A bibliometric review on nutrition of the exercising horse from 1970 to 2010

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REVIEW PAPER

Abstract

The main aims of the present review are to provide a bibliometric analysis of the research published on the nutrition of the exercising horse from 1970 to 2010 and to determine whether this research has had any practical impact on feeding practices. In addition, we evaluated whether some of the key nutritional questions posed at the beginning of the 1980s have in fact been answered. Less than 300 publications were published in the period 1970-1980, but a large increase in the number of publications was observed between the period 1981-1990 and the period 1991-2000. Most papers were published in the Equine Veterinary Journal and American researchers, universities or institutes were particularly productive. The majority of the publications were in the areas of fluid balance, fat and glucose metabolism. Using information from field studies, there appears to have been a trend for a reduction in the amount of starch rich concentrates fed to performance horses from 1979 to 2007 and an increase in the use of oil supplementation. Whilst there have been several significant advances in our scientific knowledge of nutritional practices over the past few decades that have become routine practice in the field, others have not cascaded down. Unfortunately, we have not really fully answered any of the questions posed in the early 1980s and whilst it is possible that such questions can never be fully answered, there is also a concern that lack of sufficient funding, especially for the fundamental pieces of information needed to underpin our nutrition advice, will hamper progress in the future.

Keywords: diet, feed, performance, publication, training

1. Introduction

In the review on nutritional requirements of the exercising horse in the first proceedings of the International Conference on Equine Exercise Physiology (ICEEP) in 1983, Professor Harold Hintz noted that nutrition of the performance horse had received little attention from researchers over the previous few years. Through looking at world wide databases (Scopus and CAB Abstracts in March 2010) we can confirm this conclusion, as they show that less than 300 publications related to nutrition of the exercising horse were published in the period 1970-1980. From this point however, the publication rate increased and in fact roughly doubled in each of the following two decades. There are probably several reasons behind this expansion, including the increase in the use of the horse for leisure/pleasure purposes over this time and the demand

for increased knowledge on how best to feed such animals. The main aims of the present review were to provide a bibliometric analysis of the research published on the nutrition of the exercising horse from 1970 to 2010 and to determine whether this research has had any practical impact on feeding practices. In addition, we aimed to evaluate whether some of the key nutritional questions posed in 1983 have in fact been answered.

2. Bibliometry

Topics

A bibliometric analysis was performed on publications related to nutrition of the exercising horse found in two world-wide data bases: CAB Abstracts and Scopus. The analysis included publications from 1970 to 2010 and the

analyses were executed on the 5th and 8th of March 2010 (Cab Abstracts and Scopus, respectively). First, a basic search profile in titles, abstract and keywords was executed including three words (topics): horse, exercise, nutrition and words related and synonymous to these (Table 1). After this, sub-search profiles reflecting topics like forage, fibre, fat, protein, amino acid, electrolytes, minerals, glucose, glycogen, insulin sensitivity and time of feeding were added, one at a time (Table 1).

Overall, the number of publications identified was smaller in Scopus compared to CAB (Table 1). This is due primarily to the different literature sources that each data base uses i.e. Scopus includes articles, articles in review, articles in press,

reviews, conference papers, letters, editorials and notes, whereas CAB Abstracts include journal articles as well as books, book chapters, miscellaneous, theses, abstracts only, conference proceedings, journal issues, annual reports, bulletin articles and correspondences. The results show that most publications were found in the areas of fluid balance, fat and glucose metabolism (Table 1). This most likely reflects the increased focus in the 1990s on mitigating any potential adverse effects of exercising under conditions of heat and humidity associated with the Atlanta Olympics (Jeffcott and Kohn, 1999), plus the increased popularity of endurance riding coupled with increasing awareness of the potential adverse effects of excessive grain intake (Kronfeld and Harris, 2003) which led to an increased interest in fat

Table 1. Publications from 1970-2010 related to nutrition of the exercising horse. The results are obtained from Cab Abstracts (5 March 2010) and Scopus database (8 March 2010). A basic (B) search profile was made and then a sub-search profile was added, one at a time.

B	Sub-search profiles within the basic												
		Forage ³	Fibre ⁴	Fat ⁵	Protein ⁶	Amino acid ⁷	Anti-oxidant ⁸	Electrolyte ⁹	Mineral	Glycogen	Glucose	Insulin ¹⁰	Timing ¹¹
CAB ¹													
1970-1980	336	24	11/0	50	50/1	13	12	38	11	9	39	0	11
1981-1990	591	11	39/0	46	47/3	13	8	43	10	30	38	1	7
1991-2000	1,271	65	66/3	133	124/10	22	32	174	46 ¹²	36	90	1	27
2001-2010	1,493	117	87/2	202	174/11	44	92	207	87 ¹³	58	147	23	77
Total	3,691	217	203/5	431	395/25	92	144	462	154	133	314	25	122
Scopus ²													
1970-1980	27	2	0/0	2	3/0	1	5	5	1	2	5	0	2
1981-1990	62	12	0/0	5	17/5	0	5	18	2	5	9	0	13
1991-2000	214	49	8/4	57	63/5	15	26	90	25 ¹⁴	28	52	7	36
2001-2010	325	120	17/3	93	102/9	32	48	123	32 ¹⁵	49	92	34	97
Total	628	183	25/7	157	185/19	48	84	236	60	84	158	41	148

¹ Topic=(horse OR horses OR foal* OR stallion* OR mare* OR equine OR equines OR yearling*) AND Topic=(exercise* OR 'physical activity*' OR conditioning OR training*) AND Topic=(diet* OR feed* OR intake OR supplement* OR oral OR nutrition).

²((horse OR horses OR foal OR stallion OR mare OR equine OR yearling) AND (exercise* OR 'physical activity*' OR conditioning OR training) AND (diet* OR feed* OR intake OR supplement* OR oral OR nutrition)) in article title, abstract or keywords.

³ Full search: Forage* OR roughage* OR hay* OR haylage* OR silage* OR grass*.

⁴ Fibre* OR fiber*/Soluble fibre* OR Soluble fiber*.

⁵ Fat* OR oil* OR fatty acid*.

⁶ Protein* OR crude protein*/crude protein*.

⁷ Amino acid* OR aminoacid* OR lysine* OR tryptophan* OR methionine* OR alanine* OR valine* OR leucine* OR isoleucine* OR threonine*.

⁸ Antioxidant* OR vitamin*.

⁹ Electrolyte* OR sodium OR salt OR saline OR water.

¹⁰ Insulin sensitivity OR glycaemic* OR insulinaemic*.

¹¹ Time of feed* OR timing*.

¹² A search on calcium and phosphorus* resulted in 53 publications.

¹³ A search on calcium and phosphorus* resulted in 64 publications.

¹⁴ A search on calcium and phosphorus* resulted in 2 publications.

¹⁵ A search on calcium and phosphorus* resulted in 1 publication.

supplementation. The surge in papers concerning glucose probably occurred due to an interest in the importance of glucose metabolism for performance and most likely also due to the proposed link between insulin resistance, obesity and laminitis (Coffman and Colles, 1983; Jeffcott *et al.*, 1986). The latter may also have cascaded down from the increasing concern in human medicine with respect to the emerging obesity/diabetes epidemic and awareness of the importance of the ‘metabolic syndrome’. The explosion of work in this area in humans started with the description by GM Reaven in the 1980s (Reaven, 1988) although the clustering of key factors had been noted before (see Sarafidis and Nilsson, 2006).

Many publications were also found using search topics ‘forage, roughage, hay ...’, ‘fibre/fiber’ and ‘protein, crude protein’ (Table 1). However, on closer inspection, these profiles tend to be very unspecific and include many publications where the dietary aspect was not in fact the primary focus of the publication. If the search profiles are limited to ‘soluble fibre/fiber’ or ‘crude protein’ the number of publications is in fact very small (5–25). However, the number of publications on ‘amino acids, etc.’ is almost 100 with an increasing trend over the years (Table 1). This may reflect increasing interest over this time period in amino acids within the human sport nutrition field (Blomstrand *et al.*, 1991; Kreider *et al.*, 1993) which then cascaded down to the equine.

Interestingly, the basic search profile loses more than 90% of the publications in both CAB and Scopus if the topic ‘fatigue’ is added, indicating that studies designed to evaluate nutritional impact on maximal performance are scarce, perhaps due to the difficulties in assessing such an impact or the fact that performance enhancing products are not allowed to be administered under Fédération Equestre Internationale or Jockey Club rules.

Time effects on publication

The basic search profile and almost all sub-search profiles executed in Cab Abstracts show the largest increase in the number of publications from the period 1981–1990 to the period 1991–2000 (Table 1). This could reflect society’s increased interest in horses over this period. In many western countries the number of horses decreased after the Second World War and reached a minimum around 1970. From then, until at least the early part of the 21st century and the recent economic downturn, the number of horses increased. In Sweden, for example, the number of horses increased more than 4-fold from 1970 to 2010 (Stark and Collman, 2012).

Two key search profiles, ‘glycogen’ and ‘insulin sensitivity’, however, do not show the largest increase from 1981 to 2000 in Cab Abstracts. In 1974, Lindholm and Piehl described the muscle biopsy technique in athletic horses which made studies looking at muscle glycogen possible and therefore led to the greatest increase in papers on glycogen from the period 1970–1980 to the period 1981–1990 (Table 1). Some of the main reasons behind the large increase in publications on ‘insulin sensitivity’ during 2001–2010 have been discussed previously. In addition, the availability of tests, adapted from work in humans, to assess insulin sensitivity in more detail (Hoffman *et al.*, 2003) enabled studies to be undertaken in this area.

Publishing journals, affiliations and authors

Using the Scopus database, information on the number of journals and authors (and their affiliation) publishing in a specific search profile can be quantified. Most publications related to nutrition of the exercising horse during the last 40 years have been published in the Equine Veterinary Journal. However, the Journal of Equine Veterinary Science and Journal of Animal Science also published many manuscripts (Table 2). American researchers, universities or institutes overall have been most productive (Table 3 and 4). David Kronfeld and Patricia Harris were individually the most prolific publishing researchers in this area during this time. It is interesting to note that most of the top ten publishing researchers during 1970–2010 are still active today.

Table 2. Top ten journals with respect to number of publications from 1970–2010 on research related to nutrition of the exercising horse¹. The results are obtained from the Scopus database (8 March 2010).

Journal	Publications
Equine Veterinary Journal Supplement	78
Equine Veterinary Journal	49
Journal of Equine Veterinary Science	39
Journal of Animal Science	39
Veterinary Clinics of North America Equine Practice	27
Veterinary Journal	22
Journal of the American Veterinary Medical Association	21
American Journal of Veterinary Research	21
Journal of Nutrition	17
Pferdeheilkunde	13

¹ Search profile: ((horse OR horses OR foal OR stallion OR mare OR equine OR yearling*) AND (exercise* OR ‘physical activit*’ OR conditioning OR training) AND (diet* OR feed* OR intake OR supplement* OR oral OR nutrition)) in article title, abstract or keywords.

Table 3. Top eleven authors with respect to number of publications from 1970-2010 on research related to nutrition of the exercising horse¹. The results are obtained from the Scopus database (8 March 2010).

Author and country	Publications
Kronfeld, D.S., USA	31
Harris, P.A., United Kingdom ²	30
Geor, R.J., USA	19
Valberg, S.J., USA	17
Lawrence, L.M., USA	14
Pagan, J.D., USA	14
Hinchcliff, K.W., USA	12
Coenen, M., Germany	11
Jansson, A., Sweden	10
Rose, R.J., Australia	10
Potter, G.D., USA	10

¹ Search profile: ((horse OR horses OR foal OR stallion OR mare OR equine OR yearling*) AND (exercise* OR 'physical activit*' OR conditioning OR training) AND (diet* OR feed* OR intake OR supplement* OR oral OR nutrition)) in article title, abstract or keywords.

² Another 7 publications can be found with author: Harris, P.

3. Have some of yesterday's expectations been fulfilled?

The following is a non-exhaustive review of a few key nutritional questions posed in 1983 and some of the subsequent published research that has tried to answer them.

Energy requirements and body condition

Apart from the conclusion that there was a general lack of information with respect to the nutrition of the athletic horse in his 1983 ICEEP review, Professor Hintz also highlighted some specific nutritional questions that he thought needed to be answered. Hintz suspected for example that the energy requirement suggested by the American National Research Council (NRC) 1973-1978 for high intensity exercise was too low (24-39 kcal/h/kg body weight (BW)). This was most likely based on his own findings in surveys of Standardbred horses in training (Ignatoff and Hintz, 1980; Nash and Hintz, 1981). His view has subsequently been confirmed in several other field studies (Glade, 1983; Southwood *et al.*, 1993; Zmija, 1991). In the NRC issues from both 1989 and 2007, the daily digestible energy (DE) requirements for 500 kg horses in training/ performing very heavy exercise is suggested to be around 34 Mcal which corresponds to 120-180% of the requirement suggested in 1973.

Table 4. Top ten affiliations with respect to number of publications from 1970-2010 on research related to nutrition of the exercising horse¹. The results are obtained from the Scopus database (8 March 2010).

Affiliation, country	Publications
Virginia Polytechnic Institute and State University, USA	26
WALTHAM Centre for Pet Nutrition, United Kingdom	23
Swedish University of Agricultural Sciences, Sweden	18 ²
Animal Health Trust, United Kingdom	17
Michigan State University, USA	16
University of Sydney; Australia	14
Texas A and M University, USA	15
Ohio State University, USA	14
University of Minnesota Twin Cities, USA	14
Utrecht University, the Netherlands	13

¹ Search profile: ((horse OR horses OR foal OR stallion OR mare OR equine OR yearling*) AND (exercise* OR 'physical activit*' OR conditioning OR training) AND (diet* OR feed* OR intake OR supplement* OR oral OR nutrition)) in article title, abstract or keywords.

² Often described by the Swedish name, another 4 publications can be found in English including an old faculty name.

Hintz also concluded that studies were needed to determine 'optimum body condition for optimal performance'. Around the time of his comment Henneke *et al.* (1983) published a more objective 9 point body condition scoring system originally described for assessing pregnant quarter horse mares but which has been used globally in numerous studies in all types of animals. However, until recently this had not been validated fully in the horse. Validation was needed however, especially with the increased focus on obesity and drivers of weight gain and weight loss (Dugdale *et al.*, 2011a,b, 2012). Recent work on body condition has concentrated more on weight gain/weight loss and the clinical consequences of obesity (Geor and Harris, 2009, 2013) rather than its effect on optimal performance in a competitive context. That body fat content is inversely related to both sprint and endurance running performance in humans has been known for more than 20 years (Barnard *et al.*, 1979; Thorland *et al.*, 1987). In 1992, Lawrence *et al.* (1992) showed that the most competitive horses in a 150-mile endurance race (finishers in the top 7) had lower body condition scores and less rump fat than non-competitive horses eliminated for metabolic causes. In elite Standardbred horses, a strong positive relation was observed between race time and estimated percentage of body fat in stallions (Kearns *et al.*, 2002). In that study, the one mile race time increased with approximately 1 second for every estimated percentage of increase in body fat. In French trotters a negative correlation between body condition scores/fat mass and V₄ has been observed (Leleu and Cotrel, 2006), which in turn has been correlated to

performance in the same population of horses (Leleu *et al.*, 2005). Despite all of this work relatively little has been published with respect to the original question posed by Hintz. In fact the relationship between body fatness, fat-free mass and running performance has not been studied in great detail in the horse, unlike man. It has, however, been stated that the optimal bodyweight of racehorses has a high correlation with performance (Lim, 1980) and that the optimal bodyweight for a racehorse has a range of only $\pm 1.5\%$. Lawrence *et al.* (1992) and Kearns *et al.* (2002) suggest that the performance reduction related to increased body condition is due to an increased weight load (approximately 20 and 30 kg in the endurance and Standardbred study, respectively). Obviously the amount of energy needed to run is related to the weight being moved and an increase in bodyweight therefore increases the cost of locomotion. It has been shown that the addition of a 10% load to horses exercising on a horizontal treadmill increased O_2 consumption by 15% (Garlinghouse and Burrill, 1999) and also that an acute reduction in bodyweight following administration of furosemide resulted in decreased anaerobic energy expenditure during brief high-intensity work, which may be the reason for any postulated improvement in performance (Hinchcliff, 1999). Gut fill also affects bodyweight and the metabolic response to exercise. A restricted hay intake (for 3 days at 1% BW) compared to *ad libitum* feeding resulted in a decrease of approximately 2% in BW and an increase in the mass specific rate of oxygen consumption during sprint exercise with a corresponding decrease in anaerobic energy expenditure (Rice *et al.*, 2001).

Fluid and electrolyte requirements

In the 1983 issue of ICEEP, Gary Carlson concluded that there 'remain substantial gaps in our knowledge' regarding fluid and electrolyte balance and that there were very few data on the response to orally administered fluids. In spite of that, he suggested that in most racing situations, the provision of free-choice trace-mineralized salt along with a balanced ration should provide all the electrolytes necessary for full performance. Twenty-seven years later, no one has challenged this statement by studying true performance during free-choice availability of sodium. However, there is at least one study indicating that Standardbred horses in training with *ad libitum* access to a salt block, will have a sodium intake below their expected requirements and a reduced plasma volume (Jansson and Dahlborn, 1999). In contrast, there are studies which suggest that free choice access might be sufficient for those in little or no work (Schryver *et al.*, 1987). There are also experimental studies which show that sodium deprivation reduces feed and water intake, plasma volume and sweating rate, plus it alters exercise associated fluid shifts and increases packed cell volume (Jansson *et al.*, 2010; Lindner *et al.*, 1983; Meyer 1987). Another study has shown that oral fluid and electrolyte administration

in connection with exercise improves the maintenance of plasma volume (Geor and McCutcheon, 1998). Altogether this suggests that providing an adequate sodium and fluid intake is important for the exercising horse and that, in contrast to what was suggested by Carlson in 1983, free choice salt provision cannot generally be recommended for high performance horses. However, the question that has been posed more recently is what exactly are the optimal recommendations for salt provision. Over the last few decades recommendations have ranged from trying to replace (through feed supplementation/oral dosing/strategic use of salt water) all or most of the sodium lost in the sweat based on changes in bodyweight or postulated energy expenditure (GfE, 1994; NRC, 2007) to concerns that such levels of salt supplementation either may not be required (Harris and Schott, 2013) or may actually result in a mild metabolic acidosis at least in animals in moderate work on low hay rations (Romanowski *et al.*, 2009). This debate promises to continue through published work and evidence based medicine over the next few decades.

Pre-race nutrition and true performance

At a workshop (Horse Nutrition Symposium) held in Uppsala (Sweden) in 1983, with participants from both universities and the horse industry, it was concluded that a future research task was to study how horses should be fed in the immediate time period (rather than in the weeks/months) before a race, with respect to glucose and glycogen in blood and muscle respectively. Whilst 20 years later there are several publications on the response of feeding prior to exercise on some plasma variables and muscle glycogen values (e.g. Duren *et al.*, 1999; Pagan and Harris, 1999) there have been no studies to the authors' knowledge on true performance (races). The lack of such studies is probably due to practical and economic constraints. Unless the effect of diet is dramatic (i.e. starved, obese or dehydrated animals), the effect on performance may be difficult to measure in real races since race results are influenced by many other variables not responsive to changes in the diet (e.g. rider, ground conditions, fitness of the horse, position in the race, etc.). The time difference between the first and last healthy horse (from different stables and on diets) finishing harness or flat races is often only a few seconds which makes minor treatment effects difficult to detect during field conditions. Evaluation of the effect of diet on race performance, therefore, needs to be done on a very large number of observations or in experimental races, which has not so far taken place. Although, a few research endurance rides have been undertaken in which different basal diets and electrolyte supplements have been fed (Hess *et al.*, 2005; Nyman *et al.*, 1996; Williams *et al.*, 2004). During the time period covered by this review high speed treadmills became popular as a means to evaluate changes in response to exercise at different intensities. It could be argued that data evaluating the effect of dietary

interventions on treadmill performance, could then be used to indicate the likely response in the field under actual race conditions. However, such studies are also very expensive and the actual effects on certain key parameters may be so small as to be masked by the normal within-subject variability intrinsic to any testing program as well as the sensitivity of the procedures employed. Such small changes, however, in an actual competition, could make the difference between winning or being placed. Alternatively, treadmill based studies could show a statistically significant effect of a compound or element on some physiological or biochemical function, which, in the field, is not manifest in any significant improvement in performance. This highlights a major issue – other than in actual competitions or races how can you assess performance (and across all the different disciplines)? Dose response and timing effects are other key factors that need to be taken into account and a lack of response may just reflect an inappropriate dose or timing interval rather than lack of any potential to have a benefit.

Regardless, there is evidence from several studies that the timing and composition of a meal consumed before exercise is likely to influence the metabolic response during competition (Harris and Graham-Thiers, 1999; Lawrence *et al.*, 1993, 1995; Pagan and Harris, 1999; Stull and Rodiek, 1995). An illustration of this can be seen in Figure 1. In particular, the hyperglycaemia and insulinaemia associated with the digestion and absorption of grain meals affects the mix of substrates utilised during a bout of exercise. Insulin is a potent inhibitor of lipolysis and fatty acid oxidation in skeletal muscle, and also promotes glucose uptake into muscle via recruitment of the transporter protein GLUT4 to the sarcolemma. Thus, hyperinsulinemia at exercise onset will suppress non-esterified fatty acid (NEFA) availability as well as lipid oxidation and increase reliance on carbohydrate stores (including plasma glucose) for energy transduction. The decrease in plasma glucose that occurs when horses are exercised 2-3 hours post a grain meal tends to be relatively

short term. However, plasma NEFA and lipid oxidation may remain lower in fed animals when compared to the fasted state throughout certain types of more long term exercise (Jose-Cunilleras *et al.*, 2002). These changes may not be relevant in the extreme sprinting racehorse, which does not rely on plasma NEFA as an energy source but obviously could be a factor in longer races.

When we look at the effect of the core diet on true performance in actual competitions there are only a small number of published studies, with a few more that show effects of nutrition on experimental exercise performance. As mentioned earlier, two studies indicated that body condition (and therefore energy intake) would affect Standardbred and endurance race performance (Kearns *et al.*, 2002; Lawrence *et al.*, 1992). In addition, Glade (1983) suggested that high crude protein (CP) intakes would increase race times in Thoroughbreds (average times to finish increased by 1 to 3 sec, depending on the race distances, for every 1000 g of CP ingested in excess of NRC recommendations of that time). Although a reduced performance could be a logical conclusion as high protein intakes cause increased heat and hydrogen production, factors that, at least theoretically, can be a challenge to exercise performance, the study by Glade had some confounding factors and further studies are needed to confirm or refute this suggested effect on performance. Graham-Thiers *et al.* (2001) showed that venous pH was higher during treadmill sprint exercise in horses fed a low protein diet. In another study comparing two forage-only diets, one providing recommended (NRC, 2007) CP intake and another providing 160% of the CP requirement, venous pH during Standardbred race-like exercise was not significantly affected by diet but estimated heat and evaporative losses at rest was higher on the high CP diet (Connysson *et al.*, 2006). Again, whether such effects will be clinically significant in practice has not been evaluated in depth and further work is needed in this area.

Figure 1. Plasma glucose concentrations before, during and after a standardised exercise test (Pagan and Harris 1999).

Diet and performance

The increased interest in fat/oil supplementation probably developed, at least in part, as a result of work in the mid-1970s which suggested that horses fed a diet containing 12% fat (9% added corn oil), and ridden 67 km over mountainous terrain for 8-10 hours, performed better and had higher blood glucose levels at the end of the ride than horses fed the control diet (3% fat) (Slade *et al.*, 1975). Two subsequent field studies showed improved speed or race times in horses on fat supplemented diets. Harkins *et al.* (1992) observed improved race times over 1,600 m following fat supplementation (12% dietary fat). However, this study could have been confounded by training effects. Oldham *et al.* (1990) observed horses, fed 0 and 10% supplementary fat in a switch back design, performing four 600 m gallops. Fat supplemented horses had higher pre-exercise muscle glycogen contents and galloped faster at a constant heart rate during the last 2 gallops. It was concluded that adapting exercising horses to a fat-supplemented diet increased muscle glycogen concentrations and appeared to improve performance above the anaerobic threshold. Lacombe *et al.* (1999) showed that reduced muscle glycogen content impairs endurance during high intensity exercise and Snow *et al.* (1981) observed that the horse with the lowest muscle glycogen content prior to an endurance race was eliminated early. However, in the study by Lacombe *et al.* (2001) the glycogen reduction (90%) was obtained by exercise. Several studies have suggested that fat/oil supplemented diets have an effect on glycogen utilization and some have suggested a sparing or enhancing glycogen storage effect (see Harris, 1997). Pagan *et al.* (2002) showed that fat supplementation (29 vs. 7% of daily DE intake) reduces the estimated level of whole-body carbohydrate utilisation. However, the effect of fat/oil supplementation on muscle glycogen content is disputed (Waller and Lindinger, 2010). Fat supplemented diets have in fact been suggested to lower or to have no effect on pre-exercise muscle glycogen content and to have no effect on glycogen utilization or post exercise muscle glycogen content (Geor, 2013). It is important, however, to note that the relative proportions of the different energy sources used in the ration of competition horses can have other effects that might influence performance, irrespective of any effect on muscle glycogen content. These include effects on behaviour, gut health in general and gastric ulceration in particular – all of which may influence performance, but cannot be covered here.

Two experimental studies have shown that intravenous administration of glucose during exercise increases the time to fatigue (Farris *et al.* 1998; Lacombe *et al.* 2001). From a practical, dietary perspective the importance of this finding is unclear. However, oral fluid administration (water or an isotonic electrolyte and glucose solution), after exercise induced sweat loss and prior to a second exercise bout at high environmental temperatures, was shown to reduce

the increase in body temperature seen during exercise. In the un-supplemented group, one of the horses was unable to complete the exercise protocol due to fatigue (Geor and McCutcheon, 1998). More recently published work has suggested that the restoration of hydration and electrolyte/acid-base balance may be more important to glycogen re-synthesis than any additional glucose administration (Waller *et al.* 2009). Fluid supplementation appears therefore to be of importance for performance in general.

Over the time period of this review a few studies were undertaken with the aim of assessing glycogen repletion patterns in horses and the effect of diets of varying composition. These have shown only a small positive effect of adding starch to the diet (Jose-Cunilleras *et al.*, 2006; Lacombe *et al.*, 2004; Snow *et al.*, 1987) on the rate of repletion. Perhaps the most striking finding has been that the rate of repletion is slow (compared to that in man), even in horses fed high amounts of glucose providing concentrates. The general opinion today, is that the rate of glycogen repletion post exercise can only be improved to a very limited extent by increasing the starch proportion of the diet (Harris *et al.*, 2013) and other strategies may need to be employed. There is, for example, one study indicating that a high protein intake might increase muscle glycogen stores (Essén-Gustavsson *et al.*, 2010) which is in accordance with observations in rats (De Araujo *et al.*, 2006; Morifuji *et al.*, 2005). The work in horses may, however, have been confounded as the NSC intake was also higher with the high protein diet.

4. Has research had any practical relevance with respect to current feeding practices?

Review

In order to try and answer this question a review of published field studies on feeding regimens in Thoroughbred and Standardbred race horses was conducted. The aim was to look for any trends or changes in the feeding regimens over time that could be linked back to published research.

In 1980, Ignatoff and Hintz published data on feed, energy and CP intake in 120 Standardbred horses in training at two American race tracks. They concluded, as mentioned above, that the NRC's (1978) estimates of energy requirements appeared to underestimate the needs of Standardbred race horses (fed 35 Mcal DE/day fed vs. 27 Mcal DE/day recommended) and that the average diet in the field provided more CP than recommended by NRC (1570 g/day vs. 585 g recommended). This finding that practically, horses were being fed more protein than recommended was supported by a number of observations. Mullen *et al.* (1979), for example, reported daily intakes of digestible CP greater than 1000 g in two year old British Thoroughbred horses and Glade (1983) observed CP intakes of 1,380 to 2,140 g/day in

American Thoroughbred race horses. In the 1989 issue of the NRC recommendations, the DE and CP requirement of horses in heavy training was in fact increased to about 33 Mcal/day and 1,300 g/day, respectively for a 500 kg horse. The latter was based on observations of nitrogen retention in horses in training (Freeman *et al.*, 1988) and nitrogen lost via sweat. A dietary digestible CP:DE ratio, sufficient for maintenance, was suggested to provide adequate amounts of protein across all workloads given that the total energy intake would be higher in working horses. Even though the NRC CP recommendation for race horses had been increased to 1,300 g/day, the mean CP intake was even higher (~2,100 g/day) in a field survey performed in 1992 in the USA (Gallagher *et al.*, 1992). The apparent disregard for the suggestion by Glade in 1983 that protein intakes should be kept moderate might be for a number of reasons, including the fact that many trainers/veterinarians may

not be aware of Glades' suggestions, or that practically his results are not valid and such high protein intakes are not detrimental in high performance animals with an adequate water supply and good ventilation, etc. It is also difficult to change traditional feeding strategies, especially those that are perceived to be of value. Alternatively, there may be some unknown advantages in providing such a level of protein intake (originally perhaps ensuring adequate essential amino acid intakes in cereal based rations).

Table 5 contains a review of field studies on feeding strategies used in Thoroughbred and Standardbred training stables globally from 1979 to 2007. It shows that throughout this period various grass and legume hays, oats and mixed grains and commercial feeds were the major feedstuffs being fed. No statistical differences ($P>0.05$) in feed allowances between Thoroughbred and Standardbred horses could be

Table 5. Forage and concentrate allowances (kg feed) and feed descriptions in Thoroughbred (TB) and Standardbred (SB) training stables in United Kingdom (UK), United States (USA), Germany, Australia, Sweden and New Zealand (NZ) from 1979 to 2007.

Breed, number and country	Forage	Description	Concentrates	Description	Author
TB, 13 horses, UK	UN ¹	luserne or carrots	9.5-10.9	oats	Mullen <i>et al.</i> , 1979
TB, UN, USA	7	hay	8	UN	Winter, 1980
SB, 121 horses, USA ²	8.05	timothy hay/grass-legume hay	6.4	oats, commercial grain mix, corn, wheat bran	Ignatoff and Hintz, 1980
SB, 232 horses, USA	8.4	timothy hay, grass-legume hays or alfalfa cubes	7.0	oats, corn and/or sweet feed	Nash and Hintz, 1981
TB, 171 horses, USA	6.4-11.8	timothy or timothy-clover hay	4.9-7.0	oats, commercial grain mixes (sweet feed)	Glade, 1983
SB, 124 horses, Germany ³	5.1±1.4	meadow hay/grass silage/maize silage	6.6±1.4	oats, complete feed	Zmija, 1991
TB, 122 horses, Germany ³	5.9±2.3	meadow hay/lucerne hay/grass	7.1±1.4	see above	Zmija, 1991
SB, 112 horses, USA	10.3	grass and/or alfalfa hay	5.8	mixed grain, oats	Gallagher <i>et al.</i> , 1992
SB, 25 horses, Australia	4.1±0.3	hay/cereal hay/lucerne	7.7±0.8	oats, maize, barley, rice-sweet feed, protein meals	Southwood <i>et al.</i> , 1993
TB, 25 horses, Australia	3.3±0.3	hay/cereal hay/lucerne	7.8±1.6	oats, maize, barley, rice-sweet feed, protein meals	Southwood <i>et al.</i> , 1993
SB, 2-180 horses, Germany ⁴	4.5±0.7	meadow hay	6.3±1.9	oats, commercial feed, corn, barley	Lindner and Gansen, 1995
TB, 644 horses, Sweden	7.8±4.1	roughage	6.1±2.7	UN	Redbo <i>et al.</i> , 1998
SB, 4597 horses, Sweden	8.4±2.9	roughage	5.4±1.8	UN	Redbo <i>et al.</i> , 1998
SB, 80 horses, Sweden ^{5,6}	8.5	haylage	4.0	UN	Jonsson and Egenvall, 2006 and pers. com.
	8.4	hay	4.0		
TB, 140 horses, NZ	>4.5	hay	5.5±0.1	commercial feeds, grain (mainly oats)	Williamson <i>et al.</i> , 2007

¹ UN = unknown.
² Mean value from two race tracks.
³ All values are converted from dry matter allowance to feed allowance using a DM content of 85%.
⁴ Data from 27 trainers.
⁵ Forage and concentrate intake unknown in 8 and 7 horses, respectively.
⁶ Haylage was offered to 51% of the horses (dry matter content unknown) and 12% had free access.

observed using this data (forage: 5.7 ± 0.4 vs. 5.8 ± 0.4 kg/day and concentrate: 7.4 ± 0.3 vs. 6.8 ± 0.4 kg/day (LS Means, analysis of variance including breed, time period and country in the model)), although single studies have suggested that Standardbreds are fed more roughage than Thoroughbreds (Southwood *et al.*, 1993) and Thoroughbreds more energy providing complementary feedstuffs (concentrates) than Standardbreds (Redbo *et al.*, 1998). A tendency ($P=0.06$) for a higher forage allowance in the years 1991–2007 compared to 1979–1990 was observed (6.8 ± 0.3 vs. 4.8 ± 0.8 kg/day) but there was no difference in the concentrate allowance (6.7 ± 0.3 vs. 7.5 ± 0.6 kg/day). However, using the same data as in Table 4 there is a trend for a reduction in the concentrate allowance over time (Figure 2). If we assume that the energy needs of Thoroughbred and Standardbred horses in training have not decreased over the years, this observation supports either that the forage allowance has increased or there has been an increase in the energy density of the feedstuffs used. An increased energy content of the forages used is possible, especially in countries where there is a trend for using haylage or silage instead of hay. Generally, haylage or silage can be harvested and stored at conditions promoting a higher nutritive value than hay, and silage has also been shown to have a higher digestibility than hay in horses in training (Muhonen *et al.*, 2009). However, another more likely explanation is that the energy density of the concentrates being fed has increased, probably due to an increased inclusion of fat/oil. The market-leading horse feed company in Sweden (Krafft AB, Falkenberg, Sweden), with business in 20 European countries, confirms that the oil content of their ordinary sport feeds has increased from 3% in 1970 to 5–6% in 2010. Today, they also have high oil feeds (7–8.5%) and are growing and selling a high-fat oat variety (9–10% fat). Similar trends have been seen in the UK with an increase in the level of oil in typical performance feeds and the launch of high oil feeds (~15% oil) in the 1990s (MARS Horsecare, personal communication). An increase in the oil content of the concentrates from 3 to 6% (in exchange for oats) will increase the metabolisable energy content by approximately 1 MJ/kg feed and together with an increased forage allowance this could explain the findings illustrated in Figure 2, that the concentrate intake has decreased over the years.

Another change that has occurred over the last few decades, partly in response to published research and the desire to restrict starch intakes (in order to reduce the risk of behavioural issues/gastric ulceration and other gastrointestinal disturbances, as well as clinical issues such as recurrent exertional rhabdomyolysis) and yet provide sufficient energy for the competition horse, has been the increasing inclusion of so called highly digestible fibres or super fibres into the ration. Sugar beet pulp is one example of such a fibre source where the response to exercise has been studied and positive effects like decreased glycogen utilisation and lowered plasma lactate concentration have

Figure 2. Daily hay and concentrate allowances reported in surveys performed in Thoroughbred and Standardbred training stables in six countries from 1979 to 2007 (for more information see Table 5). The regression line is fitted to the concentrate allowance. $Y = -0.1061x + 218.01$, $R^2 = 0.458$, $P = 0.0056$.

been suggested (Palmgren-Karlsson *et al.*, 2002). It has also been suggested that sugar beet pulp practically provides more DE to the horse than its crude fibre, protein, fat, etc. analysis would suggest (~20% more; Crandell *et al.*, 1999; Pagan, 1997). This is supported by a study by Lindberg and Palmgren-Karlsson (2001) in which total fibre digestibility increased with increasing sugar beet pulp inclusion in the diet (at the expense of oats). This could be an effect of the high content of soluble and highly fermentable plant fibre carbohydrates in sugar beet pulp, which will be accounted for when the fibre content is expressed as total fibre, but which are only partly included in the neutral detergent and crude fibre analyses.

5. Conclusions and future

Feeding of horses is an art and a science – the published science provides either the trigger for changes in the art or changes in the art drive science to provide explanations. Over the past few decades there have been significant advances in our scientific knowledge of nutritional practices that have become routine practice in the field, but others that have not cascaded down for cost, practicality or just time reasons.

Looking to the future some of the most important nutrition questions that still need to be answered would perhaps be the same as those posed in 1983, although widened in their scope. For example rather than just considering how diet may influence muscle development and repair, we should consider how diet may affect the 'quality' of the locomotor apparatus in general – very crucial given that the locomotor system appears to be the main 'limiter' to improved performance (Dyson *et al.*, 2008; Vigre *et al.*, 2002). In addition, there has been recently an increasing

use of so called 'supplements' or 'nutraceuticals' in both our own and our animal's diets. Diet is now seen not just as a means to provide the core nutrients required to support life but as a means to manage and help prevent certain clinical conditions and to prolong healthy life. This, therefore, is perhaps one of the biggest challenges going forward: to understand the potential benefits as well as the contraindications around nutrition in its broadest sense as it affects the short as well as long term health of the horses in our care. However, there is a major concern that lack of sufficient funding, especially for the fundamental pieces of information needed to underpin our nutrition advice going forward, will hamper progress in the future.

Finally, the increasing numbers of humans and their demand for food and energy also has the potential to either limit or make the traditional feedstuffs fed to horses too costly and alternatives are required. This is perhaps a pivotal point in the history of equine nutrition, and science should be leading the quest for sustainable food supplies for the horses in our care. It will be interesting to see what the next 3 decades bring.

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