Fibre for performance horses: A review

Abstract

Traditionally, performance horses are often fed high quantities of cereal grain-containing feeds to sustain their high energy needs and consequently the forage portion of the diet is reduced. Unfortunately such feeding practices are associated with adverse health effects and thus some investigations into alternative feedstuffs for performance horses have been undertaken. This paper reviews the ability of high energy fibrous feeds, such as haylage, sugar beet pulp and soyhulls, to meet the energy and protein requirements of performance horses, such as racing Thoroughbreds and Standardbred horses. Further, it explores the effects of these feedstuffs on bodyweight and other parameters generally associated with performance. The literature suggests that high energy fibrous feeds may have digestible energy contents comparable to grain as a consequence of enhanced volatile fatty acid (VFA) production. The inclusion of high energy fibrous feeds in performance horse diets does not appear to adversely affect glycogen utilisation or muscle lactate clearance during intense exercise, and an alkalising effect of a haylage-only diet may offset acidosis induced by intense exercise. Increases in bodyweight have been observed with haylage-only diets, but to a lesser extent than those observed for hay, and this has been attributed to the water holding capacity of the fibres. Whilst considerable research is required to fully understand the effects of high energy fibrous feeds in the diets of performance horses and its ability to sustain their nutrient requirements, the literature currently supports the replacement of at least a portion the grain fraction of the daily feed ration with high energy fibrous feed products. The implementation of such a change would likely improve the welfare of the performance horse.

1. Introduction

Diets of performance horses commonly consist of small quantities of low energy forage and large quantities of high-starch cereal grains or concentrates [1,2,3,4,5]. This practice focuses on foregut digestion aiming to capitalise on glucose delivery as a result of starch digestion in the small intestine [2]. However, such feeding regimes have been associated with alterations in the microbial population of the hind gut [6], disturbances of gastric function, promotion of colic, and an elevated risk of laminitis [2,7,8,9]. In addition, large grain-containing meals have been associated with the formation of gastric ulcers [10] and the development of stereotypical behaviours [11,12]. Thus, current feeding practices for performance horses may pose a welfare issue and consequently there is a need to explore alternative feeding regimens. A potential solution may include reducing the quantity of high starch-containing concentrates and replacing them with energy-dense fibrous feeds. This review aims to consider whether energy-dense fibrous feeds are suitable alternatives to high-starch feeds for performance horses.

2. Fibre versus grains: Energy

Grain is comprised mostly of hydrolysable carbohydrates (starch) and a small portion of fibre. When grain is fed, the hydrolysable dietary carbohydrates are digested in the small intestine, firstly, by alpha-amylase secreted by the pancreas, and then by brush–border membrane disaccharidases (sucrose, maltase, lactase) [13]. Sucrase activity is highest in the proximal portion of the small intestine, whereas maltase activity is similar throughout all regions [14]. Lactase activity is also prominent in the proximal region but expression reduces with maturity of the horse [14]. Following digestion of the hydrolysable carbohydrates, the resulting monosaccharides (D-glucose, D-fructose, D-galactose) are then absorbed across the brush-border membrane by specific monosaccharide transporters [13]. Glucose and galactose are transported via Na^+/glucose cotransporter isoform 1 (SGLT1) which is expressed most highly in the proximal small intestine and whilst it has a high affinity for the sugar substrates, its capacity is low [14]. Thus, starch digestion is somewhat limited by physiology, with the majority of digestion and absorption of sugars occurring in the proximal portion of the small intestine.

Fibrous feeds are mostly digested in the hindgut. Microbial fermentation in the hindgut produces volatile fatty acids (VFA), principally acetate, propionate and butyrate. These energy-yielding substrates are readily absorbed into the bloodstream and converted to glucose, fat, or utilised directly as an energy source. The respective concentrations of acetate, propionate and butyrate are greatly influenced by diet and this has been demonstrated by numerous investigators [15,16,17,18]. For example, Julliand et al. [19] demonstrated that the inclusion of barley in a hay-based diet led to significant changes in the microbial population of the colon resulting in a lower colonic pH, a decreased molar percentage of acetate and an increased molar percentage of propionate.

In contrast to the potentially detrimental effects of grain on hindgut dynamics and VFA production, energy-dense fibrous feeds have been shown to enhance VFA production in the equine hindgut, and the superior fermentation qualities of haylage, sugar beet pulp, and soyhulls in comparison to hay, have been demonstrated by several investigators.

Moore-Colyer et al. [20] reported sugar beet pulp to exhibit greater fermentation potential than hay cubes when fed to ponies, with sugar beet fibre yielding significantly higher levels of intra-caecal VFAs (20.46mmol/kg sugar beet fibre) compared to hay cubes (14.85mmol/kg hay cubes). Similarly, Coverdale et al. [17] reported Quarter Horses fed an alfalfa/bromegrass hay diet, substituted with 0, 25, 50 or 75% soyhulls, to have increased total caecal VFA concentration from 70.32mM to 108.50mM for 0 and 75 % soyhull supplementation, respectively. Moreover, Muller [21] assessed levels of total VFAs in the faeces of 12 horses fed haylage cut at 3 different stages of maturity. The early cut haylage (June) was found to produce significantly greater ($p<0.05$) quantities of total faecal VFAs (June 55.2mM), particularly acetate and propionate, than the later cut haylages (July 42.1mM; August 38.4mM).

The enhanced production of VFAs in the large intestine with the inclusion of haylage, sugar beet pulp, and soyhulls in the diet has been attributed to a high concentration of readily degradable non-starch polysaccharides (NSP) in these feedstuffs [20,22,23,24]. NSPs, particularly arabinose, galactose, and uronic acid from the pectin fraction, are highly fermentable [24,25] making these fibrous feeds potent sources of energy for the horse.

The significance of enhanced fermentation and subsequent increase in VFA production becomes apparent when one considers that these substrates are converted to glucose, fat, or used directly as a source of energy. The two VFAs that contribute most to energy metabolism are acetate and propionate. Acetate represents approximately 70% of all VFAs produced [16] and is a metabolic precursor to acetyl-CoA. Under aerobic conditions acetate can be utilised via the tricarboxylic acid cycle to produce adenosine triphosphate (ATP), or converted to fat [26]. Pethick et al. [27] reported acetate to account for up to 32% of the total substrate oxidation within the hind limb at rest. Pratt et al. [28] also confirmed acetate's role as an energy substrate, having observed an enhanced utilisation of plasma acetate following an infusion of sodium acetate during sub-maximal exercise compared to rest. It is important to note that haylage has been shown to positively influence plasma acetate concentration; Jansson and Lindberg [29] observed a significantly higher concentration of plasma acetate in Standardbred horses fed a haylage-only diet (timothy, meadow fescue mixture), before and after exercise, compared to a 50:50 haylage:concentrate diet.

Propionate is a gluconeogenic substrate [30] and its contribution to the glucose pool is substantial. Approximately 7% of total glucose production in ponies fed hay has been reported to originate from caecal propionate [31], with 50-61% of blood glucose in ponies fed hay derived from colonic propionate [32]. The remaining 32-43% of glucose is likely assimilated via the small intestine or from gluconeogenesis from amino acids [32].

The aforementioned studies serve to remind us that horses are designed to efficiently extract energy substrates from hindgut fermentation, if fuelled appropriately, and the old adage of "keeping the fire stoked" may be applicable in this case.

In contrast to times gone by when low energy hay was the only source of conserved forage, the highly digestible and fermentable nature of higher energy fibrous feeds may indeed potentially enable them to replace starch as an energy source for performance horses [33,34]. However, empirical quantification of the digestible energy (DE) content of these higher energy fibrous feeds needs further development if such feed types are to be accurately incorporated into feed rations. The formulas used to estimate DE are reasonably accurate for feed products including hay and most pellet feeds [35,36], but they may substantially underestimate the DE for feed products containing over 35% crude fibre (eg. soyhulls) and for fibrous products with a high content of highly fermentable fibres (eg. sugar beet pulp) [36]. Table 1 provides details of published average DE values for a variety of fibrous feedstuffs and cereal grains. According to Zeyner and Kienzle [36] it is likely the DE values for sugar beet pulp and soyhulls may be more comparable to that of oats and barley.

Despite the theory supporting the inclusion of high energy fibrous feedstuffs in performance horse diets, substantial debate exists over whether these alternative feedstuffs can meet the energy requirements of the performance horse in practise. Performance horses, such as racehorses, primarily rely on the metabolism blood glucose and muscle glycogen for energy production and replenishment of glycogen stores [18,37]. As such, an abundant supply of glucose to muscle is essential to prevent fatigue and reduced performance [38]. Moreover, as many horses in the racing industry commence their training from a young age, the diet must support growth and development, in addition to meeting the energy requirements imposed by training. In support of this notion, Ringmark et al. [39] reported that yearling Standardbred horses fed a forage-only diet grew as well as yearlings fed conventional diets, had normal body condition and muscle glycogen levels for athletic horses, and achieved conventional training goals. Thus, there is evolving evidence to suggest high energy fibrous feeds may be able to adequately support these elevated requirements.

2.1 Blood glucose

In general, fibrous feeds are considered to be relatively low contributors to blood glucose production compared to grain-containing meals due to their relatively low levels of non-structural carbohydrates and studies examining glucose levels following a meal of "fibre" versus a meal of "starch/sugars" in horses at rest have substantiated such claims [40,41,42]. For example, Karasu et al. [43] reported peak glucose concentration and plasma AUC glucose concentration in horses at rest following a meal comprised of a "fibre-enriched" compound feed (starch 7.4g, sugar 6.2g [as fed]) was 5.2±0.2 mmol/L and 163±46 mmol x min/L, respectively. In contrast, following a meal of starch-enriched compound feed (starch 33.1g, sugar 4.4g [as fed]) the peak glucose concentration and plasma AUC concentration was 7.6±0.9 mmol/L and 696±208 mmol x min/L. Interestingly, a second meal fed 8.5 hours later produced a similar glycemic response for the fibre-enriched meal, but a substantially reduced glycemic response for the starch-enriched meal. Further, Lindberg and Palmgren-Karlsson [44] replaced a portion of a meal containing oats with sugar beet pulp (145g/kg DM oats replaced with 152g/kg DM unmolassed sugar beet pulp to produce a diet containing 179g/kg DM starch and 106g/kg DM starch, respectively). Blood glucose levels were observed over a 4 hour period. At 2 hours post-meal blood glucose levels peaked at 7.5 mmol/L for the oats diet and were significantly higher than for the sugar beet pulp diet (6.8 mmol/L). However, by 4 hours post-meal blood glucose levels for both diets were equivalent.

In contrast, Crandell, et al. [45] reported that post-feeding blood glucose levels in horses fed a diet of sweet feed (cereal concentrate) compared to when 15% of the daily digestible energy intake was replaced with molassed sugar beet pulp (1.36kg dry weight) were similar, but a contribution to the blood glucose levels by molasses to the sugar beet pulp cannot be ruled out. Likewise, Groff et al. [46] observed that horses fed 0.75kg of molassed sugar beet pulp produced statistically similar peak blood glucose concentration, mean glucose concentration and area under the curve responses compared to an equal weight of whole oats. However, it was also noted that this parity in peak blood glucose concentration was most likely due to the inclusion of molasses in the sugar beet pulp, as observed by Crandell et al. [45]. However, unmolassed sugar beet pulp also elicited a blood glucose peak during the first 150 minutes post-ingestion. This effect was reportedly due to the digestion of residual sugars [46], but may also have been due to enzymatic digestion of non-starch polysaccharides (NSP) in the small intestine. Moore-Colyer et al. [24] reported that 15% of sugar beet pulp NSPs and 14% of soyhull NSPs disappeared pre-caecally in ponies.

Considering the digestion process of high energy fibrous feeds, it may be more appropriate to assess blood glucose levels over a longer time period and consider area under the curve concentrations in addition to peak blood glucose levels. Groff et al. [46] reported that whilst horses fed 0.75 kg of unmolassed sugar beet pulp exhibited lower peak blood glucose concentrations compared to a meal of 0.75kg whole oats, they produced statistically similar mean glucose concentrations and area under the curve concentrations. This is due to higher concentrations of blood glucose 150-480 minutes post-ingestion of unmolassed sugar beet pulp compared to the whole oats. A similar observation was made by Hallebeek and Beynen [47] who reported that 3 hours after ingestion of a base diet (grass hay and concentrate) supplemented with 0.375kg unmolassed sugar beet pulp, plasma glucose and insulin concentrations were significantly higher than when horses were fed the same base diet supplemented with 0.215kg glucose. The apparent delay in glucose production is hypothesised to be attributed to increased production and absorption of propionate from the fermentation of pectins in the hindgut [33].

The enhancement of propionate production by high energy fibrous feeds may translate to a greater potential for gluconeogenesis [17] specifically during performance. In contrast to cereal grain which is primarily digested in the small intestine, performance horses fed higher energy fibrous feeds may benefit from glucose produced via efficient enzymatic NSP digestion in the small intestine, in addition to a constant supply of gluconeogenic substrates from hindgut fermentation.

Thus, when examining the effects of high energy fibrous feeds on performance horse blood glucose levels it is pertinent to examine their effects during and post exercise, as this may have a direct affect on performance and recovery. Crandell et al. [45] reported statistically similar blood glucose levels for Thoroughbred horses undergoing an intensive standard exercise test when fed a diet of sweet feed (cereal concentrate) compared to when 15% of the daily digestible energy intake was replaced with molassed sugar beet pulp. During the warm down and 15 minute post-exercise time point, blood glucose levels were statistically higher when fed the sweet feed, but this may also have been due to significantly higher cortisol levels. Similarly, Palmgren Karlsson et al. [48] reported that when fed an oat/hay/molassed sugar beet pulp diet (equivalent to 2.08kg oats, 1.48kg molassed sugar beet pulp for 500kg horse) compared to an oat/hay diet (equivalent to 3.55kg for 500kg horse) the blood glucose level of Standardbred horses during or following an intensive treadmill exercise test were comparable. Similar observations in plasma glucose levels were reported by Gurbuz and Coskun [49] when Thoroughbred horses undergoing an intensive exercise test were fed either an oats-containing diet or the same diet with oats replaced by 12.5%, 25% and 37.5% of dried sugar beet pulp.

These studies confirm that whilst resting blood glucose levels may be lower when fed a high fibre diet compared to when fed a high-starch containing meal, blood glucose levels during and immediately following exercise are equivalent and during the exercise tests no detrimental effects on performance were observed.

2.2 Glycogen utilisation

During exercise both aerobic and anaerobic metabolic pathways are in operation. However, depending on the intensity and duration of the exercise, one energy metabolic pathway will predominate. At high speeds over short distances the rate of glycogen utilisation is at its fastest due to the high activity of anaerobic energy metabolism. Any impairment to the rate of glycogen utilisation during intense exercise may affect performance, and thus the effect of diet on the rate of glycogen depletion is an important consideration.

Jansson and Lindberg [29] reported that following an intense exercise test, Standardbred horses fed a grass haylage-only diet, versus a diet containing 50:50 concentrate:haylage, experienced similar glycogen depletion rates and performance was not affected. This suggests that the haylage-only diet was able to provide sufficient energy substrates to produce performance equivalent to a starch-containing diet with no adverse effects on glycogen utilisation. Similarly, Essen-Gustavsson et al. [50] reported no difference in rate of glycogen utilisation when horses undergoing an intense exercise test were fed a forage-only diet (silage/hay) containing high levels of crude protein (16.6%) versus a recommended level of crude protein (12.5%).

Palmgren Karlsson et al. [48] suggested that the inclusion of sugar beet pulp in performance horse diets may also yield positive effects on glycogen utilisation. They observed significantly higher muscle glycogen concentrations ($p<0.05$), significantly lower muscle lactate levels ($p<0.05$) and significantly lower peak plasma lactate concentrations (during Phase I ($p<0.0001$) and Phase III ($p<0.05$) of an exercise test) in Standardbred horses following an intensive treadmill exercise test when they were fed an oat/hay/sugar beet pulp diet compared to an oat/hay diet. Palmgren Karlsson et al. [48] proposed that the additional VFAs, produced as a result of the sugar beet pulp, were utilised as an aerobic energy substrate creating a glycogen-sparing effect. Whilst it is important to consider that these results may have been influenced by the presence of molasses in the diet containing sugar beet pulp, their findings display similarities consistent with findings observed by Jansson and Lindberg [29] with regards to lower plasma lactate concentrations and a trend towards higher aerobic energy metabolism in horses fed a haylage-only diet. However, a repeat of this experiment with unmolassed sugar beet pulp would help to clarify if glycogen-sparing does occur.

Based on the limited available research, the inclusion of grass haylage or sugar beet pulp in performance horse diets does not appear to adversely affect the rate of glycogen utilisation. Pending further research, it is possible that the inclusion of sugar beet pulp may exhibit a glycogen-sparing effect. Moreover, it would be valuable to explore the effects of soyhulls on glycogen utilisation and due to its highly fermentative properties it may be possible to draw some parallels with sugar beet pulp.

2.3 Glycogen replenishment

As glycogen is a limiting fuel for muscle contraction and reduced glycogen stores have been shown to impair subsequent performance [35,51], it is important that any diet must adequately facilitate glycogenesis. In humans, dietary manipulation of carbohydrates to enhance muscle glycogen stores and hasten repletion to gain a competitive advantage has been extensively researched [52]. Similar research has been conducted in horses; however, unlike humans, the process of glycogen replenishment in the horse appears to be physiologically rate limited. Feeding diets containing high levels of non-structural carbohydrates (starch, glucose) have been unsuccessful at substantially hastening the repletion process to less than 48-72 hours [53,54,55]. For example, Snow and Harris [53] investigated glycogen repletion rates in trained Thoroughbred horses subjected to a typical British training exercise programme. Following exercise, muscle glycogen loss was between 19-25% of the resting content. Horses received ~3.5kg hay and ~7kg concentrate feed providing 38.5% dietary starch per day. Despite the high levels of starch it still took 72 hours for glycogen levels to return to pre-exercise levels. Lacombe et al. [56] reported that only a grain diet containing very high levels of starch (51%) was able to replenish muscle glycogen stores in Standardbred horses depleted to 60% of baseline values within 72 hours. As the average glycogen depletion rate for racehorses is generally accepted to be around 20-35% of baseline levels due to the short duration of the intense exercise [57,58,59] providing such high levels of starch is not recommended due to potential adverse health effects.

Concern over whether all forage diets can sustain adequate glycogen reserves was highlighted when Jansson and Lindberg [29] reported significantly lower ($p<0.05$) pre- and post-exercise muscle glycogen levels (-13%) in Standardbred horses consuming an early-cut haylage-only diet (pre-exercise 560 ± 22 mmol glucosyl units/kg dry weight (DW); post-exercise 473 ± 22 mmol/kg DW) compared to a 50:50 haylage:concentrate diet (pre-exercise 644 ± 22 mmol/kg DW; post-exercise 546 ± 22 mmol/kg DW). The authors speculated that the difference in muscle glycogen levels may have been due to the horses being exercised 96 hours prior to the standardised exercise test and it was postulated that glycogen repletion may not have been complete for the haylage-only diet. However, Jansson and Lindberg [29] also considered that the low crude protein content of the haylage-only diet (~10% CP) may have influenced glycogen repletion as described by Essen-Gustavsson et al. [50].

Essen-Gustavsson et al. [50] reported that horses fed a forage-only diet (silage/hay) containing high levels of crude protein (CP) (16.6%) had higher levels of muscle glycogen at rest (pre-exercise), post-exercise and after 90 minutes of recovery than when fed a forage-only diet containing "recommended" levels for racehorses of CP (12.5%). Pre-exercise muscle glycogen levels were reported to be 630 mmol/kg dry weight (DW) for the high protein diet and 552 mmol/kg DW for the recommended protein diet, which incidentally are comparable to the pre-exercise values observed by Jansson and Lindberg [29] in horses fed a 50:50 forage:concentrate diet (644 ± 22 mmol/kg DW) and a forage-only diet (560 ± 22 mmol /kg DW). Essen-Gustavsson et al. [50] proposed that the increase in muscle glycogen concentration for the high protein group was related to either a greater synthesis of muscle glycogen or a lower degradation rate of muscle glycogen [50]. However, it is of note that the diets were not isocalorific, with the HP diet containing significantly higher metabolisable energy. Also the water soluble carbohydrate intake was

300g higher on the high protein diet but this difference in water soluble carbohydrates was not believed by the authors to be substantial enough to affect glycogen synthesis.

Studies in humans have shown that an intake of carbohydrates plus protein is more effective at replenishing glycogen than carbohydrates alone (Zawadski et al., 1992 cited by [50]; Van Loon et al., 2000 cited by [50]). The mechanism is not completely understood but may be related to the stimulation of insulin secretion by amino acids (leucine, iso-leucine) leading to increased uptake of glucose by skeletal muscles [50]. Furthermore, in rats it is thought that muscle glycogen synthesis may be stimulated by leucine activating the mTOR (mammalian Target of Rapamycin) signal pathway ultimately leading to the stimulation of glycogen synthase and production of glycogen (Morifuji et al., 2010 cited by [50]). Morifuji et al. [60] also demonstrated in rats that feeding a carbohydrate meal combined with a protein hydrolysate pre-exercise attenuated exercise induced glycogen depletion. Interestingly, it was noted by Essen-Gustavsson et al. [50] that the muscle leucine concentration in muscle was higher in the high protein diet post-exercise compared to the recommended protein diet fed to horses. Research exploring the effect of high protein haylage combined with sugar beet pulp as a supply of fibre and sugars on muscle glycogen levels would be interesting.

Pending further research regarding the ability of high energy fibrous feeds to efficiently replenish glycogen supplies it may be prudent to include a limited source of sugar/starch in equine diets following strenuous exercise, particularly if further strenuous exercise is expected to occur within a few days.

3 . Fibre versus grains: performance

Several factors may influence the athletic performance of the equine. These include accumulation of by-products from energy metabolism (lactate), perceived effects of excessive dietary protein, and increased bodyweight/gut-fill. Several studies have examined the effects of high-energy fibrous feeds on these factors.

3 .1 Muscle lactate and H^+ clearance

High intensity exercise in the equine athlete can result in marked accumulation of muscle lactate and hydrogen ions (H^+) [58], and excessive intra-muscular accumulation of lactate and H^+ can lead to intracellular acidosis resulting in fatigue [61,62]. The monocarboxylate transporter isoform 4 (MCT4) is found in glycolytic muscle fibres, and is believed to be specialised for lactate efflux [63]. MCT4 expression has been shown to be increased by induced alkalosis enhancing lactate and H^+ clearance from glycolytic muscles [64]. The resultant plasma lactate and H+ may then be taken up by MCT1 in oxidative muscle fibres for conversion to pyruvate [65]. Therefore, strategies to enhance muscle lactate and H^+ clearance via induced alkalosis have been explored [66,67]. Administration of a bicarbonate solution to horses is an example of a commonly used method to induce alkalosis [68]. A serendipitous side effect of a haylage-only diet may be to facilitate muscle lactate and H^+ clearance via a natural alkalising effect. Jansson and Lindberg [29] reported that Standardbred horses undergoing an intensive standard exercise test and fed early cut grass haylage-only diets, had significantly higher venous blood pH levels ($p<0.05$) at several testing points compared to when fed the 50:50 early-cut grass haylage:concentrate diet. The haylage-only fed horses also had significantly lower plasma lactate concentration post–exercise ($p<0.05$) and trended towards a higher plasma lactate threshold (V_{La4}) ($p=0.086$). Jansson and Lindberg [29] proposed that the lower plasma lactate concentration post–exercise test may have been due to a reduced dependency upon glycolytic metabolism and increased aerobic metabolism. However, as the rate of glycogen depletion between the two diets was similar it could be speculated that the lower plasma lactate levels may be a result of greater uptake by MCT1. This may be a consequence of enhanced muscle lactate clearance due to greater MCT4 expression as a result of the alkalising effect of the haylage-only diet. Additionally, the more alkaline blood pH may have been due to the buffering capacity (organic anions) of the haylage-only diet neutralising H^+ ions [29]. This is certainly an interesting area warranting further investigation. The capacity to offset acidosis induced by intense exercise, via natural means, may be a real benefit to the performance horse.

3.2 High protein forage and performance

The CP content of many fibrous feeds is often equivalent to, or in excess of, that found in cereal grains [69]. The average CP content of sugar beet pulp, haylage and soyhulls is 10%, 13% and 14% respectively, which is less than or comparable to cereal grain (12-13%) [35]. However, legume forages tend to have a higher CP content, often exceeding 20% of the DM content [35]. This may be of concern to some in the performance industry as the effect of high dietary protein levels on performance has been scrutinised over the years. Glade [70] reported that CP intakes were positively correlated with racehorse time to finish with ingestion of over 1630g CP/day/500kg bodyweight, increasing average "times to finish" by 1-3 seconds. Moreover, Connysson et al. [69] reported that excretion of excess protein produces hydrogen ions that may potentially affect the horse's acid-base balance, and the heat produced during excretion along with the increased urinary output contributes to evaporative fluid loss. They suggested that together these factors may potentially provide horses with unnecessary challenges during "prolonged" exercise.

Nonetheless, under experimental conditions, adverse effects of high levels of protein intake on performance are yet to be substantiated. Miller-Graber et al. [71] did not observe increased sweat loss in 6 conditioned Quarter Horse mares fed a high protein diet (18% CP) during an intense, sub-maximal exercise test when compared to a low protein diet (9.0% CP). Similarly, Jansson and Lindberg [29] reported that 6 Standardbred geldings in race training fed haylage-only (1132 ± 87g CP) or 50:50 haylage:concentrate (1467 ± 66g CP) diets did not show differences between diets for heart rate, breathing frequency or rectal temperature before, during or after an intensive treadmill exercise test. Essen-Gustavsson et al. [50] also did not report any adverse effects of a forage-only diet (16.6% CP) on the metabolic response of horses during an exercise test. Thus, the effect of excessive levels of dietary CP on performance needs further investigation and it would appear from the literature that there are few adverse effects on performance. Thus the inclusion of legume forages or haylage in moderation in performance horse diets should not be discouraged.

3.3 Bodyweight and performance

Weight and gut-fill are a major concern for performance horses as "dead weight" may confer a real handicap. The increased bodyweight may increase the overall workload of the horses, ultimately impairing performance [72]. Forages, particularly hay, are provided in limited quantities to prevent potential bodyweight increases [73] created by the extra dry matter and the water holding capacity of fibres [72]. Additionally, extra gut fill and weight may impact on the energy expenditure of a hard working horse. Kronfeld [74] proposed that 5.6% extra weight in a 500kg horse due to additional fibre and water would increase energy expenditure by 1.8Mcal/day.

Certainly increases in bodyweight have been observed when horses are fed all-hay or diets with large quantities of hay. Ellis et al. [73] showed that Thoroughbred-type geldings fed late-cut meadow hay (full bloom stage) as either 100% hay, 80% hay:20% concentrate, 60% hay:40% concentrate or 50% hay:50% concentrate experienced significant changes in bodyweight. Over the course of the study the mean bodyweight of horses on the 100% hay diet increased approximately 7kg (1.3% increase), and the 80% hay diet increased weight by approximately 3kg (0.5% increase).In contrast, the 60% hay diet decreased bodyweight by approximately 5kg (0.9% decrease), and the 50% hay diet decreased approximately 4kg (0.7% decrease). Water consumption was also greatest when horses were consuming the 100% hay diet (45 l/d) and was statistically greater than when consuming the 50% hay:50% concentrate diet (39 l/d). The increased bodyweight in the higher forage diets was attributed to increased dry matter intake, increased water intake and slower rate of passage of digesta leading to greater gut fill. Following a sub-maximal standard exercise test maximal heart rate and recovery heart rate were significantly higher when horses were fed the 100% hay diet compared to the 50% hay:50% concentrate diet. Ellis et al. [73] concluded that the increased bodyweight may have contributed to the increased heart rates and this may be detrimental to the performance of the horse.

In contrast to low energy fibres, such as hay, the high energy fibres being of higher calorific content, are fed in lower quantities than hay, and thus are expected to have a smaller impact on gut fill and body weight. Meyer [75] published findings of the effects of meadow hay and mixed feeds on gut fill in exercised horses. It is possible a diet comprised of a high energy haylage and a pelleted high energy fibre concentrate may have a similar or potentially lower gut fill (g/kg bwt) than reported for the exercised horses fed meadow hay and mixed feed [75] thus not rendering performance horses consuming high energy fibrous feeds diets at a disadvantage.

Limited research has been conducted exploring the effects of high energy fibrous feeds on bodyweight. Jansson and Lindberg [72] reported weight gain in horses fed haylage but to a lesser extent than reported by Ellis et al. [73] when hay was fed. Standardbred horses undergoing intense track work fed a haylage-only diet had a small (3-5kg) weight gain compared to the 50:50 haylage:concentrate diet [72]. However, almost all of the additional weight gain was lost during a period of feed deprivation (time between last forage meal [afternoon prior to exercise test] and just prior to warm up for exercise test) suggesting the majority of extra weight was due to feed bulk and water retention [72]. Despite the slight increase in weight performance was not adversely affected during the intensive exercise test. No impact was observed for breathing frequency, heart rate or general performance [72]. Further, Spooner et al. [76] observed that endurance horses completing a 60km exercise test trended towards greater body mass loss when fed a 50:50 grass hay:soyhull/sugar beet pulp/oil-supplemented diet compared to a grass hay-alone diet or 50:50 grass hay:alfalfa diet (p=0.08). This difference was speculated to be due to greater faecal water loss over the exercise test period [76].

The research suggests that diets containing high energy fibrous feeds may increase bodyweight due to their increased water holding capacity but this weight gain is less than that observed for diets comprised of hay alone. Strategic feeding and a short period of dietary restriction prior to competition may facilitate loss of additional weight. However, further research in this area is needed, particularly for sugar beet pulp and soyhulls, as their highly digestible properties may equate to less gut-fill, and hence, less “dead weight”.

5. Conclusion

There is strong evidence to support the need for alternative feeding practices for performance horses due to the adverse health effects associated with high-starch diets, and high energy fibrous feeds may go some way to providing a solution.

A review of the literature suggests that during and following exercise blood glucose levels are equivalent to when horses are fed starch-containing diets, and the rate of glycogen utilisation is not adversely affected by diets containing haylage or sugar beet pulp. In fact, sugar beet pulp may offer a glycogen-sparing effect due to the enhanced production of propionate and its gluconeogenic properties. Optimal strategies for facilitating efficient glycogen replenishment are still being investigated and a starch-containing meal following glycogen repletion may be necessary if periods between performances are short. High CP levels, such as those found forages such as alfalfa, may have a positive effect on glycogen synthesis.

Regarding performance parameters, the inclusion of high energy fibrous products (haylage, sugar beet pulp) in performance horse diets does not appear to adversely affect muscle lactate clearance. Moreover, an alkalising effect of a haylage-only diet may offset acidosis induced by intense exercise and promote muscle lactate clearance. Additionally, under experimental conditions high CP diets have not been shown to adversely affect performance. Weight and gut-fill may be less of an issue for high energy fibrous feeds such as haylage, sugar beet pulp, and soyhulls as they are more digestible across the total digestive tract than hay.

Whilst considerable research is required to fully understand the effects of the high energy fibrous feeds in the diets of performance horses, the present literature presents a sound argument for the replacement of at least some of the grain with high energy fibrous feeds. This change in feeding management would substantially improve the welfare of the performance horse.

Table 1: Average digestible energy content for grass haylage, Lucerne haylage, sugar beet pulp, soyhulls, Controlled Fermented Lucerne, oats and barley.

Feed product	Dietary Energy (Mcal/kg DM)	Reference
Grass haylage - Early cut Timothy/Meadow Fescue	2.96	[21]
Lucerne haylage	2.93	[77]
Sugar beet Pulp	2.64-3.10	[35,78]
Soyhulls	2.04 – 2.25	[35,78]
Controlled Fermented Lucerne	2.65 (as fed)	[79]
Oats	3.23 - 3.35	[35,78]
Barley	3.64 – 3.67	[35,78]

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