



Growth Performance, Feed Efficiency and Ingestive Behaviour of Barbari Goats Divergently Selected for Residual Feed Intake

Rohit Kumar¹, Debashis Roy¹, Ajit Kumar¹, Ram Kumar Singh¹,
Gulab Chandra², Ahmad Fahim⁴, Atul Gupta³, Anuj Kumar⁴

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ABSTRACT

Background: Residual feed intake (RFI) is the discrepancy between an animal's actual feed consumption and the anticipated feed intake, determined by its body weight and growth rate during a specific period of time. It may serve as an effective selection criterion for enhancing feed efficiency in Barbari goats.

Methods: Barbari goats (24) of similar age group were taken from Livestock farm complex II (LFC II), SVPUAT, Uttar Pradesh. All the investigational Barbari goats were fed ad libitum on TMR based diet involved of concentrate mixture: green maize fodder: wheat straw in the ratio of 50: 20:30 (on DM basis) for a period of 120 days. TMR were prepared daily by hand mixing separate for each animal and contained 13.96% CP and an estimated metabolizable energy (ME) concentration of 2.41 Mcal/kg DM. Nutrient requirement of Barbari goats were met by feeding as per guidelines of NRC (2001). The TMR were offered at 09:00 h and 18:00 h. The Barbari goats were fed the TMR in such an amount that at minimum 250 g refusals were left daily per goats.

Result: It was concluded that Body weight were found to be significant. Expected DMI in low and high RFI goat kids were -0.029 and 0.028 kg/day whereas observed DMI in low and high RFI goat kids were 0.38 and 0.47 kg/day, respectively. ADG were not found non-significant. Out of 24 experimental Barbari goats, 13 Barbari goats were having negative RFI and rest 11 Barbari goats were having positive RFI. The digestibility coefficients for most nutrients were elevated in the low RFI group with respect to high RFI group, the mean values exhibited significant differences across the groups. Significant differences between RFI classes were observed for FCR, FCE, KR and RGR. All the parameters showed that low RFI Barbari goats were more effective in feed utilization than high RFI Barbari goats. With respect to ingestive behaviour FT (min/kg DM), RT (min/kg DM) and CT (min/kg DM) shows significant variation between low and high RFI. So, it can be concluded that low RFI Barbari goats exhibit greater efficiency as they consume less feed, spend reduced time in feeding events and need less metabolisable energy for body maintenance.

Key words: Barbari goats, High, Ingestive behaviour, Low residual feed intake.

INTRODUCTION

Residual feed intake (RFI) is increasingly recognized as a critical tool for feed efficiency in livestock, including goats. It is the difference between an animal's actual feed intake and its predicted feed requirements based on its body weight, growth rate and in some cases, composition of gain or milk production (Koch *et al.*, 1963; Herd *et al.*, 2003). Animals with a lower or negative RFI are considered more efficient as they consume less feed than expected for their level of production, while those with a higher or positive RFI are less efficient, consuming more feed than predicted (Nkrumah *et al.*, 2006). The importance of RFI in goat production systems is multifaceted. Feed costs represent a substantial portion of total production expenses in most livestock operations, often ranging from 55% to 75% (Arthur *et al.*, 2001; Basarab *et al.*, 2002; NRC, 2001). Improving feed efficiency through selection for lower RFI can, therefore, lead to significant economic benefits for producers by reducing these input costs. Even modest improvements in feed efficiency can have a considerable impact on farm profitability (Basarab *et al.*, 2002). Identifying genetic markers associated with favourable RFI could further accelerate genetic progress. Ingestive behaviour, feed intake, feed digestion and associated energy utilisation are among the biological components that

¹Department of Animal Nutrition, College of Veterinary and Animal Sciences, Sardar Vallabhbhai Patel University of Agriculture and Technology, Modipuram, Meerut-250 110, Uttar Pradesh, India.

²Department of Veterinary Physiology and Biochemistry, College of Veterinary and Animal Sciences, Sardar Vallabhbhai Patel University of Agriculture and Technology, Modipuram, Meerut-250 110, Uttar Pradesh, India.

³Department of Animal Genetics and Breeding, College of Veterinary and Animal Sciences, Sardar Vallabhbhai Patel University of Agriculture and Technology, Modipuram, Meerut-250 110, Uttar Pradesh, India.

⁴Department of Livestock Production and Management, College of Veterinary and Animal Sciences, Sardar Vallabhbhai Patel University of Agriculture and Technology, Modipuram, Meerut-250 110, Uttar Pradesh, India.

Corresponding Author: Rohit Kumar, Department of Animal Nutrition, College of Veterinary and Animal Sciences, Sardar Vallabhbhai Patel University of Agriculture and Technology, Modipuram, Meerut-250 110, Uttar Pradesh, India. Email: rohitkumar112262@gmail.com

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contribute to the variability in RFI. Activity, thermoregulation and metabolism, including anabolism and catabolism (Nguyen *et al.* 2005). The identification of low RFI in farm animals and their subsequent use in breed improvement programs can significantly contribute to achieving the goals of breed enhancement and efficient nutrient utilisation. The purpose of this study is to evaluate the performance of Barbari goats that have been specifically bred for both high and low residual feed intake (RFI).

MATERIALS AND METHODS

The materials and methods followed for the above study have been described as under.

Approval from animal ethics committee

All of the procedures carried out and animal welfare were reviewed and approved by the Institutional Animal Ethics Committee of the Sardar Vallabhbhai Patel University of Agriculture and Technology (IAEC/SVPUAT/2023/132).

Animal selection and experimental design

Barbari goats (24) of similar age group were taken from Livestock farm complex II (LFC II), SVPUAT, Uttar Pradesh. For 120 days, all of the experimental Barbari goats were fed an unlimited TMR-based diet consisting of a concentrate mixture of green maize fodder, wheat straw and green maize fodder in the ratio of 50:20:30 (on a DM basis). Barbari goats were given ten days to become used to the new surroundings and food schedule during their initial (preliminary) adjustment phase at the testing site. Following this initial phase, a 120-day measurement period (growth trial) were conducted in accordance with Archer *et al.* (1997) suggestions about the ideal test duration for assessing RFI. The calculated metabolisable energy (ME) concentration of the TMR were 13.96% CP and 2.41 Mcal/kg DM. Each animal's mixture were prepared by hand each day (Table 1). The nutritional requirements of Barbari goats were met by feeding them in compliance with NRC (2001) guidelines. The TMR were available from 9:00 to 18:00. The TMR were fed to the Barbari goats in such a way that each goat had at least 250 g of refusals every day. Ad libitum fresh drinking water were provided twice a day at 8:00 and 17:00. At the conclusion of the investigation, a 6-day digestion trial were carried out. To assess the efficiency of nutrient utilisation in low and high RFI Barbari goats, a digestion experiment with a 4-day adaption time followed by a 6-day collection period were carried out at the end of the study. Every day, samples were taken for chemical analysis of the TMR offered and the refusals. For six days, faeces voided in a 24-hour period were gathered and measured every day. Chemical analysis were performed on 1/100 of the well mixed total faecal matter. In order to determine nitrogen (N), 1% of the entire faeces sample were taken every day and placed in plastic containers with 30 millilitres of a 25% sulphuric acid solution. Proximate analysis were quantified following the methodologies outlined by Van Soest *et al.* (1991).

Management of animals

Each goat had enough room and comfort in their cement floor, which were furnished with automatic feeders and watering systems. Farm management maintained a regular anthelmintic and immunisation program for all experimental animals. The goats were housed in enclosures with unrestricted mobility.

Sample analysis

All experimental Barbari goats feed efficiency, growth performance and ingestive behaviour were monitored every day for DMI for every two weeks. To calculate DM, the feed that were offered and the feed that were refused were weighed every day, sampled twice a week and totalled to reflect each 90-day period. DMI were calculated as the difference between the quantity offered and the quantity refused.

To enhance the precision of average daily gain (ADG) estimations, Barbari goats were weighed biweekly in the early morning (06:00 h) prior to the provision of feed and water. In addition to RFI, Barbari goats were examined biweekly for other feed efficiency metrics, including FCR (feed-to-gain ratio), FCE (gain-to-feed ratio), Kleiber ratio (KR) and relative growth rate (RGR). FCR were determined

Table 1: Ingredient and chemical composition of TMR fed during experimental period (expressed as g/kg unless otherwise stated).

Items	Concentrate	TMR
Wheat straw		200
Maize fodder		300
Concentrate		500
Barley grain	200	
Wheat grain	200	
Oat grain	100	
Wheat bran	100	
Gram chunni	100	
Mustard oil cake	280	
Mineral mixture	20	
TMR chemical composition (g/kg DM)		
Dry matter	473.27	
Organic matter	895.79	
Total ash	106.24	
Crude protein	139.68	
Ether extract	29.26	
Crude fibre	189.42	
Nitrogen free extract	537.11	
Neutral detergent fibre	531.5	
Acid detergent fibre	326.08	
Hemicellulose	199.42	
Acid detergent lignin	21.65	
Cellulose	307.65	
ME (Mcal/kg DM)	2.41	

TMR, total mixed ration; ME, metabolizable energy (calculated as per NRC, 2001).

as the ratio of DMI to ADG; FCE were computed as the ratio of ADG to DMI. KR were determined as the ratio of ADG to average metabolic body weight, whereas PEG were computed as the ratio of ADG to the amount of feed utilised for growth (NRC, 2001).

The RGR were computed in accordance with the methodology established by Fitzhugh and Taylor (1971).

$$\text{RGR} = 100 \times \frac{\log \text{FBW} - \log \text{IBW}}{\text{Days of experiment}}$$

During the midpoint of the trial, ingestive behaviour were assessed by observing Barbari goats for chewing, feeding, rumination, inactivity, standing and lying down. The behavioural events were manually recorded by four observers, each accountable for a daily duration of six hours. Feeding time (FT; min/d) were defined as the total duration spent by the Barbari goats eating TMR over a 24-hour period. During rumination, three rumen boluses per Barbari goats were monitored and the quantity and duration of mastication each bolus were recorded as the chewing rate (CT). Rumination time (RT) were the cumulative duration of ruminating activity in Barbari goats during a 24-hour period. Time spent on idleness (TI) were calculated by deducting the duration of events (in minutes per day) from the total duration of the day (1440 minutes). The length of diet-related activities (min/kg DM), including feeding time per kg DM (FTDM), rumination time per kg DM (RTDM) and chewing time per kg DM (CTDM), were calculated by dividing the total duration of these activities by the total amount of feed consumed.

The average daily gain (ADG) were determined by employing the linear regression coefficient of weights relative to the duration of the trial in days following Archer *et al.* (1997):

$$y_i = \alpha + \beta \times \text{DIT}_i + e_i$$

In this context,

y_i = Body weight of Barbari goats in the i^{th} observation.

α = Intercept of the regression equation related to the initial body weight.

β = Linear regression coefficient associated with average daily gain (ADG).

DIT_i = Number of days in trial for the i^{th} observation.

e_i = Random error.

The mid-test metabolic body weight (MBW) were determined using the following equation:

$$\text{MBW} = [\alpha + \beta \times \text{study period}/2]^{0.75}$$

In this context,

α = Intercept of the regression equation associated with the beginning body weight.

β = Linear regression coefficient related to average daily gain (ADG).

Barbari goats were categorised into low and high Residual Feed Intake groups. The RFI were computed *via* the subsequent formula:

$$\text{RFI (kg/d)} = \text{Actual DMI (kg/d)} - \text{Predicted DMI (kg/d)}$$

The daily measurements of provided and refused dry matter (DM) were utilised to compute the actual dry matter intake (DMI) by subtraction. The anticipated dry matter intake (DMI) of individual Barbari goats were determined by the use of multiple regression models.

$$Y_j = \beta_0 + \beta_1 \text{MBW}_j + \beta_2 \text{ADG}_j + e_j$$

In this equation,

Y_j = Anticipated dry matter intake (DMI) of the j^{th} animal.

β_0 = Regression intercept.

β_1 = Regression coefficient for metabolic body weight (MBW).

β_2 = Regression coefficient for average daily gain (ADG).

e_j = Uncontrolled error associated with the j^{th} animal.

Statistical analysis

The data were assessed for significance ($P < 0.05$) and correlation coefficient (r) using the Statistical Package for the Social Sciences (SPSS for Windows). Version 21.0; SPSS Inc., Chicago, Illinois, United States. Significance were evaluated using one-way analysis of variance (ANOVA). A significance level of 0.05 were employed to ascertain statistical significance. A Pearson square correlation coefficient more than or less than zero indicates a positive or negative association between RFI and qualities, respectively, whereas a coefficient of zero signifies no link between RFI and attributes.

RESULTS AND DISCUSSION

Intake and digestibility of nutrients

Expected and observed DMI in experimental goat kids are given in Table 2 (Fig 1). A range of 0.31 to 0.55 kg/day were observed for daily DMI. Mean daily DMI, fortnightly DMI and percent DMI (kg/100 kg BW) were observed significantly lower ($P < 0.05$) in low RFI goat kids compared to high RFI goat kids and goat kids with low RFI Barbari goats consumed 35% less DM than Barbari goats of high RFI group. Significant ($P < 0.05$) positive correlation were observed between RFI value and daily DMI ($r = 0.866$), fortnightly DMI ($r = 0.867$) and percent DMI ($r = 0.871$). Average RFI values in High and Low RFI experimental goat kids ranged from -0.029 to +0.028 kg/day, representing a difference of 0.057 kg of feed per day. Mean RFI values in low and high RFI goat kids were -0.029 and +0.028 kg/day, respectively. The values for ADG ranged from 45 to 67 g/day. ADG did not differ significantly ($P > 0.05$). Out of 24 experimental Barbari goats, 13 Barbari goats having negative RFI and rest 11 Barbari goats having positive RFI.

Bonilha *et al.* (2013) identified a 0.656 kg/day disparity in RFI between low and high RFI Nellore calves of similar body size and development rate. Zhang *et al.* (2017) found that RFI showed no link with metabolic BW (MBW) or average daily gain (ADG), but it did have a positive correlation with dry matter intake (DMI) and feed conversion ratio (FCR). Nascimento *et al.* (2015) reported that Nellore cattle with low RFI (≤ 0.128 kg/day) ingested 7.2 kg DM/day, representing a 14.0% reduction compared to those with high RFI (> 0.135 kg/day). No notable variations in average

daily gain were detected across the residual feed intake classes. Bose *et al.* (2014) documented a 10% reduction in dry matter intake (DMI) among Murrah buffalo calves exhibiting low residual feed intake (RFI) compared to those with high RFI (-0.20 vs. 0.23 kg DM/day), notwithstanding the absence of differences in body weight increase. Although high RFI beef heifers ingested 16% more feed DM than low RFI heifers, Fitzsimons *et al.* (2014) noted comparable ADG across the two groups (-0.43 vs. 0.44 kg/day). Steyn *et al.* (2014) and Sobrinho *et al.* (2011) observed that low RFI animals exhibited comparable growth rates and reduced feed consumption relative to high RFI animals. Bonilha *et al.* (2013), Nascimento *et al.* (2015) and Sharma *et al.* (2016) indicated a positive link between RFI and feed intake, however the correlation between RFI and body

weight increase were zero. Arce-Recinos *et al.* (2022) indicated that lambs exhibited an average daily dry matter intake (DMI) of 1.15 ± 0.069 kg and a daily weight gain (DWG) of 216 ± 8.68 g. Low-RFI lambs consumed 84 g/d less than anticipated ($P < 0.001$), but high-RFI lambs consumed 77 g/d more. Although the total DMI exhibited no significant difference, efficient lambs (low-RFI) consumed 150 g/d less feed than their inefficient counterparts. A reduced feed intake in more efficient calves, without a change in growth rate, indicates that these animals utilised feed resources for tissue growth more effectively, attributable to the greater metabolizability of the ingested feed.

Digestibility coefficients for most nutrients were elevated in the low RFI group with respect to the high RFI group, the mean values exhibited significant differences across the

Table 2: Intake and digestibility of nutrients in low and high RFI in Barbari goats.

Attributes	RFI		P-value	Correlation coefficient
	Low (-0.029)	High (0.028)		
Initial BW (kg)	7.61 ^a	9.16 ^b	0.009	0.652
Mid test BW (kg)	11.19 ^a	12.44 ^b	0.035	0.539
Final BW (kg)	14.43	15.52	0.075	0.447
MBW (kg)	6.26 ^a	6.74 ^b	0.045	0.518
DMI (kg/day)	0.38 ^a	0.47 ^b	<0.001	0.866
DMI (kg/100 kg BW)	3.33 ^a	3.69 ^b	<0.001	0.871
DCPI (kg/day)	49.48	52.65	0.301	0.399
ADG (kg/day)	0.057	0.053	0.122	-0.437
Apparent nutrient digestibility (%)				
Dry matter	63.48 ^a	58.15 ^b	<0.001	-0.463
OM	68.18 ^a	64.12 ^b	<0.002	-0.307
CP	73.11	69.76	0.112	-0.321
EE	84.10 ^a	81.84 ^b	<0.001	-0.312
NFE	77.32 ^a	74.18 ^b	<0.001	-0.300
NDF	50.19 ^a	43.50 ^b	<0.002	-0.277
ADF	46.28 ^a	38.978 ^b	<0.001	-0.288

βMean with different superscript in a row differs significantly ($P < 0.05$); ¥Pearson square correlation coefficient between RFI and attributes; RFI: Residual feed intake; BW: Body weight; MBW: Mid-test metabolic body weight; DMI: Dry matter intake; DMIBW: Dry matter intake in relation to body weight; DCPI: Digestible crude protein intake (estimated during digestion trial; ADG: Average daily gain.

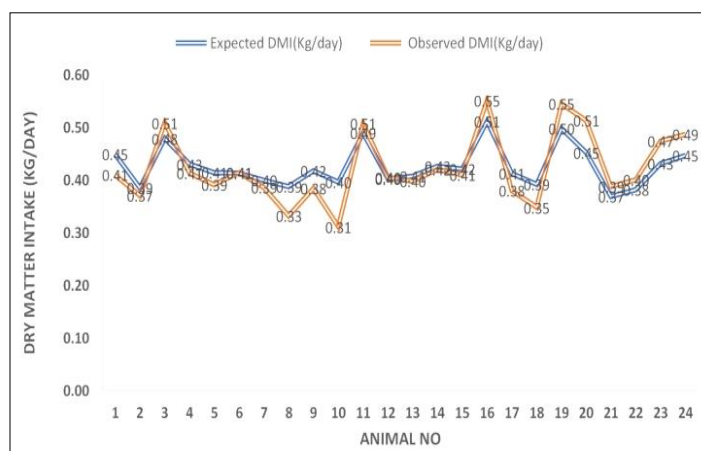


Fig 1: Relationship between RFI and expected observed DMI (kg/day).

groups. The animals with lower RFI, those that are more feed-efficient, consumed less dry matter and crude protein, especially when measured on a daily intake basis, with statistically significant differences in some variables. These lower intakes were positively correlated with RFI, suggesting that maximum feed efficiency (*i.e.*, lower RFI) is related with reduced intake requirements to maintain performance. However, no significant difference were observed in digestible crude protein or total digestible nutrient intake across most metrics, indicating that despite consuming less, feed-efficient animals were able to maintain similar levels of digestible nutrient intake. Nkrumah *et al.* (2006) noted a six percent increase in apparent digestibility of dry matter in the low RFI group compared to the high RFI group, suggesting that animals with low RFI exhibit superior nutrient utilisation efficiency relative to those with high RFI. Richardson *et al.* (2001) assessed digestibility in growing cattle that were divergently selected for low and high Residual Feed Intake after one generation. When provided with roughage-based diets, low RFI bulls and heifers exhibited superior digestibility relative to their high RFI counterparts. Nonetheless, Bose *et al.* (2014) and Sharma *et al.* (2016) observed comparable nutritional digestibility between low and high RFI animals, potentially attributable to a narrower variance in RFI within the groups classified as low and high RFI. Differences in intake and digestibility may be ascribed to the alteration in the rumen microbial population between efficient and inefficient animals (Guan *et al.*, 2008). Arce-Recinos *et al.* (2022) reported in lambs that intake were adjusted for metabolic body weight ($\text{g/kg LW}^{0.75}$), low-RFI lambs had significantly lower DMI, OMI, CPI and NDFI, indicating higher feed efficiency.

Feed efficiency and ingestive behaviour

Estimation of feed efficiency and ingestive behavior in low and high RFI Barbari goats is presented in Table 3. Significant disparities among RFI classes were detected for the other efficiency indicators examined for FCR ($P<0.01$), FCE ($P=0.002$), KR ($P=0.008$) and RGR ($P=0.007$). It is observed that low RFI Barbari goats were more efficient in utilization of feed than high RFI Barbari goat. Low RFI Barbari goats showed better FCR, FCE, KR and RGR than Barbari goats with high RFI, respectively. FCR and FCE were 22.5% and 33.3% better in low RFI Barbari goats compared to high RFI Barbari goat. RFI presented significant ($P<0.05$) moderate negative correlation with FCE, KR, RGR and positive correlation with FCR. Mean BCS values in both RFI Barbari goats were found to be similar in two groups. Animals with low Residual Feed Intake (RFI) exhibited superior residual weight gain, residual intake-weight gain and feed efficiency along with a reduced Feed Conversion Ratio (FCR) compared to those with medium and high RFI (Nascimento *et al.*, 2015). Previous studies (Bose *et al.*, 2014; Sharma *et al.*, 2014; Sharma *et al.*, 2016) indicated superior feed conversion ratios in low residual feed intake animals compared to high residual feed intake animals. Kelly *et al.* (2014) identified a negative connection between residual feed intake (RFI) and feed conversion efficiency (FCE) and average daily gain (ADG). Our findings corroborate this, suggesting that imposing selection pressure for FCR or FCE will likely result in an increase in mature size, thereby elevating maintenance energy and feed requirements.

Feeding time (FT) per day showed no significant difference between the low RFI group and the high RFI group. However, when feeding time were adjusted per

Table 3: Measures of feed efficiency and ingestive behavior in low and high RFI in Barbari goats.

Attributes	RFI		P-value	Correlation coefficient
	Low	High		
Feed efficiency measures				
RFI (kg/day)	-0.029	0.028		
Feed conversion ratio	7.72 ^a ±0.34	9.96 ^b ±0.37	<0.01	0.79
Feed conversion efficiency	0.16 ^a ±0.007	0.12 ^b ±0.008	0.002	-0.84
Kleiber ratio	0.009 ^a ±0.0003	0.008 ^b ±0.0003	0.008	-0.69
Relative growth rate	0.23 ^a ±0.009	0.19 ^b ±0.010	0.007	-0.71
Body condition score	2.86±0.35	2.85 ±0.38	0.96	0.085
Ingestive behavior (min/day)				
Feeding time (min/day)	297.92±2.58	296.55±2.80	0.721	-0.233
FT (min/kg DM)	787.66 ^a ±24.57	637.49 ^b ±26.72	<0.001	-0.878
RT (min/day)	442.23±5.42	430.36±5.89	0.152	-0.187
RT (min/kg DM)	1166.78 ^a ±35.33	925.93 ^b ±38.40	<0.001	-0.853
Chewing time (min/day)	247.69±4.26	241.27±4.63	0.319	-0.358
CT (min/kg DM)	634.37 ^a ±28.40	520.52 ^b ±30.88	0.013	-0.672
Time spent on idleness (min/day)	922.15±15.37	939.73±16.71	0.447	0.202

βMean with different superscript in a row differs significantly ($P<0.05$); ¥Pearson square correlation coefficient; RFI: Residual feed intake; FT: Feeding time; RT: Rumination time; CT: Chewing time.

kilogram of dry matter intake (FT/kg DM), a significant difference emerged. The low RFI animals spent more time feeding per kg of DM consumed compared to the high RFI animals with a highly significant and a very strong negative correlation. This suggests that while overall feeding duration were similar, more feed-efficient animals spent more time eating each unit of feed. Rumination time (RT) per day also did not differ significantly between groups. However, rumination time per kg of dry matter (RT/kg DM) showed a significant difference. Chewing time (CT), which includes both feeding and rumination, did not differ significantly on a daily basis between groups. But when normalized per kg of dry matter (CT/kg DM), low RFI animals showed significantly higher chewing time compared to high RFI animals. Total idling time were not significantly different between groups. Consistent with the findings of the current study, Kelly *et al.* (2010) observed that highly efficient animals expended less time and energy on this activity and allocated more time to sedentary pursuits, potentially conserving energy for weight increase. A shorter duration of bunk visits in more efficient animals compared to less efficient animals were also observed by Lancaster *et al.* (2009) and McGee *et al.* (2014). High-productivity animals expend less energy in physiological maintenance activities, so augmenting the net energy accessible for tissue accumulation (Castro Bulle *et al.* 2007).

CONCLUSION

Consequently, low RFI Barbari goats exhibit greater efficiency as they consume less feed, spend reduced time in feeding events and need less metabolisable energy for body maintenance.

Conflict of interest

The authors declare that there is no conflicts of interest.

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