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In situ Ruminal Crude Protein and Starch Degradation of Three Classes of Feedstuffs in Goats

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Abstract

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Ruminal crude protein (CP) and starch degradability of three classes of feedstuffs: cereals (maize, wheat, barley, buckwheat, rice, millet and sorghum), legumes (horse bean, soybean, pea and mung bean) and tubers (potato, sweat potato and cassava) were assessed using three wether goats. Experiment consisted of 14 periods. During each period, the ruminal CP and starch disappearance of each one of these feedstuffs was measured at 0, 2, 4, 8, 12, 24, 36 and 48 h, respectively. Significant differences (P<0.001) in the ruminal degradation kinetics parameters of crude protein (CP) and starch were generally observed across cereal grain, legume and tuber feedstuffs, respectively. This study enriches the database of ***in situ*** *crude protein and starch degradability of feedstuffs, which would play an important role in improving biological CP and starch efficiency for modern ruminant production system.*

Key words: Cereal, legume, tuber, degradability, crude protein, starch.

Introduction

Crude protein (CP) and starch are important nutrients for the animals. In ruminants, starch not only serves as an important source of body energy and fat deposition, but also an important source of energy for microbial growth and, therefore, has great impact on the feed nutritive value. Dietary protein is degraded in the rumen to supply ammonia nitrogen to microbes, while the ruminally synthesized microbial protein and rumen undegradable dietary protein (UDP) are sources of amino acids for absorption in the small intestine. In order to characterize a feedstuff, it is important to determine the amount of CP and starch degradable in the rumen (Woods *et al.,* 2003).

The present study was designed to determine ruminal CP and starch degradability of three classes of feedstuffs (cereal, legume and tuber feedstuffs) in goats using *in situ* nylon bag technique to update the feed database.

Materials and Methods

Three feed classes included cereal feedstuffs (maize, wheat, barley, buckwheat, rice, millet

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and sorghum), legume feedstuffs (horse bean, soybean, pea and mung bean) and tuber feedstuffs (potato, sweat potato and Cassava). Each feedstuff with two replicates was selected at the harvest period from the main planting districts in China.

Three grown wether goats (20±1.5 kg) fitted with permanent rumen fistula were used in this experiment. Goats received the same basal diet to 5% refusal, which was formulated to meet 1.3 times maintenance requirements of metabolism energy (Sun *et al.,* 2007). The basal diet consisted of 50% chopped maize stover (1 cm length), 22% ground corn, 18% wheat bran, 6% soybean meal, 0.2% rapeseed cake, 0.8% urea, 0.8% salt and 2.2% premix (containing vitamins and trace elements). Feed was offered in two equal amounts at 0700 and 1800 h. All goats were kept individually in stainless metabolic cages in a temperature-controlled (21C) and constant-lighted house and had free access to water.

The *in situ* ruminal nylon bag experiment, consisting of 14 periods, was conducted by the modified procedure of Tan *et al.* (2001). During each period one of these selected feedstuffs was incubated in the rumen of all three goats to measure the ruminal CP and starch degradability. Each period lasted 9 d. The initial 7 d were for the adaptation of animals and the last 2 d for sample collection.

Chemical compositions of feedstuffs were analyzed for DM (24 h at 103C) and ash (4 h at 550C). Ether extract from feedstuffs and nitrogen contents from feedstuffs and undegraded feedstuffs in nylon bag were analyzed according to the procedure of AOAC (1990). Starch content was determined using the procedures of Bergmeyer (1970) and Cone (1991). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the method of Van Soest *et al.* (1991).

Ruminal CP and starch degradability was calculated by the model of Ørskov and McDonald (1979) according to the following equations: $d_p = a + b\,(1 - e^{-kd(t)})$ and $ED = a + (b \times k_d)/(k_d + k_p)$, where d_p, a, b, k_d and ED were the ruminal disappearance at time t, the rapidly soluble fraction, the potentially degradable fraction, the constant rate of potentially degradable fraction, the ruminal effective degradability for CP and starch. The K_p was the outflow rate set as 0.02, 0.05, 0.06, and 0.08 h^{-1}, respectively.

The data were analyzed with the GLM procedures of SAS software (for windows release 6.12), and followed by LSD multiple comparison tests in each type of feedstuffs with significance set at $P<0.05$.

Results and Discussion

Crude protein contents of cereal grain, tuber and legume feedstuffs ranged from 93 to 170 g/kg DM, 89 to 118 g/kg DM and 232 to 403 g/kg DM, respectively (Table 1). Starch contents of cereal grain, tuber and legume feedstuffs

Table 1
Chemical compositions[1] (g/kg DM) of selected three classes of feedstuffs

Feedstuff	OM	CP	EE	Starch
Cereal feedstuff				
Barley	977	140	14.4	498
Wheat	976	170	16.7	540
Buckwheat	979	155	37.0	624
Sorghum	981	96	37.6	653
Maize	982	93	55.7	625
Millet	988	123	44.5	649
Rice	995	111	6.1	785
Legume feedstuff				
Soybean	947	403	198.3	244
Horse bean	968	322	21.8	284
Pea	971	268	17.5	318
Mung bean	860	232	17.9	223
Tuber feedstuff				
Potato	953	96	13.2	631
Sweat potato	914	118	18.7	385
Cassava	945	89	17.0	321

[1]Values are the average of two replicates.

ranged from 498 to 785 g/kg DM, 321 to 631 g/kg DM and 223 to 318 g/kg DM, respectively. With the exception of soybean and rice, EE content of tested feedstuffs ranged from 13.2 to 55.7 g/kg DM. Chemical composition of buckwheat, millet, mung bean, sweat potato and cassava was firstly reported as the ruminant feeds. Crude protein values of barley, wheat, maize, soybean, pea and potato were close to the previous reported data

Table 2
Rumen *in situ* CP degradation kinetics [1] of selected three classes of feedstuffs

	a	b	k_d	a+b	ED0.02	ED0.05	ED0.06	ED0.08
Cereal feedstuff								
Barley	548^a	291^b	0.13 b	839^b bc	799^a	756^a	744^a	725^a
Rice	309^{cd}	571^a	0.02 d	880^b	620^b	494^c	472^c	441^c
Sorghum	283^d	101^c	0.27 a	383^e	369^d	357^d	354^d	348^d
Buckwheat	386^b	348^b	0.13 b	734^c	688^b	683^b	624^b	602^b
Wheat	333^c	664^a	0.05 cd	998^a	803^a	659^b	629^b	583^b
Millet	68^f	373^b	0.06 c	562^d	443^{cd}	352^d	333^d	303^d
Maize	245^e	367^b	0.04 cd	612^d	489^c	408^d	391^d	367^d
SEM [2]	8.9	30.8	0.001	37.1	25.8	22.5	22.3	22.1
Significance [3]	***	***	***	***	***	***	***	***
Legume feedstuff								
Horse bean	555^{bc}	141^b	0.07 a	697^d	653^c	626^c	620^c	763^a
Soybean	556^{bc}	229^a	0.05 b	786^c bc	720^b	671^b	660^b	644^{bc}
Mung bean	623^b	178^{ab}	0.03 c	801^b ab	731^b	691^b	684^b	611^{cd}
Pea	723^a	110^b	0.05 b	833^a	799^a	775^a	770^a	601^d
SEM	21.3	23.0	0.003	11.7	10.6	11.5	11.9	12.8
Significance	***	*	***	***	***	***	***	***
Tuber feedstuff								
Sweat potato	593^b	121^b	0.12^a	715^c	697^c	678^c	674^b	666^b
Cassava	553^c	286^a	0.05^b	840^b	755^b	693^b	680^b	660^b
Potato	842^a	61^c	0.12^a	903^a	894^a	885^a	882^a	878^a
SEM	5.7	7.7	0.001	6.4	4.2	3.6	3.6	3.6
Significance	***	***	***	***	***	***	***	***
Mean								
Cereal feedstuff	322^b	388^a	0.09^a	715	601^b	523^b	507^b	481^b
Legume feedstuff	597^a	176^b	0.05^b	773	716^a	678^a	670^a	658^a
Tuber feedstuff	663^a	156^b	0.09^a	819	782^a	752^a	745^a	735^a
SEM	31.2	36.9	0.001	40.0	33.5	32.3	32.2	32.2
Significance	***	***	*	NS	**	NS	***	***

[1]α, rapidly soluble fraction as measured by washing loss from bag (g/kg CP); b, potentially degradable fraction (g/kg CP); K_d, constant rate of potentially degradable fraction (h^{-1}); á+b, ruminal degradable fraction (g/kg CP); ED, effective rumen degradability (g/kg CP) measured at outflow rate (K_p) at 0.02, 0.05, 0.06, and 0.08 h^{-1}.

[2]SEM: standard error of means.

[3]Values in the same column with different letters (a-f) differ at $P < 0.05$. NS, not significant; *P<0.05; **P<0.01; ***P<0.001.

(Sveinbjörnsson *et al.,* 2007) and crude protein contents of sorghum, rice and horse bean were consistent with the data of NRC (2001). Starch values of maize, sorghum, barley, wheat and pea were numerically lower than the previous data of Offiner *et al.* (2003) and Sveinbjörnsson *et al.* (2007), but starch content of rice was higher than the reported data of Offiner *et al.* (2003).

For CP of cereal feedstuffs, the values of *a*, *b*, ruminal degradable fraction (*a*+*b*), and k_d were highest for barley, wheat, sorghum and

Table 3
Rumen *in situ* starch degradation kinetics [1] of selected three classes of feedstuffs

	a	b	k_d	a+b	ED0.02	ED0.05	ED0.06	ED0.08
Cereal feedstuff								
Barley	882[a]	107[e]	0.29 a	989[a]	982[a]	973[a]	970[a]	965[a]
Rice	157[f]	585[a]	0.05 cd	742[b]	576[c]	451[c]	424[c]	383[c]
Sorghum	336[d]	165[de]	0.06 c	502[d]	464[d]	432[c]	424[c]	412[c]
Buckwheat	221[e]	273[c]	0.20 b	494[d]	469[d]	440[c]	431[c]	416[c]
Wheat	762[b]	220[cd]	0.32 a	983[a]	970[a]	954[a]	949[a]	939[a]
Millet	165[f]	494[b]	0.03 [c]d	660[c]	474[d]	363[c]	342[d]	311[d]
Maize	400[c]	509[ab]	0.02 d	909[a]	665[b]	555[b]	536[b]	509[b]
SEM[2]	5.5	2.76	0.01	27.1	18.9	13.8	12.8	11.3
Significance[3]	***	***	***	***	***	***	***	***
Legume feedstuff								
Horse bean	425[c]	164[a]	0.03	711[c]	598[c]	541[c]	530[c]	513[c]
Soybean	985[a]	9[c]	0.07	993[a]	991[a]	990[a]	989[a]	989[a]
Mung bean	962[a]	21[c]	0.12	996[a]	983[a]	978[a]	976[a]	975[a]
Pea	801[b]	63[b]	0.08	881[b]	865[b]	851[b]	847[b]	842[b]
SEM	27.2	7.6	0.03	15.4	12.0	7.5	6.9	7.1
Significance	***	***	NS	***	***	***	***	***
Tuber feedstuff								
Sweat potato	386[b]	141	0.21 a	527[a] ab	515[ab]	500[b]	496[b]	488[b]
Cassava	25.2[d]	225	0.09 b	250[c]	208[c]	169[d]	159[d]	143[d]
Potato	277[c]	207	0.05 c	484[b]	424[b]	379[c]	370[c]	356[c]
SEM	2.7	43.2	0.01	44.0	34.5	26.1	24.2	21.1
Significance	***	NS	***	***	***	***	***	***
Mean								
Cereal feedstuff	418[b]	336[a]	0.14	754[b]	657[b]	595[b]	582[b]	562[b]
Legume feedstuff	793[a]	102[b]	0.08	895[a]	859[a]	840[a]	836[a]	830[a]
Tuber feedstuff	332[b]	171[b]	0.11	504[c]	470[c]	440[c]	433[b]	422[b]
SEM	60.9	36.3	0.02	44.1	48.2	53.1	54.1	55.7
Significance	***	***	NS	***	***	***	***	***

[1]α, rapidly soluble fraction as measured by washing loss from bag (g/kg starch); b, potentially degradable fraction (g/kg starch); K_d, constant rate of potentially degradable fraction (h^{-1}); ED, effective rumen degradability (g/kg Starch) measured at outflow rate (K_p) at 0.02, 0.05, 0.06, and 0.08 h^{-1}.

[2]SEM: standard error of means.

[3]Values in the same column with different letters (a-f) differ at P<0.05. NS, not significant; ***P<0.001.

wheat, respectively. There were significant differences (P<0.001) in the values of a, b, k_d, (a+b), and ED across all cereal grain feedstuffs (Table 2). The a value of CP for barely was higher than that of previously tested barley (Woods *et al.,* 2003), but lower than that of silage barely (Mustafa *et al.,* 2000), while the values of b and k_d of CP showed reverse order. The values of a and k_d of CP for rice were lower than that reported results by NRC (2001). The a values of CP for wheat and sorghum were similar to those data of NRC (2001), while the b values were lower than those data. The k_d value was higher for wheat and lower for sorghum than those data in NRC (2001). The values of a, b and k_d of CP for maize were lower than those data of NRC (2001). For starch of cereal feedstuffs, significant differences (P<0.001) were observed in the values of a, b, kd, (a+b) and ED among all feedstuffs. The extensively varied starch degradability (Table 3) might be dependent on its nature and structure, including crystal pattern, granule size and shape, amylose and amylopectin content and presence of a protein matrix (Offner *et al.,* 2003). The present data of ruminal degradable fraction of starch indicated that ruminal degradable starch represented the majority of total starch in cereal feedstuffs. Rice contained the highest potentially degradable starch, which was in agreement with the previous finding (Bednar *et al.,* 2001). Constant rate of starch degradation ranged from 0.02 h^{-1} for corn to 0.32 h^{-1} for wheat, which was consistent to the previous study (Offner *et al.,* 2003).

For ruminal CP degradation kinetics of legume feedstuffs, there were significant differences (P<0.001) in the values of a, k_d, (a+b), ED and in the value of b (P<0.05) among all feedstuffs. The a value of CP were generally much higher than previous data in Holstein (Woods *et al.,* 2003; Rotger *et al.,* 2006); but the corresponding value of pea was lower than reported result in Holstein (Mustafa *et al.,* 2000), but was in the range presented by Mustafa *et al.* (2002). The k_d and (a+b) of presently tested legume feedstuffs were relatively lower than those corresponding values of previous literatures and ED of CP varied widely (Woods *et al.,* 2003; Rotger *et al.,* 2006). For starch degradation kinetics of legume feedstuffs, with the exception of k_d, there were significant differences (P<0.001) in the values of a, b, (a+b) and ED across all feedstuffs. The k_d of starch in soybean, mung bean and pea was in the reported range of Yu *et al.* (2002). The legume feedstuffs generally had higher degradation rate of starch than most kinds of cereal feedstuffs except for buckwheat and wheat.

For tuber feedstuffs, there were significant differences (P<0.001) in the values of a, b, k_d, (a+b) and ED of CP among three tested feedstuffs. The values of ED and a of starch were the highest for sweat potato and the lowest for cassava. Potentially degradable fraction of starch showed no difference (P>0.05) among three tuber feedstuffs. For tuber feedstuffs, sweat potato and cassava were rarely studied. The values of a and k_d of CP for potato was completely inconsistent to those data of NRC (2001). This variation in ruminal degradation kinetics could be ascribed to the different variety, growth condition, storage method and so on. Effective rumen degradability of CP varied widely among the different sources of tuber feedstuffs, which was consistent to the previous study (Woods *et al.,* 2003).

In conclusion, the present study gave valuable information on *in situ* ruminal degradation of CP and starch in three classes of feedstuffs to enrich the nutritive value database of feedstuff resources and thus encourage the full utilization of the biological efficiency of CP and starch.

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References

AOAC. 1990. *Official Methods of Analysis* (15th Ed.). Association of Official Analytical Chemists. Arlington, VA, USA.

Bednar, G.E., Patil, A.R., Murray, S.M., Grieshop, C.M., Merchen, N.R. and Fahey, J.G.C. 2001. Starch and fiber fractions in selected food and feed ingredients affect their small intestinal digestibility and fermentability and their large bowel fermentability *in vitro* in a canine model. J. Nutr., 131: 276-286.

Bergmeyer, H.U. 1970. *Methoden de Enzymatischen Analysen,* Vol. 2, second ed. Verlag Chemie, Weinheim.

Cone, J.W. 1991. Degradation of starch in feed concentrates by enzymes, rumen fluid and rumen enzyme. J. Sci. Food Agric., 54: 22–34.

Mustafa, A.F., Christensen, D.A. and McKinnon, J.J. 2000. Effects of pea, barley, and alfalfa silage on ruminal nutrient degradability and performance of dairy cows. J. Dairy Sci., 83: 2859-2865.

Mustafa, A.F., Seguin, P., Ouellet, D.R. and Adelye, I. 2002. Effects of cultivars on ensiling characteristics, chemical composition, and ruminal degradability of pea silage. J. Dairy Sci., 85: 3411-3419.

NRC. 2001. *Nutrient Requirements of Dairy Cattle.* 7th rev. ed. National Academy Press, Washington, DC.

Offner, A., Bach, A. and Sauvant, D. 2003. Quantitative review of *in situ* starch degradation in the rumen. Anim. Feed Sci. Technol., 106: 81-93.

Ørskov, E.R. and McDonald, I. 1979. The estimation of protein disappearance in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. Camb., 92: 499-503.

Rotger, A., Ferret, A., Calsamiglia, S. and Manteca, X. 2006. *In situ* degradability of seven plant protein supplements in heifers fed high concentrate diets with different forage to concentrate ratio. Anim. Feed Sci. Technol., 125: 73-87.

Sun, Z.H., Tan, Z.L., Yao, J.H., Tang, Z.R., Shan, J.G., Hu, J.P., Tang, S.X. and Jiang, Y.M. 2007. Effects of intra-duodenal provison of limiting amino acids on serum concentrations of immunoglobulins and tissue concentrations of DNA and RNA in growing goats fed a maize stover-based diet. Small Ruminant Res., 69: 159-166.

Sveinbjörnsson, J., Murphy, M. and Udén, P. 2007. *In vitro* evaluation of starch degradation from feeds with or without various heat treatments. Anim. Feed Sci. Technol., 132: 171-185.

Tan, Z.L., Lu, D.X., Hu, M., Niu, W.Y., Han, C.Y., Ren, X.P., Na, R. and Lin, S.L. 2001. Effects of dietary nitrogen sources on fibre digestion and ruminal fluid characteristics in sheep fed wheat straw. Asian-Aust. J. Anim. Sci., 14: 1374-1382.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A. 1991. Symposium: Carbohydrate methodology, metabolism and nutritional implications in dairy cattle. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci., 74: 3583-3597.

Woods, V.B., Moloney, A.P. and O'Mara, F.P. 2003. The nutritive value of concentrate feedstuffs for ruminant animals Part II: *In situ* ruminal degradability of crude protein. Anim. Feed Sci. Technol., 110: 131-143.

Yu, P., Goelema, J.O., Leury, B.J., Tamminga, S. and Egan, A.R. 2002. An analysis of the nutritive value of heat processed legume seeds for animal production using the DVE/OEB model: a review. Anim. Feed Sci. Technol., 99: 141-176.