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ORIGINAL ARTICLE

Degradation parameters of amaranth, barley and quinoa in alpacas fed grass hay

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Summary

This study was conducted to determine the compartment 1 (C1) characteristics of alpacas (fistulated male, 7 ± 1.5 years old, 61 ± 5 kg BW) fed grass hay (GH) supplemented with amaranth (AM), quinoa (Q) and barley (B) grains. Alpacas were provided water *ad libitum* while housed in metabolism crates. The GH and GH plus treatments were fed at 0700 every day. Treatment periods were for 14 days in which GH or GH plus one of the grain treatments were randomly allocated. On day 14, volatile fatty acids (VFA), pH and ammonia nitrogen (NH_3-N) were determined at 1, 3, 6, 10, 14, 18 and 24 h post-feeding. C1 degradation of each feed component was also determined with the alpacas being fed GH only and the samples incubated for 0, 2, 4, 8, 14, 24, 48 and 72 h. Dry matter (DM), neutral detergent fibre (NDF) and crude protein (CP) were determined and were divided into three categories: *a* = immediately soluble; *b* = the non-soluble but degradable; and *u* = non-degradable/unavailable, potential extent of degradation (PE), degradation rate (*c*) and effective degradation (ED). C1 passage rate was determined using acid detergent insoluble ash as a marker and was calculated to be 5.5%•h-1. Total DM intake was highest ($p < 0.05$) for B and resulted in a higher ($p < 0.05$) CP intake. GH and AM were different in mean pH (6.81 and 6.66, respectively). B NH_3-N was greater ($p < 0.05$) than the other treatments. Total VFA was greatest ($p < 0.05$) for AM, with the greatest composition differences being a shift form acetate percentage to butyrate. DM, NDF and CP degradation was different across the treatments, where PE and ED were higher ($p < 0.05$) for the grain treatments. The pseudo-grains AM and Q had similar C1 degradation characteristics to B.

Keywords alpaca, *in situ* degradation, amaranth, quinoa, volatile fatty acids

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Introduction

Amaranth (*Amaranthus* sp.) and quinoa (*Chenopodium quinoa*) are both pseudo-grains from the South American region (Rosero et al., 2010; Kubelková et al., 2013) where the grain is used primarily for human food and the plant stocks used for animal feed (Rosero et al., 2010; Kubelková et al., 2013; Robinson et al., 2013b). They are classified as pseudo-grains because they are not in the Gramineae family. The grain of these species has a higher protein content, with a higher lysine and methionine than most conventional grains fed to animals. Písaříková et al. (2005) showed that amaranth grain amino acid composition and biological value was 90.4% that of egg protein, with quinoa reported as 88.3% of egg protein (Ruales and Nair, 1992). The digestion kinetics and characteristics of these pseudo-grains has not yet been determined in ruminants. Repo-Carrasco-Valencia and Serna (2011) showed that the protein digestibility of quinoa was 76.3–80.5%, and Ruales and Nair (1992) reported in Sprague–Dawley rats that net protein utilization, biological value and total digestibility of raw quinoa were 75.7, 86.6 and 91.7% respectively. The higher protein content and availability should be beneficial to the microflora of the ruminant. The value of having protein and energy available to the rumen microflora maximizes the production of VFA from the fermentation of these components.

Bergman (1990) summarized the production and absorption of VFA from the rumen stating that all species, ruminant and non-ruminant, produce and absorb VFA from the digestive tract. Engelhardt and Sallman (1972) showed that VFA were absorbed in

large quantities from the C1 and C2 in guanaco, especially associated with the glandular saccule region. They also showed that in this region, VFA absorption occurred more rapidly. Volatile fatty acid concentrations are affected by rumen volume, dilution rates and absorption rate, and these three factors account for species differences between camelids and ruminants (Elsden et al., 1946; Abbas et al., 1995). The objective of this experiment was to determine the degradability of GH (GH) supplemented with amaranth (AM), barley (B) and quinoa (Q) and the C1 VFA production and proportion changes associated with the addition of these supplements. Our hypothesis is that the addition of the pseudo-grains AM and Q will be different from the GH for VFA production and profile, but not from B and that the grains will have a different degradation pattern than GH.

Material and methods

Four adult male alpacas (7 ± 1.5 years old; 61 ± 5 kg BW) were housed in metabolism crates during the treatment period of this study. During periods when the alpacas were not being samples, the alpacas were walked for 30 min each day. The alpacas had previously been instrumented with C1 fistula as outlined by Robinson et al. (2013a), and the care of the animals followed animal use and care guidelines (FASS, 2010) under the approval of The Camelid Center Animal Use Committee. The alpacas were fed a mixed GH (orchard, *Dactylis glomerata*; meadow bromegrass, *Bromopsis biebersteinii;* smooth bromegrass, *Bromus inermis*; GH) for 30 days prior to the experiment allowing the alpacas to acclimate to the GH forage. During this period, the alpacas were fed *ad libitum* at 0700, and water was offered *ad libitum* and dry matter intake (DMI) was measured during the last 7 days. The research outlined here was conducted in two trials: *in situ* degradation of the feeds and determination of C1 VFA concentrations of GH and GH supplemented with AM, B and Q.

In Situ degradation trial

This trial followed the 30-day acclimation. During this trial, the alpacas were fed GH at 0700 and 1900 to provide a more steady state of digestion (Vanzant et al., 1998). The DMI determined during the 30-day acclimation period was divided in half for the twice-daily feeding. The DMI was calculated using feed refusal gathered daily that was weighed and dried for each. Grab samples of the GH fed were dried throughout both trials and used to determine DM fed. From DM fed, the dried refusal was subtracted and daily DMI calculated. The daily DMI values were used to statistically determine the treatment DMI for each alpaca.

The *in situ* substrate samples included GH, AM, B and Q, and each substrate was ground through a Wiley Mill (Arthur H. Thomas Co., Philidelphia, PA, USA) with a 2-mm screen. Four samples of each substrate were prepared by weighing 5 g of each substrate into 10 × 20 cm Dacron bags (50 μm pore; Ankom Technology, Macedon, NY, USA). The Dacron bags of substrate were soaked in water (39 °C) for 20 min prior to incubation to reduce lag time associated with wetting. The substrates were incubated for 0, 2, 4, 8, 14, 24, 48 and 72 h. The bags were placed into the C1 of each alpaca so that they were all removed at the same end time. Upon removal the bags were placed in ice water to stop further microbial digestion, while each bag was rinsed until the rinse water was clear (~15 min). The 0-h samples were soaked and rinsed as outlined without incubation. Following rinsing, the bags were dried at 50 °C for at least 48 h to a constant weight.

Residual material from *in situ* incubation was analysed for DM, NDF and CP. The NDF concentration was determined using the Ankom Fiber system procedure (Ankom Technology) and the CP concentration determined using a LECO Combustion N Analyzer (LECO TruSpec, St. Joseph, MI, USA). The N values determined by the LECO analyzer were then converted to CP using the standard conversion of 6.25. Total DM, NDF and CP degradation were divided into three pool fractions: a = immediately soluble; b = the non-soluble but degradable; and u = the undegradable/unavailable fraction. Fraction a was determined as the DM and NDF percentage that was washed from the 0-h sample (100 – per cent remaining). Fractions u was determined to be the fraction of DM and NDF remaining at the 72-h time. Fraction u was then calculated as $100 - (a + b)$. Potential extent (PE) of disappearance was calculated by $100 - u$. Effective C1 disappearance (ED) of DM, NDF and CP was determined as described by Ørskov and McDonald (1979) as $a + b \times (c/(c + k_p))$, where c the disappearance rate (%•h-1) and k_p is the passage rate (%•h-1). The effective disappearance was calculated on the same alpacas that the passage rate was determined from.

Passage rate was determined using the acid detergent insoluble ash (ADIA) technique and was determined as described by Scarbrough et al. (2001). At the end of the *in situ* trial, C1 content was removed from all four alpacas at 0 and 4 h post-feeding. The fractional rate of ADIA was calculated by dividing the

mean ADIA intake (g/h) by the C1 ADIA mass in grams (Waldo et al., 1972).

Volatile fatty acid trial

Treatments consisted of GH, and GH supplemented with AM, B, or Q. Alpacas received each treatment in random order based on a 4 × 4 Latin square design. Each treatment period was 14 days. In a preliminary study, data not presented, we found 14 days to be the minimal time point where microbial flora adjusted to a new diet to provide stable VFA results. During the VFA trial, DMI was measured during day 8–14 and determined as previously outlined above. The supplement was fed at the levels outlined in Table 1 so that the supplement crude protein intake was isonitrogenous between the treatments. The supplements were fed first and most often consumed within 15 min of feeding. Hay was fed *ad libitum* upon completion of supplement consumption. Diurnal C1 VFA samples were collected on day 14 and processed as outlined by Oldham et al. (2014) at 1, 3, 6, 10, 14, 18 and 24 h post-feeding. Sample supernatant was frozen for future VFA analysis (Oldham et al., 2014). In addition, 8 ml of strained C1 fluid was added to 2 ml of 25% metaphosphoric acid, mixed and frozen for future analysis of NH_3 (Chaney and Marbach, 1962). The remaining C1 sample was used for pH determination using a pH meter (Corning 340, Tewksbury, MA, USA) with a combination probe.

Table 1 Composition of feed*

	Grass	Amaranth	Barley	Quinoa
Dry matter (g/kg fresh weight)	930	902	893	911
Crude protein (g/kg DM)	114	141	138	154
NDF (g/kg DM)	568	95	188	58
ADF (g/kg DM)	340	71	84	42
Lignin (g/kg DM)	48	22	16	17
Fat (g/kg DM)	26	76	28	64
Ash (g/kg DM)	8.8	24	32	27
Non-fibre carbohydrate† (g/kg DM)	235	674	632	703
Calcium (g/kg DM)	3.8	1.3	7.0	6.0
Phosphorus (g/kg DM)	2.4	6.5	4.9	4.8
Potassium (g/kg DM)	21.6	5.5	6.3	6.6
Supplement fed				
Dry matter fed (g)		243	253	248
Crude protein fed (g)		34.2	34.9	38.2

*Analysis of duplicate samples was performed by Dairy One Forage Lab using wet chemistry procedures.

†Fractions determined by calculations. NFC = [100−((%NDF − %NDF-CP)+ %CP + %Fat + %Ash)].

Statistical analysis

The degradation parameters were determined by fitting the *in situ* DM, NDF and CP data to the nonlinear regression model of Ørskov and McDonald (1979) using Proc NLIN of SAS (SAS, 2002). The GLM procedure (SAS Inc., 2002) was used to determine the treatment effects of the degradation estimates. Least square means for treatments were determined using unadjusted *t*-tests and a level of significance at $p < 0.05$. The diurnal VFA and pH data were analysed using a linear mixed model with treatment, time and the interaction as main effects with time treated as a repeated measure (Littell et al., 1998). The SAS (SAS Inc., 2002) procedure MIXED was used for these calculations, and a probability of $p < 0.05$ was considered significantly different. Least squares means for levels of the treatment/time factors were calculated and compared using unadjusted *t*-tests.

Results

The chemical composition of the feeds fed in this experiment is presented in Table 1. The B DM intake (Table 2) was 1029 g/day, greater ($p < 0.05$) than AM or Q. The GH intake was not different from the other treatments. The increased DM intake for B over AM and Q also resulted in B CP intake being higher ($p < 0.05$) than AM and Q.

Table 2 Dry matter intake, NH_3-N, concentration and composition of volatile fatty acids in the C1 of alpacas fed grass hay and grass hay supplemented with amaranth, barley or quinoa

	Treatment				
	Grass hay	Amaranth	Barley	Quinoa	SEM
Dry matter intake, (g/day)	965^{ab}	771^{a}	1029^{b}	804^{a}	71.9
Hay DM intake (g/day)	965^{b}	558^{a}	802^{b}	586^{a}	70.5
Crude protein intake (g/day)	110^{ab}	97.9^{a}	126^{b}	105^{ab}	8.03
NDF intake (g/day)	380^{a}	364^{a}	492^{b}	309^{a}	33.3
pH	6.81^{b}	6.66^{a}	6.78^{ab}	6.70^{ab}	0.05
NH_3-N (mg/dl)	4.21^{a}	4.62^{a}	6.92^{b}	5.21^{a}	0.48
Acetate (mmol/l)	45.7^{ab}	47.7^{b}	42.8^{a}	42.2^{a}	1.55
Propionate (mmol/l)	12.0	12.8	11.3	11.7	0.63
Butyrate (mmol/l)	5.44^{a}	7.05^{b}	7.06^{b}	6.62^{b}	0.32
Total (mmol/l)	63.1^{ab}	67.6^{b}	61.0^{a}	60.5^{a}	2.26
AC:PR	4.35	3.82	3.91	3.87	0.32
Acetate (%)	72.4^{b}	70.7^{ab}	70.2^{a}	69.9^{a}	0.70
Propionate (%)	19.0	18.9	18.3	19.4	0.64
Butyrate (%)	8.6^{a}	10.4^{b}	11.5^{c}	10.7^{b}	0.27

Row means with differing superscripts are significantly different at $p < 0.05$.

The C1 diurnal pH was not significant for the treatments over time. The mean treatment pH (see Table 2) was different ($p < 0.05$), where AM (6.66) was lower from GH, B and Q at 6.81, 6.78 and 6.70 respectively. The B NH_3-N (Table 2) was 54% greater ($p < 0.05$) than GH, AM and Q. Volatile fatty acid concentrations and proportions (Table 2) were not significant for the diurnal samples collected, so only treatment means are presented. The mean AM acetate concentration was different ($p < 0.05$) from Q (47.7 mmol/l to 42.2 mmol/l, respectively), but neither was different from the other treatments. The GH mean butyrate concentration was lower ($p < 0.05$) than the other treatments. Total VFA concentration was different ($p < 0.05$) between AM (67.6 mmol/l) and B and Q (61.0 and 60.5 mmol/l, respectively), while GH was not different from any of the other treatments. The acetate (Ac) proportion was higher ($p < 0.05$) for GH than the other treatments; the others were similar. The proportion of propionate (Pr) was similar for the treatments that ranged from 18.3% to 19.4%. Butyrate proportion was higher ($p < 0.05$) for B than the other treatments, and AM and Q were significantly higher ($p < 0.05$) than GH. The acetate:propionate ratio was not different between the treatments and ranged from 4.35 for GH to 3.8–3.9 for the other treatments.

The DM degradation parameters for the treatment feeds are found in Table 3. Fraction *a* degradation was 54.8% for Q, higher ($p < 0.05$) than the other treatments. The *b* fraction B was 63.2%, different ($p < 0.05$) from GH and AM at 50.0 and 52.9%, which are different ($p < 0.05$) from Q at 40.2%. Potential extent of degradation, based on the sum of fractions *a* and *b*, was the same for AM, B and Q at 85.7, 94.3 and 94.9%, respectively, but different ($p < 0.05$) from GH at 74.0%. The rate of DM degradation was not different between the treatments and ranged from 0.081 to 0.098% per hour for GH. The concentration of ADIA in the GH was 36.8 g/kg. The mean ADIA for the C1 contents for the 0 and 4-h evacuations was 37.1 ± 1.1 and 38.6 ± 3.9 g/kg respectively. The mean C1 DM content weight was 656 ± 93 g, and the k_p calculated for the four alpacas was 0.0553, 0.0790, 0.0392 and 0.0461 (%•h-1), with a mean of 0.0549%•h-1 $\pm$ 0.0173. The value of 0.0549 was used for the determination of the ED. Dry matter ED was the same for AM, B and Q that were greater ($p < 0.05$) than GH.

Fraction *b* NDF degradation (Table 4) was the same for B and GH, but greater ($p < 0.05$) than AM and Q. The GH treatment was not different from AM and Q. Potential extent of NDF degradation was the same for B and Q at 92.2 and 89.8%, higher ($p < 0.05$) than GH and AM at 69.3 and 72.6%. Rate of NDF degradation was not different across the treatments ranging from 0.044 to 0.095% per hour. Quinoa ED was 73.0% and was greater ($p < 0.05$) than the other treatments. The B treatment was different ($p < 0.05$) from GH and AM. The AM treatment was greater ($p < 0.05$) than GH.

Fraction *a* CP degradation was lowest for AM ($p < 0.05$), while B and GH were the same. The Q substrate had the highest ($p < 0.05$) *a* fraction CP degradation. Fraction *b* was different ($p < 0.05$) between GH and Q (least) and AM (greatest), and B was not different from any of the other treatments. The CP PE was not different between the treatments and was all in the range of 91.7–99.5%. The CP *c* was 0.019 for

Table 3 Dry matter degradation kinetics* for grass hay, amaranth, barley and quinoa from alpacas fed grass hay

	Treatment				
	Grass Hay	Amaranth	Barley	Quinoa	SEM
a	24.0[a]	32.9[b]	31.1[ab]	54.8[c]	2.82
b	50.0[b]	52.9[b]	63.2[c]	40.2[a]	1.42
c (per hour)	0.081	0.098	0.090	0.089	0.013
Potential extent (%)	74.0[a]	85.7[b]	94.3[b]	94.9[b]	2.90
Effective degradation (%)	51.5[a]	70.9[b]	70.4[b]	79.4[b]	1.88

Row means with differing superscripts are significantly different at $p < 0.05$.

*a = immediately soluble; b = the non-soluble but degradable; c = degradation rate based on the equation $a + b(1 - e^{-ct})$ Ørskov and McDonald (1979). Potential extent is the sum of $a + b$, and effective degradation is calculated as $a + (b \times c/(c + k_p))$, where k_p is 0.0549.

Table 4 NDF digestion kinetics* for grass hay, amaranth, barley and quinoa from alpacas fed grass hay

	Treatment				
	Grass Hay	Amaranth	Barley	Quinoa	SEM
a	23.9[a]	31.9[b]	41.6[c]	50.2[d]	2.43
b	45.4[ab]	40.7[a]	50.6[b]	39.6[a]	1.98
Potential extent (%)	69.3[a]	72.6[a]	92.2[b]	89.8[b]	3.08
c (per hour)	0.044	0.073	0.060	0.078	0.018
Effective degradation (%)	39.6[a]	54.4[b]	66.9[c]	73.0[d]	3.56

Row means with differing superscripts are significantly different at $p < 0.05$.

*a = immediately soluble; b = the non-soluble but degradable; c = degradation rate based on the equation $a + b(1 - e^{-ct})$ Ørskov and McDonald (1979). Potential extent is the sum of $a + b$, and effective degradation is calculated as $a + (b \times c/(c + k_p))$, where k_p is 0.0549.

GH, less ($p < 0.05$) than the other treatments that ranged from 0.084 to 0.095% per hour. Effective degradation, based on the passage rate determined in the alpacas of this study, was lowest ($p < 0.05$) for GH at 49.8%. AM and B were the same at 64.0 and 70.5% respectively. The B substrate was not different from Q (78.9%) (Table 5).

Discussion

The digestion of material in the camelid stomach is different than that of true ruminants. Contraction motility cycles of the camelid forestomach result in maximum mixing of forage material with micro-organisms and buffering components in conjunction with slower passage from the forestomach (Heller et al., 1984). Heller et al. (1986) reported that in llamas, fed a hay/concentrate diet, the prolonged retention of particles in the camelid forestomach results in extensive fermentation of high fibrous forages. Dulphy et al. (1997) concluded that the higher water turnover rate found in llama's versus sheep may increase cellulolytic activity because of the rapid passage of substances that could hinder microbial growth. The data presented in our study demonstrate the digestion characteristics of mixed meadow GH and supplements of amaranth, barley and quinoa in alpacas.

Volatile fatty acid, NH_3-N concentrations and buffering components all contribute to the physiochemical stability of the C1 environment, where all of these factors result in more efficient microbial activity. Various factors affect the digestion of grain and the starch component of the grain. Corn starch has a slower fermentability than oats or barley starch (Ørskov, 1986), with the fermentability of oats and barley at approximately 90% and 60% for corn. This is further substantiated by others who showed lower fermentation of corn versus oats or barley (Philippeau et al., 1999; Offner et al., 2003). Maximal efficiency of C1 microbial growth is influenced by the fermentability of starch and the availability of nitrogen substrate.

The AM was not accepted by the alpacas in this study as readily as the other supplements. The alpacas took longer to consume it at the beginning of the acclimation period. By the beginning of day 7, they were consuming it fully within 1 h post-feeding. Overall DM intake was numerically the lowest for AM, but was not statistically different from the GH and Q treatments. This was due to a decrease in GH consumption, as was also seen with Q. Dulphy et al. (1997) showed in llamas fed GH that B supplementation decreased overall DM intake. Robinson et al. (2013a) looked at alpacas fed GH supplemented with 454–908 g ground corn and found no decrease in total DM intake, but the alpacas receiving the 908 g level of supplementation only consumed approximately 315 g of grass forage. Lund et al. (2014) concluded that alpacas have the ability to regulate their energy intake, and this may account for our findings.

The supplement inclusion level ranged from 24.6% (B) to 31.5% (AM), which in true ruminants one would expect to cause some digestive disruption. Various studies have shown C1 pH to range from 6.6 to 8.0 in grass-and alfalfa hay-fed alpacas (Liu et al., 2009; Robinson et al., 2013a; Oldham et al., 2014), and the pH for the treatments in this study is within the published range. The pH mean AM was slightly lower ($p < 0.05$) than GH, but not enough to cause disruption and was similar to values shown by Kubelková et al. (2013). In llamas fed GH, Dulphy et al. (1997) showed similar values to ours and found no change in pH when supplemented with B, where in comparison with sheep, they saw a significant reduction in pH in the sheep with B supplementation. This pattern was also shown by Lemosquet et al. (1996). To our knowledge, there is no Q pH reported in ruminants.

Production rate of NH_3-N was also not altered by the inclusion of AM (4.21 and 4.62 mg/dl for the GH and AM, respectively). These values are similar to values found by McCarthy et al. (1989), but lower than *in vitro* data obtained by Kubelková et al. (2013) for ground amaranth of 187.5 mg/l. In alpacas fed alfalfa hay, Liu et al. (2009) showed values similar to Kubelková et al.'s at 17.7 mg/dl. Kubelková et al. (2013) pointed out that there are various factors that may influence the NH_3-N concentration and that grain

Table 5 Crude protein digestion kinetics* for grass hay, amaranth, barley and quinoa from alpacas fed grass hay

	Treatment				
	Grass Hay	Amaranth	Barley	Quinoa	SEM
a	35.3^{b}	22.3^{a}	31.1^{ab}	43.2^{c}	2.47
b	57.2^{a}	69.4^{b}	63.4^{ab}	56.4^{a}	3.88
Potential extent (%)	92.5	91.7	94.5	99.5	2.77
c (per hour)	0.019^{a}	0.084^{b}	0.090^{b}	0.095^{b}	0.005
Effective degradation (%)	49.8^{a}	64.0^{b}	70.5^{bc}	78.9^{c}	3.01

Row means with differing superscripts are significantly different at $p < 0.05$.

*a = immediately soluble; b = the non-soluble but degradable; c = degradation rate based on the equation $a + b(1 - e^{-ct})$ Ørskov and Mc Donald (1979). Potential extent is the sum of $a + b$, and effective degradation is calculated as $a + (b \times c/(c + k_p))$, where k_p is 0.0549.

processing and forage quality are two important factors. With the variable values in the literature, we conclude that NH3-N comparisons should be made within the experiment and between the treatments. Production of ammonia by ruminal micro-organisms depended on the type of substrate and substrate concentration (Eschenlauer et al., 2002). Nitrogen requirement of rumen micro-organisms for protein synthesis is met from ammonia, free AA, and peptides obtained from microbial degradation of dietary CP and recycled CP (Boucher et al., 2007). Jouany et al. (1995) demonstrated that, although camelids have a higher N recycling, feed protein degradation is not different between camelids, sheep and goats. For our study, only B had an effect on NH_3-N and may be associated with the elevation in N intake for B. Mehzer et al. (1977) stated that the maximum production of microbial protein per unit of substrate or maximum rate of fermentation dictates the optimal ammonia concentration in the rumen. Proteolysis is a major contributor to the rumen ammonia concentration (Bergman, 1990) and, with the higher CP intake for the B treatment, may account for the higher B NH_3-N.

A change in individual molar percentage is common and more telling of the treatment effect on VFA composition (Bergman, 1990) than the total VFA concentration. Bergman (1990) also concluded that the rate of VFA production in the rumen is dependent on the amount and type of feed and thus can be variable. Total VFA concentration for our study was higher ($p < 0.05$) for the AM treatment. Using an artificial rumen system, Kubelková et al. (2013) showed total VFA production was not affected by inclusion of amaranth (55.3–52.9 mmol/l), but Ac:Pr was reduced from 3.0 to 2.73 because of a molar percentage increase in Pr from 19.1 to 20.1%. Dulphy et al. (1997) showed no difference in total VFA for llamas fed GH and GH supplemented with 10% B, but did find the molar percentage of the individual VFA changed. In their study, Ac decreased and Pr and Bu increased between the GH and B treatments. The inclusion of starch feeds results in higher Pr and Bu concentrations and lower Ac. This was evident in our study where the GH treatment had a higher Ac percentage. The inclusion of the supplements altered the VFA percentages, with Bu increasing.

Dulphy et al. (1997) show tall fescue hay degradation was greater in llamas than sheep by approximately 5% starting at 24 h and continuing on to the last sample at 72 h. They also found that barley had a negative effect on hay degradation for the sheep, but not as marked for the llamas, attributing this to the llama's cellulolytic activity. Dry matter fraction *a* degradation of the mixed GH for this study was slightly higher (approximately 14% more) than that measured by Stevens et al. (2014) for alpacas fed tall fescue. Fraction *b*, rate of digestion and PE for this study were similar to Stevens et al. (2014). *In vitro* degradation of quinoa was shown to range from 65 to 69%, more in line with the starch digestion of corn starch (Repo-Carrasco-Valencia and Serna, 2011). Ørskov (1986) reported that 90% of oats and barley starch are fermented in the rumen. The DM PE for the grain treatments was greater than GH, even though Q *b* fractional degradation was lower than GH. The PE percentage degradation is a sum of the *a* and *b* fractional degradation, and the point of interest is that the Q has a higher rapidly degrading fraction when compared to B. Although Ørskov (1986) reported 90% degradation, our data indicate that there is a difference in the degradation of the fractions. The ED for the pseudo-grains was the same as B and the grains were approximately 20% higher than GH, all with the degradation rates being the same. Písaříková et al. (2005) showed the *in vitro* degradation of amaranth protein to be 68%. The CP ED of AM for our study was 64%. Ammonia-N is associated with microbial cellulolytic activity. A higher B NH3-N would be assumed to correlate with a higher B ED. The ED was not higher and is speculated to be due to the readily degradable B starch and not be associated with the B ED.

Conclusions

These data demonstrate the degradation kinetics of AM, B and Q in camelids fed GH. Amaranth and quinoa grains are not typically fed to ruminants, but these data show the degradation and VFA production are similar to barley. To our knowledge, these are the first data presenting the degradation of amaranth and quinoa in camelids and are a basis for further studies.

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