journal of Animal Science. 73:773–784.
31) Hug K. 2008. Genetically modified organisms: do the benefits outweigh the risks? Medicina (Kaunas) 44, 87–99.
32) Hyun Y, Bressner GE, Ellis M, Lewis AJ, Fischer R, Stanisiewski EP, and Hartnell, GF. 2004. Performance of growing-finishing pigs fed diets containing Roundup Ready corn (event nk603), a nontransgenic genetically similar corn, or conventional corn lines. Journal of Animal Science, 82(2), 571–580. https://doi.org/10.2527/2004.822571x
33) Hyun Y, Bressner GE, Fischer RL, Miller PS, Ellis M, Peterson BA, and Hartnell GF 2005. Performance of growing-finishing pigs fed diets containing YieldGard Rootworm corn (MON 863), a nontransgenic genetically similar corn, or conventional corn hybrids. Journal of Animal Science, 83(7), 1581-1590.
34) ISAAA. 2023. Maize (Zea mays L.) GM Events (244 Events). Available at: https:// www.isaaa.org/gmapprovaldatabase/ crop/ default.asp?CropID=6&Crop=Maize [9 MAY 2023]
35) James C. 2010. Global status of commercialized biotech/GM crops: 2010. ISAAA brief no. 42. ISAAA, Ithaca, NY.
36) Koziel MG, Beland GL, Bowman C, Carozzi NB, Crenshaw R, Crossland, L, Dawson J, Desai N, Hill M, Kadwell S, Launis K, Lewis K, Maddox D, McPherson K, Meghji MR, Merlin E, Rhodes R, Warren GW, Wright M, and Evola SV. 1993. Field performance of elite transgenic maize plants expressing an insecticidal protein derived from Bacillus thuringiensis. Biotechnology 11: 194–200.
37) Low-Phytate Corn Works for Finishing 2011. National Hog Farmer. https:// www.nationalhogfarmer.com/ mag/farming_lowp hytate_corn_works
38) MAFRI. 2004. Corn Production in Manitoba. Available: http:// 3)www.gov.mb.ca/ agriculture/ crops/ specialcrops/ bii01s00.html
39) Malarkey T. 2003. Human health concerns with GM crops. Mutation Research. 544,217–221.
40) Melo-Durán D, Perez JF, González-Ortiz G, Villagómez-Estrada S, Bedford MR, Graham H, and Sola-Oriol D. 2021. Growth performance and total tract digestibility in broiler chickens fed different corn hybrids. Poultry science, 100(8), 101218. https://doi.org/10.1016/j.psj.2021.101218
41) Moses V. 1999. Biotechnology products and European consumers. Biotechnology Advances 17, 647–678.
42) NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. National Academy Press, Washington, DC.
43) Nielsen SS, Alvarez J, Bicout DJ, Calistri P, Depner K, Drewe JA, Garin- Bastuji B, Gonzales Rojas JL, Gortázar Schmidt C, Michel V, Miranda Chueca MÁ, Roberts HC, Sihvonen LH, Spoolder H, Stahl K, Viltrop A, Winckler C, Candiani D, and Velarde A. 2020. Welfare of pigs at slaughter. EFSA Journal, 18(6). https://doi.org/10.2903/j.efsa.2020.6148
44) Niyazov, N.S.-A., Ostrenko, K.S. 2020. Effect of low-protein diets on the nitrogen balance and productivity of pigs. Journal of Livestock Science 11:106-109 doi.10.33259/JLivestSci.2020.106-109
45) Opapeju FO, Nyachoti CM, House JD, Weiler H, and Sapirstein HD. 2006. Growth performance and carcass characteristics of pigs fed short- season corn hybrids. Journal of Animal Science, 84(10), 2779-2786.
46) Paparini A, and Romano-Spica V. 2004. Public health issues related with the consumption of food obtained from genetically modifiedorganisms. Biotechnology Annual Review. 10, 85–122.
47) Patience JF, Rossoni-Serão MC, and Gutiérrez NA. 2015. A review of feed efficiency in swine: biology and application. Journal of Animal Science and Biotechnology, 6(1), 1-9.

48) Piva G, Morlacchini M, Pietri A, Piva A, and Casadei G. 2001. Performance of weaned piglets fed insect protected (MON810) or near isogenic corn. Journal of Animal Science, 79(1), 106.
49) Reichert M, Kozaczyński W, Karpińska TA, Bocian L, Jasik A, Kycko A, Swiatkiewicz M, Swiatkiewicz S, Furgal-Dierzuk I, Arczewska- Wlosek A, Strzetelski J, Kwiatek K. 2012. Histopathology of internal organs of farm animals fed genetically modified corn and soybean meal. Bulletin of the Veterinary Institute in Pulawy 56, 617-622.
50) Rentfrow G, Sauber TE, Allee GL, Berg EP. 2003. The influence of diets containing either conventional corn, conventional corn with choice white grease, high oil corn, or high oil high oleic corn on belly/bacon quality. Meat Science. 64:459–466.
51) Reuter T, Aulrich K, and Berk A. 2002. Investigations on Genetically Modified Maize (Bt-Maize) in Pig Nutrition: Fattening Performance and Slaughtering Results. Archiv Für Tierernährung, 56(5), 319– 326. https://doi.org/10.1080/00039420215628
52) Reynolds TL, Nemeth MA, Glenn KC, Ridley WP, and Astwood JD. 2005. Natural variability of metabolites in maize grain: differences due to genetic background. Journal of Agricultural and Food Chemistry, 53(26), 10061–10067. https://doi.org/10.1021/jf051635q
53) Schnepf E, Crickmore N, Van Rie J, Lereclus D, Baum J, Feitelson J, Zeigler DR, and Dean DH. 1998. Bacillus thuringiensis and its pesticidal crystal proteins. Microbiology and Molecular Biology Review. 62, 775–806.
54) Spencer, J. D., Allee, G. L., & Sauber, T. E. (2000). Growing-finishing performance and carcass characteristics of pigs fed normal and genetically modified low-phytate corn. Journal of Animal Science, 78(6), 1529-1536.
55) Stein HH, and Shurson, GC. 2009. Board-invited review: the use and application of distillers dried grains with solubles in swine diets. Journal of Animal Science, 87(4), 1292-1303.
56) Stein HH, Sauber TE, Rice DW, Hinds MA, Smith BL, Dana G, Peters D N, and Hunst P. 2009. Growth Performance and Carcass Composition of Pigs Fed Corn Grain from DASØ15Ø7-1 (Herculex I) Hybrids 1. The Professional Animal Scientist 25 (2009):689–694
57) Swiatkiewicz M, Bednarek D, Markowski J, Hanczakowska E, and Kwiatek K. 2013. Effect of feeding genetically modified maize and soybean meal to sows on their reproductive traits, haematological indices and offspring performance. Bulletin of the Veterinary Institute in Pulawy 57, 413-418.
58) Torres JRV, dela Cruz JF, Khasanah H, Purnamasari L, Widianingrum DC. 2022. Effect of Transgenic and Non-Transgenic Corn Hybrids on the Performance of Quails and Chicken: A Review. Jurnal Ilmu Peternakan dan Veteriner Tropis, 12(3): 217-231.
59) Unruh JA, Friesen KG, Stuewe SR, Dunn BL Nelssen JL, Goodband RD, and Tokach MD. 1996. The influence of genotype, sex, and dietary lysine on pork subprimal cut yields and carcass quality of pigs fed to either 104 or 127 kilograms. Journal of Animal Science. 74:1274– 1283.
60) US EPA. 2000. Bt plant- pesticides, biopesticides registration action document. Scientific Advisory Panel Meeting Report, 2000 Oct. 08– 20.
61) Walsh MC, Buzoianu SG, Gardiner GE, Rea MC, Paul Ross R, Cassidy J P, and Lawlor PG. 2011. Effects of short-term feeding of Bt MON810 maize on growth performance, organ morphology and function in pigs. British Journal of Nutrition, 107(03), 364–371. doi:10.1017/s0007114511003011
62) Walsh MC, Buzoianu SG, Gardiner GE, Rea MC, Ross Cassidy JP, Lawlor PG. 2012a. Effects of short-term feeding Bt MON810 maize on growth performance, organ morphology and function in pigs. British Journal of Nutrition, 107, 364-371.
63) Walsh MC, Buzoianu SG., Gardiner GE, Rea MC, O'Donovan O, Gelencsér E, Ujhelyi G, Ross RP, Gardiner GE, and Lawlor PG, 2012b. Effects of feeding Bt MON810 maize to pigs for 110 days on peripheral immune response and digestive fate of the cyr1Ab gene andtruncated Bt toxin. PLoS ONE, 7, e36141.
64) Walsh MC, Buzoianu SG, Gardiner GE, Rea MC, O'Donovan O, Ross RP, and Lawlor PG. 2013. Effects of feeding Bt MON810 maize to sows during first gestation and lactation on maternal and offspring health indicators. British Journal of Nutrition, 109, 873-881.
65) Yonemochi C, Suga K, Harada C, Hanazumi M. 2010. The evaluation of transgenic event CBH 351 (StarLink) corn in pig. Journal of Animal Science, 81, 94-10.