Dietary Management of Endocrine Disorders in the Older Horse

Raymond J. Geor, BVSc, PhD, Diplomate ACVIM (LAIM), ACVSMR, ACVN (Honorary)

Control of ration quantity and composition is important in the management of horses with pituitary pars intermedia dysfunction (PPID) or equine metabolic syndrome (EMS) that exhibit obesity and/or hyperinsulinemia. In obesity, restriction of daily dry matter intake to 1.25% to 1.5% of current body weight will facilitate weight loss and improvement in insulin sensitivity in most horses, although the rate of response will vary between animals and more severe restriction (dry matter intake 1.0% body weight) may be needed. Access to pasture grazing should be limited during management of obesity (eg, use of grazing muzzles). Insulin resistance and hyperinsulinemia may persist after weight loss, dictating the need for long-term restriction of dietary nonstructural carbohydrates (<10–12% dry matter), including restricted pasture grazing. Author's address: Department of Large Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, 736 Wilson Road, East Lansing, MI 48824; e-mail: geor@cvm.msu.edu.

1. Introduction

The proportion of the horse population that can be regarded as "older" or "aged" appears to have increased in recent years. One retrospective study reported that in 1989 only approximately 2% of the equine referral cases at a university veterinary hospital were over 20 years of age, but this had increased to 12.5% by 1999[1] and approximately 20% by 2003.[2] In a survey of the horse population in the United States performed in 2005, 7.6% of the total population was reported to be over 20 years old.[3] A more recent study in the United Kingdom reported that 30% of horses were aged 15 years or older,[4,5] with 11% between 20 and 30 years and 2% over 30 years of age.[5] An increased willingness of owners to maintain older horses together with improved health care and nutrition may account for this apparent increase in prevalence of old horses.

The two most common endocrine disorders of horses and ponies are pituitary pars intermedia dysfunction (PPID; *aka* equine Cushing's disease) and equine metabolic syndrome (EMS).[6,7] PPID is more prevalent in aged horses; in general, affected animals are >15 years of age when clinical signs are first recognized, and the risk of PPID increases with age.[6] In EMS, the age of onset is less well defined, although a recent consensus statement indicated that the syndrome is often initially detected in animals between 5 and 15 years of age.[7] A primary clinical concern with both PPID and EMS is laminitis, hence the term *endocrinopathic laminitis*. The true prevalence of laminitis in horses with PPID is unknown, although some authors suggested that it may be as high as 50% to 80%,[8,9] whereas by definition, EMS animals are predisposed to laminitis, especially when kept at pasture.[7] The mechanisms underlying endocrinopathic laminitis have

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not been fully elucidated, but insulin resistance (IR) and hyperinsulinemia are thought to be contributing factors. IR and/or evidence of abnormal insulin dynamics is a defining feature of EMS. As well, hyperinsulinemia can be detected in PPID, and, in one study, a serum insulin concentration of >188 mU/L was a poor prognostic indicator for 1- to 2-year survival in affected horses.[10] Obesity and/or regional adiposity are additional factors that may directly or indirectly affect the risk of endocrinopathic laminitis. First, increased adiposity may underlie or exacerbate IR; second, dysregulated adipose tissue in obesity may release proinflammatory cytokines and adipokines that contribute to lamellar injury; and third, increased weight-bearing with obesity may increase strain on the digital dermal-epidermal interface. A major goal in the nutritional management of EMS and PPID, therefore, is to minimize the risk of laminitis through dietary strategies that correct obesity, enhance insulin sensitivity, and avoid exacerbations of hyperinsulinemia. Other age-related problems with nutritional implications, such as poor dentition and reduced digestive efficiency, must also be considered in the development of a feeding program for the older horse with PPID or EMS.

This report briefly reviews some of the nutritional implications of aging and then focuses on dietary management of obesity, IR, and hyperinsulinemia in the context of PPID and EMS. Note that some horses with PPID are not insulin-resistant or hyperinsulinemic; these animals can be fed according to nutritional recommendations for older horses.

2. Selected Aspects of Aging in Horses

Digestive Function

Early studies reported decreased digestive capacity in aged (>20 years of age) horses[11] with reduced apparent digestion of fiber, phosphorus, and protein. However, a subsequent study did not support these findings,[12] and it has been suggested that chronic parasitic scarring of the large intestine contributed to the apparent reduction in digestive capacity observed in earlier studies.[11] The reported decrease in fiber digestion also might have been caused in part by dental abnormalities, because dentition was not assessed in early studies of older horses. However, common dental abnormalities such as small points or hooks (<3 mm in size) do not appear to affect nutrient digestibility. On the other hand, extremely poor dentition can impair feed intake and contribute to weight loss. Severe dental problems in the older horse (eg, wave mouth, loss of several molar teeth) can make it necessary to provide a "no long-stem fiber" diet or a commercial "senior feed." Commercial senior feeds can be blended with other fiber sources (eg, alfalfa cubes, hay pellets, and soaked sugar beet pulp) to ensure adequate fiber intake.

Overall, current evidence suggests that advanced age (>20 years) alone does not significantly affect digestive efficiency in horses. Many healthy old horses that are provided adequate internal parasite control and dental care can maintain good body condition and nutritional status when they are fed rations that provide calories and nutrients in quantities that meet or exceed the recommended amounts.[13]

Body Condition

Weight loss or difficulty in maintaining adequate body condition is a common complaint in old horses. In one study, 17% of older horses were reported to lose weight within the 12-month period before examination.[14] Weight loss may arise for many reasons, such as dental abnormalities, renal and hepatic disease, or PPID. Cold climatic conditions also may contribute to weight loss; it has been suggested that old horses are less tolerant to temperature extremes. Ralston et al[15] reported that horses over 20 years of age required higher feed intake during winter months to maintain body condition when compared with younger horses kept in the same environment. Temperatures below the lower critical temperature (LCT) will increase caloric needs regardless of age.[13,16] Although the LCT may be affected by several factors (eg, acclimatization), in northern temperate climates the LCT is estimated to be −1ºC to −5ºC for horses kept outdoors. As a general guideline, caloric intake should be increased by 2.5% for each degree Celsius below the LCT. Most importantly, body condition should be monitored carefully during prolonged bouts of cold weather and the amount of feed should be adjusted according to condition loss or gain.

Pro-Inflammatory State and IR

Recent studies have reported that aged horses, like humans, show evidence of a pro-inflammatory state (ie, "inflamm-aging") that may contribute to the development of age-associated IR and other morbidities (eg, osteoarthritis).[17–19] In one study, old horses (>20 years) had higher levels of inflammatory interleukins (blood mRNA for interleukin [IL]-1, IL-15, IL-18, and tumor necrosis factor [TNFα]) and increased frequency of interferon gamma (IFNγ)- and TNFα-producing cells in the circulation when compared with horses <10 years of age.[18] Additionally, obesity appeared to exacerbate the age-related increase in inflammatory cytokine production by blood mononuclear cells.[19] Reduction of body weight and body condition in overweight old horses significantly reduced the percentage of IFNγ- and TNFα-positive lymphocytes and monocytes as well as circulating concentrations of TNFα.[19]

In humans, it is well documented that advancing age is associated with a decline in insulin action, with a 40% to 60% reduction in insulin sensitivity reported in healthy older adults (>55–60 years)

compared with younger adults.[20,21] Malinowski et al[22] observed a markedly higher insulinemic response to oral glucose administration in old Standardbred mares (>25 years of age) compared with middle-aged (~15 years) and young (~7 years) Standardbred mares, suggesting that aging in horses also results in a decline in insulin action. The insulinemic response to dietary starch and sugars is therefore likely to be more pronounced in older horses and may justify the feeding of a diet with restricted starch and sugar, regardless of EMS or PPID status.

3. Management of Obesity

As discussed elsewhere in these proceedings, not all horses with EMS are obese; however, dietary restriction, in combination with increased physical activity, is indicated for overweight or obese horses (body condition score [BCS] ≥7/9) because the obesity is a likely contributor to IR and possibly other metabolic abnormalities. Obesity and/or regional adiposity are sometimes evident in PPID although, more commonly, weight loss is reported by owners and clinical examination reveals moderate-to-thin BCS with poor muscle mass.[6]

"Eating less" and "exercising more" are key strategies to achieve a more ideal body weight (BW) and condition.[23] An evaluation of the current feeding program and housing is the starting point for any weight loss program—what feed is currently being provided (including supplementary feed, hay, pasture quality, and time allowed for grazing) and in what quantities? Proximate analysis of feeds and forage will enable estimation of true digestible energy (DE) and nutrient intake, but simply weighing the ration and using "book" or manufacturer-supplied nutrient values for each component will provide reasonable estimates of feed, energy, and nutrient intake. Maintenance energy requirements for horses typically range between 30 and 35 kcal DE per kg BW per day, for example, 15.0 to 17.5 Mcal DE/d for a 500-kg horse[13]; the low end of this range has been used to estimate maintenance needs of "easy keeper" horses or ponies with a tendency to be overweight or obese.

It is important to set realistic goals for weight loss. Consistent with anecdotal clinical observations, recent studies have demonstrated considerable between-animal variation in the rate of weight loss when obese (BCS ≥7/9) horses and ponies were subjected to dietary restriction. Specifically, weekly weight losses of 0.16% to 0.55% of BW (relative to BW at the end of the first week of restriction) were observed when animals were provided daily dry matter intake (DMI) at 1.25% of BW for 16 weeks.[24] Thus, a target weight loss of up to 0.4% to 0.5% per week is reasonable, but it is important for owners to be aware of the between-animal variation in response to identical dietary restriction. The following guidelines are recommended for the development of a weight loss program.

- The diet should be based on forage or a forage substitute. In most situations, grain and manufactured, calorie-dense feeds should be eliminated from the diet (eg, commercial sweet feeds, feeds containing added fats). Excessive feeding of other "treats" such as carrots and apples also should be curtailed.
- Early-maturity hay with a high leaf-to-stem ratio should be replaced by later-maturity hay that typically has lower energy content (no more than 2 Mcal per kg DM). When mature grass hays are fed, intake of vitamin E, copper, zinc, and other minerals may not meet requirements, and provision of a vitamin-mineral supplement is therefore recommended. Many feed companies market low calorie "ration balancer" feeds for this purpose. In addition to vitamins and minerals, these products contain sources of high-quality protein and are usually designed to be fed in small quantities (eg, 0.5 kg/d, fed as is or mixed with hay chop). Alternatively, forage-based, low-calorie feeds that contain added vitamins and minerals are now available commercially. This type of feed offers convenience and may be used as a substitute for hay or fed as a component of the ration along with hay.
- The amount of forage and feed provided will depend on the severity of obesity as well as the previous level of feeding, but in general weight loss is induced when energy intake is restricted to 70% to 75% of requirements at current body weight. On the basis of recently published work, a restriction of DMI to approximately 1.25% of BW daily results in clinically safe and effective rates of weight loss as well as improvements in indices of IR.[24,25] The author recommends initially providing no more than 1.5% of current BW in feed and forage (DM basis, noting that most forages and feeds are approximately 85–90% DM), that is, 3.7 kg for a 250-kg pony and 7.5 kg for a 500-kg horse. If there has been minimal weight loss after 6 to 8 weeks, daily DMI should be decreased to 1.25% BW for a further 6- to 8-week period. Some animals may require more severe restriction to 1.0% BW as daily DMI. The feeding of lower amounts of feed (<1.0% BW as DMI) is not recommended.
- The substitution of straw for up to 50% of the hay ration may be considered. This is one way to lower the energy density diet and maintain a reasonable level of DMI. On average, the energy content of straw is lower than that of grass hay. The straw should be clean and contain minimal cereal head; thoroughly shaking the straw before feeding will remove any loose cereal.
- The ration should be divided into three or four feedings per day. Strategies to prolong feed

intake time should also be considered, such as the use of hay nets with multiple small holes.
- Access to pasture grazing should be restricted. It is preferable to maintain turnout, either in a large dry lot or at pasture with the horse wearing a "grazing" muzzle that restricts but does not eliminate grazing. In a recent study of ponies provided 3 hours of access to autumn pasture, the application of a grazing muzzle reduced DMI by approximately 80% when compared with no muzzle.[26] Turnout into a large dry lot is another way to restrict grazing while still encouraging exercise. It should be noted that simply restricting the time allowed for grazing may not be an effective strategy for weight loss. Ponies have been observed to consume up to 1% of BW as DM within 3 hours of pasture turnout.[26]
- Make all dietary changes gradually, and avoid prolonged periods of feed withholding. Abrupt starvation in obese ponies, donkeys, and miniature horses (especially pregnant animals) carries the risk of hyperlipemia and is not recommended. In addition, severe dietary restriction (daily DMI <1.0% BW) may increase the risk of gastric ulceration and stereotypic behaviors.
- Develop, and continually update, an appropriate weight maintenance program once the target weight and body condition have been achieved. This will include monthly assessment of BW and BCS to ensure that the feeding program is appropriate to the current level of physical activity and other environmental influences on energy requirements (eg, ambient conditions).

The BCS system is useful for estimation of subcutaneous fat mass in equids but may not be a sensitive indicator of weight loss, at least during the early phase. In two recent studies, changes in BCS were poorly correlated with changes in BW during weight loss programs.[24,27] On the other hand, significant decreases in heart and belly (at the level of the umbilicus) girth measurements as well as the depth of the retroperitoneal (ventro-abdominal) fat depot was detected during weight loss. It is therefore recommended that in addition to BCS, heart and belly girth (and, if feasible, ultrasound fat depth) be recorded. These measures should be recorded at monthly intervals during the weight loss program and every 6 to 8 weeks during weight maintenance.

4. Countering IR/Hyperinsulinemia

In obese animals, weight loss can be accompanied by improvement in insulin sensitivity.[24,25] However, IR and exaggerated insulin responses to consumption of feeds rich in nonstructural carbohydrates (NSC; starches, sugars, and/or fructans) can persist after weight loss. Furthermore, some animals at initial diagnosis of EMS or PPID are not obese but do have evidence of IR and abnormal insulin dynamics. Marked postprandial increases in circulating insulin are a concern because of the potential for high insulin concentrations to cause laminitis.[28,29] Restriction in dietary NSC is therefore important in the long-term management of EMS and PPID animals with IR. Key approaches are listed below.

(1) No grain or sweet feeds (ie, feedstuffs rich in starch and/or sugars). The starch content of oats, barley, and corn are approximately 45% to 50%, 60% to 65%, and 65% to 70% of DM, respectively. Sweet feeds contain grains plus molasses, and the NSC content of some of these feeds can exceed 40% to 45% DM. Provision of these feeds to insulin-resistant equids is likely to exacerbate hyperinsulinemia.

(2) Restricted or no access to pasture. At certain times of the year, pasture forage NSC content may approach 30% DM or more. In susceptible animals, ingestion of this NSC-rich forage will increase risk for development of laminitis (even with moderate NSC content, if there is a plentiful supply of grass, overall NSC intake over a relatively short period of time can be quite high).

(3) A diet based on grass hay (or hay substitute) with low (<10–12% DM) NSC content.

(4) Feeding for maintenance of BW and BCS.

Weight gain will typically exacerbate IR, so it is important to avoid overfeeding. Regular evaluation of BW and/or BCS is the best way to assess the adequacy or otherwise of energy provision.

The core diet for IR animals should be based on grass hay. Mature hay is preferred because of lower digestible energy and NSC content when compared with less mature hay. Ideally, the results of proximate nutrient analysis, including direct measurement of starch and sugars (ie, NSC), should be reviewed before selection of the hay. An NSC content of less than 10% to 12% DM is currently recommended. In the absence of data on hay NSC content, a common recommendation is to soak the hay in water for 30 to 60 minutes before feeding to leach water-soluble carbohydrates (WSC; sugars and fructans). However, recent work has suggested that under typical management conditions, this practice is variable in outcome and may not result in substantial change in the WSC content of some hays.[30] Soaking hay should therefore be used as an adjunct to choosing low-NSC–containing hay. Although sufficient scientific evidence is not currently available to determine whether the 10% to 12% DM upper limit of NSC content is optimal, clinical experience suggests that this advice is reasonable. Additionally, in a small study of healthy Quarter horses versus horses affected by polysaccharide storage myopathy, hay with an NSC content of <10.8% did not affect glycemic and insulinemic responses, whereas a moderate increase in serum insulin concentration was observed after consumption of hay with NSC >16%.[31]

A ration of mostly hay may not meet energy requirements, particularly for PPID animals in which

weight gain is desired or for insulin-resistant horses that are in work. In these situations, the goal is to provide additional calories without exacerbating hyperinsulinemia/insulinemic responses to feeding. One approach is to add nonmolassed sugar beet pulp to the ration, for example, 0.5 to 1.0 kg/d. Beet pulp is rich in highly digestible fibers, provides more DE when compared with most hay types, and does not elicit a marked glycemic or insulinemic response unless molasses is added at the time of processing. Beet pulp shreds should be soaked in a volume of water 3- to 4-fold higher than that of the beet pulp before feeding. The energy density of the ration also can be increased by feeding vegetable oil mixed with sugar beet pulp shreds or with hay cubes that have been softened in water. Corn and soy oils are commonly used in horse diets but must be fresh, nonrancid, and introduced gradually to the ration. One standard cup (approximately 225 mL or 210 g) of vegetable oil provides 1.7 Mcal of digestible energy. Depending on energy requirements, one-half to 1 cup of oil can be fed once or twice daily (up to a maximum of ~1 mL oil/kg BW). Smaller amounts (eg, one-fourth cup once daily) should initially be fed, with a gradual increase over a 7- to 10-day period. Stabilized rice bran (~20% fat) is another option for increasing the energy density of the diet, provided that the calcium:phosphorus ratio of the final ration is considered. A number of commercial feeds are available that contain relatively low starch and sugar content (<20–25% NSC, DM basis) and can be used to add calories to the diet of the lean EMS or PPID horse.

Pasture Access

Pasture access is another consideration in the management of the insulin-resistant, hyperinsulinemic horse. In general, most affected horses can be allowed access to pasture after resolution of the most recent bout of laminitis, but some restriction of grass intake (ie, application of a grazing muzzle) is usually recommended, especially during periods when pasture forage NSC is likely to be high—during spring and early summer; after summer or fall rains that cause the grass to turn green; and when pastures have been subjected to drought or frost stress, all conditions that favor fructan accumulation.

Dietary Supplements

A number of supplements are marketed with claims for improved insulin sensitivity or reduced risk of laminitis, but evidence of efficacy is scant.[32] Many products contain magnesium, chromium, and/or cinnamon. Chromium is thought to potentiate insulin action through activation of insulin receptor kinase and/or inhibition of insulin receptor tyrosine phosphatase.[33] However, the feeding of a supplement containing 5 mg/d chromium, 8.8 g/d magnesium, and other unspecified nutraceuticals for 16 weeks did not alter morphometric measurements, resting serum glucose and insulin concentrations, or insulin sensitivity in obese horses with a history of laminitis.[34] Daily supplementation with 45 g short-chain fructo-oligosaccharide (scFOS) for 6 weeks resulted in a modest improvement in insulin sensitivity and a decrease in resting serum insulin concentrations of obese Arabian horses fed a 50:50 grass hay and sweet feed diet.[35] In EMS horses undergoing dietary restriction (1.25% of body weight as DMI); however, loss of body weight and improvement in insulin sensitivity were unaffected by the addition of scFOS to the diet.[24] More work is needed to evaluate the effects of various nutraceutical supplements marketed for the management of EMS or PPID. Nonetheless, owners should be encouraged to focus on caloric restriction, forage NSC, and so forth rather than the feeding of supplements with unproven efficacy in the management of IR.

References

1. Brosnahan MM, Paradis MR. Demographic and clinical characteristics of geriatric horses: 467 cases (1989–1999). *J Am Vet Med Assoc* 2003;223:93–98.
2. Brosnahan MM, Paradis MR. Assessment of clinical characteristics, management practices and activities of geriatric horses. *J Am Vet Med Assoc* 2003;223:99–103.
3. National Animal Health Monitoring System. 2006. Equine 2005, Part II: Changes in the US Equine industry, 1998–2005. USDA-APHIS-VS, Fort Collins, Colorado.
4. Ireland JL, Clegg PD, McGowan CM, et al. A cross sectional study of geriatric horses in the United Kingdom, part 1: demographics and management practices. *Equine Vet J* 2011;43:30–36.
5. Hotchkiss JW, Reid SWJ, Christley RM. A survey of horse owners in Great Britain regarding horses in their care, part 1: horse demographic characteristics and management. *Equine Vet J* 2007;39:294–300.
6. McFarlane D. Equine pituitary pars intermedia dysfunction. *Vet Clin North Am Equine Pract* 2011;27:93–113.
7. Frank N, Geor RJ, Bailey SR, et al. Equine metabolic syndrome. *J Vet Int Med* 2010;24:467–475.
8. Johnson PJ, Slight SH, Ganjam VK, et al. Glucocorticoids and laminitis in the horse. *Vet Clin North Am Equine Pract* 2002;18:219–236.
9. Donaldson MT, Jorgensen AJ, Beech J. Evaluation of suspected pituitary pars intermedia dysfunction in horses with laminitis. *J Am Vet Med Assoc* 2004;224:129–135.
10. McGowan CM, Frist R, Pfeiffer DU, et al. Serum insulin concentrations in horses with equine Cushing's syndrome: response to a cortisol inhibitor and prognostic value. *Equine Vet J* 2004;36:295–298.
11. Ralston SL, Squires EL, Nockels CF. Digestion in the aged horse. *J Equine Vet Sci* 1989;9:203–205.
12. Ralston SL, Malinowski K, Christensen R. Digestion in aged horses: revisited. *J Equine Vet Sci* 2001;21:310–311.
13. Anon. *National Research Council Nutrient Requirements of Horses.* 6th edition. Washington, DC: National Academy Press; 2007.
14. Ireland JL, Clegg PD, McGowan CM, et al. A cross sectional study of geriatric horses in the United Kingdom, part 2: health care and disease. *Equine Vet J* 2011;43:37–44.
15. Ralston SL, Nockels CF, Squires EL. Differences in diagnostic test results and haematological data between young and aged horses. *Am J Vet Res* 1988;49:1387–1392.

16. Cymbaluk NF, Christison GI. Environmental effects on thermoregulation and nutrition of horses. *Vet Clin North Am Equine Pract* 1990;6:355–372.
17. McFarlane D, Holbrook TC. Cytokine dysregulation in aged horses and horses with pituitary pars intermedia dysfunction. *J Vet Int Med* 2008;22:436–442.
18. Adams AA, Breathnach CC, Katepalli MP, et al. Advanced age in horses affects divisional history of T cells and inflammatory cytokine production. *Mech Ageing Dev* 2008;129:656–664.
19. Adams AA, Katepall MP, Kohler K, et al. Effect of body condition, bodyweight and adiposity on inflammatory cytokine responses in old horses. *Vet Immun Immunopath* 2009; 127:286–294.
20. DeFronzo R. Glucose intolerance with aging. *Diabetes Care* 1981;4:493–501.
21. Chen M, Bergman R, Porte D Jr. Insulin resistance and beta-cell function in aging: the importance of dietary carbohydrates. *J Clin Endocrinol Metab* 1988;60:13–20.
22. Malinowski K, Betros CL, Flora L, et al. Effect of training on age-related changes in plasma insulin and glucose. *Equine Vet J* 2002;34(Suppl):147–153.
23. Geor RJ, Harris PA. Dietary management of obesity and insulin resistance: countering risk of laminitis. *Vet Clin North Am Equine Pract* 2009;25:51–65.
24. Argo CM, Curtis GC, Grove-White D, et al. Weight loss resistance: a further consideration for the nutritional management of obese equidae. *Vet J* 2012;194:179–188.
25. McGowan CM, Dugdale AH, Pinchbeck GL, et al. Dietary restriction in combination with a nutraceutical supplement for the management of equine metabolic syndrome in horses. *Vet J* 2013;196:153–159.
26. Longland AC, Barfoot C, Harris PA. The effect of wearing a grazing muzzle vs not wearing a grazing muzzle on pasture dry matter intake by ponies. *J Equine Vet Sci* 2011;31:282–283.
27. Dugdale AHA, Curtis GC, Cripps P, et al. Effect of dietary restriction on body condition, composition and welfare of overweight and obese pony mares. *Equine Vet J* 2010;42: 600–610.
28. Asplin KE, Sillence MN, Pollitt CC, et al. Induction of laminitis by prolonged hyperinsulinemia in clinically normal horses. *Vet J* 2007;174:530–535.
29. de Laat MA, McGowan CM, Sillence MN, et al. Equine laminitis: induced by 48 h hyperinsulinemia in Standardbred horses. *Equine Vet J* 2010;42:129–135.
30. Longland AC, Barfoot C, Harris PA. Effects of soaking on the water-soluble carbohydrate and crude protein content of hay. *Vet Rec* 2011;168:618–622.
31. Borgia L, Valberg S, McCue M, et al. Glycaemic and insulinaemic responses of feeding hay with different non-structural carbohydrate content in control and polysaccharide storage myopathy-affected horses. *J Anim Phys Anim Nutr* 2011; 95:798–807.
32. Tinworth KD, Harris PA, Sillence MN, et al. Potential treatments for insulin resistance in the horse: a comparative multi-species review. *Vet J* 2010;186:282–291.
33. Lau FC, Bagchi M. Sen CK, et al. Nutrigenomic basis of beneficial effects of chromium(III) on obesity and diabetes. *Mol Cell Biochem* 2008;317:1–10.
34. Chameroy KA, Frank N, Elliott SB, et al. Effects of a supplement containing chromium and magnesium on morphometric measurements, resting glucose, insulin concentrations, and insulin sensitivity in laminitic obese horses. *Equine Vet J* 2011;43:494–499.
35. Respondek F, Myers K, Smith TL, et al. Dietary supplementation with short-chain fructo-oligosaccharides improves insulin sensitivity in obese horses. *J Anim Sci* 2011;89:77–83.