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Liveweight gain and metabolisable energy requirements of young entire male Australian Rangeland goats in response to supplementation

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ABSTRACT

Context. High international demand for goat meat and high prices for goat in Australia have resulted in a transition from opportunistic harvesting to more managed production systems for Rangeland goats. There is limited information available to establish feeding strategies to maximise growth rates of Rangeland goats within these developing managed production systems. **Aims.** The aim of these experiments was to determine the response to supplements and the metabolisable energy requirements for maintenance and liveweight gain of young entire male Rangeland goats. **Methods.** Dose–response relationships to various supplements were established in two experiments with young entire male Rangeland goats. In Experiment 1, 54 goats were allocated to rolled-wheat grain, rolled-sorghum grain, or lucerne pellet supplements offered from 0 (control) to 24 g dry matter/kg liveweight.day. In Experiment 2, 24 goats were allocated to a commercial starch-based pellet offered from 0 (control) to *ad libitum*. In both experiments, goats were held in individual pens and offered their daily supplement allowances with *ad libitum* access to Mitchell grass hay and drinking water for 70 days. **Key results.** Total intake (30 to 32 g dry matter/kg liveweight.day) increased in a linear fashion with an increasing intake of all supplements. Maximum intake of rolled-wheat, rolled-sorghum, lucerne pellets and the commercial starch-based pellet supplements ranged from 18 to 22 g dry matter/kg liveweight.day. Unsupplemented goats lost liveweight (−20 to −32 g/day), while supplemented goats gained liveweight (0 to 126 g/day) in a linear fashion with an increasing supplement and metabolisable energy intake for all supplements, with the highest response in goats supplemented with the commercial starch-based pellets. Estimated metabolisable energy requirements to maintain liveweight (372 kJ/kg liveweight$^{0.75}$.day) and for liveweight gain (35 kJ/g) of the goats were the same in both experiments. **Conclusion.** Liveweight gain increased in a linear fashion with metabolisable energy intake, with the maximum rates of liveweight gain occurring when starch-based supplement intake was approximately 20 g dry matter/kg liveweight.day. **Implications.** Supplementation with starch-based rations will increase liveweight gain and decrease age at turn-off of young entire male Rangeland goats; however, the local availability and cost of these supplements need to be considered.

Keywords: Australian Cashmere goat, bush goat, digestibility, energy source, feral goat, growth, intake, supplement.

Introduction

High global demand for goat meat has recently led to historically high prices for goats in Australia. These high prices have resulted in a transition from traditional opportunistic harvesting of Rangeland goats to semi-managed extensive production systems (MLA 2020). However, there is limited information regarding the nutritional requirements of Rangeland goats and their potential response to supplements when fed low-quality native grasses. Such information is required to develop feeding strategies to increase liveweight (LW) gain (LWG) and decrease turn-off age of Rangeland goats within these evolving production systems in semi-arid extensive environments.

Previous nutritional studies with Rangeland goats (also referred to in the literature as Australian Cashmere, Feral or Bush goats) in Australia have tended to utilise pelleted diets containing formaldehyde-treated protein (Ash and Norton 1987*a*, 1987*b*; McGregor 1988), or investigated responses within intensive grazing systems (Norton *et al*. 1990*a*, 1990*b*), the impact of photoperiod on production (Walkden-Brown *et al*. 1994, 1997), short-term feeding periods for live export (McGregor 1994), pre-weaning nutritional management of the doe and kid (Eady and Rose 1988; Allan *et al*. 1991) and have often incorporated a cross-breeding or genotypic component (Pattie and Restall 1989; Mills *et al*. 2000). Very few studies have examined the response of young, weaned Rangeland goats to supplementation when fed a low-quality basal diet. Ash and Norton (1987*c*) reported that 21% crude protein (CP) and 18.6 MJ/kg dry matter (DM) gross energy were required to maximise LWG of young Rangeland goats.

Estimates of the metabolisable energy (ME) requirements for maintenance (ME_m) and LWG (ME_g) of goats in the literature are highly variable and are dependent on the breed, maturity and physiological status of the goat, the conditions under which the experiments were conducted (pen vs grazing), the climate and photoperiod, the activity costs, and the method of estimation (Norton 2020). For Rangeland goat equivalents, Ash and Norton (1987*c*) estimated that ME_m was 376 kJ ME/kg $LW^{0.75}$ (MW, metabolic weight).day and a ME_g 24.8 kJ ME/g of LWG, while McGregor (1988) estimated a lower ME_m (250 kJ ME/kg MW.day). Higher ME_m (489 kJ ME/kg MW.day) and ME_g (19.8 kJ/g of LWG) of indigenous goats were reported by Luo *et al*. (2004) and were adopted by the NRC (2007). The variations in these estimates of energy requirements in the literature may lead to the formulation of rations for Rangeland goats that are inadequate to reach targeted levels or are an inefficient use of ME in rations.

The objective of the experiments described in this paper was to determine the response of young entire male Rangeland goats to energy and protein supplements when fed Mitchell grass hay as a basal diet and to determine the ME_m and ME_g of young entire male Rangeland goats by using a dose–response design over a wide range of intakes. It was hypothesised that LWG of young entire male Rangeland goats would increase in a curvi-linear fashion with increasing supplement and ME intake, reaching a plateau at higher supplement intakes as maximum rates of LWG were achieved.

Materials and methods

Two supplement dose–response experiments were conducted at the Queensland Animal Science Precinct (QASP), The University of Queensland, Gatton, Queensland, Australia. Experiment 1 was conducted between 19 November 2019 and 28 January 2020, and Experiment 2 was conducted between 14 October and 23 December 2020 within the same research infrastructure. All procedures were conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes and were reviewed and approved by The University of Queensland Animal Ethics Committee (approval no. SAFS/294/18/MLA).

Animals, experimental design and treatments

Young (no permanent incisors), entire male Rangeland goats (n = 80/experiment) were sourced from semi-managed commercial Rangeland goat flocks in south-western Queensland. A single source flock was used within each experiment, but these were different sources for Experiments 1 (19.5 ± 2.2 kg LW; mean ± s.d.) and 2 (23.7 ± 4.7 kg LW). Goats were transported by road to QASP where they were vaccinated for clostridial diseases (Glanvac-6; Zoetis, NSW, Australia) and treated for internal (Panacur25; Coopers Animal Health, Sydney, NSW, Australia) and external (Nucidol 200 EC; Zagro, Perth, WA, Australia) parasites. Goats were adapted to feeds, feeding procedures and handling over 7 or 8 days (Experiments 1 and 2 respectively) in a single outdoor group pen with enrichment provided. Goats were then moved to individual indoor pens for a further 14 (Experiment 1) or 11 (Experiment 2) days adaptation to experimental procedures, after which shy feeders, poor temperament and outlying LW goats were omitted from the experiments.

Both experiments incorporated a supplement dose–response surface where zero or increasing amounts of supplements were offered to goats maintained in individual indoor pens each day throughout the 70-day experimental period, with the individual goat being considered the replicate. In both experiments, goats were ranked and blocked on LW and randomly allocated to treatment diets within LW blocks. The allocated goats were adapted to the experimental diets over 7 days prior to commencement of the experiments.

In Experiment 1, 54 goats (19.4 ± 1.7 kg LW kg) were selected for inclusion and allocated to one of four supplement allowances (6, 12, 18 and 24 g DM/kg LW.day; n = 4 replicates/allowance) for each of three supplements (rolled-wheat, rolled-sorghum or lucerne pellets) and to an unsupplemented (control) treatment (n = 6 replicates). In Experiment 2, 24 goats (24.9 ± 1.8 kg LW kg) were selected for inclusion and allocated to one of three commercial starch-based pellet supplement allowance (8, 16, 24 g DM/kg LW.day; n = 4 replicates/allowance) and to unsupplemented (control; n = 6 replicates) and *ad libitum* pellet (n = 6 replicates) treatments.

Diets

During the adaptation period, goats had access to either rolled-wheat (Experiment 1, wheat; final composition, 959 g organic matter [OM], 145 g CP, 624 g starch, 202 g ash-free neutral detergent fibre [NDF], 3.4 g Ca, 1.9 g Mg, 2.4 g P, 1.7 g S and 3.5 g Na/kg DM) or a commercial goat pellet (Experiment 2; 895 g OM, 153 g CP, 31 g Ca, 2.8 g Mg, 5 g P, 4.9 g S and 0.1 g Na/kg DM) with barley straw (900 g OM, 38 g CP, 730 g NDF, 2.4 g Ca, 1.3 g Mg, 9.3 g P, 0.5 g S and 9.3 g Na/kg DM). Water was available *ad libitum* during the adaptation and experimental periods of both experiments.

In Experiment 1, Mitchell grass (*Astrebla* spp.) hay (892 g OM, 46 g CP, 683 g NDF, 3 g Ca, 1.2 g Mg, 1.1 g P, 23 g S and 0.4 mg Na/kg DM) was sourced from the Barkly Tableland (NT, Australia), was chaffed to 20–40 mm length in a horizontal mixer wagon (Samurai 5, 450/90; Seko) prior to feeding and offered *ad libitum*. Wheat (as described above for adaptation period) and sorghum were rolled and mixed with urea and a mineral mix (sorghum; final composition, 964 g OM, 146 g CP, 619 g starch, 203 g NDF, 2.5 g Ca, 1.5 g Mg, 2.0 g P, 1.5 g S and 2.6 g Na/kg DM), while lucerne pellets (lucerne; 888 g OM, 197 g CP, 9.4 g starch, 393 g NDF, 13 g Ca, 3.1 g Mg, 2.8 g P, 3.6 g S and 3.7 g Na/kg DM) were sourced from a commercial supplier (Lockyer Lucerne, Qld, Australia). Control goats had *ad libitum* access to a multi-mineral salt block (370 g NaCl, 60 g molasses, 40 g P, 148 g Ca, 400 mg Co, 180 mg Zn, 167 mg I, 600 mg Mn, 930 mg K, 200 mg Mg, 200 mg F, 650 mg Fe, and 1100 mg S/kg DM; Olssons, Sydney, NSW, Australia).

In Experiment 2, a separate batch of Mitchell grass hay (894 g OM, 27 g CP, 694 g NDF, 4 g Ca, 1.3 g Mg, 0.24 g P, 0.97 g S and 0.06 g Na/kg DM) sourced from the Barkly Tableland was used and processed the same as Experiment 1 and offered *ad libitum*. The commercial starch-based pellets (starch-based pellets; 890 g OM, 137 g CP, 424 g starch, 242 g NDF, 23 g Ca, 2.8 g Mg, 3.3 g P, 1.4 g S and 3.8 g Na/kg DM) were sourced commercially (Ridley Agri-products, Vic., Australia). Control goats had *ad libitum* access to the same multi-mineral salt block used in Experiment 1.

Procedures

In both experiments, goats were weighed every 7 days, prior to feeding. Daily supplement allowances were calculated after each LW measurement and prepared for the subsequent 7 days. Mitchell grass hay was offered *ad libitum* to all goats at the same time each morning and replenished in the afternoon as required to target approximately 20% residues over 7 days. Daily supplement allowances were offered either as a single feed in the morning (for 6 and 12 g DM/kg LW.day allowances) or in two approximately equal portions, in the morning and afternoon (for the 18 and 24 g DM/kg LW.day allowances). Hay and supplements were offered in separate feed bins with residues collected separately each morning and bulked over each 7-day period for each goat. Subsamples of the bulked Mitchell grass and supplements offered, and residues, were collected each week, ground through a 2 mm screen (Retsch Mühle rotary grinder, Germany) and stored in sealed containers at room temperature prior to analysis.

Total faecal output was collected from all goats over seven consecutive days (Days 42 to 49 in Experiment 1, and Days 22 to 28 in Experiment 2) of the experimental period by using modified harnesses. The total daily faecal collection was bulked and stored at 4°C. Total bulk faecal output was weighed, mixed, subsampled and the DM, OM, NDF and starch content were determined.

Laboratory analysis

The DM content of feeds, residues, and faeces were determined by drying samples in an oven at 60°C for approximately 72 h (120 h for faecal samples). Organic matter was determined by combusting dried samples at 600°C in a muffle furnace (Modutemp, Perth, WA, Australia) for 3 h. The N content was determined using a combustion method (AOAC 2002) in a LECO analyser (LECO FP928; St Joseph, MO, USA). Ash-free NDF content was determined according to the method of Goering and Van Soest (1970), modified by Mertens *et al.* (2002), by using the ANKOM system (ANKOM 200 Fiber Analyzer, Macedon, NY, USA). Total starch contents in feeds and faeces were determined by sequential hydrolysis with thermostable α-amylase and amyloglucodase, according to the Megazyme total starch assay procedure (Megazyme 2020).

Calculations and statistical analyses

Individual LWG was determined by regression of change in LW over time. The ME content of the nutritional treatments was estimated from the digestible OM in DM (DOMD; Equation 1.12C in Freer *et al.* (2007). Energy retention (ER) was estimated from LWG and the energy content of empty body weight gain (EVG; eqn 1.29 in Freer *et al.* 2007), with a standard reference weight (SRW) of male sheep (56 kg) used to calculate EVG in the absence of a specific SRW for goats. The efficiency of use of ME for LWG (K_g) was predicted from the ME content of the diet (eqn 1.36 in Freer *et al.* 2007).

Data from Experiments 1 and 2 were analysed separately using RStudio (R version 4.0.0, 2020). A simple polynomial regression model was fitted to determine the relationship (linear or quadratic) between supplement intake (as the independent variable) and each of the other variables individually. If the linear model showed a significant ($P < 0.05$) response, a quadratic model was tested to determine the best fit. On some occasions, a significant quadratic equation was replaced with an asymptotic equation when it made biological sense to do so. When responses to supplements were determined to be significant at the same polynomial order, additional multiple regression analysis was conducted to determine whether these responses were significantly different.

Results

Liveweight gain

Unsupplemented goats lost 20 ± 3 (mean ± standard error of the mean) and 32 ± 13 g/day in Experiments 1 and 2 respectively. The LWG of supplemented goats increased in a linear fashion with an increasing intake for all supplements in both experiments (Table 1). In Experiment 1, LWG of goats supplemented with wheat (individual LWG ranged from −10 to 105 g/day; with a mean LWG at the maximum supplement intake of 77 g/day) was significantly ($P < 0.01$) higher than those of goats supplemented with sorghum (−2 to 78 g/day; 50 g/day) and lucerne (−43 to 73 g/day; 50 g/day). The LWG response of goats fed the sorghum supplement was not significantly different from that of goats fed the lucerne supplement. In Experiment 2, the LWG of supplemented goats increased (−1 to 178 g/day; 126 g/day) in a linear fashion with an increasing pellet intake on a daily, LW and MW basis.

The LWG above unsupplemented goats (Y intercept of response equations set to 0) was potentially higher in goats supplemented with the starch-based pellets (157 g/day at the maximum supplement intake), followed by wheat (101 g/day), and sorghum and lucerne pellets (61 g/day) (Fig. 1), although statistical comparison across experiments was not possible.

Intake and digestibility of the diet

Mitchell grass hay intake of unsupplemented goats was 18.9 ± 0.4 and 17.6 ± 0.9 g DM/kg LW.day in Experiments 1 and 2 respectively. Total consumption of supplements was achieved at low to medium allowances; however, incomplete consumption occurred at the highest supplement allowances for the grains and starch-based pellets. Mean maximum supplement intakes at the highest supplement allowances were 18, 19, 22 and 21 g DM/kg LW.day for wheat, sorghum, lucerne pellets and the starch-based pellets respectively. Mitchell grass hay intake declined while total DM intake increased in a linear fashion with an increasing supplement intake in both experiments, with no significant difference between supplements in Experiment 1. Total DM intake reflected that of supplement intake and increased in a linear fashion in both experiments, with no significant difference between supplements in Experiment 1. Starch intake of goats was lowest in response to an increasing lucerne intake and highest in response to an increasing wheat supplement, with the response to sorghum intake being intermediate in Experiment 1. The mean starch content of the consumed diets at maximum supplement intake were 13, 440, 482, and 296 g starch/kg DM consumed (or 0.4, 13, 15, and 9 g starch/kg LW.day) for lucerne pellets, wheat, sorghum and starch-based pellets respectively. As expected, the intake of ash-free NDF decreased in a linear fashion with an increasing wheat and sorghum supplement intake but not with lucerne pellet (15 g ash-free NDF/kg LW.day) and starch-based pellet intake (10 g ash-free NDF/kg LW.day). At maximum supplement intakes, the mean ash-free NDF contents of the consumed diets were 467, 301, 265 and 323 g ash-free NDF/kg DM consumed (or 15, 9, 8 and 10 g ash-free NDF/kg LW.day) for lucerne pellets, wheat, sorghum and starch-based pellets respectively.

The apparent DMD of the Mitchell grass hay alone was 43% and 46% in Experiments 1 and 2 respectively. The maximum DMD of the diet in response to an increasing supplement intake was estimated at 70%, 67%, 55% and 68% for the wheat, sorghum, lucerne pellets, and starch-based pellets respectively.

Digestibility of starch in the diets containing the wheat and sorghum supplements increased in a curvi-linear fashion with an increasing supplement intake. The digestibility of starch of the wheat supplement diet was higher ($P < 0.01$) than that of the sorghum supplement diet. Digestibility of starch in the diets supplemented with lucerne pellets increased in a linear fashion with an increasing lucerne intake and was lower than that of the wheat and sorghum supplement diets. The ash-free NDF digestibility (NDFD) of all diets increased in a linear fashion with an increasing supplement intake and was significantly ($P < 0.01$) higher in the diet containing the wheat supplement than in diets containing the sorghum and lucerne supplements, with no significant difference between the latter two supplements. The intake of digestible OM and ME both increased in a linear fashion with an increasing supplement intake, when expressed on a daily, LW and MW basis.

Energy requirements for maintenance and gain of liveweight

The LWG (g/kg MW.day) of Rangeland goats increased in a linear fashion with ME intake in Experiments 1 and 2, with no difference between supplement types in Experiment 1 (Fig. 2). The ME intake required for ME_m calculated from this relationship was 372 kJ/kg MW.day with 35 kJ ME/g of LWG in Experiment 1, and 372 kJ/kg MW.day, with 35 kJ required/g of LWG in Experiment 2. The estimated ER of the Rangeland goats fed Mitchell grass hay increased significantly with increasing supplement and ME intake ($P < 0.001$) of all supplements in Experiments 1 and 2, with no difference in this response between supplements in Experiment 1. The K_g of goats supplemented with wheat

Table 1. Effect of supplement intake on liveweight gain, dry matter intake, nutrient digestibility, and energy utilisation of entire male Rangeland goats fed Mitchell grass hay alone or supplemented with increasing amounts of wheat, sorghum and lucerne pellets (Experiment 1) or starch-based pellets (Experiment 2).

Y	Supplement	Equation	R^2	RSE	Lin.	Quad.
Experiment 1						
LWG (g/day)	Wht	$Y = 4.61\ SI - 24.04$	0.83	15.4	***	n.s.
	Sor, Luc	$Y = 3.03\ SI - 17.01$	0.60	18.6	***	n.s.
LWG (g/kg MW.day)	Wht	$Y = 0.46\ SI - 2.59$	0.85	1.42	***	n.s.
	Sor, Luc	$Y = 0.30\ SI - 1.82$	0.60	1.86	***	n.s.
Mitchell grass hay intake (g DM/kg LW.day)	Wht, Sor, Luc	$Y = 19.83 - 0.52\ SI$	0.83	1.60	***	n.s.
Total intake (g DM/kg LW.day)	Wht, Sor, Luc	$Y = 19.83 + 0.48\ SI$	0.81	1.60	***	n.s.
Starch intake (g/kg LW.day)	Wht	$Y = 0.39 + 0.59\ SI$	0.82	2.04	***	n.s.
	Sor	$Y = 0.14 + 0.66\ SI$	0.94	1.31	***	n.s.
	Luc	$Y = 0.17 + 0.01\ SI$	0.84	0.02	***	n.s.
Ash-free NDF intake (g/kg LW.day)	Wht	$Y = 14.20 - 0.23\ SI$	0.46	1.76	***	n.s.
	Sor	$Y = 14.42 - 0.29\ SI$	0.69	1.50	***	n.s.
DMD (%)	Wht	$Y = 83.47 - 40.79\ (0.95^{SI})$	0.93	2.30	***	*
	Sor	$Y = 70.27 - 27.53(0.91^{SI})$	0.86	3.76	***	*
	Luc	$Y = 58.44 - 15.67\ (0.93^{SI})$	0.89	1.74	***	*
Starch digestibility (%)	Wht	$Y = 98.98 - 33.81\ (0.42^{SI})$	0.89	5.33	***	***
	Sor	$Y = 91.09 - 25.90\ (0.69^{SI})$	0.76	6.26	***	**
	Luc	$Y = 66.72 + 0.73\ SI$	0.60	4.99	***	n.s.
Ash-free NDFD (%)	Wht	$Y = 49.87 - 0.29\ SI$	0.26	3.51	*	n.s.
	Luc, Sor	$Y = 52.55 - 0.47\ SI$	0.44	3.97	***	n.s.
DOMI (g DM/kg LW.day)	Wht, Sor, Luc	$Y = 9.16 + 0.38\ SI$	0.53	2.45	***	n.s.
ME (MJ/kg DM)	Wht	$Y = 13.59 - 7.94\ (0.94^{SI})$	0.93	0.56	***	*
	Sor	$Y = 5.93 + 0.20\ SI$	0.80	0.79	***	n.s.
	Luc	$Y = 7.22 - 1.57\ (0.87^{SI})$	0.74	0.36	***	*
ME intake (kJ/kg MW.day)	Wht, Sor, Luc	$Y = 371.65 + 35.26\ LWG$	0.68	72.4	***	n.s.
ER (kJ/kg MW.day)	Wht, Sor, Luc	$Y = 3.10\ MEI - 1018.71$	0.67	277	***	n.s.
K_g	Wht	$Y = 0.58 - 0.33\ (0.95^{SI})$	0.93	0.02	***	*
	Sor	$Y = 0.26 + 0.01\ SI$	0.79	0.03	***	n.s.
	Luc	$Y = 0.31 - 0.07\ (0.88^{SI})$	0.75	0.01	***	*
Experiment 2						
LWG (g/day)	Plt	$Y = 7.12\ SI - 30.32$	0.83	27.8	***	n.s.
LWG (g/kg MW.day)	Plt	$Y = 0.58\ SI - 2.72$	0.85	2.09	***	n.s.
Mitchell grass hay intake (g DM/kg LW.day)	Plt	$Y = 18.37 - 0.40\ SI$	0.69	2.30	***	n.s.
Total intake (g DM/kg LW.day)	Plt	$Y = 18.38 + 0.60\ SI$	0.83	2.32	***	n.s.
Starch intake (g/kg LW.day)	Plt	$Y = 0.12 + 0.42\ SI$	0.86	1.46	***	n.s.
DMD (%)	Plt	$Y = 46.80 + 0.97\ SI$	0.89	2.97	***	n.s.
Starch digestibility (%)	Plt	$Y = 99.72 - 17.77\ (0.64^{SI})$	0.95	1.74	***	***
Ash-free NDFD (%)	Plt	$Y = 57.20 - 0.40\ SI$	0.20	6.28	*	n.s.
DOMI (g DM/kg LW.day)	Plt	$Y = 8.57 + 0.47\ SI$	0.72	2.51	***	n.s.
ME (MJ/kg DM)	Plt	$Y = 6.44 + 0.17\ SI$	0.88	0.53	***	n.s.
ME intake (kJ/kg MW.day)	Plt	$Y = 371.65 + 35.16\ LWG$	0.89	64.4	***	n.s.

(*Continued on next page*)

Table 1. (*Continued*).

Y	Supplement	Equation	R^2	RSE	Lin.	Quad.
ER (kJ/kg MW.day)	Plt	$Y = 4.88$ MEI − 1515.22	0.78	572	***	n.s.
K_g	Plt	$Y = 0.28 + 0.01$ SI	0.88	0.02	***	n.s.

P-values are given for the linear (Lin.) and quadratic (Quad.) coefficients in the regression equations; $^*P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.
LW, liveweight; LWG, LW gain; MW, metabolic weight = $LW^{0.75}$; DM, dry matter; DMD, DM digestibility; OMD, organic matter digestibility; DOMD, digestible organic matter in dry matter; DOMI, digestible organic matter intake; ME, metabolisable energy; NDF, ash-free neutral detergent fibre; NDFD, NDF digestibility; MEI, metabolisable energy intake; ER, energy retention; K_g, efficiency of use of metabolisable energy for weight gain; Wht, wheat; Sor, sorghum; Luc, lucerne; Plt, starch-based pellet; SI, supplement intake (g DM/kg LW day); n.s., non-significant ($P > 0.05$); RSE, residual standard error; R^2, adjusted *R*-square.

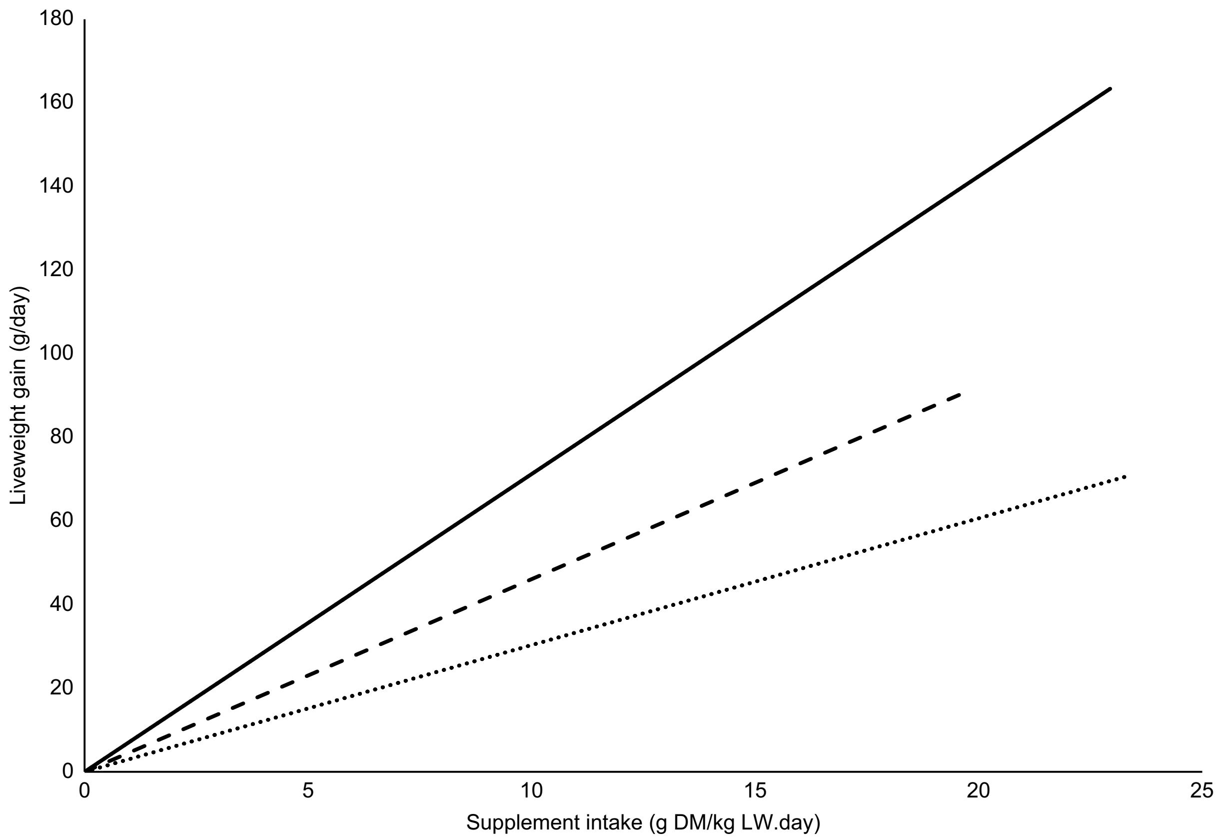

Fig. 1. Liveweight gain above control of young entire male Rangeland goats fed increasing amounts of lucerne pellets and sorghum (·········), wheat (-------), and a starch-based pellet (———) supplements. Response lines are from Table 1, with the Y intercept set to 0 for each equation.

and sorghum in Experiment 1 and the starch-based pellets in Experiment 2 increased in a curvi-linear fashion, while K_g increased in a linear fashion in response to intake of the lucerne pellets in Experiment 1. In Experiment 1, the efficiency of ME utilisation for LWG was higher in response to wheat than to sorghum and lucerne pellet supplements.

Discussion

This paper presents the responses of young entire male Rangeland goats to a range of supplements when fed dry-season Mitchell grass hay as a basal diet. The experiments were conducted to develop dose–response relationships to a range of supplements to provide practical information on the optimal supplement intake for young entire male Rangeland goats and to derive more theoretical information on the ME requirements for maintenance and LWG of this class of goat.

Mitchell grass hay intake in Experiments 1 and 2 decreased by approximately 0.5 and 0.4 g DM respectively, per 1 g DM of increasing supplement intake. A similar reduction in forage intake was reported by cattle in response to an increasing energy and protein supplement intake (McLennan *et al.* 2017).

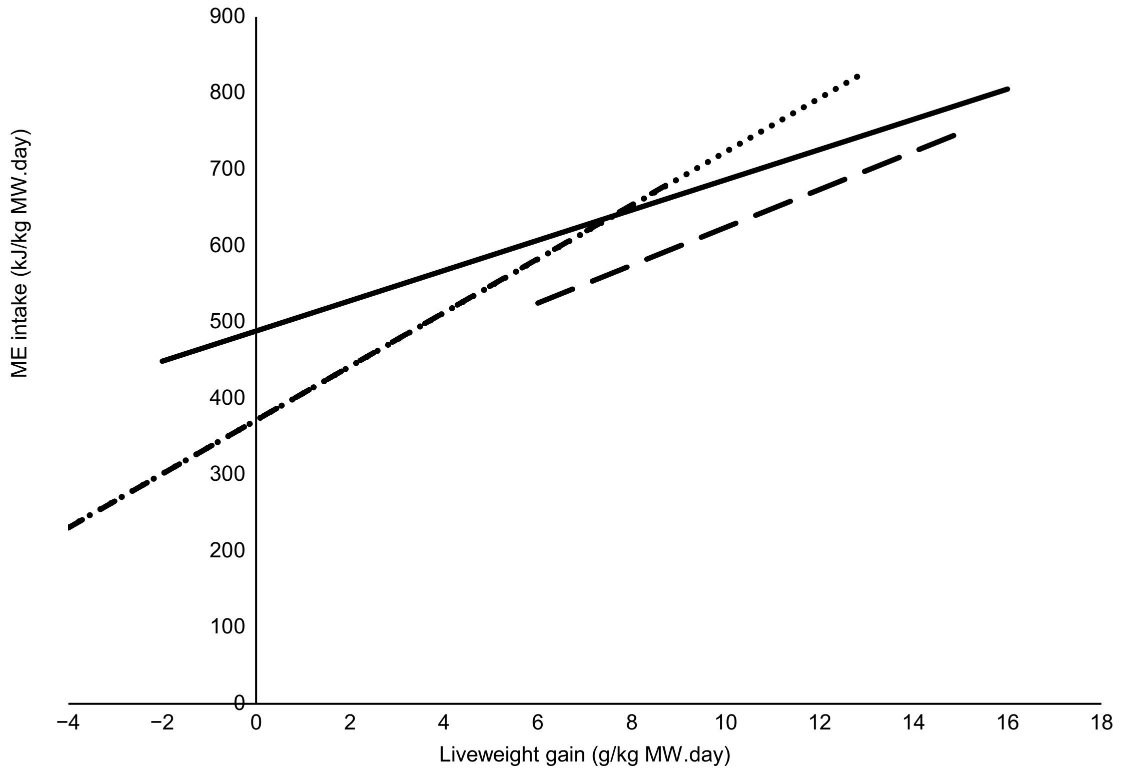

Fig. 2. Predicted metabolisable energy (ME) intake in relation to liveweight gain of entire male Rangeland goats on a metabolic liveweight (MW) basis. Response lines shown are from Experiment 1 (-------), Experiment 2 (·········), Ash and Norton (1987*c*) (– – – –), and Luo *et al.* (2004) (———).

Increasing supplement intake was associated with a linear increase in total DM intake. The total DM intake (31.6 g DM/kg LW.day) of the starch-based diets in Experiment 2 was comparable to the DM intake (31 and 38 g DM/kg LW.day respectively) of young Australian Cashmere goats fed a pelleted complete ration of medium CP content (15.5%), but lower than the DM intake of the goats fed the same form of diet with a higher CP (21%) and ME content (8.4 MJ ME/kg DM; Ash and Norton 1984, 1987*c*). The current experiments were conducted during a period of increasing photoperiod to avoid the reduction in DM intake associated with a decrease in photoperiod (Walkden-Brown *et al.* 1994).

In both experiments, unsupplemented goats lost LW, while LWG of goats increased in a linear fashion with an increasing intake for all supplements. The LW loss of unsupplemented goats demonstrated that the Mitchell grass hay provided insufficient nutrients to meet the maintenance requirements of the goats. This result was lower than previous results where a similar class of goat fed a low-quality basal diet gained 7 g/day (S. P. Quigley, pers. comm.). McGregor (2005) suggested that a CP content of 7% was required to maintain LW, while the CP content of the Mitchell grass hay used in the current experiments was below the recommendation. A similar LW loss was also reported for Australian Cashmere goats consuming a low-quality Pangola grass hay (6.9% CP) during the autumn (Norton and Ash 1985; Walkden-Brown *et al.* 1994), although these results may have been a function of both diet quality and decreasing photoperiod. The difference in LWG of unsupplemented goats in Experiments 1 and 2 was attributed to the marginally lower CP content of the Mitchell grass hay fed in Experiment 2.

The linear relationship between LWG and supplement intake demonstrated that the maximum potential growth of the goats was not reached in these experiments. A maximum LWG (149 g/day) of young male Rangeland goats was reported by Ash and Norton (1987*c*) when goats were fed a high ME and high CP content diet. This was higher than the maximum LWG measured in the current experiments (50–126 g/day). The LWG responses recorded in Experiment 1 were in agreement with previous reports for young male Rangeland goats fed a restricted amount of ME (75% of estimated requirements; Ash and Norton 1987*c*). The low R^2 values (0.83 for wheat and starch-based pellets, and 0.60 for sorghum and lucerne pellets) for the LWG and supplement-intake relationships are indicative of high individual variation, which may be related to genetic variation. While behavioural influences on intake and LWG may contribute to this variation, the extreme diversity in the goat phenotypes used in these experiments may suggest that there was significant genetic variation among the experimental goats, and this would likely reflect the variation in the Rangeland goat population in Australia; an increased number of replicates per supplement allowance may have reduced the variance associated with the response equations. Significant variation in LWG has also been observed for young Rangeland goats in lot-feeding scenarios (S. P. Quigley, pers. comm.). Some of the highest rates of LWG reported for Rangeland goats in Australia were for lines of goats where selection was applied on the basis of LW at weaning, suggesting that there is potential to harness the existing genetic variation within the Rangeland goat population to increase LWG (Allan and Holst 1989). Regardless of the cause, the results reported here are based on an industry-relevant animal model and, as such, are likely to reflect the variability in responses to supplementation observed under commercial conditions.

The results indicated that goats have a higher LWG (above control) in response to energy supplements (starch-based pellets and wheat) than to lucerne pellets fed as a protein supplement. The higher LWG in response to lucerne than to sorghum supplement is explained by higher maximum lucerne intake (22 vs 19 g DM/kg LW.day); however, the overall LWG in response to both supplements was not significantly different. The lower LWG in response to sorghum supplement than to wheat may be explained by the lower digestibility.

The approach used to determine the ME_m in the current experiments generated values that were identical in Experiments 1 and 2 (372 kJ ME/kg MW.day) and comparable to that reported by Ash and Norton (1987*c*; 376 kJ ME/kg MW.day; Fig. 2) and were within the range (267–485 kJ ME/kg MW.day) reported by McGregor (2005). This value of 372 kJ ME/kg MW.day is also comparable to the ME_m reported for young Anglo-Nubian × feral and Angora × feral goats and Dorset Down × Coopworth lambs in New Zealand (370–440 kJ ME/kg MW.day; Alam *et al.* 1991), but lower than the value of 489 kJ ME/kg MW.day estimated for indigenous goats by Luo *et al.* (2004) and adopted by the NRC (2007). In contrast, while the current estimate of the ME requirement per unit of LWG (35 kJ/g) was within the range (24–54 kJ/g) reported by McGregor (2005), it was higher than that estimated by Ash and Norton (1987*c*) and Luo *et al.* (2004; 25 and 20 kJ/g of LWG respectively), which would imply that the efficiency of use of ME_g was lower in the current experiments than the published estimates. Reasons for these discrepancies may be related to how the different values were derived within the different sources. For example, the values adopted by the NRC (2007) used a meta-analysis of published data sets (Luo *et al.* 2004), in which the goats (class, age, sex, production), experimental conditions (grazing- or pen-based trials), feed types and quality, LW and potentially the environmental conditions under which the experiments were conducted varied. The value derived by Ash and Norton (1987*c*) utilised a dataset derived from goats with a high LWG and assumed a linear relationship between ME intake and LWG to maintenance, with no data points near maintenance. Data in the current experiments would suggest that this is a valid assumption, as the response relationships within the current experiments were linear over the range tested.

Conclusions

The results of these experiments demonstrated the potential role of supplementation to increase ME intake and LWG of young entire male Rangeland goats. From a biological viewpoint, supplements with a high available starch content are likely to provide the highest ME intake and, hence, LWG and are recommended for supplementation at approximately 20 g DM/kg LW.day, which was the maximum intake of these types of supplements when fed with a low-quality basal diet. While this approach will undoubtedly result in a decreased age at turn-off of young entire male Rangeland goats, from a practical viewpoint, it is important that the local availability and cost of these supplements, and prices received for the additional LWG, are considered.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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