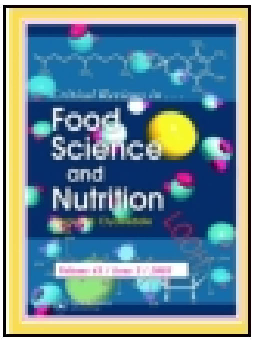

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A review: nutrition and process attributes of corn in pet foods

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REVIEW

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A review: nutrition and process attributes of corn in pet foods

Isabella Corsato Alvarenga, Amanda N. Dainton, and Charles G. Aldrich

Department of Grain Science and Industry, Kansas State University, Manhattan, Kansas, USA

ABSTRACT

Corn is one of the largest cereal crops worldwide and plays an important role in the U.S. economy. The pet food market is growing every year, and although corn is well utilized by dogs, some marketing claims have attributed a negative image to this cereal. Thus, the objective of this work was to review the literature regarding corn and its co-products, as well as describe the processing of these ingredients as they pertain to pet foods. Corn is well digested by both dogs and cats and provides nutrients. The processing of corn generates co-products such as corn gluten meal and distillers dried grains with solubles that retain quality protein, and fibrous components that dilute dietary energy. Further, corn has much functionality in extrusion processing. It may yield resistant starch under certain processing conditions, promoting colonic health. Carotenoids in corn may enhance immune support in companion animals if concentrated. Mycotoxin contamination in grains represent a health hazard but are well controlled by safety measures. Genetically modified (GM) corn is still controversial regarding its long-term potential for mutagenicity or carcinogenicity, thus more long-term studies are needed. In conclusion, the negative perception by some in the pet food market may not be warranted in pet foods using corn and its co-products.

KEYWORDS

Animal health; co-products; corn; extrusion; nutrition; processing

Introduction

Global pet food sales have enjoyed a nearly 6% annual growth rate since 2013 and were estimated to be U.S. $91.1 billion in 2018 (Philipps-Donaldson 2019). The majority of dogs and cats are fed dry foods as whole meals or treats. Dry foods, like extruded kibbles, generally contain between 30% and 60% starch ingredients, which provide kibble binding and expansion properties due to starch when cooked in the presence of water and heat. Corn is an example of a starch ingredient that can be used in dry pet foods due to its physical properties. It also provides energy and nutritional value to pets, which will be discussed in this review.

Although corn has been used in pet foods for decades with few issues or concerns regarding pet health, recent marketing claims have contributed to a negative image of this cereal. One claim is that corn and other grains cause allergies. Veterinary reports have shown that the main cause of allergies is peptides or glycoproteins, and that grains cause less than 1.5% of all food allergy cases (Laflamme et al. 2014). Some pet owners also have the perception that corn has no nutritional value, and that it is added to the food as a "filler" or as an ingredient to lower production cost. A review of the existing literature should be conducted to determine whether there is validity to the claims or not.

The research question posed was what the effect of corn in dog or cat diets may have on animal health, diet utilization, and potential physiological implications. Thus, the goal of this review was to explore the breadth of published research regarding corn in pet foods, and to summarize research regarding this cereal along with its co-products for their nutritional value, antioxidant potential, and functional properties as it pertains to pet nutrition and health. A literature search was conducted utilizing scientific search engines and key words to identify all peer-reviewed publications with corn and pets as common themes. Specifically, Google Scholar and Scopus were used with key words including "pet food," "dog," "cat," "corn," "digestibility," "lutein," "corn co-product," "distillers' grains," "antioxidants," "starch," "obesity," "hypersensitivity," "food allergy." Only original research featuring dogs or cats that had a corn component as a dietary treatment were selected. Additional supporting literature and published reviews were utilized where appropriate. Only publications evaluating corn inclusions of 30% or more were considered in this review. In cases where corn inclusion level in experimental diets was insignificant and (or) not the research target of the particular manuscript it was excluded from the summary tables.

Corn ingredient: US production, usage and composition

Corn is a major crop for farmers in the United States. In 2018, U.S. corn growers produced 14.626 billion bushels of corn (USDA ERS 2018), which at 56 pounds per bushel is approximately 366 million US tons (1 US ton = 2000 pounds). From this supply, 5.5 billion bushels (154 million

CONTACT Charles G. Aldrich aldrich4@ksu.edu 201 Shellenberger Hall, 1301 Mid Campus Drive, Manhattan, KS 66502, USA.

Table 1. Nutritional composition of whole corn used in various pet food studies.

		Nutrient, dry matter basis[a]					
Authors	Corn type[b]	DM, %	Ash, %	CP, %	AHF, %	Starch, %	TDF, %
Murray et al. (1999)	Corn	90.1	0.6	5.6	3.2	88.3	3.0
Bednar et al. (2001)	Corn	86.8	1.4	12.8	4.9	NR[d]	19.6
Gajda et al. (2005)	Conventional corn	87.0	1.6	8.5	6.8	78.1	12.0
Gajda et al. (2005)	High-protein corn	87.5	1.3	10.2	5.8	79.1	10.7
Gajda et al. (2005)	High protein, low phytate corn	87.8	1.5	10.1	6.2	79.1	11.2
Gajda et al. (2005)	High-amylose corn	86.9	1.7	11.6	7.2	69.1	18.8
Carciofi et al. (2008)	Corn	88.8	1.9	10.5	5.2	78.4	4.1
Cutrignelli et al. (2009)	Corn	88.4	1.6	8.8	1.2[c]	79.4	9.1
Fortes et al. (2010)	High oil maize	88.2	1.3	9.5	8.5	71.7	8.7
Bazolli et al. (2015)	Maize	88.3	1.3	9.1	6.3	71.9	11.2
Averages	–	88.0	1.4	9.8	6.0	77.2	10.8

[a]DM, dry matter; CP, crude protein; AHF, acid-hydrolyzed fat; TDF, total dietary fiber.
[b]Corn variety as described in each study.
[c]Not reported in the study.
[d]Measured by ether extract. This fat value was not included in the average.

US tons) were used for animal feed and residual use, 0.2 billion bushels (5.85 million US tons) for cereals and related products, 0.39 billion bushels (10.92 million US tons) for glucose and dextrose uses, 0.46 billion bushels (12.88 million tons) for high-fructose corn syrup production, 0.03 billion bushels (0.87 million US tons) for use as seeds, and 0.24 billion bushels (6.72 million US tons) were used for starch production (USDA ERS 2018).

Unfortunately, there is very little information about the amount of corn that is used in the United States pet food industry. But one could extrapolate from a few assumptions. The pet food market in North America is approximately 8.5 million metric tons (approximately 9.4 million US tons). Around 80% of pet foods have grains (Corsato Alvarenga and Aldrich 2020), which comprise 30–60% of the food (consider 45%). Corn is approximately 25% of these grains, so it might contribute to 0.67 million metric tons (approximately 0.74 million US tons) of the pet food market. That remains a substantial portion, but corn has lost market share to the grain-free segment since the beginning of the millennium (nearly 20% of the market). This resulted from disparaging information and the lack of consolidated information that contradicted incorrect statements.

Corn (*Zea mays L.*) is considered as one of the most important cereals in the world. Kernel types can be grouped as dent, flint, flour, sweet, pop, and pod (Watson and Ramstad 1991). Dent hybrids are grown in the US corn belt and certain countries in Europe, and the yellow endosperm is the predominant type. Flint kernels are grown in South America and Northern Europe, floury corn is one of the oldest types produced by the Aztecs and Incas, and sweet corn is an important crop consumed as fresh, frozen, or canned by humans (Győri 2010).

Corn used in pet foods is usually dent hybrids, or co-products of other corn varieties from the human food chain. Its nutritional composition may benefit both health and different food processes that transform corn ingredients into a final product. The whole kernel can be divided into three anatomical parts: the pericarp, endosperm, and the germ (Győri 2010). Some authors also consider the tip as an anatomical part of corn. The corn endosperm is divided into the horny endosperm, which contains protein and starch, and the floury endosperm, with mostly starch granules. The germ (embryonic tissue) contains high amounts of lipids and protein, and the bran, which includes the pericarp and hull, is the fibrous fraction of corn with primarily cellulose, hemicelluloses, lignin, and pectic substances (Győri 2010). Corn varieties used in pet foods have on average 88.0% DM, 1.42% ash, 9.79% CP, 6.01% fat, 77.2% starch, and 10.8% TDF (Table 1).

The largest nutrient fraction of the corn kernel is starch, which is located in the endosperm. The endosperm has large (15–18 μm) and small (5–7 μm) starch granules with non-smooth cuboid or rounded shapes (Singh and Singh 2003). The starch granule is composed of the polymers amylose and amylopectin. Amylose is a linear molecule composed of anhydroglucose units linked by α-1,4 bonds, whereas amylopectin is a branched glucose polymer with α-1,4 and α-1,6 bonds. While amylose has a low molecular weight, amylopectin is a much larger polymer (Buléon et al. 1998). There are certain cultivars within species that differ in their ratio of amylose to amylopectin, such as waxy maize with almost 100% amylopectin, or high-amylose corn.

Effects of corn on pet health and nutrition

Corn utilization by dogs and cats

Corn is included in many pet food recipes due to its structure-forming properties, economics, and history of nutritional utility. Nutritional value is commonly measured by difference from the fecal disappearance of nutrients, from which one can calculate the apparent total tract digestibility (ATTD). Dogs and cats can obtain glucose from dietary sugars or synthetize it from other substrates through a process called gluconeogenesis (Tanaka et al. 2005). A moderate intake of starch ingredients like corn adds energy to the diet, besides providing some fiber, protein, and fatty acids.

When corn starch is digested by pancreatic alpha-amylase in the duodenum, the end products are maltotriose, alpha-limit dextrins, and maltose. These are further digested by maltase-glucoamylase, sucrase, and isomaltase into glucose. Monosaccharides are absorbed in the SI, mainly in the jejunum region, enter the bloodstream, and are then transported into cells with the aid of insulin and other hormones.

Table 2. Dry matter (DM) apparent total tract digestibility (ATTD) by adult dogs fed diets containing at least 30% corn.

Authors	Corn ingredient[a]; inclusion, %	Dog breed	Diet type	Digestibility method[b]	DM ATTD, %
Wolter et al. (1978)	Corn; 50.0	Beagle	Wet food	TFC	91.9
Walker et al. (1994)	Maize; 67.0	Mature mongrel	Extruded kibbles	TFC	87.2
Murray et al. (1999)	Corn flour; 43.6	Hound bloodline	Extruded kibbles	CO	85.4
Gajda et al. (2005)	Conventional corn; 31.9	Hound bloodline	Extruded kibbles	TFC	77.1
Gajda et al. (2005)	High-protein corn; 32.0	Hound bloodline	Extruded kibbles	TFC	75.5
Gajda et al. (2005)	High-protein, low phytate corn; 32.4	Hound bloodline	Extruded kibbles	TFC	77.6
Gajda et al. (2005)	High-amylose corn; 33.2	Hound bloodline	Extruded kibbles	TFC	60.6
Gajda et al. (2005)	Amylomaize, 26.0	Hound bloodline	Extruded kibbles	TFC	66.9
Twomey et al. (2002)	Maize; 53.5	Mixed-breed	Extruded kibbles	Celite	92.0
Carciofi et al. (2008)	Corn; 53.5	Mixed-breed	Extruded kibbles	CO	78.6
Kore et al. (2009)	Maize; 70.5	Spitz	Pressure cooked	TFC	83.8
Fortes et al. (2010)	Maize; 66.7	Mixed-breed	Extruded kibbles	TFC	84.9
Bazolli et al. (2015)	Maize ground at 360 um ; 53.5	Beagle	Extruded kibbles	CO	80.5
Bazolli et al. (2015)	Maize ground at 451 um ; 53.5	Beagle	Extruded kibbles	CO	82.1
Bazolli et al. (2015)	Maize ground at 619 um ; 53.5	Beagle	Extruded kibbles	CO	75.9
Schauf et al. (2018)	Maize; 34.0	Beagle	ND[c]	TFC	82.2
Domingues et al. (2019)	Corn; 30	Beagle	Extruded kibbles	TFC	81.7

[a]As described by each author.
[b]TFC, total fecal collection; CO, chromic oxide marker method; Celite, celite marker method.
[c]ND, not defined.

The extent of processing, inclusion of starch ingredients and type of starches all influence the extent to which glucose is absorbed. Highly digestible starches rapidly increase plasma glucose and insulin (Carciofi et al. 2008). Intake of these diets chronically can lead to insulin resistance (André et al. 2017) and eventual development of type II diabetes. Carciofi et al. (2008) reported that dogs fed a diet with 53.5% corn as the only starch ingredient led to peak blood glucose and insulin levels within a few minutes postprandial, in a manner similar to dogs fed a brewer's rice diet.

For ground whole corn or corn starch included in a pet food and properly cooked, the starch is almost entirely digestible by the end of the ileum (89.9–99.5%; Gajda et al. 2005; Murray et al. 1999; Walker et al. 1994). Any remaining undigested starch that reaches the colon is fermented. Schünemann et al. (1989) demonstrated that canine ileal digestion of raw corn was increased after cooking, and Moore et al. (1980) found no difference in starch ATTD between cooked and uncooked corn. This is evidence that the portion of raw corn starch that escaped small intestinal digestion was fermented in the colon, and thereby absent in the feces. When comparing different corn hybrids, Gajda et al. (2005) found that DM ileal digestion of extruded high protein corn was higher than conventional, low protein and low phytate corn, high-amylose corn and amylomaize (64.6% vs. average 57.8%). These authors concluded that high-amylose corn should not be used in dog diets because it had low ATTD and lower in vitro fermentation.

The DM ATTD in corn-based diets has been reported to be high (average 80.23%; Table 2) and comparable to other grains like sorghum, and similar or slightly lower than rice (Bazolli et al. 2015; Carciofi et al. 2008; Fortes et al. 2010; Kore et al. 2009; Twomey et al. 2002). Another study found that DM ATTD of a corn-based diet was similar to rice, wheat, and potato-based foods, and higher than barley and a sorghum-based diets by 2.9 and 5.7 percent units, respectively, when fed to dogs (Murray et al. 1999). Dogs fed corn-based diets were also reported in several studies to produce firm, high quality feces (Kore et al. 2009; Murray et al. 1999; Twomey et al. 2002; Walker et al. 1994). So, the notion that corn is an indigestible filler does not appear to be valid based on these results. However, controlling glucose absorption in rapidly digested corn-based diets is beneficial for animal health. This can be accomplished by combining different starch sources in the diet (Sunvold 2002) and/or modifying the process to favor the retention of slowly digestible or resistant starches (Ribeiro et al. 2019; Peixoto et al. 2018).

Impact of corn on nutrient digestibility

Mean values for corn content in the diet and the resulting ATTD by dogs were extracted from peer-reviewed papers where conventional corn comprised at least 30% of the diet formulation (Table 2). This yielded 11 data points with DM digestibility, 10 data points with both crude protein and fat digestibility, nine data points with gross energy and starch digestibility. Organic matter and total dietary fiber digestibility were excluded from analysis due to the low number of data points (4 and 3, respectively). Pearson correlation coefficients between dietary corn content and each nutrient digestibility were determined with statistical analysis software (SAS 9.4, Cary, NC). Correlations were considered significant at p values less than .05 and the absolute r value was used to determine the strength of the association (0–0.4 = weak; 0.4–0.7 = moderate; 0.7–0.9 = strong; 1 = perfect). Only starch digestibility exhibited a correlation ($p = .0189$) with dietary corn content; a strong linear association ($r = 0.754$) was observed, meaning that canine ATTD of starch increased with increased corn in the diet. Digestibility of DM ($r = 0.395$, $p = .2291$), crude protein ($r = 0.332$; $p = .3490$), fat ($r = 0.033$; $p = .9282$), and gross energy ($r = -0.244$; $p = .5263$) did not exhibit significant correlations with corn content. While this analysis cannot determine causation, specifically if increasing dietary corn content is detrimental to nutrient digestibility, it does show that dietary corn content does not have a significant relationship with most macro-nutrients except for a strong positive linear relationship with starch digestibility.

Colonic health

The starch contained in the corn endosperm can be classified into digestible or resistant to digestion. Digestible starches completely disappear by the end of the ileum, and the undigested fraction, called resistant starch (RS), is readily fermented by bacteria in the colon. The most studied fermentation products are short chain fatty acids (SCFA) acetate, propionate, and butyrate. These SCFA can shift the microbiota toward more beneficial bacteria in the colon, promote trophic effects on the gastrointestinal tract (GIT) mediated by GLP-2 (NRC 2006), and support the GIT immune function and homeostasis (Corrêa-Oliveira et al. 2016). Butyrate is almost entirely used by colonocytes as an energy source, whereas acetate and propionate are transported to the liver through the portal vein (Haenen et al. 2013) and converted to energy substrates. Cutrignelli et al. (2009) found that corn fermentation pattern using dog fecal inoculum was similar to most carbohydrate sources (rice, potato, spelt) in acetate, propionate, and butyrate production (approximated ratio 5:5:1 acetate, propionate, and butyrate).

Cooking disrupts the compact crystalline structure of raw granules and improves starch digestion (Murray et al. 2001). Cereals like corn do not contain a high level of naturally occurring RS (type II) like legumes and some tubers (Dhital et al. 2017), but some may be preserved or developed upon processing. Pet food extrusion is considered a medium moisture/high energy cooking process (Rokey 2000) which fully gelatinizes starch (Murray et al. 1999) and yields low RS in the kibble (Corsato Alvarenga and Aldrich 2020). When extruded at low mechanical energy, corn-based pet foods might retain a small amount of RS and benefit the colonic health of both dogs (Peixoto et al. 2018; Ribeiro et al. 2019; Jackson, Waldy, Cochrane, et al. 2020) and cats (Jackson, Waldy, and Jewell 2020). Other less intensive cooking processes like baking were observed to have lower starch gelatinization compared to extrusion (Gibson and Alavi 2013). Thus, baked kibbles should retain more RS than the same extruded recipe, but this must be confirmed.

The extent of corn grinding (before extrusion) also affects its utilization. Bazolli et al. (2015) found that kibbles with coarse maize (ground at 521 µm mean geometric diameter) tended to be less digested by dogs. They noted that the portion that escaped digestion was fermented and produced feces with lower pH and more butyrate in comparison to the same diet extruded with fine corn (277 µm mean geometric diameter). Thus, these authors found benefits from under-processing corn. Peixoto et al. (2018) also found that a diet produced with coarser corn ground at 312 µm mean geometric diameter (vs. 224 µm mean geometric diameter of fine corn) and a lower extruder specific mechanical energy (SME) of 11.6 kW h/ton (vs. high SME of 21.5 kW h/ton) benefited colonic health of geriatric Beagle dogs. Additionally, the diet with less processing had a tendency to increase gastrointestinal mucosa crypt depth, which suggests an improvement in nutrient absorption. Ribeiro et al. (2019) produced diets in a similar manner as Peixoto et al. (2018) and confirmed that dogs fed a diet with coarsely ground corn (312 µm mean geometric diameter) extruded at 11.4 kW h/ton SME had greater fecal SCFA.

Some marketing claims suggest that high protein diets are better for pets, but this depends on factors such as protein quantity, quality, and the amino acid profile. Hang et al. (2013) reported benefits in feeding a high corn diet vs. high protein greaves-meal to dogs. Dogs fed the high corn diet produced firm feces with low ammonia (835 µg/g of wet feces) and neutral fecal pH (7.2). These were similar to dogs fed a dry commercial diet, and lower than those fed the high protein greaves-meal diet (fecal ammonia 1191 µg/g of wet feces and pH 7.5; Hang et al. 2013). A low fecal ammonia and lower pH could indicate that less protein reached the colon for putrefaction. Other indicators of protein putrefaction like polyamines may be attenuated by the addition of a fiber bundle to the diet (Jackson and Jewell 2019). Dogs fed a corn-rich diet also produced 30% more fecal SCFA than a diet rich in greaves-meal protein (Hang et al. 2013). Thus, from a gastrointestinal health perspective, a diet rich in fiber and resistant starches might be preferred over a high protein food resulting in undigested proteins reaching the large intestine, which are fermented into unhealthy nitrogen compounds like indoles and phenols.

Antioxidants

Corn and some foods derived from it are considered to be high in the carotenoids lutein and zeaxanthin (Masisi et al. 2015). Lutein and zeaxanthin are xanthophylls that have been related to eye protection in humans against age-related macular degeneration due to their antioxidant capacity. Perry, Rasmussen, and Johnson (2009) measured xanthophylls in corn and corn products and found that yellow corn was high in *trans* zeaxanthin (531 ppm) and was comparable to cooked egg yolks (587 ppm). Conversely, Moreau, Johnston, and Hicks (2007) reported that lutein and zeaxanthin in whole ground corn was much lower (2.63 and 4.59 ppm, respectively). Carotenoids like lutein have been found beneficial to dogs and cats. For example, Kim et al. (2000a) fed dogs crystalline lutein at 5, 10, and 20 mg/d and detected a significant improvement in the immune system after just two weeks. Kim et al. (2000b) also found that crystalline lutein improved humoral and cellular immune responses in cats.

Corn alone would likely not reach the target xanthophyll levels necessary to improve the immune response. A level of 5 mg of lutein would be required and whole corn was reported to have 2.63 ppm lutein, which would mean that a dog would need to consume >19 kg of corn per day to have an immune effect. While concentrations for a measurable effect are not there today, some co-products of corn may provide a future benefit.

The process of hydrolyzing cereal protein to enhance antioxidant activity has been well explored in the last decade. Zhuang, Tang, and Yuan (2013) hydrolyzed corn gluten meal (60% crude protein) with alkaline protease and measured antioxidant activities of different hydrolysate sizes. They observed that free radical scavenging, metal ion chelating activities and lipid peroxidation inhibition increased as hydrolysate size decreased, and was greatest with hydrolysate molecular weight less than 10 kDa. Zhou et al. (2015) also found that the antioxidant activities of corn gluten meal hydrolyzed proteins was highly correlated to small peptide molecules and antioxidative amino acids such as tyrosine, lysine, histidine, and methionine. More specifically, Li, Han, and Chen (2008) reported that the highest antioxidant activity of corn gluten meal hydrolysates occurred when peptides were in the range of 500–1500 kDa. Hence, corn has the potential to produce functional food ingredients high in antioxidants derived from hydrolyzing proteins from corn gluten meal, and(or) from concentrating carotenoids.

Food allergy

Consumers may perceive that pet foods produced with corn and other grains are allergens. Interestingly, the prevalence is very low. Verlinden et al. (2006) compiled data from seven studies and concluded that most food allergies were caused by animal protein (36% beef, 28% dairy, 10% egg, 9.6% chicken, 4% pork, 1% rabbit, and 1% fish), 15% were caused by wheat, and none by corn. More recently, Laflamme et al. (2014) reported that animal proteins were involved in most cases of food allergy in dogs, while wheat had a prevalence of 15%, and no cases ($N = 198$) of food allergenicity were due to corn consumption. In France, Carlotti, Remy, and Prost (1990) gathered veterinarian reports of 33 cases of canine food allergy and, again, no dog on the research reviewed was allergic to corn. Clearly the public perception does not match the data.

Mycotoxins & genetically modified corn

Corn is a functional ingredient that provides nutrition to pet foods, but some issues exist that cannot be overlooked. Mycotoxins are naturally occurring secondary metabolites of fungal metabolism that can easily grow in cereals under certain conditions. These toxins are known to cause severe acute or chronic health conditions in both animals and humans, even at low concentrations. In pet foods, the most problematic mycotoxins are aflatoxin, fumonisin, and deoxynivalenol, among others (Atungulu, Mohammadi-Shad, and Wilson 2018). The Food and Drug Administration (FDA) issued guidelines and allowances for aflatoxins in corn used in pet foods, for a maximum legal limit of 20 ppm. A recent study found that mycotoxins were present in dry commercial grain-based diets but were below the threshold established by the FDA (Tegzes, Oakley, and Brennan 2019). They concluded that more long-term studies should be conducted to assess the effect of chronic low-dose intake of these toxins.

There have been pet food recalls due to mycotoxin contamination around the world, but none in the US since 2001 (Atungulu, Mohammadi-Shad, and Wilson 2018). This is mainly because pet food companies are more aware of safety measures needed to prevent fungal growth and, therefore, the release of mycotoxins to the food. These control points can be implemented during pre-harvest, post-harvest and storage of grains, which are well described by Atungulu, Mohammadi-Shad, and Wilson (2018). It is not the focus of this review to provide a full description of mycotoxins, but to acknowledge that this concern exists and that mycotoxins are controlled by pet food and ingredient companies through testing in order to be in compliance with the FDA and Food Safety Modernization Act (FSMA) regulations.

Although genetically modified (GM) corn is viewed as a negative by some consumers, GM corn may have additional benefits when compared to traditional corn. For instance, the most common GM corn in the US, the Bt corn, has a gene that encodes for a protein derived from *Bacillus thuringiensis* that controls lepidopteran insect infestations (Hammond et al. 2004). The GM Bt corn also has a lower incidence of mycotoxin contamination and, therefore, contributes to a reduction in crop losses and positively impacts the economy (Hammond et al. 2004).

The controversial topic of GM cereals was explored in depth by Domingo (2016). According to this review, the vast majority of studies conducted in the last decade regarding GM corn showed no adverse health effects in rats, mice, or miniature pigs. The few studies that reported issues with GM corn consumption were suspect, which led Domingo (2016) to suggest a need for more long-term safety studies assessing mutagenicity, carcinogenicity and teratogenicity.

Secondary products from corn: application in pet foods and their benefits to pet health

Many sources of corn used in dog and cat foods are secondary products from corn processing for human food or biofuels. Corn as an industrial input is processed by three methods with different primary and secondary finished products: wet milling, dry milling, and dry grind. The nutrient composition (Table 3) of the secondary products and utilization by the animal will be heavily influenced by these processing methods.

Starch is the primary product from the wet milling process and can be converted into fuel ethanol, high-fructose corn syrup, or modified starches. The purified starch can also be included in a pet food formulation. Compared to the whole corn kernel, corn starch is nearly 100% nitrogen free extract (NFE) with minute amounts of ash, crude protein (CP), and acid-hydrolyzed fat (AHF; Bednar et al. 2001). In their study, Bednar et al. (2001) reported that the starch component of the ingredient was 70.0% rapidly digestible, 20.0% slowly digestible, and 7.9% resistant to digestion. This translates into very high starch digestibility with a rapid release of energy in the form of glucose. As such, corn starch could be included in diets to provide rapidly available energy.

Secondary products from corn wet milling include corn gluten meal, corn germ, and corn gluten feed. Corn gluten meal is a concentrated protein source with low amounts of ash, CP, AHF, and TDF and moderately low amounts of NFE (de Godoy et al. 2009; Smith 2018; Table 3). Corn gluten meal has been included in extruded experimental diets (34.6% of the diet) for cats (Funaba et al. 2005). Dry matter ATTD was lower than for cats fed meat meal or chicken

Table 3. Nutritional composition of corn co-products used in various pet food studies.

		Nutrient, dry matter basis[a]						
Authors	Corn co-product	DM, %	Ash, %	CP, %	AHF, %	TDF, %	NFE[b], %	GE, kcal/kg
Guevara et al. (2008)	Corn fiber, hydrolyzed	94.2	0.5	12.0	6.8	79.9	0.8	4900.0
Guevara et al. (2008)	Corn fiber, hydrolyzed extracted	96.4	0.5	10.8	2.4	88.2	0.0	4700.0
Guevara et al. (2008)	Corn fiber, native	92.1	1.0	12.0	5.6	71.1	10.3	4800.0
Guevara et al. (2008)	Corn fiber, native with fines	87.4	0.7	14.1	4.9	63.0	17.3	4800.0
de Godoy et al. (2009)	Corn germ meal	90.1	3.9	28.4	6.0	45.0	16.7	4559.0
Kawauchi et al. (2011)	Corn gluten feed	89.4	6.7	24.9	4.5	42.7	12.5[c]	4943.7
de Godoy et al. (2009)	Corn gluten meal	90.5	1.8	73.9	7.8	0.3	16.2	5743.0
Smith (2018)	Corn gluten meal	89.8	1.1	74.7	1.8[d]	ND[e]	22.4	NR[f]
Bednar et al. (2001)	Corn flour	92.1	0.6	11.2	2.6	2.8	84.3[c]	NR[f]
Bednar et al. (2001)	Corn starch	91.2	0.2	0.6	0.9	0.0	102.5[c]	NR[f]
de Godoy et al. (2009)	Distillers dried grains with solubles	91.8	4.3	27.6	15.2	30.5	22.4	5175.0
Silva et al. (2016)	Distillers dried grains with solubles	90.8	2.0	30.1	9.0	9.3[g]	40.7	4805.6
Smith (2018)	Next-generation distillers dried grains	93.3	4.6	54.4	4.2[d]	4.4[g]	32.3	NR[f]

[a]DM, dry matter; CP, crude protein; AHF, acid-hydrolyzed fat; TDF, total dietary fiber; GE, gross energy.
[b]Calculated as 100 − (ash + CP + fat + fiber).
[c]Reported as starch content.
[d]Reported as crude fat.
[e]Not detected.
[f]Not reported in the study.
[g]Reported as crude fiber.

Table 4. Dry matter (DM) apparent total tract digestibility (ATTD) by adult pets fed diets containing a corn co-product.

Authors	Corn ingredient; inclusion, %	Species, breed	Diet type	Digestibility method[a]	DM ATTD, %
Guevara et al. (2008)	Corn fiber, hydrolyzed; 7.0	Dog, beagle	Extruded kibbles	CO	94.2
Guevara et al. (2008)	Corn fiber, hydrolyzed extracted; 7.0	Dog, beagle	Extruded kibbles	CO	96.4
Guevara et al. (2008)	Corn fiber, native; 7.0	Dog, beagle	Extruded kibbles	CO	92.1
Guevara et al. (2008)	Corn fiber, native with fines; 7.0	Dog, beagle	Extruded kibbles	TFC	87.4
Kawauchi et al. (2011)	Corn gluten feed; 7.0	Dog, beagle	Extruded kibbles	TFC	79.4
Kawauchi et al. (2011)	Corn gluten feed; 14.0	Dog, beagle	Extruded kibbles	TFC	75.2
Kawauchi et al. (2011)	Corn gluten feed; 21.0	Dog, beagle	Extruded kibbles	TFC	72.8
Funaba et al. (2005)	Corn gluten meal; 34.6	Cat, mixed-breed	Extruded kibbles	TFC	77.7
Smith (2018)	Corn gluten meal; 20.5	Dog, beagle	Extruded kibbles	TD	83.4
Silva et al. (2016)	Distillers dried grains with solubles; 6.0	Dog, beagle	Extruded kibbles	TFC	85.2
Silva et al. (2016)	Distillers dried grains with solubles; 6.0 and xylanase	Dog, beagle	Extruded kibbles	TFC	84.1
Silva et al. (2016)	Distillers dried grains with solubles; 12.0	Dog, beagle	Extruded kibbles	TFC	82.6
Silva et al. (2016)	Distillers dried grains with solubles; 12.0 and xylanase	Dog, beagle	Extruded kibbles	TFC	81.5
Silva et al. (2016)	Distillers dried grains with solubles; 18.0	Dog, beagle	Extruded kibbles	TFC	83.2
Silva et al. (2016)	Distillers dried grains with solubles; 18.0 and xylanase	Dog, beagle	Extruded kibbles	TFC	80.6
Smith (2018)	Next-generation distillers dried grains; 25.0	Dog, beagle	Extruded kibbles	TD	78.2

[a]CO, chromic oxide marker method; TFC, total fecal collection method; TD, titanium dioxide marker method.

meal (Table 4). Their feces were more moist, which suggests corn gluten meal may have a higher water holding capacity than the animal proteins. However, cats fed the corn gluten meal diet had more acidic urine (pH 6.08), and fewer struvite crystals. One item of note – corn gluten meal as the primary protein source may require supplementation of arginine.

Compared to corn gluten meal, corn germ meal is lower in CP and gross energy (GE), but higher in TDF and ash and similar in AHF. An assay utilizing cecetomized roosters to measure amino digestibility found that corn germ meal was less digestible than corn gluten meal in terms of total amino acids (79.0% vs. 95.4%), essential amino acids (80.4% vs. 94.3%), and non-essential amino acids (76.8% vs. 97.0%) and could be influenced by the greater fiber content (de Godoy et al. 2009). However, greater protein efficiency for chicks fed corn germ meal compared to corn gluten meal (2.83 vs. 0.76, respectively) suggests that corn germ meal may have a more favorable amino acid profile (de Godoy et al. 2009).

Corn gluten feed is similar to corn germ meal in that it contains moderate amounts of TDF and CP. Increasing the level of corn gluten feed in an extruded diet for dogs decreased the digestibility of all nutrients (Kawauchi et al. 2011; Table 4), indicating this ingredient could act as a fiber source in complete diets. Very little research has compared the use of corn gluten feed to similar ingredients in pet diets. However, research has been published assessing the benefits of using the fiber stream often incorporated into corn gluten feed. Depending on the process used to obtain the corn fiber product, TDF can vary from 63.0% to 88.2% on a DMB (Guevara et al. 2008). Adult Beagles dogs fed diets containing 7% of beet pulp, native corn fiber with or without fines, hydrolyzed corn fiber, or hydrolyzed extracted corn fiber did not show differences in food intake, fecal excretion, stool quality, AHF ATTD (83.8–94.7%), and CP ATTD (81.2–83.5%). Using native corn increased DM ATTD (82.3%; Table 4) compared to the other fiber sources, including beet pulp. Additionally, TDF ATTD by dogs of the native corn fiber diet was higher than the native corn fiber with fines and hydrolyzed corn fiber diets (30.9%, 19.1%, and 17.8%, respectively), with the beet pulp and hydrolyzed extracted corn fiber diets intermediate (average 23.9%). While minor differences were observed, these corn fibers appear to have a similar value in pet foods as a fiber option to beet pulp, a readily accepted and well researched fiber source.

The primary products from dry milling are flaking grits, which are commonly used in the human food industry as corn flakes. Secondary products from this process include corn flour and hominy feed. Corn flour is predominantly used in baked products with high NFE, and low CP (Bednar et al. 2001). Hominy feed contains germ and bran and is commonly included in livestock diets (MacGregor, Sniffen, and Hoover 1978). There is no information regarding the use of corn flour or hominy feed in pet diets. There might be potential for them in extruded or baked pet food products.

Dry grind corn processing is primarily directed toward ethanol production and produces distillers dried grains with or without solubles as secondary products. Solubles are the product resulting from the evaporation of water from the thin stillage distillation process effluent. These solubles are usually added to the distillers wet grains before drying. Because distillers dried grains with solubles (DDGS) is a secondary product, the composition fluctuates between 27.6% and 30.1% CP, 9.0% and 15.2% AHF, and 2.0% and 4.3% ash, on a DMB (de Godoy et al. 2009; Silva et al. 2016). Some evaluations in pet food have been reported, but the acceptance by pet owners has been limited and the greatest use occurs in value-based pet foods.

The protein in DDGS is similar to that in corn germ meal, with comparable amino acid digestibility and protein quality rankings (2.63 vs. 2.83, respectively; de Godoy et al. 2009). Increasing the level of DDGS from 0% to 18% resulted in reduced ATTD (Table 4; Silva et al. 2016). Fecal pH was more acidic when DDGS were included in the diet. This suggests that the diet containing DDGS provided substrate for colonic fermentation and supported gastrointestinal health. Interestingly, as the level of DDGS increased, dogs preferred the diet over the control, indicating ready acceptance. Clearly, DDGS could be a viable protein source for pet foods with the potential to provide fermentable fibers and improve pet gut health if consumer attitudes were more accepting.

Recently, modified DDGS with elevated protein has become available. This “next-generation” distillers dried grains (NG-DDGS) were incorporated into a dog food at 25% and fed to adult Beagle dogs (Smith 2018). They observed that dogs fed NG-DDGS had lower DM (Table 4), organic matter, crude fat, crude fiber, and GE digestibility than those fed a diet containing soybean meal or corn gluten meal. Although the feces of these dogs were of acceptable firmness and consistency and palatability was similar to soybean meal. Cats preferred the diet with NG-DDGS or soybean meal relative to corn gluten meal. These results suggest that NG-DDGS may be used with success in diets that traditionally contain soybean meal or corn gluten meal.

Even though secondary products from corn processing have been stigmatized as low-quality by-products, published research suggests otherwise. Depending on the specific ingredient, secondary products from corn can be quality sources of concentrated protein and/or fiber. They can also contribute more targeted benefits, such as high quality protein, energy, or fiber. They may also add to the sustainability of corn.

Processing of pet foods with corn

The majority of dogs and cats are fed extruded dry kibbles, with market estimates of $72.64 billion worldwide by 2022 (Research and Markets 2017). Pet food extrusion is a complex and versatile process that involves cooking under predetermined conditions of pressure, moisture, mechanical and thermal energies. Nearly all extruded pet food is formulated to be nutritionally complete and balanced to meet the animals’ nutrient requirements by combining ingredients with different physical and nutritional attributes.

The macro-ingredients in a diet have an impact on extrusion performance. According to the Guy Classification System (Guy 2001), ingredients can be structure-forming, dispersed phase fillers, or plasticizers. Structure-forming ingredients like starches and (or) vegetable proteins promote binding, homogenization, and structuring of the dough. Starchy ingredients like ground corn or corn flour are the most common structure-forming ingredients. At the other end of the spectrum, ingredients classified as dispersed phase fillers or plasticizers do not contribute to the physical matrix formation and can negatively affect the structural quality of the dough. Thus, corn by-products high in fiber or high in overly processed proteins like corn gluten meal tend toward dispersed phase fillers.

Prior to extrusion processing, corn, along with the other dry ingredients, must be ground. The particle size may influence the outcome. For example, coarsely ground corn using a sieve size 3.0 mm was reported to produce less expanded, denser kibbles (438 g/L) due to low particle surface area to mass compared to a finely ground corn using a sieve size 0.8 mm (Bazolli et al. 2015). Mathew, Hoseney, and Faubion (1999b) also reported lower kibble expansion and a 6% decrease in SME from when corn was ground using a hammermill screen size of 1.5 mm when compared to 0.75 mm sieve size. During pre-conditioning and cooking in the extruder barrel, water and heat (energy) promote starch gelatinization, which increases cold water solubility and starch viscosity, and releases amylose during pasting (Cheftel 1986). The increase in viscosity due to gelatinization aids in binding and homogenization. The coarser the corn, the less gelatinized the kibble will be (Ribeiro et al. 2019; Bazolli et al. 2015). Phase transition of the starch polymer from glassy to rubbery and, finally, melt occurs inside the extruder barrel (Moraru and Kokini 2003). When the extrudate reaches the end of the barrel, the air bubbles were got entrapped during the process grow as the melt leaves the die due to moisture vaporization, where the high pressure of the water nuclei overcomes the mechanical resistance of the melt, and expansion occurs (Moraru and Kokini 2003). Liu et al. (2006) found that as low as 15% corn flour increased expansion of a corn and oat flour blend. Some expansion is required in pet foods to produce a kibble with the right appearance and texture. Conversely, kibbles with less starch and high dietary fiber tend to expand less (Alvarenga and Aldrich 2018) and to be less palatable (Koppel et al. 2015).

The amylose:amylopectin ratio plays an important role in extrusion processing. Waxy starches (low amylose, high amylopectin) have a tendency to form a sticky paste with a light, elastic, and homogeneous texture, whereas starches with higher amylose content form a harder and less expanded extrudate (Moraru and Kokini 2003). Chinnaswamy and Hanna (1988) reported that the expansion ratio of corn starch almost doubled as amylose content increased from 0% to 50%, but decreased with further increases in amylose. Thus, around 50% amylose in the starch granule led to the greatest expansion. Different corn genotypes may also vary in fiber and protein, which can further influence extrusion. In a study evaluating three different corn samples with similar grinding and extrusion parameters, corn variety significantly affected expansion, breaking strength, and bulk density of a pet food (Mathew, Hoseney, and Faubion 1999a). Thus, the corn variety, growing conditions, the amylose:amylopectin ratio, and the amounts of each nutrient may influence pet food processing.

Medium moisture and high-heat extrusion, which is common for pet foods, results in near complete gelatinization of the starch with a significant increase in its digestibility (Dust et al. 2004; Murray et al. 2001). Murray et al. (2001) reported that high temperature relative to low temperature extrusion increased the rapidly digested starch fractions of corn, and decreased slowly digested and resistant starch fractions. This finding means that the more starch is cooked, the easier it is digested. Milder cooking processes like baking and pelleting of kibbles have been reported to result in less starch gelatinization when comparing the same extruded recipe (İnal et al. 2018; Gibson and Alavi 2013). Pelleting is not a common process for dog food and pellets have been reported to be less palatable than extruded kibbles (İnal et al. 2018). This is likely because of the lower starch gelatinization and different texture of pellets. Wolter et al. (1978) reported that the extent of cooking and gelatinization of the corn starch improved palatability.

Wet or canned pet foods are another common product in the market, but studies exploring different aspects of corn in canning are scarce. Corn starch can be used as a binder in canned loaf format products or to create structured pieces in chunks and gravy recipes. Similarly, a study with buffalo meat nuggets used corn starch as a binder and reported that it produced a more stable emulsion than wheat semolina, wheat flour, or tapioca starch (Devadason, Anjaneyulu, and Babji 2010). This same study found that corn starch contributed to a firmer texture and more chewiness of the product, resulting in higher sensory scores and overall acceptability by humans. In canned pet foods, stronger binders like egg white or porcine plasma are often used instead.

Studies using ground corn as the main starch source in baked pet foods or treats are nonexistent. Corn does not contain functional gluten and, therefore, does not bind as efficiently as wheat flour, but might produce quality baked kibbles if a complementary binding ingredient were identified to replace the gluten. The high starch content that promotes particle binding and matrix formation in corn-based pet foods has been evaluated extensively and reported to provide a quality functional ingredient.

Conclusion

Corn has many benefits when included in pet foods. It has been reported to be nutritionally available, lead to quality stools and regular elimination, promote palatability, and possess functional benefits to extrusion. But research is limited to extruded products. Work describing corn's impact on processing of treats, raw foods, thermally processed wet foods, or alternatively processed foods is very limited. While extruded products represent the majority of pet food products sold in the US, these alternative formats are popular and may represent new markets for corn.

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