Short-term supplementation with maize increases ovulation rate in goats when dietary metabolizable energy provides requirements for both maintenance and 1.5 times maintenance

Daniel M. Nogueira [a, b*], A. Eshtaeba [b], John Cavalieri [b], Lee A. Fitzpatrick [b], Bruce Gummow[b,c], Dominique Blache [d], Anthony J. Parker [b,e]

[a] Embrapa Semiá rido, BR 428, Km 152. Caixa Postal 23. CEP 56302-970, Petrolina, PE, Brazil.
[b] College of Public Health, Medical and Veterinary Sciences, James Cook University, Townsville, QLD 4811, Australia.
[c] Faculty of Veterinary Science, University of Pretoria, Pretoria, South Africa.
[d] School of Animal Biology/Institute of Agriculture, University of Western Australia, Crawley, WA, Australia.
[e] Department of Animal Science, The Ohio State University, Wooster Ohio, USA.
*Corresponding author. Email: daniel.nogueira@embrapa.br

ABSTRACT.

This study aimed to evaluate ovarian follicular dynamics in goats submitted to synchronization of estrus and supplemented with diets that differed in the metabolizable energy source and amount of energy. The experiment was carried out using 42 does allocated into three treatments, fed for nine days with a ration providing 1.0 times maintenance containing maize (1MM, n = 14) or without maize (1M, n = 14) or a ration providing 1.5 times maintenance containing maize (1.5MM, n = 14). Estrus was synchronized with two injections of cloprostenol given seven days apart. Does were also treated with intravaginal progesterone inserts and eCG. The number of ovulations and size of the follicles were measured using ultrasonography on Days 10, 11 and 12 after the start of the dietary treatment. The interval to estrus and duration of estrus did not differ between treatments (P = 0.382). Does fed with 1MM and 1.5MM had a similar number of ovulations, but a greater number of ovulations than goats fed with 1M (P = 0.028). The mean number of small, medium, large and total number of follicles on Days 10 to 12 of ultrasound evaluations did not differ (P = 0.204) between treatments, but mean numbers changed over time (P < 0.001). The mean frequency and amplitude of LH pulses and concentrations of glucose, insulin, leptin and IGF-1 in plasma were not significantly affected (P > 0.258) by any of the treatments. In summary, the inclusion of maize in the ration can stimulate ovulation rate at

maintenance level. Similar results between groups fed diets that included maize and provided metabolizable energy at 1.0 and 1.5 maintenance demonstrate that in order to increase ovulation rate when synchronizing estrous cycles in does, dietary supplementation with maize can be restricted to provide a maintenance level of metabolizable energy only, which would reduce dietary costs.

Keywords: breeding season, corn, follicular dynamics, reproduction.

1. Introduction

Nutrition exerts a significant influence on reproductive function through changes in body weight and body condition, affecting processes such as follicular development and ovulation rate [1-3]. Nutritional supplementation influences the selection of dominant follicles, increases follicular growth and improves the quality of oocytes [4-6]. These changes in follicular development are enhanced through supplementation with high-energy and/or high-protein diets, as energy balance is a powerful regulator of reproductive function in ruminants [7].

There are limited data on the effect of a short-term supplementation with maize in goats on follicular development, ovulation rate, hormone and metabolic profiles during supplementation. Several studies have shown that short-term nutritional supplementation for four to 11 days can promote an increase in ovulation rate in sheep [8-10]. In contrast, most studies have failed to demonstrate that short-term nutritional supplementation can increase ovulation rate, but can cause an increase in the number of large follicles or the total number of follicles in sheep [11-14] and an increase in concentrations of glucose and insulin in goats [15]. Furthermore, a limited number of studies have evaluated the effect of supplementation with maize on ovarian function in sheep [14] and in goats [16, 17].

Multiple hormones and metabolites appear to influence follicular development, for example FSH, LH, GH, glucose, insulin, leptin and IGF-1 [5, 11]. Viñoles *et al.* [11] suggested that in ewes the effect of five to nine days nutritional supplementation on follicle development is

not mediated by an increase in FSH concentrations, but by increased concentrations of glucose, insulin, IGF-1 and leptin acting directly at the ovarian level to promote an increase in follicular steroidogenesis without affecting peripheral changes in serum concentrations of FSH. The results of other studies have also suggested that the stimulatory effects of short-term nutritional supplementation on folliculogenesis are mediated directly at an ovarian level with glucose, fatty acids and several metabolic hormones having a direct action on the follicle [5, 18]. These findings suggest that short-term nutritional supplementation that is likely to exert changes in metabolic hormones may exert changes in follicular development, which may confer production advantages if factors such as prolificacy can be influenced.

Previous studies have tried to address changes in ovarian function by changing the amount of energy provided in diets to experimental animals [11, 15]. It has been shown that the efficiency of utilization of energy for maintenance increases when sheep and cattle are supplemented with maize [19]. However, there are no reports of the effects of changing the dietary ingredients that make up the metabolic energy requirement for maintenance as an alternative to increase follicular development. This method of changing the nutrient composition of the diet without changing the overall amount of metabolic energy could provide a novel method of influencing ovarian function in goats at a more modest cost compared with supplementing does above their maintenance requirements.

We hypothesized that goats supplemented with maize for nine days, with diets designed to provide metabolizable energy at either maintenance or 1.5 times maintenance, will increase concentrations of glucose and IGF-1 in plasma and increase the number of small and large follicles and ovulation rate, when compared with goats fed a diet that provides a maintenance level of metabolizable energy without the inclusion of maize. To confirm this hypothesis, this study aimed to evaluate the follicular dynamics and changes in LH, insulin, glucose, leptin and IGF-1 in goats that were undergoing estrous cycles and supplemented with diets that differed in the amount of maize and the level of metabolizable energy provided.

2. Material and Methods

2.1. Location, animals and evaluation period

The experiment was carried out at James Cook University, Townsville, Queensland, Australia (19°19'30"S; 146 °45'44"E). The experiment was conducted between May and July, during the normal breeding season. A total of 42 nulliparous and non-pregnant does (21 Boer and 21 rangeland goats) were used in this study. At the start of the experiment, does were 2.2 ± 0.1 years-of-age old and had a live weight of 40.9 ± 1.0 kg (Mean ± SEM). All experimental procedures were approved by the Animal Ethic Committee of James Cook University (approval number: A1695).

2.2. Animal management and experimental design

The study was conducted in two blocks of 21 animals each, with seven animals allocated to one of three treatment groups in each block. A Block was the period when homogeneous subgroups of animals were evaluated in the same design. Different individual animals were used in each block, but Boer and rangeland goats were evenly distributed within the blocks. The second block commenced on the day after the first block was completed.

Prior to commencement of treatments associated with each block, goats were adapted to individual pens in a building with natural light for five days. Does were supplemented daily with a base ration consisting of lucerne pellets and rhodes grass (*Chloris gayana*) hay which provided nutritional requirements for maintenance (6.7 MJ ME/day) for a goat weighing 40 kg [20]. On Day 0 of the study, does were fed either 1.0 times maintenance without maize (1M), 1.0 times maintenance with maize (1MM) or 1.5 times maintenance with maize (1.5MM); (**Table 1**). The maize and lucerne pellets were offered at 8:00 h and Rhodes grass was offered at 17:00 h. To ensure that cracked maize was all eaten in the groups fed maize, it was offered first and then lucerne pellets were offered about 15 minutes later. The feed intake of animals was monitored individually to confirm that the animals ate all the feed allocated each day. On Days 10 to 12,

Table 1: Dietary and chemical composition of different diets fed to does within each treatment, with the aim of providing the energy required for maintenance without maize (1M), maintenance with maize (1MM) and 1.5 times above maintenance with maize (1.5MM).

Components	Treatments		
	1 M (n =14)	1 MM (n =14)	1.5 MM (n =14)
Cracked Maize (g/day)	0	220	220
Lucerne pellets (g/day)	720	403	765
Rhodes grass hay (g/day)	300	300	300
Total Intake (g/day)	1020	923	1285
Chemical composition			
Dry matter (g/day)	874	773	1092
Ash (g/day)	56	38	60
Acid detergent fibre (g/day)	248	176	258
Neutral detergent fibre (g/day)	359	266	380
Crude protein (g/day)	118	88	139
Metabolizable Energy (MJ/day)	**6.7**	**6.7**	**10.0**

Table 2. Percentage of does in estrus, mean (±SEM) interval to onset of estrus, duration of estrus, ovulation rate and diameter of the largest follicles of goats.

Variables	Treatments			P
	1M	1MM	1.5MM	
Animals (n)	14	14	14	
Females in estrus (%)	100.0	100.0	92.9	0.359
Interval to estrus (h)*	18.3 ± 2.3	15.7 ± 0.8	16.6 ± 0.9	0.582
Duration of estrus (h)	38.0 ± 2.5	36.0 ± 3.1	41.5 ± 2.8	0.386
Ovulation rate/doe (n)*	1.7 ± 0.1^{b}	2.2 ± 0.1^{a}	2.2 ± 0.1^{a}	0.028
Largest follicle on Day10 (mm)	8.1 ± 0.3	7.6 ± 0.3	8.3 ± 0.3	0.084

Values with different letters in the same row are significantly different.

*The effect of the initial bodyweight was significant and was therefore retained as a covariate in these analyses.

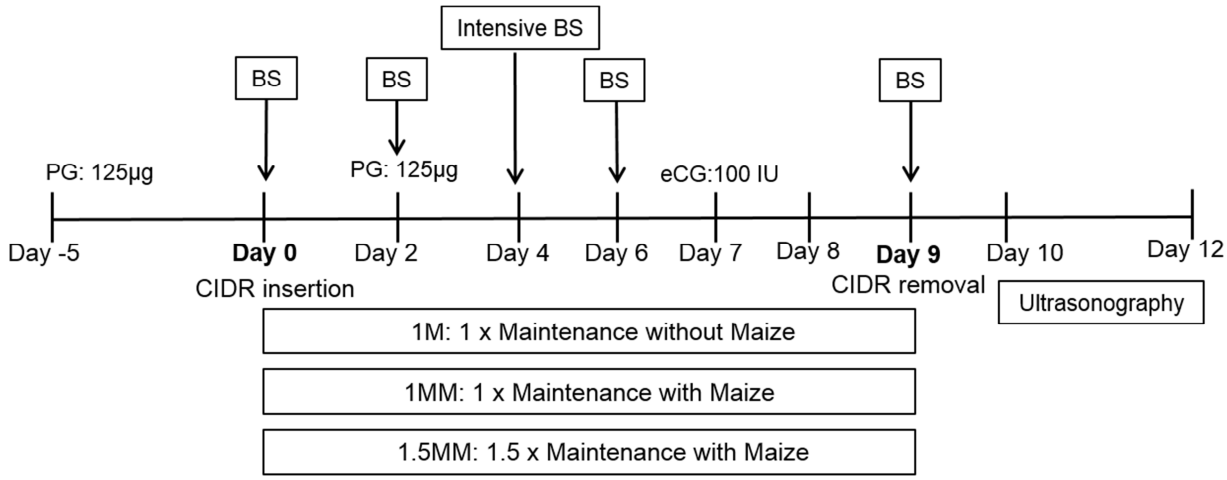

Fig. 1: Schematic representation of the experimental treatments outlining the timing of administration of the experimental diets and the protocol used to synchronize estrus (PG: prostaglandin, eCG: equine chorionic gonadotropin and CIDR: progesterone releasing device), and the timing of blood sampling (BS) and ultrasonographic evaluations.

every doe was fed the maintenance diet that consisted of lucerne pellets and Rhodes grass hay only.

On Day 0, does were treated with an intravaginal progesterone releasing insert (CIDR, Eazi-Breed®CIDR®, Pfizer Australia, NSW), which was removed nine days later (**Fig. 1**). In addition, does were treated with two injections of 125 µg cloprostenol IM (EstroPlan®, Parnell, Australia) administered seven days apart (Days -5 and 2) and 100 IU eCG IM (Equine chorionic gonadotropin; Folligon®, Intervet, Australia) on Day 7 (**Fig. 1**).

Does were tested for behavioural signs of estrus using two mature bucks, for 30 min, starting from 12 h after removal of CIDR inserts, and then every 4 h until 60 h after removal of inserts. The does that allowed any buck to mount were classified as being in estrus. Intromission by the buck during mounting was prevented by manual withdrawal of the buck from the doe before mating occurred.

2.3. Blood samples, hormonal and metabolic assays

Blood samples were collected from the jugular vein into 10 mL evacuated tubes containing heparin (BD Vacutainer®, Plymouth, UK) at the time of insertion of CIDRs (Day 0) and again on Days 2, 6 and 9. Samples were collected two hours after goats were fed the morning ration. On Day 4, indwelling intravenous catheters were inserted into the jugular vein of six goats from each treatment in both blocks and blood samples were collected every 15 minutes for 5 hours. Blood samples were stored on ice then centrifuged (2500 g for 15 min) within two hours of collection. Plasma was isolated and frozen (-20 ^{o}C) until the time of assays. Plasma samples were analysed for concentrations of glucose, insulin, leptin, IGF-1 and LH.

Plasma concentrations of glucose were measured using a commercial analyser (AU480 Beckman Coulter Australia Pty Ltd, Brisbane, QLD) with an enzymatic test (hexokinase method) for quantitative determination (Glucose reagent OSR6521). The sensitivity of this assay was 0.04 mmol/L.

Concentrations of insulin in plasma during intensive blood collection (Day 4) were quantified by a porcine insulin RIA kit (Millipore Porcine Insulin, MPPI12K; Abacus ALS, Brisbane, QLD). The sensitivity of the assay was 1.611 μU/mL. The inter-assay coefficients of variation for low (2.5 μU/mL) and high (30.1 μU/mL) quality controls were 16.2% and 9.4%, respectively. The corresponding intra-assay coefficients of variation were 12.5% and 7.0%, respectively. The ratios for observed to expected values for dilution parallelism with the standard curve for the assay was assessed using five serial dilutions of three plasma samples collected from two goats that were injected with 50 mL of a 50% glucose solution (500 g/L)/animal. Spiking recovery was assessed by the addition of a 50 μl aliquot of standards that contained a concentration of 6.25, 12.5, 25 and 50 μU/mL of purified recombinant human insulin into 150 μl of each of the three goat plasma samples. The average (mean ± SEM) observed/expected ratios (efficacy) was 125.6 ± 5.9% for parallelism and 104 ± 3.5% for spiking recovery.

Plasma concentrations of insulin on Days 0, 2, 4, 6 and 9 were measured by a double-antibody RIA that had been validated for ruminant blood samples [21]. All samples were processed in a single assay and the limit of detection was 0.39 μU/mL. Six replicates of three control samples containing 2.74 μU/mL, 4.97 μU/mL and 10.75 μU/mL were included in the assay to estimate the intra-assay coefficients of variation of 7.4%, 1.7% and 3.8%, respectively.

Plasma concentrations of leptin were measured by double-antibody RIA method described by Blache *et al.* [22]. All samples were processed in a single assay and the limit of detection was 0.05 ng/mL. The assay included six replicates of three control samples containing 0.28 ng/mL, 0.62 ng/mL and 1.16 ng/mL, which were used to estimate the intra-assay coefficients of variation of 5.3%, 5.5% and 5.0%, respectively.

Plasma concentrations of IGF-1 were measured by double-antibody RIA method validated for ruminant samples by Breier *et al.* [23]. All samples were processed in a single assay and the limit of detection was 0.05 ng/mL. Four replicates of two control samples

containing 0.21 ng/mL and 1.53 ng/mL were included in the assay to estimate the intra-assay coefficients of variation of 8.3% and 6.4%, respectively.

Plasma concentrations of LH during intensive blood collection on Day 4 were measured by double-antibody RIA described by Hâzel *et al* . [24] using ovine LH (NIDDK-oLH-I-3). All samples were processed in a single assay and the limit of detection was 0.18 ng/mL. The assay included six replicates of three control samples containing 0.5 ng/mL, 1.3 ng/mL and 2.0 ng/mL, which were used to estimate the intra-assay coefficients of variation of 6.2%, 3.3% and 2.4%, respectively.

Pulses of LH and amplitude in individual profiles on Day 4 were defined as described by Merriam and Wachter [25]. A pulse was defined when the concentration of LH exceed the mean concentration in a single point 5 times the standard deviation (SD), or at two consecutive points $\geq$3 times the SD or three consecutive points $\geq$2.5 times the SD. Amplitude was defined as the change in concentration from the mean concentration to the maximum concentration of that pulse. The pulse frequency and the mean amplitude were calculated for each goat profile.

2.4. Follicular status of ovaries

Ovarian follicular development was monitored in goats using a 6.6 MHz transrectal transducer (MyLab^{TM} FiveVET, Medical Plus Australia Pty Ltd, Tullamarine, Victoria) on Days 10, 11 and 12 after removal of inserts. Video recordings of each ultrasound examination were made. All follicles $\geq$2 mm in diameter were measured using electronic callipers and ovarian maps were drawn. Follicles were classified according to the diameter into three categories: small (2 to 3 mm), medium (>3 and <5 mm) and large follicles ($\geq$5 mm). The day of ovulation was defined by the sudden disappearance of a follicle $\geq$5 mm in diameter followed by the development of a corpus luteum within the same ovary. Ten days after ovulation, the total number of corpora lutea were recorded in the ovaries of each doe and recorded as the ovulation rate for each doe. During the present study, all ultrasound examinations were performed by the same operator.

2.5. Statistical analyses

A completely randomized block design of three treatments with 14 animals each was conducted. Statistical analyses were conducted using the statistical software package IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp. Released 2013, Armonk, NY). Analysis of variance (ANOVA) was used to compare the effects of treatment on breed (rangeland or Boer goats), interval from device removal to onset of estrus, maximum diameter of the largest follicle, number of ovulations, and number of small, medium and large follicles. Body weight on Day 0 was included as a covariate in analyses when the effect was significant. Tukey's test was used as a Post-hoc multiple comparison test to determine differences between treatments. Repeated measures ANOVA was used to compare the effects of treatments, time and interactions between time and treatment for the variables: the mean total number of small, medium and large follicles, plasma concentrations of glucose, insulin, leptin and IGF-1 and LH. If the Mauchly's test indicated violation of the assumption of sphericity, probability values were obtained after degrees of freedom were adjusted using Greenhouse-Geisser statistic. The data expressed as percentages were compared by Chi-square test. Results are presented as mean ± SEM and differences were considered significant when $P \leq 0.05$.

3. Results

For all analyses, effects due to breed and interactions of breed with treatment or breed with block were not significant and were removed from statistical models. A significant interaction ($P = 0.016$) between block and treatment for the concentrations of insulin was found so block was included in the statistical model used to analyse concentrations of insulin.

There was no significant difference among treatments for the percentage of does detected in estrus, the interval to onset of estrus and duration of estrus (**Table 2**). The number of

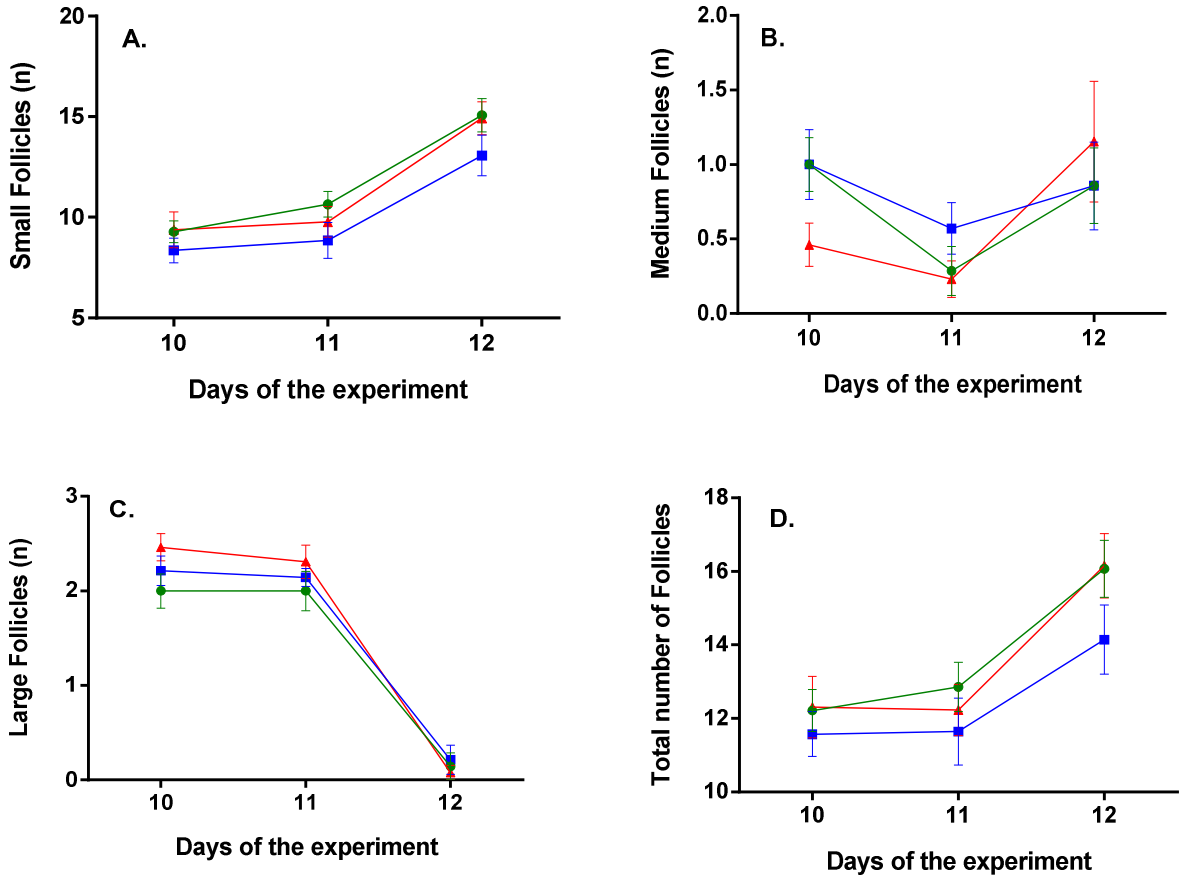

Fig 2. Number of (A) small (2 to 3 mm), (B) medium (>3 and <5 mm), (C) large (≥5mm), and (D) total number of follicles ≥ 3 mm on Days 10 to 12 of the study for goats supplemented with diets that provided energy at 1M with (■) or 1M without (●) the inclusion of maize, or 1.5M with maize (▲) in the diets.

ovulations observed was similar between goats treated with 1MM and 1.5MM, but was greater ($P < 0.05$) in does fed these diets compared with does fed the 1M treatment (**Table 2**).

The mean number of small, medium and large follicles and total number of follicles between Days 10 to 12 of ultrasound evaluations did not differ ($P = 0.204$) between treatments and there were no significant interactions between time and treatments ($P = 0.110$) for these variables (**Fig. 2**). The number of small ($P < 0.001$) and total number of follicles ($P < 0.001$) increased from Days 10 to 12, while the number of large follicles decreased from Days 10 to 12 ($P < 0.001$).

Concentrations of glucose and insulin on Day 4 of the study are shown in **Figure 3**. Between 2 h and 5.30 h after feeding, concentrations of glucose increased with time ($P = 0.018$), but concentrations of glucose were not affected by treatment ($P = 0.579$) or the interaction of time and treatment ($P = 0.298$; **Fig. 3a**). Similarly, concentrations of insulin on Day 4 of the study were affected by time ($P = 0.001$) and significantly increased within the first 30 minutes of sampling, but then remained relatively constant throughout the remainder of the sampling period (**Fig. 3b**). Concentrations of insulin during the intensive sampling period were not significantly affected by treatment ($P = 0.114$) or the interaction of time and treatment ($P = 0.876$).

Concentrations of insulin, leptin and IGF-1 on Days 0, 2, 6 and 9 were not affected by treatment ($P > 0.586$), but there were changes over time ($P < 0.001$) and an interaction between treatment and time ($P < 0.037$) (**Fig. 4**). Concentrations of insulin and IGF-1 significantly decreased from Days 0 to 2 and remained relatively constant between Days 2 and 9. On Day 0, concentrations of IGF-1 were greater ($P = 0.042$) in the group fed at 1.5MM compared with both groups fed at 1M and 1MM (**Fig. 4c**). Between Days 0 and 2, concentrations of leptin significantly increased in the group fed at 1.5MM, but decreased in both groups fed at 1M and 1MM (**Fig. 4b**), then concentrations of leptin remained relatively constant between Days 2 and 9 (**Fig. 4b**).

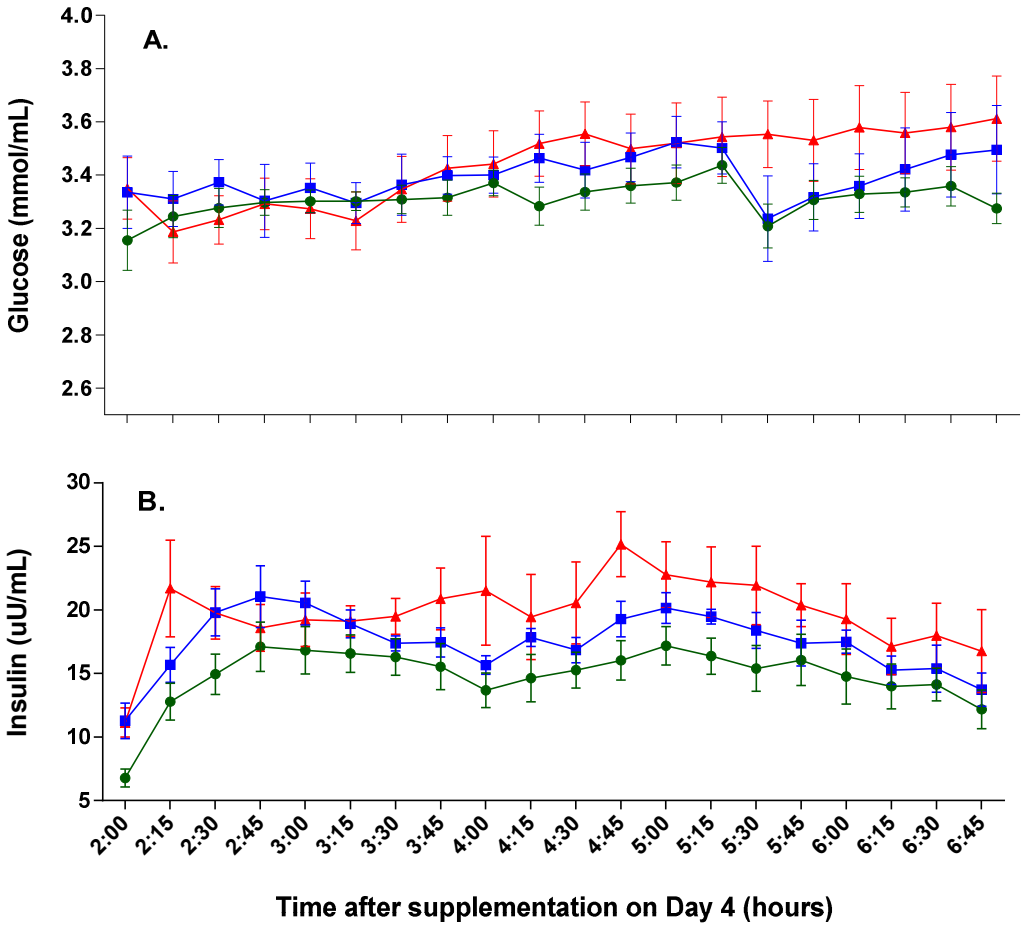

Fig. 3. Plasma concentrations of glucose (A) and insulin (B) on Day 4 of the study in goats supplemented with diets that provided energy at 1M with (■) or 1M without (•) the inclusion of maize or 1.5M with maize (▲) in the diets.

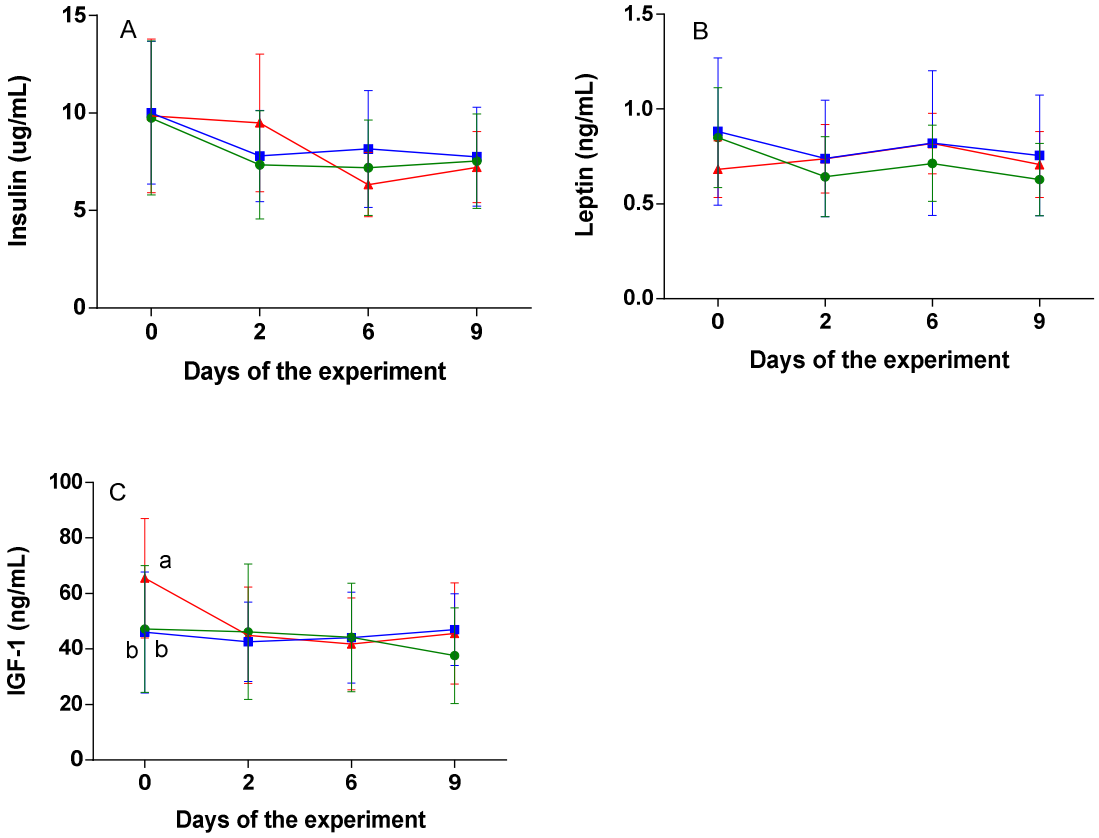

Fig. 4. Concentrations of insulin (A), leptin (B) and IGF-1 (C) of goats supplemented with diets of 1M without maize (•), 1M with maize (■) or 1.5M with maize (▲) during the breeding season (different letters, within days indicate differences between groups; $P < 0.05$).

During the period of intensive blood sampling on Day 4 of the study, the mean concentrations of LH tended to differ between treatments (P = 0.050; **Table 3**). Overall, the mean concentration of LH was greater in the 1.5MM group than in both the 1M and 1MM groups. Mean concentrations of LH fluctuated over time (P = 0.008) and significantly decreased within 2 h and 3 h after commencement of sampling, but there was no interaction of treatment with time (P = 0.240). The LH pulse frequency and amplitude of LH were not significantly affected by treatment (**Table 3**).

4. Discussion

To the authors' knowledge, this is first study to demonstrate that short-term nutritional supplementation with maize increases the ovulation rate in goats with synchronized estrous cycles during the breeding season. An additional novel finding of this study was that the ovulation rate was increased when maize was included in diets that provided metabolizable energy requirements for maintenance and 1.5 times above maintenance. The present study demonstrates that 9 days supplementation with relatively small amounts of maize to the diets of goats with synchronized estrous cycles can enhance ovulation rate and may improve prolificacy with little additional cost. These results, therefore, support the hypothesis that the principal nutritional factors that stimulate increases in the ovulation rate in sheep [26] and goats are the energy-yielding nutrients.

The lack of statistical differences between treatments on the number of small, medium, large and total number of follicles from Days 10 to 12 suggest that the number of follicles recruited and selected were not influenced by the level or dietary precursors of energy supplied. The reported effects of nutritional supplementation on the number of follicles are not consistent. For instance, there were no significant effects observed on the number of small and large follicles by Somchit et al. [27] after dietary supplementation of ewes with lupins associated with synchronization of estrus during the breeding season. On the other hand, ewes fed with a twice-

Table 3. Frequency (pulses/5h), amplitude of LH pulses and mean concentrations of LH on Day 4 of the study in goats supplemented with (1MM) or without maize (1M) at maintenance or 1.5 times above maintenance with maize (1.5MM).

	Treatments			
Variables	1M	1MM	1.5MM	P
Animals (n)	6	6	6	
Pulses/5h (mean ± SEM)	0.5 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.821
Amplitude of LH (ng/mL)	0.15 ± 0.03	0.13 ± 0.03	0.13 ± 0.03	0.939
Mean concentrations of LH (ng/mL)	0.18 ± 0.02^{b}	0.17 ± 0.02^{b}	0.24 ± 0.02^{a}	0.050

Values with different letters in the same row are significantly different at P = 0.050.

maintenance diet during the course of one estrous cycle increased the number of small follicles [28]. Furthermore, supplementation with steam-flaked corn for five days in ewes with synchronized estrous cycles increased the number of follicles greater than 4 mm in diameter without any effect on the number of smaller follicles [14].

Supplementation with maize appeared to have selective effects on ovarian follicular development before the time of ovulation in this study. Maize has been reported to be partially degradable in the rumen of sheep [29, 30] and this provides undegradable starch to be digested in the rest of the gastrointestinal tract, increasing the entry rate of glucose and other energy-yielding substrates into the bloodstream for a greater period of time [31, 32]. This may promote greater uptake of glucose by the ovaries which may enhance follicular development [33].

Dietary treatments did not significantly affect the numbers of small, medium, large follicles and total number of follicles between Days 10 and 12, but did increase the ovulation rate. A sudden reduction in the number of large follicles (**Fig. 2c**) and increase in the number of small follicles (**Fig. 2a**) was observed on Day 12, which was most likely a result of most goats ovulating after Day 11 and an emergence of a new follicular wave which occurs close to the time of ovulation [34]. The greater ovulation rate in the groups supplemented with maize (1 MM and 1.5 MM) could be attributed to a lower atresia rate of large follicles [11, 35]. During the latter stages of follicular development, the reduction in circulating concentrations of FSH is thought to induce atresia of smaller follicles, while larger, dominant follicles avoid atresia by shifting their dependence from FSH to LH [5, 18, 36]. In the present study, it is possible that the lower rate of atresia and the greater survival of large follicles led to a greater ovulation rates in does supplemented with maize. Thus while we could not demonstrate that the total number of follicles changed, perhaps there was a change in the number of follicles that retained ovulatory capacity at the time of the preovulatory LH surge.

The results of this study did not demonstrate any effect of supplementation of maize on plasma concentrations of hormones and metabolites. Ovulation rate increased when

supplementation with maize occurred which could not be attributable to any measurable increase in concentrations of glucose, insulin, leptin and IGF-1 from Days 0 to 9 of the experiment, or on the pattern of secretion of LH from 2 to 7 h after supplementation on Day 4. No significant effects of dietary short-term supplementation on concentrations of glucose, IGF-1, leptin and LH pulse frequency were also observed when anestrous does were supplemented with maize [37]. Circulating concentrations of glucose are not always increased when maize is fed to ruminants [38] but appears to be affected by the degradability of maize or other energy substrates in the rumen and hence rumen glucogenic activity [39]. Our results suggest that increasing ovulation rate in association with supplementation with diets containing maize at maintenance and 1.5 times maintenance occurred without any change in plasma concentrations of hormones and metabolites. Further study is needed to determine if changes in dietary composition mediates an increase in ovulation rate by inducing changes in gluconeogenic substrates, which are able to either directly or indirectly affect ovarian function.

We suggest two possible explanations why there were no significant effects of the diets on the concentration of glucose, insulin, leptin and IGF-1. First, the difference in the level of energy between experimental groups used in this study (1.5 times maintenance versus 1.0 times maintenance) was possibly not large enough to promote any effect of treatment. Some studies have reported greater concentrations of metabolites in ewes and goats fed greater compared with lower energy diets. For example, in Shiba goats supplemented either at maintenance or 2.5 times above maintenance requirements, concentrations of glucose and insulin were greater in the goats fed the greater-energy diet [15]. In addition, greater concentrations of glucose, insulin and leptin were recorded in ewes supplemented twice the maintenance diet compared with ewes fed at maintenance [11, 12]. Second, blood samples were collected two hours after goats were fed and this may have influenced the concentrations of metabolic hormones that were measured. After feeding, there is an increase in rumen volume and weight that may activate ascending pathways in the vagus nerve, which may change the concentrations of insulin and leptin [40],

independently of the quantity of nutrients that are fed. This may explain why we found a significant effect of time after feeding, but no effect of treatment.

It is unclear why the mean concentration of LH on Day 4 tended to be greater in the 1.5MM group than both 1MM and 1M groups, while the frequency and amplitude of LH pulses were not affected by the dietary treatments (**Table 3**). There is also conflicting evidence on the potential effect of nutritional supplementation on gonadotrophin secretion with some studies suggesting that gonadotrophin secretion is enhanced with supplementation [24, 40] and others suggesting that nutritional effects on follicular development and ovulation rate operate independent of influences on gonadotrophin secretion [11, 18]. The results of this study may suggest that the quantity of nutrients fed, the total rumen nutrient composition or the pattern of uptake of nutrients were unable to affect gonadotrophin secretion. Further study will be needed, using a longer duration of sampling, additional time periods when LH secretion is monitored and different supplementation rates with maize, to determine if dietary supplementation with maize can affect gonadotrophin secretion.

Most studies have focused on increasing ovulation rates by increasing dietary sources of energy [9, 10]. In this study, we demonstrated that by simply altering dietary composition without necessarily increasing dietary energy intake could be used as a strategy to improve ovulation rates in does. We also demonstrated that smaller elevations in dietary energy consumption (1.5 times maintenance) than demonstrated previously in other studies [15] can also be used to increase ovulation rate in does. Our results also suggest that short-term changes in dietary composition can be used to influence ovarian function in does as supplements were only fed for 9 days. Altering the composition of the diet without altering the amount of energy provided or increasing the degree of energy supplementation could both be used as strategies to improve prolificacy in does. As only modest changes were made to alter the composition of diets in this study, the results could suggest that the dietary changes required could be an economic means of improving productivity in goat herds.

4.1. Conclusion

Goats supplemented with maize in diets designed to provide metabolizable energy at a level of 1.0 or 1.5 times maintenance significantly increased ovulation rates compared with goats fed a diet that did not contain maize, but provided metabolizable energy at the level of 1.0 times maintenance. When attempting to increase ovulation rates in Boer and rangeland goats with synchronized estrous cycles it is, therefore, not necessary to increase the level of energy of a diet above maintenance when maize is a part of the diet. The implications of this management strategy are that the costs associated with a short-term supplementation strategy can be reduced when a diet that provides metabolizable energy at a level of 1.0 times maintenance with maize is fed compared with a diet that provides metabolizable energy at a rate of 1.5 times maintenance with maize. This illustrates the exquisite sensitivity of the ovary to changes in dietary composition and highlights the fact that prolificacy could potentially be altered by a modest change in the diet and during a relatively short period of supplementation.

Acknowledgments

We would like to thank the technical assistance throughout the experiments from Jo Penny, Virginia Simpson and Sally Watts at James Cook University. We also thank Ms Margaret Blackberry from the University of Western Australia for her help with the LH, insulin, leptin and IGF-1 assays.

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Short-term supplementation with maize increases ovulation rate in goats when dietary metabolizable energy provides requirements for both maintenance and 1.5 times maintenance

Research highlights

- Nine days nutritional supplementation with maize can increase ovulation rate in goats
- Inclusion of maize in the ration can stimulate ovulation rate at maintenance level
- Metabolizable energy at 1.0 or 1.5 times maintenance increased ovulation rates in goats