

A Difficult Reality to Digest: The Effects of a Corn-Based Diet on the Digestive System of Cattle

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Abstract

A complex system of economic and political policies has led to the mass over production of corn in the United States. As a result of this overproduction, we now see corn in the majority of processed foods as well as animal feeds, in particular cattle feed. However, evolutionarily cattle are adapted to pasture diets not corn-based diets. Cattle have complex digestive systems, consisting of the rumen, the reticulum, the omasum, and the abomasums, which allow them to digest cellulose and hemicellulose found in grass blades. The addition of corn to the diet of a steer changes the chemistry of its digestive system and leads to serious illnesses, including bloat and acidosis. This illness, which is extremely painful for cattle, brings into question the ethics of feeding cattle a corn-based diet and the ethics of the policies surrounding corn production.

Introduction

Over the past century, Americans have become increasingly alienated from their food. Although I have always been somewhat aware of this ignorance, I was shocked when I heard the story of a child who thought the word “chicken” referred exclusively to food. This smart kindergartener did not realize his chicken nuggets contained animal products. In recent years, people have begun to speak out on the state of our food system and agricultural practices, mainly due to health and environmental concerns, with a number of people also protesting in the name of animal rights. Popular books, such as Michael Pollan’s *The Omnivore’s Dilemma* and *In Defense of Food*, as well as, documentaries such as *Food Inc.*, *King Corn*, and *Super Size Me*, have begun to expose the horrors of America’s eating habits and agricultural practices and the consequence they have for human health.

One modern agricultural practice that has become common in developed nations, especially the United States, is the production of monocultures, mass production of a single crop. Monocultures cause a wide expanse of complex environmental, health, and economic problems. In the United States the three most common monoculture crops are corn, soybeans, and wheat. Of these three, corn is most commonly villainized, and for good reasons. A complex system, of economics and subsidies has led to the mass-over production of corn in the US. This has led to the use of corn in processed foods and as a common component in animal feeds, in particular cattle feed. The idea that America’s diet is unhealthily rich in corn is fairly common; however, among the general public it seems that little thought is given to the effect this corn has on welfare of an individual steer raised for our meat consumption.

It is easiest to feed cattle grains, including corn, because as Michael Pollan points out, in his book *The Omnivore’s Dilemma*, feeding such a large number of

animals in one place on corn is cheap. Consequently, meat has become affordable for the average American household, which has subsequently increased the demand for meat and the amount of beef produced in feedlots. Contrary to their feedlot corn diets, cattle evolved as grazers, and thus their natural diet consists of a mixture of perennial grasses (Britton). In addition to the cramped and unsanitary living conditions of a feedlot, an individual steer must also deal with the digestive problems associated with eating an unnatural, grain-concentrated, diet.

Grain-rich diets have severe negative effects on the well-being of the individual steer. The rumen enables cattle to take advantage of fibrous grasses that contains cellulose and hemicelluloses. The steer’s rumen evolved as a result of the competitive advantage it provided for the ancestors of the steer. Thus, the addition of grain, primarily corn, into the steer’s diet directly causes digestive problems including, but not limited to, bloat and acidosis. The following paragraphs introduce the mechanisms of the digestive system of a steer, and explain how problems may arise with the introduction of corn into the steer’s diet.

Introduction to the Digestive System of Cattle:

Cattle evolved as grazers and thus are adapted to eating highly fibrous foodstuffs. Consider for a moment the limitations of a human diet. Humans are omnivores and can eat and digest almost anything, except highly fibrous plant material such as grass blades. Like humans, most animals cannot digest these fibrous plant materials because they are unable to digest the cellulose and hemicelluloses found in the plant cell wall. For the ancestors of cattle, the development of a method enabling the digestion of these foodstuffs was evolutionarily advantageous because there was little competition for this abundant fibrous plant material. During this evolutionary process, those individuals that were able to digest fibrous plant materials survived and passed this altered method of digestion onto their offspring. Through this evolutionary process cattle evolved with the mechanisms to eat and digest grasses (Britton).

Cattle belong to a category of mammals known as ruminants. In contrast to the single stomach of monogastric animals, such as humans, the stomach of a ruminant is divided into four compartments: the rumen, the reticulum, the omasum, and the abomasum; these organs comprise approximately three-fourths of a steer’s abdominal cavity (Bowen, 2006). In addition to this unique and complex stomach system, ruminants are home to a diverse flora of microorganisms. The presence of these microorganisms aids in the digestion of fibrous plant materials, which contain cellulose and hemicellulose. Cattle share what is called a mutually beneficial, or mutualistic, relationship with these gut microorganisms. By ingesting foodstuffs, the steer provides the food material necessary for the microbes to produce their own simple nutrients, which enables them to survive and reproduce. These microbes then undergo a process known as rumen fermentation, which in addition to producing their own required cellular energy, produce waste products, such as volatile fatty acids and B vitamins, which are of no use to the microbes, but provide the steer with essential nutrients (Bowen 2006, Herd). Some of these microorganisms then pass through the digestive tract and provide the steer with additional proteins (Herd). Understanding the physiological and molecular processes that occur in each stage of a steer’s digestion will provide us with insight into the problems that occur when a steer is fed a high corn diet.

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*In the Rumen**Physical Components of Digestion*

When a steer eats, large quantities of saliva along with the feed and water ingested flow through the esophagus and into the rumen. This saliva is rich in bicarbonate and thus very alkaline, or basic, meaning it has a pH above 7 (Bowen, 2006). This plethora of saliva performs two main functions. First, it maintains the fluid level in the rumen, which is necessary for fermentation to occur. Second, it acts as an alkaline buffer to neutralize the large amount of acid produced during rumen fermentation (Bowen, 2006). This is necessary to maintain the pH of the rumen within the range 5.5 - 7.0, which is required for the fermentation process (Herd).

After a steer masticates, or chews, the particles flow down the esophagus and into the rumen. This food material, or digesta, can flow freely between the rumen and the reticulum and thus they are often referred to singularly as the rumen-reticulum (Herd). The rumen-reticulum complex contains approximately half of the digest systems capacity, as well as, the majority of the microbial activity (Herd). Upon primary mastication, ruminants do not break up their food well enough for effective microbial fermentation to commence, and thus perform rumination, or what is commonly known as "chewing cud" (Bowen, 2006). Rumination is the regurgitation, re-mastication, and re-swallowing of food particles (Bowen, 2006). This process increases the surface area of the food for microbial fermentation, which makes it a more efficient process (Bowen, 2006). Rumination is a physical process, in contrast to the chemical process of fermentation (which will be discussed in detail later) that aids in a steer's digestion. Another such physical process is rumen motility. The rumen is not a static organ; it undergoes contractions every 1-3 minutes (Bowen, 2006). These contractions serve to mix the contents of the rumen, which increase the contact between microorganisms and foodstuffs, aid in eructation, or "belching" of gases produced during fermentations, and moves fluids and fermentation products into the omasum (Bowen, 2006).

Fermentation Overview

Fermentation is a process by which organic molecules are broken down without oxygen. It often occurs in the absence of oxygen, under what are known as anaerobic conditions. However, in some organisms, such as yeast, fermentation is the primary source of metabolism even under aerobic conditions. The fermentation process occurs in microorganisms, which do not require oxygen to survive and reproduce. It also occurs in muscle cells, in the absence of oxygen, as an alternative to the citric acid cycle, which occurs in the presence of oxygen. In both cases, fermentation follows a process called glycolysis. Glycolysis breaks down glucose molecules from food and produces two molecules of pyruvate, which in the presence of oxygen will be converted to acetyl CoA and enter into the citric acid cycle; in a process commonly known as cellular respiration. However, in the absence of oxygen these pyruvate molecules enter into the fermentation process. The cycle of glycolysis and fermentation produces much less cellular energy than that of cellular respiration. Lactic acid fermentation in muscle cells leads to the synthesis of NAD⁺, which an electron acceptor, and lactate, while fermentation in yeast leads to the synthesis of NAD⁺, CO₂, and ethanol. It is important to note that NAD⁺ produced is essential for the continuation of glycolysis, which produces ATP (cellular energy). However, the lactate, CO₂, and ethanol produced are waste products of the process. Rumen fermentation, similar to the process that takes place in muscle cells and yeast, is outlined in more detail in the section below.

(Information in this paragraph was obtained from Alberts *et al.* 2010)

Rumen Fermentation

Rumen fermentation is the process by which rumen microbes metabolize fibrous plant material, containing cellulose and hemicellulose, other carbohydrates, proteins, and fats to produce cellular energy and waste products valuable to cattle. As mentioned above, the rumen of a steer is colonized by a wide variety of microorganisms. These microbes include both protozoa and bacteria. Protozoa are "free-living, non-photosynthetic, motile eukaryotic organisms" (Alberts *et al.* 2010, G: 18). Rumen protozoa ingest soluble sugars, starches, and some cellulose. Both the sugars and starches are converted and stored as starches, while the cellulose is converted to sugars (Hungate, 1975, p. 41). Rumen bacteria, which are prokaryotic, are much smaller than protozoa. Although there are types of rumen bacteria that digest all different types of carbohydrates, proteins, and lipids, they most importantly digest cellulose and hemicellulose, which is of primary importance in rumen digestion (Herd).

In rumen microbes, organic compounds, including carbohydrates, fats, and proteins, are broken down via fermentation. As explained in the section above, this fermentation process produces NAD⁺, which enables the continuation of the energy producing pathway of glycolysis. Thus, the rumen microbes utilize the cattle's feed to survive and reproduce (Hungate, 1975, p. 44). However, while creating energy for themselves, the microbes also generate waste products that are of great importance to the nutrition of the steer (Hungate, 1975, p. 44). These waste products include volatile fatty acids (VFAs), vitamin B, CO₂, and methane gas (Hungate, 1975, p. 44).

Fatty acids are carboxylic acids, a type of organic acid, that are characterized by the presence of a carboxyl group. Volatile fatty acids are fatty acids with a carbon chain of six or fewer carbons. The three most prominent VFAs produced in rumen fermentation are acetic acid, propanoic acid, and butyric acid (Hungate, 1975, p. 44). Although all of the volatile acids are absorbed through the rumen wall, or epithelium, into the blood stream, each VFA has a distinct metabolic destination. Little acetic acid is removed from the blood stream by the liver, and instead is oxidized to generate ATP throughout the body (Bowen, 2006). The liver almost completely removes propanoic acid from the blood stream, where it becomes the major substrate for the glucose generating process of gluconeogenesis (Bowen, 2006). This production of glucose is essential because the majority of the glucose ingested as food goes through the fermentation process and thus is not absorbed as might be expected in the small intestine (Bowen, 2006). The absorption of propanoic acid followed by the process of gluconeogenesis is a steer's main source of carbohydrate. Although ruminants do not require as many carbohydrates as monogastric animal, these carbohydrates are still important components of a steer's nutrition (Bowen, 2006). Butyric acid, similarly to acetic acid, after absorption into the blood is oxidized in a variety of tissues (Bowen, 2006). These volatile fatty acids produce approximately seventy-percent of a steer's energy supply and are thus their production by rumen microorganisms is of great importance (Bowen, 2006).

Although fermentation that results in methane still results in the synthesis of cellular energy for the microbe, this waste product is of no use to the steer. Even though the methane waste product does not benefit the steer, these microbes are still beneficial because they are often a direct source of energy to the steer (Bowen, 2006; Herd; Hungate, 1975). As Round and Herd describe, "the microorganisms also pass from the rumen to the lower digestive tract, where

they are digested and their constituent protein, vitamins, and other nutrients are absorbed" (Herd). The fermentation by-products methane and CO₂ are the main gases produced during fermentation, which are eructed, or "belched" out by the steer (Bowen, 2006).

In the Omasum and Abomasum:

After passing through the rumen, the not yet digested digesta flows into the omasum. The omasum has many thick folds of skin and is often thought to resemble a "partially open book" and is believed to assist in the re-absorption of water from the digesta (Herd). After passing through the omasum, the digesta enters the abomasum, which is referred to as the "true stomach" because it best represents the stomach of a monogastric animal (Herd). The abomasum secretes digestive enzymes, which aid in absorption of nutrients by the small intestine.

Addition of Corn to a Steer's Diet:

The use of corn in cattle feed is economically viable for a number of reasons. First, because of the extreme over production that occurs in the United States, corn provides a cheap feed. Second, the use of grains in animal feed enables the use of feedlots to raise animals -- in particular cattle -- and the use of feedlots is the only possible way to raise as many cattle the huge number of cattle that the US currently produces. Third, and most applicable to this topic, a corn concentrated diet aids in quickening the rate of weight gain in cattle. It is important to understanding of the implications of this deviation from their natural diet on a steer's digestive system.

Physiological Basis of Desired Weight Gain

This desirable rapid weight gain is prompted by two biological changes caused by the change in diet from forage to corn concentrate. First, as shown by Shaw *et al.* in their 1960 study, there is a change in the ratio of fatty acids that are produced via microbial fermentation. In a steer on a natural diet of mostly forage, the ration of acetic to propanoic to butyric acids is approximately 70:20:10 (Bowen, 2006). In a steer fed primarily a corn-based diet the percentage of propanoic acid increases compared to that of acetic acid. As discussed above, propanoic acid enables the synthesis of the majority of the carbohydrates employed by a steer and an increase in these carbohydrates produced causes weight gain. This weight gain is also facilitated by an increase in the fermentation rate of the carbohydrates present in corn (Herd). This increased fermentation rate increases the rate at which the microbes, and thus the steer, digest the food, causing quickened weight gain (Shaw, 1960). These examples demonstrate how this weight gain, due to a high corn concentrate diet, is achieved only at the expense of the digestive chemistry.

Physiological Basis of Bloat

One serious digestive problem that arises from the addition of corn to the diet of a steer is what veterinarians have termed bloat. Bloat is caused by a combination of changes that occur in the rumen. There are two types of bloat: frothy bloat and free gas bloat (Bowen 2006). Frothy bloat occurs when the fermentation gases are trapped in thick foam and is mainly due to an increase in digestion rate. This form of bloat can occur under both pasture conditions and feedlot conditions. Under pasture conditions, frothy bloat occurs when the steer has a diet rich in legumes, such as alfalfa or clover, which quickly undergo fermentation in the rumen. This increased digestion rate produces extensive quantities of gas as well as a high concentration of fine digesta particles that trap the gas (Bowen, 2006). Such pastoral bloat most commonly occurs when the steer's diet includes

interrupted feeding, where it is taken off pasture and then suddenly put back on pasture (Bowen, 2006). In feedlot situations, because corn carbohydrates are more digestible, the rate of fermentation increases and the rate at which gases are produced in the rumen also increase (Herd; Shaw, 1960). In feedlot cattle, bacteria are often present that produce a thick slime that enhances the foamy layer preventing eructation (Bowen, 2006). Cattle afflicted with free gas bloat are unable to eructate gases even though they are unhindered by a foam layer. Situations of free gas bloat may occur due to an obstruction of the esophagus, for example a tumor or abscess, which may also result from a high corn diet (Bowen, 2006).

In addition to the increase of fermentation rate, the rate of rumen contractions decreases when cattle are fed a high corn concentrate diet instead of a diet high in forage (Bowen, 2006). Thus, even though fermentation of corn food leads to the production of more gases fewer contractions occur to aid in eructation and this gas build up leads to bloat. As fermentation gases build-up the rumen expands and places pressure on the lungs of the steer. In all cases this makes breathing difficult for the steer and in some instances the steer may even die of asphyxiation, or loss of air to the brain (Bowen, 2006). This is a slow and painful death.

Physiological Basis of Acidosis

Acidosis is another common feedlot disease, intensified by corn concentrated feed, which may cause severe discomfort, pain, and even death. Acidosis is a disorder caused by the rapid production and absorption of acids in the rumen that is caused by the increased rate of fermentation of corn carbohydrates (Britton). Feedlot diets trigger rapid digestion of food in a number of ways. First, as discussed previously, corn carbohydrates undergo fermentation more quickly than roughage, and so acids build up more quickly in the rumen. Second, corn feed is often steamed, a process that, again, increases the digestibility and the rate of fermentation. Thirdly, the feed is often ground into fine particles, increasing the ease of digestibility yet again. In addition, the reduction in particle size reduces the quantity of saliva produced upon mastication and thus the amount of neutralizing bicarbonate that flows into the rumen diminishes, once again raising the acidity of the rumen. Almost all cattle raised in feedlots experience acidosis at some point in their life; however, some experience what is known as acute acidosis (Britton). In acute acidosis, the pH levels of the rumen drop to levels between 4 and 5, damaging the rumen epithelium and causing inflammation in the abomasal and intestine lining, which leads to poor nutrient absorption (Britton). This drastic drop in pH levels can also harm the microbial flora of the rumen. For example, in acute acidosis specific bacteria that produce thiamine may die (Britton). Thiamine, or vitamin B₁, is an amino acid that enhances brain function. As Richard Britton and Rick Stock describe, "managers often observe cattle that are wondering aimlessly in the pen or cannot stand and appear to have brain damage" (Britton). This apparent "brain damage" is due to the absence of thiamine production. Acidosis persists as an extremely prevalent and detrimental feedlot disease intensified by the addition of corn to the diet of feedlot cattle.

Conclusion

Corn provides a cheap means of feeding a large number of cattle in a feedlot situation. Although this feedlot diet is economically beneficial, it causes severe health problems in the cattle. The digestive system of a steer is not meant to digest corn, and other grains, and thus digestive problems arise that can be detrimental to the steer's health. These problems bring the question: is it ethical to raise cattle on a

corn-based diet? Although we will never be able to conclude whether animals feel emotions, such as happiness, we do know they experience pain and science has shown that a corn based feedlot diet causes pain in cattle. If scientific research shows that a corn-based diet is inhumane, why does this practice continue? The answer lies in the government policies that surround the production of corn in the United States. These policies require that farmers continuously increase production in order to make even the slightest profit. Thus these government regulations encourage the overproduction of corn. This corn must go somewhere and thus industry has found a way to incorporate it into traditionally corn free products, including corn-fed beef. Since the over production of corn originated from government regulations, it may appear that fixing this problem may also have to originate from government policy. However, this is not necessarily the case. As consumers, Americans can vote with their wallet. By refusing to buy corn fed beef and supporting grass fed cattle farms, we can point out that we do not support the inhumane production of meats. If we regain contact with the way our food is produced, we can help improve the health of the animals we eat, our health, and the health of the environment.

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