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Review: Could *Molinia caerulea* Be an Alternative Forage Feed for Horses?

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ABSTRACT

Molinia caerulea (Molinia) is a native plant species that dominates large tracts of the UK uplands, with detrimental impacts on floristic diversity and related habitat value. Harvesting Molinia supports biodiversity restoration and conservation, yet there is little incentive for farmers to manage this increasingly dominant species. Our aim was to evaluate Molinia's potential as an alternative forage for feeding horses based on published nutrient analysis data. Though research is limited, chemical analysis suggests Molinia is typically comprised of high energy, low water-soluble carbohydrate (WSC), but is high in fibre, resulting in poor digestibility and low metabolisable energy provision in cattle. However, low WSC, high fibre diets are favoured for feeding domestic horses where inappropriate nutrition is typically associated with obesity and metabolic disorders. Ryegrass hay, commonly fed to horses, typically has a WSC concentration of around 180 g/kg DM, which exceeds recommended thresholds and is far greater than reported for Molinia (50–70 g/kg DM). We recommend further research to understand how this plant is degraded in the equine hindgut, using in vitro gas simulation and production experiments, to explore how Molinia is degraded in the hindgut and the extent to which it could contribute to or affect gastrointestinal health, prior to in vivo studies. Were the potential of Molinia as an equine feed proven, three-fold benefits would result: a new source of low WSC forage suitable for domestic horses susceptible to weight-related metabolic disorders; a new income stream for farmers in marginal areas; improved upland grassland biodiversity.

1 | Introduction

Molinia caerulea (L.) Moench (purple moor-grass; hereafter Molinia) is a common European and UK native plant species that grows on a variety of soil types, and is commonly found in open areas of moorland, heaths, bogs, mountain grassland and peatlands (Taylor et al. 2001). Although some benefit to Molinia coverage of peatlands is apparent in reducing greenhouse gas emissions, the species is frequently dominant over large upland areas, often at the expense of other plants (Taylor et al. 2001), including peat-forming *Sphagnum* mosses (Glaves 2016). The increase in Molinia cover in upland ecosystems has been of growing concern for many years due to its detrimental impact on habitats of international conservation concern (Lunt et al. 2021). Furthermore, the relatively low acceptability (Chambers et al. 1999) and nutritional value (Fraser et al. 2013) of Molinia-dominated swards for grazing livestock mean that as stock numbers have declined, such grasslands have frequently become under grazed or abandoned across the UK and EU, thereby exacerbating habitat loss (Hermoso et al. 2018; Keenleyside and Tucker 2010).

In the UK, farm incomes from land management activities and agriculture are considered inadequate in relation to expenditure,

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especially in upland regions (Holden et al. 2007), and with agricultural support schemes changing this is a time of considerable uncertainty for producers in less favoured areas and related rural communities. Studies have demonstrated that horses readily graze Molinia (Lunt et al. 2021; Putman et al. 1991), and chemical analyses indicate that while Molinia may have limited nutritional value for livestock its carbohydrate profile may be well suited to equids; fundamentally, high fibre and low starch/sugar (Hoffman 2013). Importantly, should Molinia prove to be a high fibre, low sugar forage, it offers a valuable feed, particularly appropriate for horses for whom weight management is critical, for example, to manage Cushing's disease or to prevent and/or manage equine metabolic syndrome (EMS) which may give rise to laminitis. The aetiology of EMS is complex and multifactorial but includes when an overabundance and persistence of fat cells or adipose tissue produce high levels of adipokines. As a result of the abnormal adipokine production, the horse's normal response to the hormone insulin is disrupted (Radin et al. 2009). Hyperinsulinaemia leads to the horse being unable to properly metabolise dietary non-structural carbohydrates, including starches and sugars, triggering the laminitis pathology in susceptible individuals (Karikoski et al. 2015). Overweight British native ponies are frequently affected by EMS with prevalence reported of up to 23% for these breeds. While Welsh Section A ponies (a Welsh Mountain Pony, less than 121.9 cm tall) appear to have a particularly high risk (Carslake et al. 2021), all breeds and types can be affected (Pollard et al. 2019). One in 10 horses or ponies in the UK develop an episode of laminitis every year, and again UK native ponies are at particular risk (Pollard et al. 2019). To manage equine metabolic conditions, feeding low-energy roughage alternatives has been investigated, impelling discovery and validation of candidate forages. A range of UK native ponies kept on pasture and fed a 50:50 hay: straw mix induced a significant weight loss over the four-month study period (Dosi et al. 2020). However, straw is a product of arable systems that have negative impacts on biodiversity, and straw prices in the UK have risen steeply in recent years due to market forces. Harvesting Molinia as an equine feed could potentially offer two-fold benefits: (i) a valuable forage alternative to high sugar pasture or conserved grass, suitable for feeding horses and ponies susceptible to EMS and/or laminitis; and (ii) an opportunity for upland producers to diversify into an enterprise that complements existing farm activities while providing crucial additional revenue. The aim of this review is to explore the potential of Molinia as a feed for horses in greater detail.

2 | Characteristics of *Molinia caerulea* Growth in the UK

Molinia is a perennial grass that forms either dense circular tussocks or extensive swards (Taylor et al. 2001) (Figure 1). It is widespread on a variety of habitats, including but not limited to moors, heaths, bogs, fens and mountain grasslands (Taylor et al. 2001). At the end of the last century, the area dominated by Molinia in Great Britain was estimated to be around 600,000 ha, which constituted around 10% of the uplands (Grant et al. 1996). The presence of plant species has been mapped over decades by the Botanical Society of Britain & Ireland and a Molinia distribution map demonstrates the widespread growth of the species across the UK (Figure 2). Data collected in 2008 to 2009 as part



FIGURE 1 | Photograph of *Molinia caerulea* showing its distinctive tussock-forming growth habit.

of a national sample survey of the condition of English blanket bog provided valuable information on Molinia frequency, cover, and distribution in the uplands (Critchley 2011; Glaves 2016). It was estimated that approximately 27,000 ha of upland habitats (i.e., blanket bog, flushes, fens, swamps, and wet heath) in England have Molinia cover of ≥ 75% and the total area with ≥ 50% cover may be up to 44,000 ha (Critchley 2011; reviewed in Glaves 2016). Such over-dominance is detrimental to vegetation diversity, with the number and cover percentage of habitat indicator species decreasing significantly with the increase of Molinia cover (Critchley 2011; reviewed in Glaves 2016).

The increase in Molinia cover in the uplands of England, Wales and in parts of Scotland has been at the expense of heather moorlands (Chambers et al. 1979) as a result of human perturbation such as heavy grazing of livestock and muirburning, as well as atmospheric pollution (Grant et al. 1963; Thompson et al. 2015; Yeo and Blackstock 2002). More recently, destocking of these areas and related under grazing and/or agricultural abandonment has led to even greater dominance and related habitat loss. Molinia is therefore considered a major threat to moorland conservation (Marrs et al. 2004). Dramatic loss of heathland ecosystems is evident across Europe, including in the UK (Webb 1998). In the Peak District, England, 36% loss of heather moorlands has been reported since the early 20th century (Anderson and Yalden 1981). Consequently, conservation schemes aiming to reduce Molinia prominence and to encourage the development of

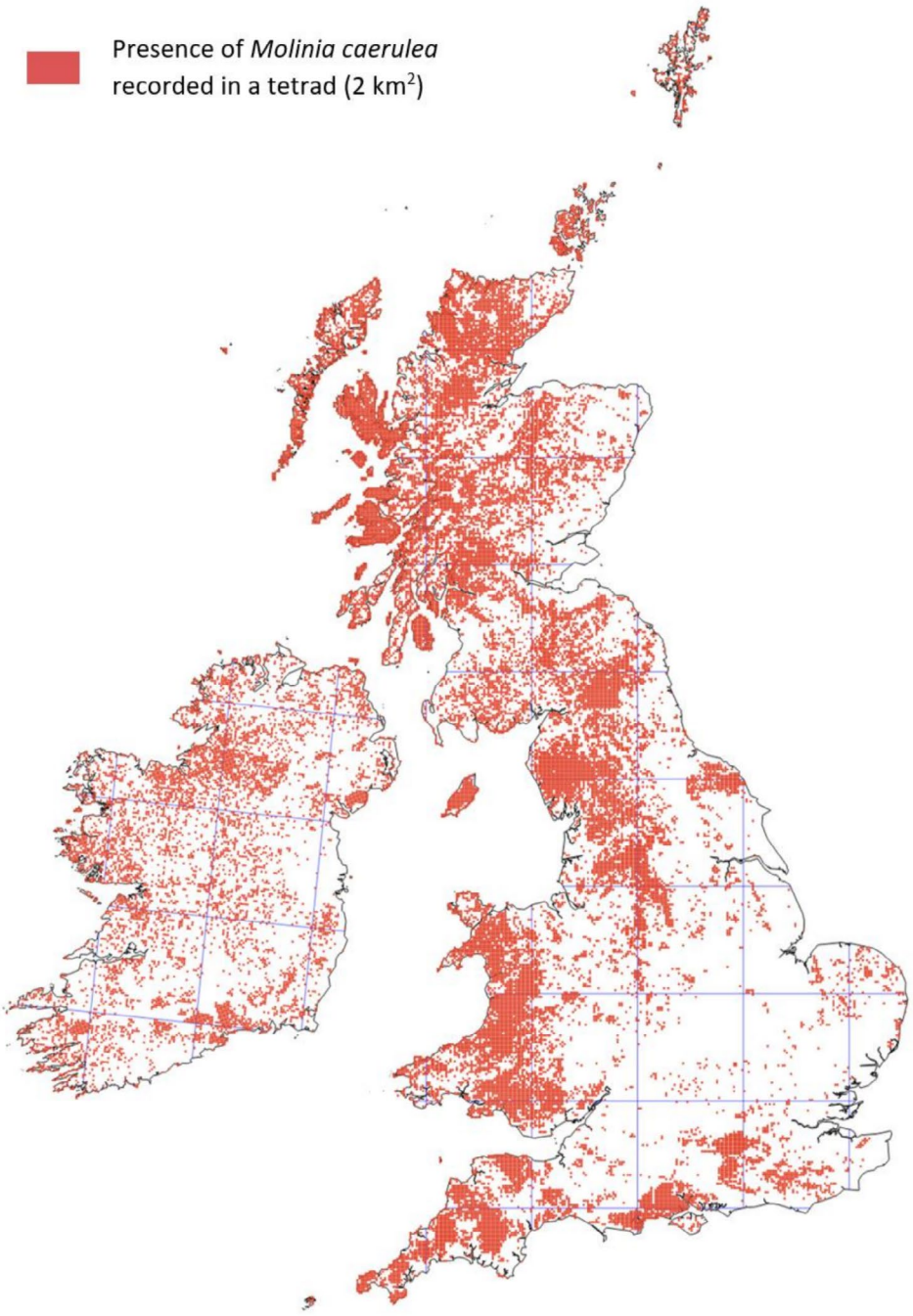


FIGURE 2 | Presence and distribution of *Molinia caerulea* in the British Isles (*Molinia caerulea Distribution Map* (*BSBI*), n.d.)

dwarf shrub vegetation have been in place for some time (Marrs et al. 2004; Todd et al. 2000).

3 | Methods for Controlling Molinia Dominance

Continued management of upland habitats affected by Molinia is needed as the species has been shown to re-establish even after prolonged periods of disturbance (Sansen and Koedam 1996). Several methods for controlling Molinia encroachment, including grazing, cutting, burning, and application of herbicide, have been applied with varying degrees of success (Fraser et al. 2011; Grant et al. 1963; Grant et al. 1996; Marrs et al. 2004; Milligan et al. 2004; Rook et al. 2004; Todd et al. 2000).

Traditional management of upland moors includes free-range grazing of livestock, most commonly sheep and periodic muirburning (Webb 1998). Muirburning is the practice of burning the dead vegetation on moorlands to encourage new growth for grazing (Grant et al. 1963; Holland et al. 2022). However, burning has been shown to significantly increase Molinia dominance in heathland communities (Marrs et al. 2004; Ross et al. 2003) and is one of the main underlying causes of Molinia encroachment (Grant et al. 1963). Grazing cattle have been shown to be beneficial in controlling Molinia encroachment (Critchley et al. 2008; Fraser et al. 2011) and enhancing moorland foliage biodiversity (Marrs et al. 2004; Milligan et al. 2004; Rook et al. 2004). This is because cattle are less selective grazers than sheep and will more quickly switch to consuming Molinia as the availability of

preferred grass species (e.g., *Agrostis* spp., *Festuca* spp.) declines. In contrast, sheep select individual leaves of Molinia rather than grazing into tussocks, and Marrs et al. (2004) reported negligible effects on Molinia sward height and cover after 6 years of summer grazing with sheep. Therefore, the efficacy of grazing as a control method can be inconsistent (Critchley et al. 2008; Fraser et al. 2011; Marrs et al. 2004; Milligan et al. 2004; Todd et al. 2000). Marked variability has been noted in the reduction of Molinia in response to grazing between apparently similar vegetation types on different sites and between different years (Marrs et al. 2004; Milligan et al. 2004; Todd et al. 2000). Moreover, while grazing cattle can slow Molinia encroachment, the reduction of Molinia cover achieved with grazing treatments is unlikely to be enough to reverse the long-term increase in dominance (Fraser et al. 2011). Horses remove more foliage per unit body weight than cattle (Menard et al. 2002), although the considerable variation in the average weight of different native pony breeds needs to be accounted for. However, where sufficient numbers are used, even light breeds of pony may be considered a valuable tool for plant management (Menard et al. 2002). Recently, Lunt et al. (2021) demonstrated that grazing native ponies on Molinia dominated upland habitats was efficient in reducing Molinia cover, and native Welsh ponies have been observed as willingly consuming Molinia even when this is not the dominant grass species (*M.D. Fraser, pers. obs.*).

Cutting has been proven to be beneficial in controlling Molinia (Grant et al. 1996; Milligan et al. 2004), and government agencies and conservation charities across the UK are resorting to mechanical removal of vegetation, including for example, using a tractor with a flail mower or a remote-control cutting machine (Henry 2019). Once cut, the foliage should be removed (Taylor et al. 2001). Both cutting and removal of Molinia are costly however (Taylor et al. 2001), limiting both the viability of on-farm management and the extent of cutting that can be afforded by conservation groups. This highlights the considerable social and environmental benefits that would be associated with identifying applications for cut Molinia that generate revenue. One such application proposed is the sale of conserved Molinia to horse owners for use in more managed (yard/livery) settings. Upland farmers in mid Wales had a tradition of preparing hay from Molinia-dominated grasslands (A. Davies, pers. com), demonstrating the practical feasibility of this concept, but this practice has largely died out due to declining livestock numbers and unpredictable weather. Haylage could be a more versatile option for conservation of Molinia as a forage, though the use of a silage additive would be recommended to offset the low WSC concentrations. Given the comparatively short growing season of Molinia a single cut per annum would optimise yield and environmental benefits.

4 | Molinia as an Animal Feed

Herbaceous plant species are the main components in the diets of cattle, sheep and horses free ranging on complex indigenous vegetation communities incorporating a range of plant types (Ferreira et al. 2013; Grant et al. 1985; Putman et al. 1987). The larger body size and digestive capacity of cattle compared to sheep lead them generally to prioritize maintaining the quantity (rather than the quality) of forage consumed and they will switch to grazing Molinia more readily than sheep (Fraser et al. 2011; Grant et al. 1985). While few grazing studies have incorporated equids, a comparison of the diets of free-ranging cattle and ponies feeding on various natural and improved grasslands found the diet of the cattle to scarcely include Molinia, whereas Molinia was present in the diet of the ponies year-round and made up nearly a quarter of the diet in summer (Putman et al. 1987). Thus, it can be inferred that equids are more willing to consume Molinia than cattle, and sheep. Nonetheless, dedicated feeding trials to determine whether voluntary intakes on conserved Molinia match those of common forages currently fed (hay, haylage, silage and alfalfa) are recommended.

Nutritional evaluations of Molinia to date have only considered its value as a feed for sheep and cattle (Fraser, Theobald, et al. 2009; Fraser et al. 2011; Fraser et al. 2013). Stock performance levels that can be achieved by grazing sheep and cattle on Molinia-dominated semi-natural grasslands have been quantified (Fraser, Theobald, et al. 2009; Fraser et al. 2011; Fraser et al. 2013), and while the growth rates reached by grazing steers on Molinia-dominated swards were significantly lower than those on improved permanent pasture, the animals still gained 800 g/d (Fraser, Davies, et al. 2009). The Molinia pasture in question was a biodiverse sward designated a Site of Special Scientific Interest classified as being in favourable condition as a habitat, however. In a separate experiment on rank, under-grazed Molinia, the performance of yearling heifers was inconsistent, achieving acceptable levels of weight gain during some grazing periods but losing weight during others (Fraser et al. 2011). During the same experiment, consistently positive weight changes occurred in sheep, largely due to the lower nutritive requirements of non-lactating ewes compared to growing cattle (Fraser et al. 2011). Taken together, these results reflect the lower nutritive value of Molinia-dominated swards, especially when underutilised, and the undesirable reduced performance of grazing livestock.

Chemical analyses conducted on Molinia samples taken over the course of four growing seasons (Table 1; Fraser et al. 2013) reveal low WSC concentrations and high fibre concentrations, resulting in a relatively low in vitro digestible organic matter in the dry matter (DOMD) (460–699 g/kg DM). In separate studies, bulked samples of Molinia from different locations have been reported as having WSC concentrations of between 39 and 91 g/kg DM, and crude protein concentrations of between 106 and 169 g/kg DM (Fraser, Theobald, et al. 2009; Moorby et al. 2015). These findings suggest further work is required to explore site-to-site variation in the nutritional value of Molinia, and the extent to which this is influenced by abiotic factors such as soil chemistry, soil moisture, altitude and weather patterns. To the authors' knowledge, no specific measures of lignin content have been conducted for Molinia, yet the direct measures of DOMD in fresh matter (Table 1) suggest that in comparison to typical wheat straw and Timothy hay (453 g/kg DM digestibility), Molinia is likely more digestible, notwithstanding harvest conditions (Table 1). Further investigations into seasonal variation in the nutritional value of Molinia are also required. Molinia is the UK's only deciduous grass, with the plant senescing completely in the winter months (Taylor et al. 2001). An exploratory study collected material from Molinia plants across the same upland location at monthly intervals during the growing season

TABLE 1 | Mean chemical composition of season's growth of *Molinia caerulea* within Molinia-dominated semi-natural rough grazing from years 2005–2008, adapted from Fraser et al. (2013). Data for straw and hay adapted from http://Feedipedia.org; industry standard animal feed resource information system.

	DM	CP	WSC	NDF	DOMD
	(g/kg FM)	(g/kg DM)	(g/kg DM)	(g/kg DM)	(g/kg DM)
2005	371	126	69	675	699
2006	373	116	50	695	460
2007	391	120	56	717	482
2008	330	124	50	722	493
Mean	366.3	121.5	56.3	702.3	533.5
Wheat straw	910	420	ND	775	ND
Timothy hay	880	91	75	654	ND but horse DM digestibility 453

Abbreviations: CP, crude protein; DM, dry matter; DOMD, digestible organic matter contained in the dry matter; FM, fresh matter; ND, no data; NDF, neutral detergent fibre; WSC, water-soluble carbohydrates.

of 2009 (S. Doran & J. Corton, *unpublished data*). The herbage was cut at a height equivalent to that used for mechanical harvesting. The bulked material was analysed for chemical composition using standard methodologies as described in Fraser et al. (2013). Concentrations of CP and WSC increased sharply in spring, before peaking in June (at 167 g/kg DM) and August (at 89 g/kg DM), respectively (Figure 3). Conversely, concentrations of neutral-detergent and acid-detergent fibre declined until mid-summer, before increasing again.

While dry matter degradability of Molinia in ruminants has been previously estimated in vitro (Fraser, Theobald, et al. 2009; Fraser et al. 2013; Moorby et al. 2015), the data do not directly translate to fermentability in the horse's hindgut. Horses have a lower digestive efficiency of fibre compared to ruminants (Cymbaluk 1990). However, owing to their high food intake, equids can extract more nutrients per day than bovids (Duncan et al. 1990) from low-quality forages such as highly fibrous graminoids (e.g., Molinia) (Celaya et al. 2011). Therefore, it can be hypothesised that the digestible energy that is, the amount of energy in the feed that horses are able to utilise, and the amount of extracted nutrients may be sufficiently high for horses on a Molinia-based diet.

Taken together the research on Molinia as an animal feed is limited but, in terms of ruminants, evidence to date suggests it is generally unsuitable as a forage for productive stock. However, there is some indication that Molinia could be an appropriate forage for horses.

5 | Nutrient Requirements for Horses

Horses have gastrointestinal tracts that are well adapted to digesting high-fibre feedstuffs and deriving significant nutrition from them through microbial fermentation, primarily in the cecum and colon (Harris and Geor 2014; Ralston 2007). The large caecum and colon of equids are inhabited by a diverse microbial community, including bacteria, protozoa and fungi (Al Jassim and Andrews 2009; Ang et al. 2022). Maintenance of the complex microbiome and its undisturbed fermentative function is crucial for the health and well-being of the horse (Ang et al. 2022; Dougal et al. 2013; Garber et al. 2018). Forage-based, high-fibre diets favour slow fermentation and the production of acetate, propionate, and butyrate (Hoffman 2013). However, rapid fermentation of non-structural carbohydrates facilitates the production of lactate thereby lowering the pH in the caecum and colon, depressing the cellulolytic bacteria, increasing the concentration of lactate-utilising bacteria (Hoffman 2013; Julliand et al. 2001) and increasing the risk of diarrhoea, colic, and laminitis. Consequently, starch intake thresholds of <1 g/kg BW per meal, <2 g/kg BW per day (Goer and Harris 2013; Hoffman 2013) or rations with $<10\%$ non-structural carbohydrate content (Borgia et al. 2011; Durham et al. 2019) have been recommended. Forages are invariably low in starch (NRC 2007) and the non-structural carbohydrate content is primarily determined by the amount of WSC, primarily fructans, stored in the vegetation (Richards et al. 2021). Furthermore, a suitable forage-based diet can enable management and prevention of EMS. Crucially, this should contain low levels of soluble carbohydrate. Studies investigating hay routinely fed to horses in the UK, commonly harvested from cultivated ryegrasses, have reported WSC content between 174 and 182 g/kg DM (Argo et al. 2015; Mack et al. 2014) exceeding the recommended threshold for non-structural carbohydrates. Molinia, has been shown to have consistently low WSC concentrations, and thus may be well suited as an alternative forage for horses that require a diet low in non-structural carbohydrates, yet high in fibre.

Inappropriate levels of nutrition can limit horses' ability to train and compete (Harris and Geor 2014), lead to obesity (Lindase et al. 2016). Furthermore, metabolic disorders such as insulin dysregulation, can be induced when overfeeding high-energy diets comprising starch and sugar (d' Fonseca et al. 2020). Nutritional requirements of equids have been estimated through numerous feeding experiments and compiled in feeding standards (Hintz and Schryver 1972; Olsman et al. 2003; Pagan and Hintz 1986; Patterson et al. 1985; Reitnour 1978; Slade et al. 1970; Vermorel et al. 1991; Vermorel, MartinRosset, and Vernet 1997; Vermorel, Vernet, and Martin-Rosset 1997) which are assimilated in the industry standard text, Nutrient Requirements of Horses, published by the US National Research

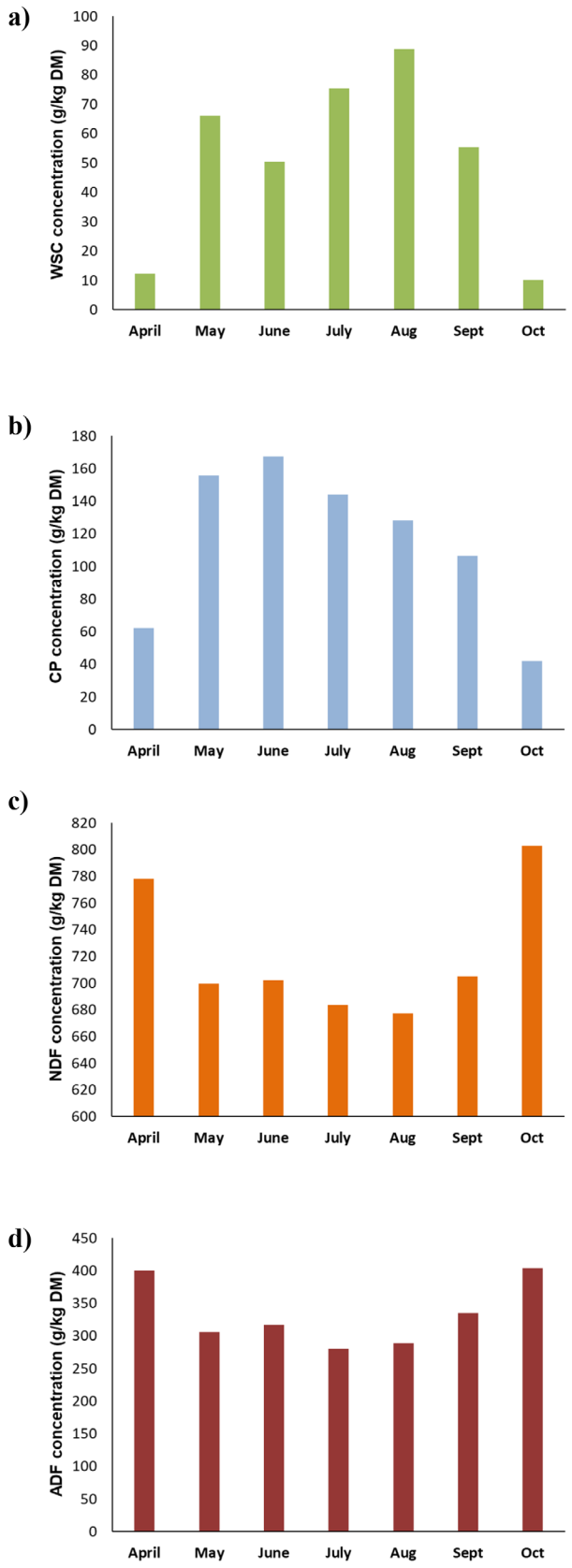


FIGURE 3 | Seasonal variation in the (a) water-soluble carbohydrate, (b) crude protein, (c) neutral-detergent fibre, and (d) acid-detergent fibre concentrations of *Molinia caerulea* leaf samples collected monthly from the same upland location (S. Doran & J. Corton, *unpublished data*).

TABLE 2 | Daily DE and CP requirements of an adult horse with 500 kg bodyweight and minimum nutritive content of feed assuming DM intake of 2% BW under various levels of activity based on recommendations of NRC (2007).

	DE		CP	
	MJ per day	MJ/kg DM	g per day	g/kg DM
No work				
Minimum	63.60	6.36	540	54.0
Average	69.87	6.99	630	63.0
Elevated	76.15	7.61	720	72.0
Working				
Light exercise	83.68	8.37	699	69.9
Moderate exercise	97.49	9.75	768	76.8
Heavy exercise	111.29	11.13	862	86.2
Very heavy exercise	144.35	14.43	1004	100.4

Note: Minimum = horses with sedentary lifestyle and/or a docile temperament; Average = horses with alert temperaments and/or moderate voluntary activity; Elevated = horses with nervous temperament and/or high levels of voluntary activity; Light exercise = 1–3 h per week; Moderate = 3–5 h per week; Heavy = 4–5 h per week; Very heavy = ranges from 1 h per week speed work to 6–12 h per week slow work.
Abbreviations: CP, crude protein; DE, digestible energy.

Council (NRC) and last updated in 2007 (NRC 2007). Several other rationing systems, including the Institute National de la Recherche Agronomique (INRA; last updated in 2015), are used globally (McDonald et al. 2022) but the most well-known and commonly used are the NRC and INRA. While the equations for estimating requirements presented in these systems differ considerably, the values obtained using these equations are often relatively consistent (Harris 1997).

Similarly to livestock species, nutritional requirements of horses are affected by several factors, including but not limited to age, breed, gender, temperament, level of activity and environmental temperature (Harris 1997). In fact, interindividual variability of maintenance energy requirements has been found to be as high as 8% (Martin-Rosset and Vermorel 1991). Thus, nutrient requirements are presented for a specific life stage, productive status, and level of activity of the horse (Becvarova et al. 2009). The NRC system (NRC 2007) includes equations to calculate nutrient requirements for non-working adult horses, working adult horses, stallions, pregnant mares, lactating mares and growing animals. Daily digestible energy and CP requirements of an average sized (500 kg) adult horse according to NRC (2007) are presented in Table 2 (NRC 2007). If the energy digestibility (ED) of forages for horses is calculated as ED (%) = 0.034 + 1.1 + 0.9477 OMD (%), and digestible energy (DE) is estimated from ED

and gross energy values using the equation DE = GE × ED/100, then based on and demonstrated GE contents of Molinia of 20.1 MJ kg DM (Moorby et al. 2015) the corresponding DE value of Molinia will be ~10 MJ kg DM. Thus, where voluntary intake is sufficient, the digestible energy content would be predicted to be sufficiently high for adult horses at maintenance (and that are non-lactating and non-pregnant) as well as those in light to moderate work.

6 | Conclusions

Research on Molinia as an animal feed is highly limited and the few studies published have solely focused on its value as a livestock forage. Laboratory analysis of Molinia has produced an overview of the chemical composition in terms of WSC, NDF, ADF and CP, which suggest it could be an appropriate feed for equids. However, while dry matter degradability of Molinia in ruminants has been investigated, such results do not directly translate to fermentability in the horse's hindgut. To accurately predict the energy and nutritive value of Molinia as an equine feed, equine-specific evaluations are recommended: in vitro determinations using equine caecal/faecal inoculum and/or in vivo feeding experiments; more in-depth nutrient analyses supplemented by nutrient degradability coefficients to give an indication of any requirements for complementary feeds and/or supplementation in a Molinia-based equine diet; hindgut simulation study and a gas production study to provide invaluable information about how the feed is degraded in the hindgut of the horse and how it might contribute to and/or affect gastrointestinal health. Were the apparent potential of Molinia as an equine feed to be realised, there could be multiple wins: a new source of low NSC forage, a new income stream for farmers in marginal areas, and improved upland biodiversity.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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