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Comparison of Gayal (*Bos frontalis*) and Yunnan Yellow Cattle (*Bos taurus*): *In vitro* Dry Matter Digestibility and Gas Production for a Range of Forages

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ABSTRACT : Three male Gayal, two years of age and with a mean live weight of 203±26 kg, and three adult Yunnan Yellow Cattle, with a mean live weight of 338±18 kg were fed a ration of pelleted lucerne hay and used to collect rumen fluid for *in vitro* measurements of digestibilities and gas production from fermentation of a range of forages. The forages were: bamboo stems, bamboo twigs, bamboo leaves, rice straw, barley straw, annual ryegrass hay, smooth vetch hay and pelleted lucerne hay. There were significant ($p<0.05$) effects of the source of rumen fluid on *in vitro* dry matter digestibility (IVDMD) and gas production during fermentation of forage. For the roughage of lowest quality (bamboo stems and rice straw), gas production during fermentation was higher ($p<0.05$) in the presence of rumen fluid from Gayal than Yunnan Yellow Cattle. Differences for these parameters were found for the better quality roughages with gas production being enhanced in the presence of rumen fluid from Yunnan Yellow Cattle. Moreover, the IVDMD of investigated roughages was significantly higher ($p<0.05$) in Gayal than Yunnan Yellow Cattle. The results offer an explanation for the positive live weight gains recorded for Gayal foraging in their natural environment where the normal diet consists of poor quality roughages. (**Key Words :** Gayal, Yunnan Yellow Cattle, Roughages, *In vitro* Dry Matter Digestibility, Gas Production)

INTRODUCTION

Different ruminant species have demonstrated different degradabilities of forages particularly under feeding condition of low quality roughages. For example, Zebu cattle (*Bos indicus*) are capable of utilising poor quality forages more efficiently than European cattle (*Bos taurus*) (Varel and Dehority, 1989). A number of studies revealed that digestibilities of nutrients in the rumen of water buffalo (*Bubalus bubalis*) are significantly higher than for cattle (Sangwan et al., 1987; Wanapat, 1989; Sommart et al., 1993; Saardrak et al., 1994; Hussain and Cheeke, 1996; Terramoccia et al., 2000; Wanapat et al., 2003). Moreover, wild herbivores also have been found to utilise low quality roughages more efficiently than their domesticated counterparts (Nelson et al., 2003).

Recently, we have reported that the semi-wild bovid species, the Gayal or Mithun (*Bos frontalis*), which is found naturally in harsh environments of Indo-China (Rajkhowa et al., 2006) where the diet consists predominantly of bamboo, reeds and woody plants, exhibit rumen characteristics which differ from those of cattle (Deng et al., 2007a, b). Gayal can attain greater mature body weight than cattle maintained in similar environments (Cheng, 1984; Giasuddin and Islam, 2003; Mao et al., 2005). Gayal also demonstrate good beef traits (Giasuddin et al., 2003) and better meat quality than native Yellow Cattle (Ge et al., 1996). Moreover, local government authorities have encouraged development by using locally specific livestock resources including the Gayal and black-boned sheep (*Ovis aries*) to improve cash income for impoverished local communities (Mao et al., 2005; Deng et al., 2006, 2007c).

Current researches have been focused on hormonal secretion of Gayal (Dhali et al., 2006a, 2006b; Mondal et al., 2005a, 2005b, 2006a, 2006b). However, up to now, rumen ecology and nutrient strategies of Gayal have received little attention. The objective of the present study was to investigate differences between Gayal and domesticated

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cattle in *in vitro* digestibility and gas production during fermentation in the presence of rumen fluid for a range of roughages. This result could provide a theoretical basis on nutrient schemes for feeding Gayal switching from wild to domesticated.

MATERIALS AND METHODS

Animals and feeding

Three male Gayal, 2 years of age and with a mean live weight of 203±26 kg, and three adult male Yunnan Yellow Cattle (*Bos taurus*), with a mean live weight of 338±18 kg, were used for the study. They were kept indoors in an open shed lit naturally and fed pelleted lucerne (*Medicago sativum*). The daily allocation of 7.4 kg for the Gayal and 6.7 kg for the Yunnan Yellow Cattle was offered in equal portions at 08:00 and 18:00 h (Deng et al., 2006a). Water was available *ad libitum*.

The composition of the diet, expressed as percent of dry matter, was as follows: dry matter (DM), 90.8; organic matter (OM), 89.7; crude protein (CP), 13.7; crude fibre (CF), 35.5; ash, 10.3; neutral detergent fibre (NDF), 52.8; acid detergent fibre (ADF), 44.1; acid detergent lignin (ADL), 8.8; and total digestible nutrients (TDN), 55.9. The diet was offered for 24 days before samples of rumen fluid were collected as described below.

Collections of rumen fluid and forages

The procedure described by Deng et al. (2007a) was used to collect rumen fluid. Briefly, in the morning of the 25^{th} day after commencing feeding of the pelleted lucerne and before offering fresh feed, approximately 500 ml of rumen fluid was collected from the middle part of the rumen of each animal using a stomach tube connected to a vacuum pump. The first 100 ml of fluid from each collection was discarded and the remaining fluid collections from each group of animals were pooled then filtered through four layers of cheese cloth into pre-warmed (39°C), insulated containers to give a pool of Gayal rumen fluid and a second pool of Yunnan Yellow Cattle rumen fluid. All handling of rumen fluid in the laboratory was carried out under a continuous flow of CO_2 (Srinivas and Krishnamoorthy, 2005).

Bamboo (*Sinarumdinaria* spp.), harvested from the mountain area adjacent to the Gayal Research Station (N25°47’2.6”; E99°5’56.5”, at an elevation of 2,260 m), was separated into leaf, stem and twig portions. Rice straw (*Oryza sativa*) was obtained from the area nearby the Gayal Research Station. Smooth vetch hay (*Vicia villosa*), annual ryegrass hay (*Lolium multiflorum*) and barley straw (*Hordeum vulgare*) were obtained from the Yunnan Beef and Pasture Research Centre, Xiaoshao, Yunnan Province, China. Pelleted lucerne hay was purchased from a local supplier.

Experimental design

The experiment was conducted as a 2×8 Factorial arrangements in a Randomised Complete Block Design (Steel and Torrie, 1980). The two factors were animal species (Gayal vs. Yunnan Yellow Cattle) and roughage type (bamboo leaf (BoL), bamboo stem (BoS), bamboo twig (BoT), barley straw (ByS), rice straw (ReS), smooth vetch hay (SmV), annual ryegrass hay (AnR) and pelleted lucerne hay (LuP)).

Chemical analyses of feedstuffs

The eight roughage feedstuffs were analysed for DM, CP, CF, ether extract (EE) and ash using the procedures described in AOAC (1990). The procedures described by Goering and van Soest (1970) were used to measure NDF, ADF, ADL and acid insoluble ash (AIA). Neutral detergent solution without α-amylase was used to measure NDF which was expressed with residual ash included. The concentrations of hemicellulose (HC = NDF-ADF) and cellulose (C = ADF-ADL) were calculated from measured components.

Measurements of *in vitro* dry matter digestibility (IVDMD) and gas production

The two-stage technique described by Tilley and Terry (1963) was used to measure digestibility of each roughage type *in vitro*. Briefly, each roughage was subjected to anaerobic incubation in rumen fluid (10 ml from either Gayal or Yunnan Yellow Cattle) and buffer (40 ml) for 48 h before further digestion for 48 h in acid pepsin solution (50 ml, pH 1.5). Each incubation was conducted in triplicate.

Gas production *in vitro* was measured as described by Menke and Steingass (1988). Known amounts (200±10 mg) of each air-dried feedstuff were weighed into glass syringes (70 ml) fitted with plungers. Syringes were filled with 30 ml of medium consisting of 10 ml rumen fluid (from either Gayal or Yellow Yellow Cattle) and 20 ml of buffer. Gas production was recorded at intervals over the following 120 h. For each roughage×rumen fluid combination analyses were conducted on five replicates. The exponential equation described by Ørskov and McDonald (1979) was used to analyse the kinetics of gas production. The equation was as follows:

$$GP = a+b\times(1-e^{-c\times t})$$

Where GP = gas production at time t; a = the rapidly produced gas fraction; b = the slowly produced gas fraction;

Table 1. Proximate analyses and fibre contents of bamboo stems (BoS), twigs (BoT) and leaves (BoL), rice straw (ReS), barley straw (ByS), smooth vetch hay (SmV), annual ryegrass hay (AnR) and pelleted lucerne hay (LuP) for which *in vitro* dry matter digestibility and gas production during fermentation were measured

Components	Roughages							
	BoS	BoT	BoL	ReS	ByS	SmV	AnR	LuP
Dry matter (%)	93.9	92.7	92.4	92.6	91.3	90.2	90.5	91.3
Organic matter (%DM*)	93.8	92.6	92.3	92.5	85.6	84.5	83.1	91.2
Crude protein (% DM)	3.3	4.6	17.7	3.9	4.2	12.6	14.0	14.7
Crude fibre (% DM)	50.6	38.5	22.6	35.7	37.6	36.5	25.6	34.6
Ether Extract (% DM)	0.03	0.7	2.9	1.2	2.0	1.5	3.4	1.5
Ash (% DM)	0.1	0.1	0.1	0.1	5.7	5.7	7.4	0.1
Neutral detergent fibre (% DM)	82.0	78.2	64.6	72.2	78.2	47.6	45.3	49.2
Acid detergent fibre (% DM)	63.7	54.5	36.5	50.1	54.5	43.5	29.3	43.0
Acid detergent lignin (% DM)	13.2	8.7	4.3	6.0	8.7	6.4	1.8	7.8
Hemicellulose (% DM)	18.3	23.8	28.2	22.1	23.8	4.1	16.0	6.2
Cellulose (% DM)	50.5	45.8	32.2	44.2	45.8	37.1	27.5	35.2
Acid insoluble ash (% DM)	4.0	6.6	6.9	6.2	6.6	0.5	0.5	2.1

* Percent of dry matter.

Table 2. Mean values (n = 3) for *in vitro* dry matter digestibilities of the seven roughages incubated in rumen fluid from Gayal or Yunnan Yellow Cattle together with standard error of the means (SEM) and the p values

Roughages	Rumen fluid from		SEM	p values
	Yunnan Yellow Cattle	Gayal		
Bamboo stems (BoS)	8.85	26.91	4.08	0.001
Bamboo twigs (BoT)	18.20	33.33	3.97	0.031
Bamboo leaves (BoL)	38.54	56.92	4.39	0.006
Rice straw (ReS)	26.64	46.23	4.53	0.002
Barley straw (ByS)	36.96	46.37	2.50	0.036
Dried Smooth vetch (SmV)	43.24	55.93	2.95	0.002
Pelleted lucerne hay (LuP)	44.15	66.83	5.15	0.001

c = the rate of gas production (% h) of fraction b; a+b = the potential extent of gas production; and t = the incubation time (h).

Statistical analyses

The parameters a, b, a+b and c from the measurement of gas production were estimated using non-linear regression by the DUD method, an iterative least squares procedure (SAS, 1989).

All data derived from the measurements of gas production were subjected to one way analysis of variance for the 2×8 Factorial arrangements of treatments using the General Linear Model of SAS (1989). Treatment means were compared using the Duncan's New Multiple Range Test (Steel and Torrie, 1980).

The significance of differences measured for *in vitro* digestibilities of roughages were assessed using t-tests (Steel and Torrie, 1980) and the statistical package of SAS (1989).

RESULTS

Composition of the roughages examined

The proximate and fibre analyses for the eight roughages are presented in Table 1. It is clear that based on these analyses the BoS was the poorest quality roughage with a very low CP and high fibre content (CF, ADF and ADL). Whilst the BoL had the highest CP of all feedstuffs examined, the quality of AnR, SmV and LuP exceeded that of ReS and ByS which in turn were of better quality than the BoS and BoT.

IVDMD

The measured IVDMD of the seven roughages are summarised in Table 2 (AnR was missing). For all roughages tested, IVDMD was significantly greater ($p<0.05$) when the roughage was incubated in the presence of rumen fluid from Gayal than from Yunnan Yellow Cattle.

Gas production

The profiles of gas production for the roughages examined are presented in Figure 1. Overall, gas production from fermentation *in vitro* of BoS, BoT and ReS in the presence of rumen fluid from Gayal exceeded that when rumen fluid from Yunnan Yellow Cattle was incubated with these roughages. In the cases of LuP and AnR gas production was higher in the presence of rumen fluid from Yunnan Yellow Cattle compared to Gayal. The production

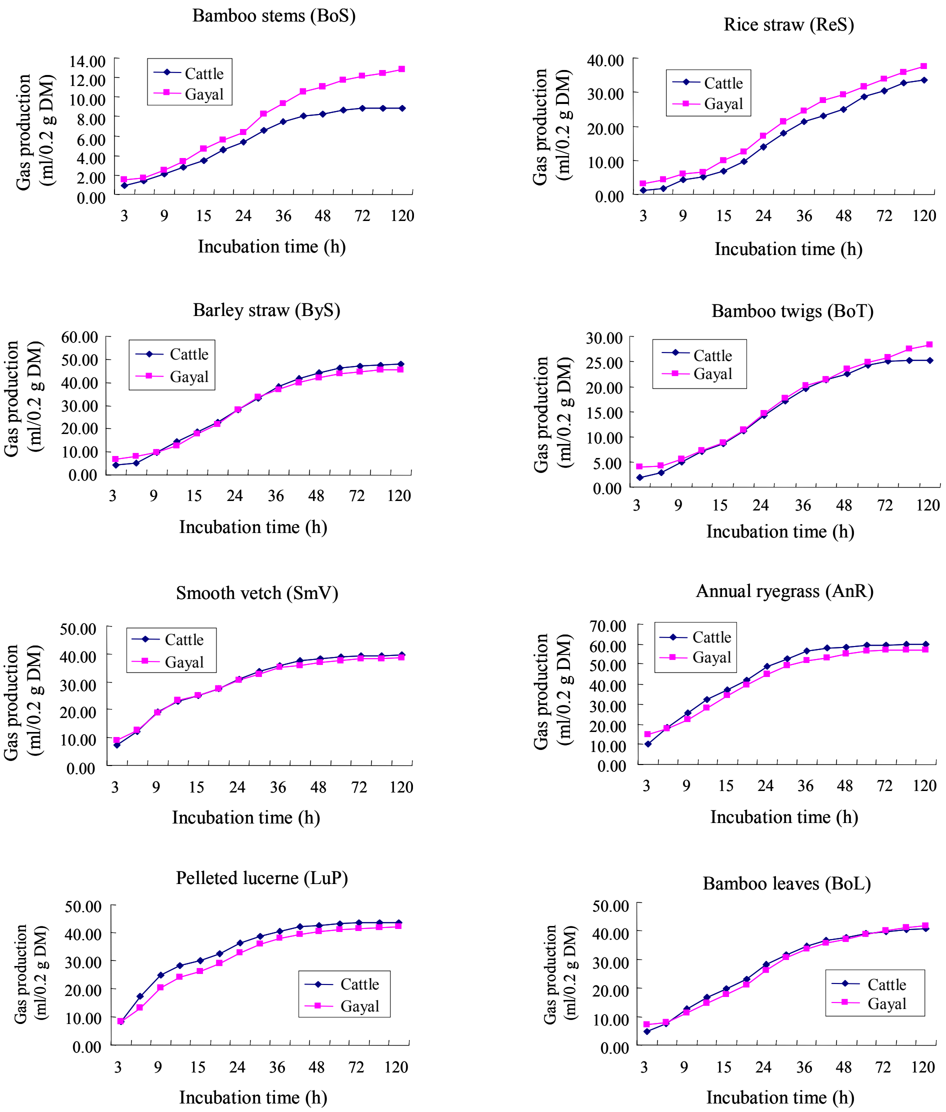

Figure 1. Production of gas during fermentation of roughage feedstuffs over 120 h in the presence of rumen fluid from Gayal (■----■) or Yunnan Yellow Cattle (Cattle, ♦-----♦).

of gas from BoL, SmV and ByS was similar for both sources of rumen fluid.

The kinetic parameters for gas production are summarised in Table 3. The intercept value (a) for the different roughages, representing gas production from the soluble fractions, ranged from -5.90 to 0.34 for the Yunnan Yellow Cattle and -3.10 to 3.00 for the Gayal. The gas production at the asymptote (b) represented the fermentation of the insoluble fractions of the respective roughages. For the Yunnan Yellow Cattle the ranking for this parameter was: AnR>ByS>BoL>LuP>ReS>SmV>BoT >BoS. A different ranking for the Gayal was: AnR>ByS> BoL>ReS>LuP>SmV>BoT>BoS.

The potential for gas production (a+b) was significantly higher ($p<0.05$) for BoS and ReS in the incubations containing rumen fluid from Gayal compared to Yunnan Yellow Cattle. For the remaining roughages the potential for gas production was similar in the presence of rumen fluid from both Gayal and Yunnan Yellow Cattle. Significantly lower ($p<0.05$) rates of gas production (c) were measured for BoL, BoT, LuP and AnR incubated with rumen fluid from Gayal than fromYunnan Yellow Cattle.

DISCUSSION

It has been observed that Gayal fed exclusively BoT and BoL *ad libitum* are able to achieve live weight gains of more than 100 g/d (Deng et al., will published elsewhere). The present results provide clear evidence that both Gayal and Yunnan Yellow Cattle are able to digest the nutrients contained in these poor quality roughages with Gayal having a greater capacity to do so than Yunnan Yellow Cattle.

In the present study the roughages with the highest

Table 3. Mean values (n = 5) for the derived parameters for the kinetics of gas production from the fermentation of roughages in the presence of rumen liquor from Gayal or Yunnan Yellow Cattle. The roughages were: bamboo stems (BoS), twigs (BoT) and leaves (BoL), rice straw (ReS), barley straw (ByS), smooth vetch hay (SmV), annual ryegrass hay (AnR) and pelleted lucerne hay (LuP), respectively

Items[1]	Treatments[2]																SEM[3]	Contrast[4]		
	Yunnan Yellow Cattle								Gayal									A	R	A×R
	BoS	ReS	ByS	BoT	SmV	AnR	LuP	BoL	BoS	ReS	ByS	BoT	SmV	AnR	LuP	BoL				
a, ml	-0.91^{bcd}	-4.18^{ab}	-5.90^{a}	-2.90^{abc}	0.03^{bcd}	-2.78^{abc}	0.34^{bcd}	-2.95^{abc}	-0.86^{bcd}	-2.78^{abc}	-3.10^{abc}	-0.74^{bcd}	2.10^{d}	3.00^{d}	0.93^{cd}	-0.63^{bcd}	0.335	**	**	NS
b, ml	10.21^{a}	40.85^{e}	55.88^{g}	29.49^{c}	39.47^{de}	63.28^{h}	42.85^{e}	44.27^{e}	14.29^{b}	42.47^{e}	50.70^{f}	30.30^{c}	36.15^{d}	55.18^{g}	41.06^{e}	43.44^{e}	1.536	*	**	**
a+b, ml	9.30^{a}	36.67^{d}	49.98^{h}	26.60^{c}	39.50^{def}	60.50^{j}	43.19^{fg}	41.32^{ef}	13.43^{b}	39.69^{ef}	47.60^{gh}	29.56^{c}	38.25^{de}	58.18^{i}	41.99^{ef}	42.81^{fg}	1.525	NS	**	**
c, %h	0.043^{d}	0.025^{a}	0.041^{cd}	0.038^{cd}	0.068^{g}	0.069^{g}	0.082^{h}	0.050^{e}	0.034^{bc}	0.027^{a}	0.040^{cd}	0.030^{ab}	0.067^{g}	0.057^{f}	0.065^{g}	0.040^{cd}	0.002	**	**	**

$^{a, b, c, d, e, f, g, h, i, j}$ Values in the same row with different superscripts differ ($p<0.05$).

[1] The gas parameters were calculated with exponential equation described by Ørskov and McDonald (1979) as: $GP = a+b\times(1-e^{-c\times t})$, where, GP = gas production at time t, a = the rapidly gas production fraction, b = the slowly gas production fraction, c = the rate of gas production (% h) of fraction b, a+b = potential extent of gas production, t = the incubation time (h).

[2] Treatments came from a 2×8 Factorial arrangements in a Randomised Complete Block Design (Steel and Torries, 1980) and indicated 16 combinations.

[3] SEM: standard error of the means.

[4] Probability of main effects of A (animal species: Gayal vs. Yunnan Yellow Cattle), R (roughages types: BoS vs. ReS vs. ByS vs. BoT vs. SmV vs. AnR vs. LuP vs. BoL), or the A×R interaction.

* $p<0.05$, ** $p<0.01$, NS: $p>0.05$.

quality, as assessed by the proximate analyses and fibre contents, were BoL, SmV, ByS, AnR and LuP. These roughages were either digested to a similar extent in the presence of rumen fluid from both Yunnan Yellow Cattle and Gayal or better digested in the presence of rumen fluid from Gayal than Yunnan Yellow Cattle.

The data for gas production from roughages are of interest in this connection. Thus the potential for gas production from the poorest quality roughages (BoS and ReS), which had the lowest contents of CP and high CF, was greater in the presence of rumen fluid from Gayal than Yunnan Yellow Cattle. For the other 6 roughages tested there was no significant effect of the source of rumen fluid on the potential for gas production. It has been reported that gas production is related positively to the degradability (digestibility) of feed as determined both *in vivo* and *in vitro* (Cone et al., 1997; Lee et al., 2001; Dhanoa et al., 2004; Kamalak et al., 2005; Ozkan and Sahin, 2006; Ozturk et al., 2006). The present results are in accord with this with the poorest quality roughages showing higher gas production and greater digestibility in the presence of rumen fluid from Gayal than Yunnan Yellow Cattle.

The differences for IVDMD and gas production (indicative of fermentation of the roughage) measured are considered to reflect the differences in the number and types of rumen microbes in the rumen fluid of Gayal and Yunnan Yellow Cattle. The higher digestibility and gas production from poor quality roughages in the presence of rumen fluid from Gayal certainly offers an explanation for the capacity of Gayal to utilise such poor quality roughages to meet their nutrient requirements.

The composition of the microbial populations in buffalo and cattle could provide a comparison between Gayal and Yunnan Yellow Cattle. Devendra (1987) and Wanapat (1989) reported that swamp buffalo have higher population of cellulolytic bacteria in the rumen. Singh et al. (1992) reported the populations of total viable, cellulolytic and amylolytic bacteria in buffalo were higher than in cattle. The average number of total viable bacteria was 16.20 and 13.20×10^{8} cells/ml for buffalo and cattle, respectively. The cellulolytic bacteria population in buffalo (6.86×10^{8} cells/ml) was 2-3 times higher than in cattle (2.58×10^{8} cells/ml) fed wheat straw-concentrate diet containing 10% CP. Wanapat et al. (2000) summarized the microorganism differences between buffalo and cattle and pointed out that buffalo have higher bacterial numbers compared with cattle. Digesta transferred from buffalo to cattle showed improved rumen ecology (Wanapat et al., 2003). Furthermore, water buffalo revealed greater digestibilities of diets than cattle fed identical diets (Wanapat et al., 1994; Hussain and Cheeke, 1996; Terramoccia et al., 2000).

In connection with the nature of the rumen microbes in Gayal and Yunnan Yellow Cattle, substantial differences have been reported recently. Deng et al. (2007a) showed that that there were more total (2.18 vs. 0.77×10^{9} CFU/ml) as well as cellulolytic (1.68 vs. 0.62×10^{9} CFU/ml) and amylolytic (2.64 vs. 0.61×10^{8} CFU/ml) bacteria in rumen fluid and higher concentrations of volatile fatty acids and NH_3-N, which is a major limiting factor, in rumen fluid in Gayal, compared to Yunnan Yellow Cattle, fed pelleted lucerne hay. Thus 2-3 folds higher total viable and fibrolytic bacteria in Gayal than Yunnan Yellow Cattle were measured. More recently, Deng et al. (2007b, 2007d) demonstrated that rumen fluid of Gayal fed fresh bamboo leaves and twigs contain a plethora of species of fibre digesting bacteria. Furthermore, the proportion of not-yet-cultured rumen bacteria was obviously higher in Gayal (68.6%) than Yak (*Bos grunniens*, 50%) and Jinnan Yellow Cattle (*Bos taurus*, 36%) (An et al., 2005; Deng et al., 2007d) but similar with swamp buffalo (69.3%) which were kept same environment (Gayal Research Station) and fed rice straw *ad libitum* (Deng et al., unpublished data). Similarly, Kobayashi (2006) pointed out that rumen samples of wild and semi-wild ruminants could contain novel bacteria to a greater extent than those of domestic counterpart. Thus, these reports hint that Gayl also have higher rumen degradabilities than cattle. Moreover, in the present study, our results provide these direct proof.

It is of interest to note that others have reported greater digestibilities for poor quality roughages for wild as opposed to domesticated ruminants. For example, Richmond et al. (1977) reported that Bison (*Bison bison*) had greater digestibilities than cattle for sedge and grass hays containing 7-8% CP but a similar digestibility for lucerne hay containing 19% CP. Similarly, Hawley et al. (1981) found that digestibilities of DM, CP, fat and ADF in hay containing 6% CP were greater for Bison than Hereford cattle whereas Peters (1958) reported similar digestibilities in bison and cattle fed good quality grass/lucerne with a supplement of grain.

CONCLUSIONS

In conclusion, the results of the present study offer an explanation for the greater live weight gains of Gayal, as compared to Yunnan Yellow Cattle, foraging in the areas where these animals are found naturally. Their capacity to utilise the poor quality roughages which constitute their normal diet has been confirmed by the *in vitro* measurements of digestibilities of a range of roughages and the gas produced during fermentation of these roughages. It would be appropriate to further confirm the capacity of Gayal to utilise poor quality forage by conducting feeding trials.

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REFERENCES

An, D., X. Dong and Z. Dong. 2005. Prokaryote diversity in the rumen of yak (*Bos grunniens*) and Jinnan cattle (*Bos taurus*) estimated by 16S rDNA homology analyses. Anaerobe. 11:207-215.

AOAC. 1990. Official Methods of Analysis. 15th edn. Association of Official Analytical Chemists, Arlington, Virginia.

Cheng, P. 1984. Livestock Breeds of China. Animal Production and Health. Paper 46 (E, F, S). Publication by FAO, Rome.

Cone, J. W., A. H. van Galder and F. Driehuis. 1997. Description of gas production profiles with a three phasic model. Anim. Feed Sci. Tech. 66:31-45.

Deng, W. D., D. M. Xi, H. M. Mao and M. Wanapat. 2007d. The use of molecular techniques based on ribosomal RNA and DNA for rumen microbial ecosystem studies: a review. Mol. Biol. Rep. DOI 10.1007/s11033-007-9079-1.

Deng, W. D., D. M. Xi, X. Gou, S. L. Yang, X. W. Shi and H. M. Mao. 2007c. Pigmentation in black-boned sheep (*Ovis aries*): association with polymorphism of the *tyrosinase* gene. Mol. Biol. Rep. DOI 10.1007/s11033-007-9097-z.

Deng, W. D., L. P. Wang, S. C. Ma, T. B. He, Z. F. Yang and M. Wanapat. 2007a. Comparison of Gayal (*Bos frontalis*) and Yunnan Yellow Cattle (*Bos taurus*): rumen function, digestibilities and nitrogen balance during feeding of pelleted lucerne (*Medicago sativum*). Asian-Aust. J. Anim. Sci. 20:900-907.

Deng, W. D., M. Wanapat, S. C. Ma, J. Chen, D. M. Xi, T. B. He, Z. F. Yang and H. M. Mao. 2007b. Phylogenetic analysis of 16S rDNA sequences manifest rumen bacterial diversity in Gayal (*Bos frontalis*) fed fresh bamboo leaves and twigs (*Sinarumdinaria*). Asian-Aust. J. Anim. Sci. 20(7):1057-1066.

Deng, W. D., S. L. Yang, Y. Q. Huo, X. Gou, X. W. Shi and H. M. Mao. 2006. Physiological and genetic characteristics of black-boned sheep (*Ovis aries*). Anim. Genet. 37:586-588.

Devendra, C. 1987. Herbivores in the arid and wet tropics. In: The Nutrition of Herbivores (Ed. J. BHacker and J. H. Ternouth). Academic Press. Australia. Parkville, NSW 2204. pp. 23-46.

Dhali, A., D. P. Mishra, M. Karunakaran, A. Mech and C. Rajkhowa 2006a. Secretion patterns of luteinising hormone, follicle-stimulating hormone and 17beta-oestradiol during oestrus and the mid-luteal phase of the oestrous cycle in mithun (*Bos frontalis*). Reprod. Fertil. Dev. 18:619-626.

Dhali, A., D. P. Mishra, A. Mech, M. Karunakaran and C. Rajkhowa. 2006b. Role of LH and prostaglandin F2alpha on the development and regression of corpus luteum in mithun (*Bos frontalis*) estrous cycle. Gen. Comp. Endocrinol. 149:173-181.

Dhanoa, M. S., J. France, L. A. Crompton, R. M. Mauricio, E. Kebreab, J. A. N. Mills, R. Sanderson, J. Dijkstra and S. López. 2004. Technical note: A proposed method to determine the extent of degradation of a feed in the rumen from the degradation profile obtained with the *in vitro* gas production technique using feces as the inoculum. J. Anim. Sci. 82:733-746.

Ge, C. R., Y. B. Tian, T. Chen and Y. Wu. 1996. Studies on the meat feature of gayal (*Bos frontalis*) (in Chinese). Scientia Agri. Sinica. 29:75-78.

Giasuddin, M. and M. R. Islam. 2003. Physical feature, physicalogical character and behavior study of gayal (*Bos frontalis*). Asian-Aust. J. Anim. Sci. 16:1599-1603.

Giasuddin, M., K. S. Huque and J. Alam. 2003. Reproductive potentials of gayal (*Bos frontalis*) under semi-intensive management. Asian-Aust. J. Anim. Sci. 16:331-334.

Goering, H. K. and P. J. van Soest. 1970. Forage Fibre Analysis (Apparatus, Reagent, Procedures and Some Application). Agricultural Handbook No. 379. Agricultural Research Service, United States Department of Agriculture, Washington, DC.

Hawley, A. W., L. D. G. Peden and W. R. Stricklin. 1981. Bison and Hereford steer digestion of sedge hay. Can. J. Anim. Sci. 61:165-174.

Hussain, I. and P. R. Cheeke. 1996. Evaluation of annual ryegrass straw:corn juice silage with cattle and water buffalo: digestibility in cattle vs. buffalo, and growth performance and subsequent lactational performance of Holstein heifers. Anim. Feed Sci. Tech. 57:195-202.

Kamalak, A., O. Canbolat, Y. Gurbuz, C. O. Ozkan and M. Kizilsimsek. 2005. Determination of nutritive value of wild mustard, sinapsis arvensis harvested at different maturity stages using *in situ* and *in vitro* measurements. Asian-Aust. J. Anim. Sci. 18:1249-1254.

Lee, S. S, J. K. Ha and K. J. Cheng. 2001. Effects of LCFA on the gas production, cellulose digestion and cellulase activities by the rumen anaerobic fungus, *Neocallimastix frontalis* RE1. Asian-Aust. J. Anim. Sci. 14:1110-1117.

Mao, H. M., W. D. Deng and J. K. Wen. 2005. The biology characteristics of gayal (*Bos frontalis*) and potential exploitation and utilization (in Chinese). J. Yunnan Agri. Univ. 20:258-261.

Menke, K. H. and H. Steingass. 1988. Estimation of the energetic feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid. Anim. Res. Dev. 28:7-55.

Mondal, M., B. Prakash, C. Rajkhowa and B. S. Prakash. 2005b. Twenty-four-hour secretion patterns of luteinizing hormone in mithuns (*Bos frontalis*). Gen. Comp. Endocrinol. 144:197-203.

Mondal, M., C. Rajkhowa and B. S. Prakash. 2005a. Secretion patterns of luteinizing hormone in growing mithuns (*Bos frontalis*). Reprod. Biol. 5:227-235.

Mondal, M., C. Rajkhowa and B. S. Prakash. 2006a. Exogenous GH-releasing hormone increases GH and LH secretion in growing mithuns (*Bos frontalis*). Gen. Comp. Endocrinol. 149:197-204.

Mondal, M., C. Rajkhowa and B. S. Prakash. 2006b. Oestrous behaviour and timing of ovulation in relation to onset of oestrus and LH peak in Mithun (*Bos frontalis*) cows. Reprod. Domest. Anim. 41:479-484.

Nelson, K. E., S. H. Zinder, I. Hance, P. Burr, D. Odongo, D. Wasawo, A. Odenyo and R. Bishop. 2003. Phylogenetic analysis of the microbial populations in the wild herbivore gastrointestinal tract: Insights into an unexplored niche. Environ. Microbiol. 5:1212-1220.

Ørskov, E. R. and L. McDonald. 1979. The estimation of protein degradability in the rumen fromincubation measurements weighed according to the rate of passage. J. Agric. Sci. (Camb). 92:499-504.

Ozkan, C. O. and M. Sahin. 2006. Comparison of *in situ* dry matter degradation with *in vitro* gas production of oak leaves supplemented with or without polyethylene glycol (PEG). Asian-Aust. J. Anim. Sci. 19:1120-1126.

Ozturk, D., M. Kizilsimsek, A. Kamalak, O. Canbolat and C. O. Ozkan. 2006. Effects of ensiling alfalfa with whole-crop maize on the chemical composition and nutritive value of silage mixtures. Asian-Aust. J. Anim. Sci. 19:526-532.

Peters, H. F. 1958. A feedlot study of bison, cattle and Hereford calves. Can. J. Anim. Sci. 38:87-90.

Rajkhova, S., D. K. S. Arma and C. Rajkhova. 2006. Seroprevalence of *Toxoplasma gondii* antibodies in captive mithuns (*Bos frontalis*) from India. Vet. Parasitol. 135:369-374.

Richmond, R. J., R. J. Hudson and R J. Christopherson. 1977. Comparison of forage intake and digestibility by American bison, yak and cattle. Acta Theriol. 22:225-230.

Saardrak, K., K. Sommart, C. Wachirapakorn and M. Wanapat. 1994. A comparative study on ruminal degradabilities between cattle and swamp buffalo. In: Proceedings of the First Asian Buffalo Association Congress. Jannary 17-21, 1994, Khon Kaen, Thailand. pp. 262-264.

Sangwan, D. C., K. Pradhan and V. Sagar. 1987. Effect of dietary fibre and protein sources on rumen metabolites and nutrient digestibility in cattle and buffalo. Indian J. Anim. Sci. 57:562.

SAS. 1989. SAS/STAT User's Guide: Version 6. 4th edn. SAS Institute Inc. Cary, North Carolina.

Singh, S., K. Pradhan, S. K. Bhatia, D. C. Sangwan and V. Sagar. 1992. Relatives rumen microbial profile of cattle and buffalo fed wheat straw-concentration diet. Indian J. Anim. Sci. 62:1197-1202.

Sommart, K. M., M. Wanapat, W. Wongsrikeao and S. Ngarmsak. 1993. Effect of yeast culture and protein levels on ruminal fermentation, intake, digestibility and performance in ruminants fed straw-based diets. In: World Conference on Animal Production (Volume II). Edmonton, Alberta, Canda. pp. 60-61.

Srinivas, B. and U. Krishnamoorthy. 2005. Influence of diet induced changes in rumen microbial characteristics on gas production kinetics of straw substrates *in vitro*. Asian-Aust. J. Anim. Sci. 18:990 -996.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd edn. McGraw-Hill Book Company, New York, New York.

Terramoccia, S., S. Bartocci, A. Amici and F. Martillotti. 2000. Protein and protein-free dry matter rumen degradability in buffalo, cattle and sheep fed diets with different forage to concentrate ratios. Livest. Prod. Sci. 65:185-195.

Tilley, J. M. A. and R. A. Terry. 1963. A two stage technique for *in vitro* digestion of forage crops. J. Br. Grassl. 18:104-111.

Varel, V. H. and B. A. Dehority. 1989. Ruminal cellulolytic bacteria and protozoa from Bison, cattle-bison hybrids and cattle fed three alfalfa-corn diets. Appl. Environ. Microbiol. 55:148-153.

Wanapat, M. 1989. Supplementary feeds: Their effects on performance of drought animals and their acceptability to Southeast Asian farms. In: Draught Animals in Rural Development. (Ed. D. Hoffman, J. Nari and R. J. Petheram). ACIAR, Australia. pp. 617-622.

Wanapat, M., K. Sommart, C. Wachirapakorn, S. Uriyapongson and C. Wattanachant. 1994. Recent advances in swamp buffalo nutrition and feeding. In: Proceedings of the First Asian Buffalo Association Congress. January 17-21. Khon Kaen, Thailand. pp. 155-187.

Wanapat, M., N. Nontaso, C. Yuangklang, S. Wora-anu, A. Ngarmsang, C. Wachirapakorn and P. Rowlinson. 2003. Comparative study between swamp buffalo and native cattle in feed digestibility and potential transfer of buffalo rumen digests into cattle. Asian-Aust. J. Anim. Sci. 16:504-510.

Wanapat, M., O. Pimpa, A. Petlum, C. Wachirapakorn and C. Yuanklang. 2000. Participation scheme of smallholder dairy farmers in the northeast Thailand on improving feeding systems. Asian-Aust. J. Anim. Sci. 13:830-836.