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Extrusion of sorghum starch enhances ruminal and intestinal digestibility, rumen microbial yield and growth in lambs fed on high-concentrate diets

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ABSTRACT

This study consisted of two experiments that investigated the effect of extrusion of sorghum starch on *in situ* ruminal and post-ruminal disappearance of dry matter (DM), starch and nitrogen (N) and the effects of substituting barley by the extruded sorghum on digestion characteristics, microbial N supply and growth in finishing lambs. Sorghum was extruded using the following four temperature and pressure combinations: T1 = 90 °C/17 bars, T2 = 115 °C/24 bars, T3 = 150 °C/55 bars and, T4 = 175 °C/95 bars. Ruminal, intestinal and total tract DM content, starch and N degradability of the extruded sorghum (T1, T2, T3, T4), unprocessed sorghum (T0; control) and barley grain (B) were determined using nylon bag and mobile bag techniques in a completely randomized block design (CRBD). Extrusion under T3 conditions increased *in vitro* ruminal digestibility, solubility (*a*), fractional disappearance rate (*c*) and effective degradability (*ED*) of DM and starch in sorghum to near similar to those of B. T3 also had higher ($P<0.05$) ruminal and intestinal digestion rates for DM, starch and N compared to T0, T1, T2 and T4 suggesting that extruding sorghum under T3 conditions could be used as replacement of barley in lamb diets. In the second experiment, eighteen male Iranian Baluchi lambs were randomly allocated into three dietary treatments in a complete randomized design (CRD). Dietary grain in the treatment-concentrates were barley (B) as control, barley and extruded sorghum (under T3 conditions) in equal proportion (BS_E) and extruded sorghum (S_E). Dry matter and N intakes were not affected by source of grain, but because of the higher starch content in sorghum, lambs on S_E diet had greater starch intake (995 g/d) and higher ($P<0.01$) starch (291 g/d) and N (53.1 g/d) outflow to the small intestine. Of the total input of starch to the small intestine, higher ($P<0.01$) amount (253 g/d) disappeared in S_E compared to B and BS_E lambs which was reflected by the higher

Abbreviations: ADG, average daily gain; bun, blood urea nitrogen; DMF, dry matter flow; CP, crude protein; DM, dry matter; DOMI, digestibility of organic matter intake; ED, effective degradability; FCR, feed conversion ratio; GIT, gastro intestinal tract; MN, microbial nitrogen; N, nitrogen; NDF, neutral detergent fibre; OM, organic matter; PD, purine derivatives; TMR, total mixed rations; VFA, volatile fatty acid.

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glucose concentration in the portal vein of S_E lambs. Lambs fed S_E diet also had greater ruminal microbial N (MN) yield (24.1 g/d), although ruminal pH and total VFA did not show any significant difference among treatments. Consequently, S_E lambs recorded greater averaged daily gain (ADG) and more efficient ($P<0.01$) feed conversion ratio (FCR) compared to B or BS_E lambs. It can be concluded that extrusion under 150 °C/55 bars improves digestibility of sorghum starch and provides an option to completely replace barley in lambs.

1. Introduction

Use of cereal grains with different starch degradation rates allows for a more synchronized release of energy and nitrogen (N) that prevents a sudden drop in ruminal pH (Horadagoda et al., 2008; Xu et al., 2009). It also increases outflow of starch from the rumen for more efficient digestion in the small intestine (McLeod et al., 2001; Abramson et al., 2005). However, excessive outflow of ruminal starch may lead to energetically less efficient fermentation in the hind gut (Huntington et al., 2006; Harmon, 2009).

Yahaghi et al. (2012) reported that partial substitution of barley with sorghum grains improved starch digestion, microbial N production and growth rate in growing lambs. However, when barley was fully replaced by sorghum, ruminal outflow rate of starch was increased but a large proportion of the escaped starch was undigested and fermented in the hind gut or excreted as waste in the faeces (Yahaghi et al., 2013). Starch granules in the sorghum grain are embedded in a dense protein matrix rich in disulphide bonds which make them highly resistant to microbial fermentation and enzymatic digestion in the small intestine (Ljøkjel et al., 2003a; Mahasukhonthachat et al., 2010). Thus, in order to increase the substitution rate of quickly fermentable grain such as barley with sorghum, the highly resistant structure of sorghum starch must be destroyed or reduced. Extrusion of grains has been shown to alter the physicochemical characteristics of its starch because starch gelatinizes when treated at adequate temperature and pressure (Dehghan-Banadaky et al., 2007). The objective of this study was to examine whether extrusion will increase the outflow and digestibility of sorghum starch in the small intestine to allow for a more efficient replacement of barley grain by sorghum in high concentrate diet in lambs. Prior to the *in vivo* trial, the optimal extrusion conditions for sorghum grain was tested based on *in situ* rumen and intestinal nutrient disappearance studies.

2. Materials and methods

2.1. In situ trial

2.1.1. Experimental feed preparation

Sorghum grain (*Sorghum bicolor L. Moench*) obtained from Khorasan-Razavi Agricultural and Natural Resource Research Centre, Mashhad, Iran, was ground to 2 mm and extruded. Extrusion was carried out using a single-screw extruder (Yemmak Makina Sanayi A.S. Turkey), running at screw speeds of 160, 185, 210 and 235 rpm and 8 mm die-plate nozzle to generate a combination of temperature and pressure to produce the following treatment groups: T1 = 90 °C/17 bars; T2 = 115 °C/24 bars; T3 = 150 °C/55 bars and T4 = 190 °C/95 bars. The above extrusion conditions were selected based on previous studies which used temperatures ranging between 100 and 180 °C to extrude sorghum (Al-Rabadi et al., 2011; Lankhorst et al., 2007). After extrusion, the grains were transferred into a container to cool, dry (8–9% humidity) and to equilibrate for 30 min. After that, the extruded sorghum was re-ground through 2 mm sieve and kept for later use. Untreated sorghum (T0) and barley (*Hordeum* spp.) (B) grains were used as negative and positive controls respectively. The chemical compositions of barley and various sorghum samples used for this study are shown in Table 1.

2.1.2. Management of rumen fluid donor animals

Three rumen-cannulated and two duodenal-fistulated Holstein steers (316 ± 31 kg), fed a mixed ration (67:33; concentrate:roughage) near to maintenance level (*circa* 6 kg DM) were used, respectively to estimate *in situ* DM, N and starch disappearances from nylon bags and disappearances in the intestine using mobile bags. Animals were fed alfalfa hay (NDF: 430, CP: 160 g/kg) as roughage source. The diet was offered twice daily in equal meals at 8:30 and 16:30 h.

2.1.3. Experimental design

In situ DM, N and starch disappearances from nylon bags were determined following the methods of Ørskov and McDonald (1979) in the rumen and that of Donnem et al. (2010) through the lower gut. For the former, four nylon bags (13 cm × 7 cm and 45 μm pore size) contained approximately 5 g of ground samples (2 mm) of each experimental ingredient (6 ingredients × 6 incubation durations × 2 duplicates × 2 replicates) were prepared and incubated for 2, 4, 8, 16, 24 and 48 h. At any one time, a total of 36 bags [6 treatments in duplicates (12) × 3 incubation durations] were incubated in each animal [considered as the experimental unit (block), $n = 3$]. When bags were removed at their assigned incubation time, they were replaced by duplicate sets of the same ingredient for another incubation duration. Similar procedure was repeated for the second run to obtain the experimental replicates for each treatment. Prior to insertion into the rumen, bags were soaked (5 min) in