



Review Article

The Dietary Components and Feeding Management as Options to Offset Digestive Disturbances in Horses

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ABSTRACT

Equines are faced with digestive disorders derived from abrupt feed changes from mainly forages to high-starch cereal grains. This diet change aimed at meeting the nutritional requirements to optimize the horse's performance causes microbial imbalances in the gut, which results in unintended but inevitable health problems such as colic, diarrhea, gastric ulcer, and laminitis. Several strategies are recommended to control these problems. This review is meant to offer plausible and adoptable solutions to digestive disturbances in equines. High-forage diets seem to be the primary solution. However, there are other options such as feeding horses with alfalfa hay for gut pH modulation and gastric ulcer management, avoidance of the off-feed for long periods within a day especially between 01:00 AM and 09:00 AM, yeast supplementation, feeding equines about 2–3 times a day without increasing the quantity of the daily ration, and dietary fatty acid supplementation such as eicosapentaenoic acid and docosahexaenoic acid to increase insulin sensitivity. Protozoa and faunation seem to be a good modulator of gut pH because they help to control the rate of starch degradation without generating methane in horses because acetogenesis is the main hydrogen sink in equines. An appropriate grain mixture of barley–corn or barley–oat avoids gut pH depression. Furthermore, the use of crop by-products such as soybean hull and pectin are good alternative sources of energy for equines. Therefore, the use of some sources of fiber in the diet of equines can replace high-starch cereal grains in equine diets because they are capable of providing the required energy to support the energy demands during work.

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1. Introduction

Domesticated horses have adapted to increase in concentrate/forage or hay ratio [1]. This adaptation involves a smaller diameter of the small intestine [2] and larger diameter of cecum of horses [3]. Equines are herbivores and could also be classified as companion animals. Improvement and evolution in war strategies and weapons have necessitated alternative function for horses. Nowadays, horses are mainly used for recreation such as for non-

competitive riding, trail riding, or hacking, photography, and flat racing and jump racing. Naturally, equines are designed to eat forages to meet up their nutritional requirement. In the gut, nutrients such as energy, protein, lipids, and vitamins are hydrolyzed in stages while running from the stomach to the colon. To meet the nutritional demand of equine for sporting activity, there was an alteration from mainly forages to grain or starch diet. To facilitate energy release, cereal grains are often included in equine diets when the horse's energy requirements cannot be met by the forage component alone [4]. This dietary shift alters the rate of digestion, substrate release and microbial balance in the gut, and the proportion of short chain fatty acid produced [5], which contributes about two third of the energy absorbed by equines [6]. However, such feeding practice affects the welfare of animal [7], hence the need for alternatives feeding practices. One of these alternatives

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may be to reduce the grains and replace them with fibrous feeds containing good energy density.

Microbial fermentation of diet starts from the stomach and runs through the hindgut [8], and they produce different substrates such as acetate, propionate, butyrate, and methane. In the gut, there are bacteria such as *Firmicutes* and *Bacteroidetes* [9]. However, the percentage of dominance of one is influenced by the type of substrate available in the gut such as oat, barley, wheat, corn, and so on [10].

Digestive disturbance such as microbial dysbiosis increases plasma lipopolysaccharide (LPS), which compromises gut integrity, resulting in laminitis because of diets high in starch [11,12]. A diet high in starch causes a decline in the hindgut pH [13] leading to acidosis. Acidosis is a major cause of microbial dysbiosis (dysbacteriosis) that potentially causes laminitis and colic [14]. This pH alteration is responsible for many digestive disturbances, guts structural alterations [15], and subsequent animal welfare challenges. The challenges are not only the change in diet but are partly due to gut pH change due to drastic changes in the diet. Although gastrointestinal (GI) pH changes impact the microbial community, several other factors related to diet may affect microbial community structure, function, and equine nutrient utilization. Maintaining the microbial balance in the gut is immutable if equine health is to be maintained and metabolic disorders avoided.

To exclude animal from these digestive disorders and its associated challenges, the easiest solution would be to stop feeding cereal grains or high-starch diet to equines. However, such recommendation without proven alternative seems unadoptable irrespective of how fanciful they are. Hence, there is a need to find alternative form of offering energy replacing starch or a mechanism that would help to increase gut pH in the hindgut. This review is intended to elaborate on methods that would help to avoid gut disorders.

2. Diet and Microbial Shift in the Gut

The gastrointestinal tract (GIT) of an equine is populated with diverse microbial communities such as bacteria, fungi, protozoa, acetogens, and methanogens, which contribute largely to equine nutrition and health. Maintaining the delicate balance of this microbial community is essential to prevent microbial dysbiosis and ensuing problems during fermentation, which can contribute to acidifying the ecosystem and increasing the occurrence of diseases [5]. Diet influences the microbial community in the gut of livestock because microbes' response or population growth is based on substrate availability [5]. Alteration in feeding practices and changes in the activity of modern-day equine farms has led to an increased level of grain/starch and lowered levels of fiber in their diet [14,16,17]. One of the reasons for this nutritional changes is to enhance quick energy release to match the high pace activity of the horse. Furthermore, high-starch diets increase energy density of the diet and also availability of starch for enzymatic digestion by the horse. For sports horses, this is a very good practice because energy dense feedstuffs support the energy demands placed on them during work. Consequently, this shift in the diet has partly, although not singularly, influences the alteration of intestinal microbial community because of the drastic changes in substrates. The microbes in the equine's gut are similar to the rumen in their reaction to abrupt changes in the diet, which subsequently cause disruption in microbial growth [18,19].

Bailey et al [20] demonstrated that high-starch diets disrupt normal hindgut microflora when compared with fibrous diets. This microbial change is caused by alterations in hindgut pH and could affect the cellulolytic activity in the hindgut. For instance, it was observed that switching diet from 100% haylage to 50% hay and 50%

concentrate led to a 10-fold increase in the population of *Lactobacilli* and *Streptococci* in the feces of horses [18]. Among cellulolytic microbes *Ruminococcus flavefaciens*, *Ruminococcus albus*, and *Fibrobacter succinogenes* were abundant in the gut of horses receiving 100% haylage [20]. This indicates that there is a similarity between the microbial community shifts in both gut fermenter either foregut as in ruminant or in hindgut fermenters, especially when concentrate feeds are offered. Because the hindgut is the channel through which the feces pass, it may be assumed that such changes in microbial community would also occur in the cecum–colon chamber. This indicates that irrespective of the digestive structure of an animal that performs fermentation, the predominant substrate in the diet would influence the microbial distribution in the fermentative chamber and feces. There is microbial stability and larger diversity of microorganisms when horses are fed forage only than when a starch-rich ration is offered [9].

Pasture feeding is important to equine health. Fernandes et al [21] reported that changes occur in the microbial community when the diet is changed from commercial ensiled conserved forage-grain-based ration to feeding on pasture. This led to about a 20% decrease in the relative population of *Firmicutes*, and *Ruminococcaceae* was decreased about 50%–25% in the feces within 4 days of the dietary change. It is important to note that among these *Firmicutes* are *Lactobacilli* and *Streptococcus*, which are starch fermentators, and subsequently supports acidification of volatile fatty acids (VFA) through lactic acid production.

Diet and pH can be responsible for gut microbial disruption. Thus, diet, gut pH, and gut microbes exist in a triangular/tridimensional relationship rather than a bidirectional relationship between diet and pH.

3. Gut pH

The pH of the hindgut of equines is about 6.0 and is optimal for microbial breakdown of pectin and hemicellulose [22] by the fiber-degrading consortium of anaerobic bacteria, fungi, and protozoa. However, Frappe [5] proposed that pH 6.5 is the optimum required for adequate microbial fermentation in the equine hindgut. Gut pH is very important in equines, and it influences the movement of VFA across the epithelium. Movement of VFA across intestinal epithelium occurs when intestinal pH is close to the pK_a of the VFA [23]. The challenge of nonstructural carbohydrate is that continuous accumulation of lactic acid may occur 24–36 hours after it enters the fermentative chamber [5], which will lower the pH. Therefore, hindgut pH seems to play a very important role in absorption of VFA, epithelial integrity, endotoxin and toxin movement across the gut, and so on. In addition, a prolonged depression of pH to 5.8 may lead to hindgut acidosis, anorexia, epithelial damage, and suboptimal nutrient absorption because of gut villi reduction. Acidosis is usually associated with lactic acid build up, and VFA production varies among animals [24]. This implies that susceptibility to laminitis derived from high-grain feeding depends on individual animals. In other word, equines have a laminitis-inducing factor, which makes the animal tolerant or resistant to this metabolic disorder.

Gut pH also seems to undergo circadian rhythm without dietary influence. For instance, stabled horses usually experience lower pH in the proximal stomach between 01:00 AM and 09:00 AM [25]. Low fecal pH and disorder in equine gut motility due to variation in pH [16] are common attributes in high-starch diets. Gut motility is important to equines as it influences the rate at which food moves out in the gut.

Changes in gut pH, especially to a low level, can also reverse the function of a metabolite. In an acidic condition, butyric acid causes gastric ulceration in horses [26]. The ulcerating ability of VFA,

especially butyric acid in equines, is dependent on a low or high pH. This is because the nondissociation of VFA that occur at high pH prevent them from being able to penetrate the squamous epithelium of the mucosa cell. However, dissociation at low pH environment might cause gastric injury [27], thereby reverting the epithelial renewing fuel role of butyrate to a destructive function.

4. Diet, Microbial Shift, and LPS

Carbohydrate overload results in microbial shift from predominantly gram-negative microbes to gram-positive bacteria, mainly gram-positive rods in feces [28]. Diet is influential in hindgut microbial composition [29]. Diets containing high starch cause a state of hindgut dysbiosis [5]. This is characterized by a reduction of fibrolytic bacteria and a concomitant proliferation of amylolytic microbes and lactic acid using bacteria [11,30]. The gram-positive microbes have peptidoglycan in their membranes, whereas the gram-negative microbes have LPS in their outer membrane. During microbial fermentation, proliferation or excessive lysing of gram-negative bacteria leads to an increase in LPS concentration in the fermentative fluid [12]. Moreover, prolonged lowering of pH affects the gut epithelium and leads to erosion of gut villi. The combination of weakened gut integrity alongside LPS (endotoxin) leads to an increased gut permeability, which allows endotoxin into the bloodstream. Plaizer et al [12] reported that endotoxin increases in blood, rumen, ileum, cecum, and feces of ruminants fed high-grain diet; a similar scenario would likely occur in the hindgut of horses when abundant starch escapes from the stomach and end up in the cecum–colon. Control of LPS and its production may be key in the avoidance of laminitis [31].

The study of Grimm et al [11] shows that there was 91.8% and 93.9% increase in fecal LPS at 10 and 20 days after horses started consuming hay plus barley compared to when they were fed 100% hay. This points to a possible lysing or proliferation of gram-negative bacteria because of cereal grains in the diet. Conversely, plasma LPS concentration on Day 20 in hay- and barley-fed horses was lower (6.4 vs. 7.2 ng 3-hydroxymyristic acid/mL) compared with the control group, indicating that the gut wall was not yet compromised. Surprisingly, a switch back to 100% hay diet, from barley and hay diet, increased plasma LPS concentration 10 days after the diet switch as LPS increased to 8.2 ng 3-hydroxymyristic acid/mL from the previous 6.4 ng 3-hydroxymyristic acid/mL in plasma. This shows that there is a possible aftermath/carry over consequence even after the cereal grain was removed from the diet. It could also be due to an increase in fibrolytic microbes such as *Fibrobacter succinogenes*, which is a gram-negative microbe because of the presence of fiber substrate. Thus, the use of hay diet or lowering of the ratio of hay to starch might be a way of reducing the volume of LPS in equines and a possible consequence of plasma LPS concentration.

5. Digestive Disturbances in Horses

High concentrate feeding, infrequent feeding, and inadequate inclusion of fiber in the diet are challenges of modern horse feeding [32]. These problems occur because there is a greater microbial instability when equines consume concentrate-rich diet evidenced by lower microbial count and the specificity of lactic acid-producing microbes [9]. Percentage of starch in the diet influences the percentage of digestion in the stomach. High-starch intake causes an increase in starch escape into the ceaco-colon segment when cereal grains exceed 20% in diet, leading to <58% diet digestibility. However, when starch is lower than 20%, there is about 80% digestibility in the stomach [33]. Increase in the guild of amylolytic bacteria such as *Streptococcus* and *Lactobacillus* could

affect fiber digestibility because of suboptimal pH environment for cellulolytic microbes as a result of lactic acid accumulation, thereby causing hindgut acidosis—a state of continuous pH depression.

5.1. Gastric Ulceration

Ulceration of the distal esophagus, proximal and distal stomach, and duodenum is referred to as gastric ulcer syndrome and is influenced by nutrition and diet management [34]. The nonglandular mucosa is susceptible to gastric ulcer because it lacks the protection of the mucus and bicarbonate [35]. The contribution of gastrin to gastric ulceration stems from the fact that, when high-grain diet is fed to equines, the HCl and acidic VFA produced at pH 4 prevent sodium transportation in nonglandular stomach mucosal cell, which in turn causes cellular inflammation and subsequent ulceration [34]. In addition, exercise predisposes horses to gastric ulcer because of the contraction in the stomach, which pushes the gastric acid from the glandular section to nonglandular section [34].

Feeding frequency also influences digestive discomfort. It is evident that equine stomach pH undergoes circadian rhythm, as they are at their lowest value between 1:00 AM and 9:00 AM of the day. Not feeding them during this time could lead to a continuous pH drop predisposing them to acidic ulceration.

5.2. Colic

Colic is an important medical problem in horses that frequently results in death; it is a common cause of abdominal pain in the horse due to distension of the gut [36]. Accumulation of fine sand, coarse grain ingesta accumulation primarily composed of ammonium magnesium phosphate are all reasons for intestinal obstruction in horses [37]. Feeding high-grain diet has been associated with dehydration in the colon compared with when forage is consumed [38]. This is because of the promotion of water absorption from colonic contents after feeding, which increases absorption of water and sodium alongside VFA or perhaps the fiber content of diet holds water in the GIT [39].

5.3. Laminitis

Laminitis (pododermatitis aseptica diffusa) is a painful disease affecting the hooves of equines with a sign of lameness caused by damage or inflammation of tissues around the pedal bone [40], which is the dermal layer inside the foot [41]. The excess of amines (endotoxin) from lysing of *Enterobacteriaceae* leads to laminitis [40]. Lactic acidosis decreases luminal pH to about 6.0 during lactic acidosis; this disrupts cellulolytic bacteria microbes reducing acetate production as a consequence of poor fiber fermentation, and this subsequently causes increased endotoxin absorption, dehydration of digesta, gaseous distention, and colon displacement [38].

Inflammation of the lamellar tissue is a response to acidosis or LPS in ruminant, which results in laminitis. The degradation of the endothelial basal lamina destroys the lamellar detachment by the activation of metalloproteinases enzymes, resulting in laminitis [42]. Thus, minimizing lamellar inflammation might help to reduce the incidence of laminitis.

5.4. Endotoxins

Endotoxins are prevalent in ruminant plasma and rumen fluid when high-grain diet is fed to animals. Moreover, Sprouse et al [43] observed increased plasma endotoxin when horses were given excess cereal grains in the diet. This damage has been primarily attributed to low pH due to increases in lactic acid accumulation

and changes in osmolarity of the hindgut. Acidosis caused by lactic acid accumulation provokes the epithelium to lose its integrity such that endotoxin from gram-negative bacteria enters in large quantity through the tight junction of the epithelial cells. This could lead to immune suppression, making them susceptible to diseases; it gets worse if there is organ damage such as liver, which would have helped to detoxify these toxins [31]. This leakage or absorption of LPS triggers an immune response stimulating the production of proinflammatory cytokines and chemokines [44].

6. Strategies to Offset Digestive Disturbances

Hindgut microbiome is important in digestion, and their balance would help to prevent many metabolic diseases. The key or most effective strategy would be aimed at stabilizing gut microbes and preventing the fluctuation of hindgut pH. Importantly, forage-based diets, which contain low starch and meet the energy demand of equines, help to lower the incidences of digestive disorder [19]. Diets high in fiber would lead to increased acetate production; yet, Waller et al [45] suggest that the use of oral acetate has the potential to be an energy source for sports horses. Fibrous feeds such as sugar beet can replace cereal grains in sports horses without any negative effect on the hindgut integrity [46] as shown in Table 1.

6.1. Alfalfa Hay

Hay and grain fed to equines contain different level of rapidly fermentable carbohydrates [47]. This is reflected in the presence of amylolytic lactic acid microbes in the hindgut of equines. Nadeau et al [47] showed that 50% compared with 83.3% of horses had gastric lesion ulcer in their nonglandular mucosa when fed alfalfa hay combined with concentrate compared with a bromegrass hay diet. The horses fed alfalfa hay–grain diet had higher gastric pH even 5 hours after the diet had been removed, which was not so with horses fed bromegrass hay.

High-calcium content in diet helps to inhibit gastric acid secretion with alfalfa hay having 14.4 mg, bromegrass hay of 7.4 mg, and grain of 3.2 mg per gram of dry matter of the diet. The buffering ability of alfalfa hay–grain diet results from its high crude protein content [47]. The mechanism of action for gastric acid inhibition is that when alfalfa is consumed, there is increasing calcium absorption, which results in higher level of extracellular calcium, which influences the calcium concentration in gastric acid–producing cells [48].

Alfalfa hay could also be used to prevent and heal gut lesions. Stowers et al [48] reported that fermented alfalfa prevented and healed gastric ulcers at 40%–60% and 70%–100% dry matter intake, respectively. This is because alfalfa hay has a prolonged effect on pH reduction. Alfalfa hay could also play a role in increasing the

proliferation of beneficial microbes. For instance, alfalfa hay increased fecal guild of lactic acid utilizer 6.93 versus 6.35 (\log^{10} cfu/g) compared with sunflower meal, which resulted in a slight increase in fecal pH 6.34 versus 6.29. Similarly, there was an increase in fecal amylolytic microbes in alfalfa-fed versus sunflower-fed animals. Pectinolytic microbes increased in feces of horses fed alfalfa (7.03 vs. 6.39) than sunflower meal. In the stomach, sunflower meal increased in stomach guild of lactic acid utilizer 7.32 versus 7.00, amylolytic microbes 6.35 versus 6.02 than dehydrated alfalfa. An increase in microbes' amylolytic or lactic acid utilizer in the stomach results in the decrease or increase of the same microbe in the feces [54].

Perhaps, the inclusion of limestone (calcium carbonate) in the diet of equine could help reduce gastric ulcer. However, proper research must be done before recommending this product. This is because although diets high in calcium inhibit gastric secretion, there is a subsequent hypersecretion of gastric acid after usage [47]. Care must be taken with the use of alfalfa because diets containing a high amount of alfalfa may predispose equines to develop lithiasis because high protein and magnesium content predispose horses to intestinal obstruction [36].

6.2. Yeast Addition

The welfare, digestive soundness, and efficacy in digestion of equines are dependent on the balance of intestinal microbiota. Microbial imbalances can cause disease such as colic or laminitis [11]. Undigested starch enters the hindgut when starchy feeds are fed to horses. Yeast inclusion in the diet of ruminants and non-ruminants improves performance, gut microbial stability, and pH balance. One of the functions of yeast is gut pH regulation. Moore et al [55] observed an increase in lactate using bacteria and cecal pH in ponies when supplemented with yeast in a diet containing 70:30 concentrate to roughage.

The study of Gobesso et al [56] shows that inclusion of *Saccharomyces cerevisiae* led to increasing in total VFA production by 14.8% and 81.2% in nonexercising and exercising horses, respectively, which were fed concentrate: hay diet in a ratio of 45:55. Similarly, no effect on yeast was observed on bacterial group residing in the hindgut of horses when subjected to changes in hay diets [11]. Although yeast addition to the diet did not affect the microbial activity in the gut, inclusion of yeast in the horses' diet when forages hay is changed would not negatively affect the hindgut fermentation. In the colon, the VFA content on days 1 and 15 after abrupt changes from one hay feed to another hay improved the total VFA from 65.0 mmol/L in control to 76.4 and 77.7 on days 1 and 15, respectively. The acetate was increased from 49.28 mmol/L in control to 58.56 and 58.58 mmol/L on days 1 and 15 after yeast was added. Similarly, propionate was 10.3, 12.3 mmol and 13.3 mmol/L in control on days 1 and 15. This indicates that yeast

Table 1
Diet nutrients and ingredients responsible for digestive disorders and suggested nutrient treatments.

Digestive Disorders	Diet Nutrients	Suggested Treatment	Reference
Gastric ulcer	High-grain diet	Alfalfa hay	[19,46]
Low insulin sensitivity	High-starch diet	Dietary fatty acid supplementation using Marine and Flax oil	[63]
Microbial disruption	Feeding frequency	Feeding two to three times per day leads to reduction of <i>Streptococcus</i> and lactic acid–producing bacteria.	[55]
Depressed pH	High-grain diet (barley)	Mixture with oat or a mixture of corn and oat	[3]
Low stomach pH	Naturally depressed between 01:00 AM and 09:00 AM	Feeding between 01:00 AM and 09:00 AM	[16]
Alternative energy sources	Not available	Soybean hull	[67,68,71]
Endotoxin/laminitis	High starch diet	High hay diet or 100% hay diet	[26]

has a short- and long-term benefit in improving the VFA proportion in horse gut. This implies that yeast helps to improve the energy derived from the diet.

Supplementation of yeast to equines improves digestion of low-fiber forages, and it is beneficial for the horse health [39]. The inclusion of 2 mg/g of dry matter of Procreatin 7, Biocell F53, and Biosaf SC47 yeast culture resulted in increased VFA *in vitro* (6.62 vs. 6.79 vs. 6.82), respectively. In addition, Biocell F53 yeast culture increased short-chain fatty acids (mmol/g dry matter) from 4.98 to 5.41 [57].

Digestion of corn stover and oat hay with the inclusion of 4 mg/g dry matter of *S. cerevisiae* increased corn stover gas production by 51, 56.6, and 58.4% in 24, 48, and 70 hours, respectively [58]. Similarly, gas production from oat hay was 35.4, 56.0, and 64.0%, respectively in 24, 48, and 70 hours than control. The implication of this is that as efforts to find alternative source of energy to starch/grain increases, the usual slow fibrous digestion could be enhanced by yeast inclusion. In addition, during degradation of corn gluten, oat grain, soybean meal, steam-rolled barley, and wheat bran, the pH range for the digestion was 6.2–6.7 when yeast was added compared with 5.8–6.8 without yeast inclusion. It could be deduced that yeast inclusion in starch digestion would help to stabilize hindgut pH when added to the equine's diet.

Increasing the population of cellulolytic *R. flavefaciens* and *F. succinogenes* and reducing the population of saccharolytic bacteria (*S. equinus* and *S. bovis*) are good steps. This is because *F. succinogenes* is an important fibrolytic microbial species in the equine hindgut [59].

6.3. Feeding and Time Management

About 60% of equine owners constantly overfed their horses [60]. Surprisingly, about two-thirds of these horses are fed by visual assessment such as scooping or handful rather than following an appropriately designed diet [61] or standardized rate such as body weight, as applicable in ruminants. The GI microbes of horses are very important to equine health and digestion, and this feeding pattern or approach would cause a great dynamism in the gut microbial population.

Feeding frequency affected the gut microbiota. Generally, feeding horses at 6 AM, 12 PM, and 4 PM compared with 6 AM only or 6 AM and 4 PM only led to a reduction of *Firmicutes* and increase in *Bacteroidetes* microbes [50]. Feeding horses three times a day of total feed volume reduced *Lactobacillus* population by 35.3% compared with horses fed two times a day the same quantity of feed. *Lactobacilli* are known to be producer and utilizer of lactic acid; however, most of the times they are producers rather than utilizer (usually due to substrate availability). The utilizer's bacteria become overwhelmed by lactic acid production, which leads to accumulation in the foregut or hindgut and subsequently causes acidosis, which could be acute or subacute. Similarly, horses fed at 6 AM and 4 PM and 6 AM, 12 PM, and 4 PM had lower *Streptococcus* by 60.0% and 66.6%, respectively, when compared with those fed the same quantity of feed at 6 AM alone. *Streptococcus* and *Lactobacilli* are acid-tolerant microbes, and their presence further depresses gut pH. Such reduced microbial population is a good approach for preventing digestive upsets. Equines fed at 6 AM, 12 PM, and 4 PM had highest *Blautia*, which are acetogens responsible for acetogenesis, which are preferred to methanogens, and are important in hydrogen sinking [62]. *Prevotella* is known to act as inhibiting agent for acidosis in the ruminant fermentative vat [63], which is lower in horses fed more than once daily.

Grain mixture may help to correct the VFA produced and gut pH. A mixture of corn–oat, barley–wheat, and barley–oat fed to equines resulted in gut pH of 6.41, 6.02, and 6.29, respectively [33].

However, the butyrate value was 8.37 versus 13.6 versus 11.2 for corn–oat, barley–wheat, and barley–oat. The higher butyric acid in barley–wheat despite the low pH may be due to the fibrous content of the barley and wheat. This implies that cereals combination may help to temper the degree of gut pH reduction.

In human and animal health, discontinuations of pharmacologic therapy in a chronic disease usually result in relapse of the situation if other management practices are not put in place. Similarly, if a pharmacologic treatment for gastric ulceration is stopped and nothing else is done to manage the ulcer, it could go from bad to worse if appropriate feeding management is not established [34].

Husted et al [25] showed that proximal stomach pH is usually low in the morning around 1:00 AM to 9:00 AM. Feeding of forages or pasture during this period could increase the pH and influence the hindgut microbes and subsequently the stomach pH due to buffering capacity of saliva that accompanies fiber intake as a result of frequent mastication, which might help to control this challenge. It also is advisable to avoid long periods without feed availability within a day. From another perspective, rotational feeding of forages and grain may be useful. During the exercise period, horses could be fed grains, which would give them access to quick energy based on increase glucogenic VFA production. On the one hand, after the exercise or during the early morning hours between 1:00 AM and 9:00 AM, they could be fed hay to counterbalance the gut acidification and to enhance butyrate production to aid in epithelial proliferation.

Reese and Andrews [34] suggested that sweet food and all cereal grains should be kept to a minimum in the horse's diet. Those that have quick digestibility should be used more than those that have slow digestibility. The quick digestible one would be quickly degraded in the stomach, which would reduce starch substrate entering the hindgut, whereas those slow digestible would lead to sugar availability in the hindgut causing microbial instability for a longer period of time.

6.4. Dietary Fatty Acid Supplementation

Diet is a factor that can predispose a horse to lower insulin sensitivity, and it is associated with the occurrence of Laminitis [64]. Hence, supplementation that would increase insulin sensitivity should be the priority to reduce the incidence of laminitis and metabolic syndrome. Omega 3 fatty acids, alpha-linolenic acid, and their long chain fatty acid of eicosapentaenoic acid and docosahexaenoic acid help in modifying inflammation in many livestock species [65].

Dietary supplementation of n-3 polyunsaturated fatty acids improves sensitivity in nonruminant omnivores [66] and could do so in other farm animals. The mechanism of the dietary eicosapentaenoic acid and docosahexaenoic acid is their ability to penetrate the cell membrane, thereby increasing the flexibility due to higher unsaturation of the membrane, hence increasing the glucose transport function [67,68]. Hess et al [49] observed that on Day 90 of Ω -3 [n-3] fatty acid supplementation with marine and flax oil, improved insulin sensitivity 93.9 for control versus 95.7 for marine versus 96.8 for flax. Furthermore, Ross-Jones et al [65] showed that direct supplementation of marine oil (algae and fish oil supplement added to basal diet of equines) increased the level of alpha-linolenic acid, arachidonic acid, docosahexaenoic acid, docosapentaenoic acid, and eicosapentaenoic acid in the synovial fluid more than the ones not supplemented. This indicates that dietary fatty acid supplementation could help alleviate or inhibit laminitis. Consequently, dietary supplementation of these fatty acids may help to reduce inflammation incidence, which usually occurs in animal consuming high-energy diet in lactating cows and feedlot beef cattle.

6.5. Crop By-Products

An alternative solution to overcome the nutritional problems of equines is feeding high-fiber diets [69]. Sugar beet pulp, haylage, and soybean hulls are energy dense [7] crop by-product used as feed ingredients for livestock. Richardson and Murray [7] reported that when horses are fed diets high in haylage or sugar beet pulp, blood glucose concentration is similar to those fed starch-rich diets, and glycogen utilization is not negatively affected. The fermentative energy obtained from intracellular VFA in horses fed sugar beet fiber was higher than hay cubes (20.5 vs. 14.9 mmol/kg).

Fibrous feed material reduces gut ulceration in horses. Luther-sson et al [70] showed that hay and haylage feeding reduces the chance of ulceration compared with the use of straw as fibrous material only. Besides, straw is very low in nutrient composition and even the nutrient compositions are usually inaccessible, hence the incomplete digestion due to the high lignin and cellulose content.

Gastric ulcer incidence could be reduced with feeding management practice and changes from pasture feeding to stall confinement and regular feeding [71]. In addition, Woodward et al [71] reported that feeding Egusin supplements twice a day for 35 days might reduce gastric ulcers without surpassing bicarbonate concentration threshold.

Despite the lignocellulosic limitation of agricultural waste, these feeds could be used as energy sources in equine nutrition [51]. Use of fibrous feed may tend to increase acetate concentration, yet, acetate is a potential source of energy in entertainment horses [45]. Soybean hulls could provide energy without causing feeding disorders [52]. This is because of the quick degradation of this feed by cecal microbes [72], which is caused by the low lignin content and high cellulose and hemicellulose [73]. Ott and Kivipelto [53] demonstrated that feeding weanling horses with soybean hulls combined with medium grass hay of medium quality have similar energy value to horses than oat grain. This shows that soybean hull can be used to substitute oat in diets for equines. Kabe et al [74] showed that inclusion of soybean hull up to 28% as concentrate did not adversely affect *Streptococcus* spp. and *Lactobacillus* spp. Inclusion of unpelleted soybean hull at a rate of 0, 25, 50, and 75% led to an increased in total cecal VFA from 70 to 109 mM with increasing level of soybean [52]. Furthermore, propionate increased with increasing level of soybean hull at 15.7, 18.0, 16.6, and 21.9 mol/100 mol total VFA for the 0, 25, 50, and 75% soybean hulls concentration in diets, respectively. Inversely, there was a linear decrease with increasing level of soybean from 5.3 to 3.9 mol/100 mol of total VFA. However, inclusion of 75% of soybean hay had the lowest acetate: propionate ratio of 3.3, indicating increased glucogenic VFA level. The increasing level of propionate acid and VFA shows that there was a substantial amount of nutrient present in the soybean hull and could be used as alternative feed for horses.

6.6. Pectin

In the quest to feed animals with forages, poor quality forages and those poor in digestibility should be not be adopted when changing concentrate diet to forages. This is because the slow degradability would cause gut fill and reduce feed intake and affect VFA production and the subsequent performance of livestock. Crop by-products with relatively higher digestibility should be researched before recommendation for adoption. Pectin-rich diet is one of those feeds. Crop by-products that are rich in pectin have high digestible energy, which reaches the cecum and could replace the starch-rich grains [74]. From the microbial point of view, pectin is almost totally degraded by gut microflora that resides in the hindgut [75], which results in VFA production for equine and

provides energy needed for performance and maintenance. Citrus pulp contains higher pectin, and it is a by-product of orange extract and other citrus families such as lemon, tangerine, and pineapple [5]. Microbes with pectinolytic activity such as *Lachnospiraceae* (including the genus *Butyrivibrio*) and *Succinivibrionaceae* and *F. succinogenes* have been isolated from equine hindgut [76], which supports the idea that good pectin fermentation occurs in the hindgut to provide extra VFA [54]. Addition of mint or garlic to the equine diet might encourage fibrous feed intake [77].

6.7. Exogenous Fibrolytic Enzyme

Neutral detergent fiber digestibility is improved when exogenous fibrolytic enzymes are added to horses' diet although their effect varies on fermentation depending on the feed they are used on [78]. The activity of fibrolytic enzyme is based on their ability to break the chemical bond of forages that cannot be broken down by host enzyme [79].

Mohammadabadi et al [51] show that using the enzyme Natu-zyne at 6 g/kg dry matter in gas production from wheat straw and alfalfa hay improved neutral detergent fiber digestibility by 61 and 47% of alfalfa hay at 24 and 48 hours, respectively. Similarly, there was 60.3% in neutral detergent fiber digestibility of wheat straw when the enzyme was used. This shows that inclusion of cellulolytic enzymes could help to improve hindgut fibrous degradation to enhance hemicellulose and cellulose breakdown.

In vitro digestion of oat straw by Kholif et al [78] with xylanase at 1 and 3 $\mu\text{L/g}$ dry matter increased the degradability by 31.7 and 35.6%, respectively, while cellulase increased gas production by 16.8 and 18.7% for 1 and 3 $\mu\text{L/g}$ dry matter inclusion of cellulase. This implies that addition of xylanase or cellulase but preferably xylanase would aid fiber digestion.

6.8. Use of Protozoa and Faunation

Protozoa role in cellulose degradation seems to be of negligible importance in cellulose breakdown [80]; however, fungi are very important to plant cell wall degradation. Still, forage digestion is supported by large fibrolytic protozoa in hindgut fermentation [81]. Modulating the population of individual microbes might actually help to reduce some digestive problems. For instance, increasing the cellulolytic microbes or increasing the protozoa, which are known to have special preference for soluble starch and starch granules. Although there might be skeptics about protozoa because of their relationship with methanogens, it is important to note that acetogenesis is the main hydrogen sink in the hindgut of equine, not methanogenesis, and that is the reason why there is a high portion of acetate compared with propionate acid.

7. Conclusion

Diet characteristics are the main cause of digestive upset in equines. Feeding management, time of feeding, and dietary fatty acid supplementation avoid metabolic disorder. Alfalfa hay-based diet could be used for the prevention and healing of gastric ulcer. The inclusion of yeast in diet for equines increases gut pH and increases the growth of lactic acid using bacteria. Therefore, inclusion of yeast increases VFA production from fibrous diets providing adequate energy needed by equine during exercise and as a substitute for cereal grain inclusion. Avoiding a lengthy period without feed availability within a day reduces ulceration. It is important to feed equine periodically (two to three times) rather than once daily. This would help to reduce the growth of acidophilic bacteria such as *Lactobacilli* and *Streptococcus*, which lead to gut acidosis. A mixture of barley with either corn or oat increases gut pH during digestion

and increases butyrate acid production. Supplementation of equine diet with marine and flax oil could be used to improve insulin sensitivity. Therefore, following these strategies would reduce metabolic disorders that are triggered by high-cereal grain feeding, depression of pH, and microbial instability.

8. Implications and Recommendations

The present review was conducted to provide detailed and current information on grain feeding practices within the equine industry and to determine the likely impact of these practices on the hindgut environment. However, horses suffering gastric ulcer could be fed alfalfa hay because it helps to prevent it and aid the healing process of the ulcer. Horse owner should feed their horses two to three times daily making sure that horses have feed available between 1:00 AM and 5:00 AM.

Crop by-products such as citrus pulp, lemon, tangerine, and pineapple could be used as excellent alternative sources of energy to replace high-starch cereal grains. Alternatively, high-fiber feeds such as sugar beet pulp, haylage, and soybean hull may also be used as these feeds supply the energy required during equine performance and 2–4 mg/g dry matter of yeast may be included to boost energy release through increased digestion. However, if cereal grains are required for horse's diet, the animals would benefit if they are offered a diet including a mixture of barley grains combined with corn or oat grains.

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