The meat goat industry in Australia: geographical, seasonal and nutritional influences on reproduction in female goats

Thesis submitted by

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College of Public Health, Medical and Veterinary Sciences

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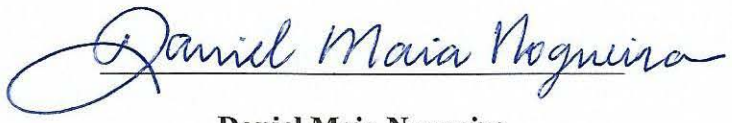
Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. All information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.



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The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the National Statement on Ethics Conduct in Research Involving Humans (1999), the Joint NHMRC/AVCC Statement and Guidelines on Research Practice (1997), the James Cook University Policy on Experimentation Ethics; Standard Practices and Guidelines (2001), and the James Cook University Statement and Guidelines on Research Practice (2001).

The proposed research methodology received clearance from Human Ethics Committee (ID H4415) and Animal Ethics Committee (A1695, A1725 and A1800) from the James Cook University.

Daniel Maia Nogueira

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Statement of the Contribution of Others

I, the undersigned, the author of this work, wish to recognise that this thesis has been completed with the grateful assistance of the below mentioned individuals.

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Abstract

Australia is the largest exporter of goat meat worldwide. However, little data is available regarding goat production systems, goat enterprises and productivity of Australian commercial goat operations. The general aims of this thesis were to provide an overview of meat goat producing enterprises in Queensland and New South Wales, to understand the seasonality of the reproductive cycle in Boer and rangeland goats in the tropics and to gain further knowledge on the effect of nutrition on the development of ovarian follicles during the breeding and non-breeding seasons.

This thesis is divided in six research chapters that are mentioned as scientific studies. **Studies 1 and 2** present a survey of the meat goat industry conducted on properties located in Queensland and New South Wales that derived a significant proportion of their income from goats. This survey covered 31 landholders with a total land area of 567,177 ha and a reported number of 160,010 goats. **Study 1** showed that 55% of producers were involved in 'opportunistic harvesting of rangeland goats' and 45% were specialized Boer goats producers. Stocking rate varied considerably (0.3 to 9.3 goats/ha) within and across surveyed properties and was found to be negatively associated with property size and positively associated with rainfall. The results have confirmed the importance of the international market as a source of income and the utilisation of goats to control weeds on many properties. The reasons for use of fencing appeared to be an important issue for goat farmers and this could potentially add to capital costs associated with better goat management and production. The strategies for pasture management, setting and adjusting the stocking rates, nutrition to meet market specifications and regional location of processing plants within 600 km of major areas of production could improve the utilisation and production of rangeland goats in New South Wales and Queensland.

Study 2 showed that producers who engage in opportunistic goat harvesting maintain few records related to herd production, animal health and reproduction. On the other hand, commercial and seedstock producers generally keep more records and they are trying to improve the productivity of their goatherds. In general, properties in the pastoral regions showed low pregnancy and kidding rates, early age at first mating, high mortality rates, poor performance of Boer bucks and lower weights and weight gain compared to properties in the high rainfall regions. Few registered veterinary chemicals

are available to control parasites of goats, and goat producers are using chemicals that are registered for use in sheep. The meat goat survey has highlighted areas that required further studies to validate the observations of producers. For instance, identifying management strategies that could improve the reproductive performance of Boer and rangeland goats, identify the timing of commencement of the breeding season in Boer and rangeland goats raised in the Queensland tropics and to gain further knowledge on the effect of nutrition on the development of ovarian follicles during the breeding and non-breeding seasons.

The aim of **Study 3** was to determine the timing of the onset of the breeding season in Boer and rangeland goats raised in a tropical region of northern Queensland. In this study, the ovarian activity in Boer does was more precocious than rangeland goats, which indicates that there are likely genetically driven differences in sensitivity to photoperiod between these breeds. Boer goats started to ovulate in December (8.3%) and had all ovulated by March, while most rangeland does started ovulating in March (84%) and had all ovulated by the end of April. Understanding the normal physiological patterns in follicular dynamics in female goats during the non-breeding and breeding seasons would help to illuminate physiological causes of differences in fertility and prolificacy when goats are bred at different times of the year.

Therefore, **Study 4** described the ovarian follicular dynamics in Boer goats during the non-breeding season and the following breeding season in the tropics of Queensland. The results of this study identified that 90% of Boer does were in anoestrus during the summer period (September to October) at latitude of 19˚19'30" South. The pattern of follicular dynamics evaluated by ultrasonography over 21-day period was characterized by four follicular waves in the breeding season and five waves in the non-breeding season, but the number of codominant follicles was greater in the breeding season. In addition, follicular dynamics in the breeding season compared to the non-breeding season was characterised by the development of larger follicles and greater follicular growth rates. These results demonstrated some similarities and differences between follicular dynamics within does between the breeding and non-breeding seasons.

The most common strategies to improve productivity in goats during the non-breeding season in the tropics are the use of hormonal synchronisation of oestrus and nutritional supplementation. Therefore, **Study 5** evaluated the reproductive response of seasonally

anoestrus goats that were either hormonally treated and/or supplemented with maize to determine which treatment combination was the most effective to stimulate follicular dynamic, and whether these responses were associated with increases in circulating concentrations of glucose, insulin, leptin and LH in anoestrus goats. The findings of this study showed that hormonal synchronisation of oestrus was a highly effective method of inducing oestrus and ovulation in seasonally anoestrus goats. A short-term nutritional supplementation with maize increased the concentrations of insulin, leptin and IGF-1 and appeared to have some influence on follicular development, but these changes were not mediated by an increase of the mean concentrations of LH and frequency of LH pulses. Nutritional supplementation with maize in combination with hormonal treatment increased the ovulation rate by 43%, although differences were not found to be statistically significant. Numerical differences in ovulation rates suggested that supplementation with maize in combination with the synchronisation of oestrus as a mechanism of potentially increasing ovulation rate did require further investigation in goats with larger groups of animals.

Finally, **Study 6** evaluated the ovarian follicular dynamics in goats, which were undergoing oestrus cycles supplemented with diets that differed in the composition of maize and the metabolisable energy content. In this study, it was used double the number of animals per group than in **Study 5** to increase the statistical power. In **Study 6**, it was possible to demonstrate that the addition of maize in a diet to provide nutritional requirements for maintenance during nine days can be used as a management strategy to increase the ovulation rate in female goats undergoing oestrus cycles in the tropics. Similar results between groups 1.0 and 1.5 maintenance with maize showed that there is no necessity to increase the level of energy of a diet above maintenance when maize is a part of the diet, because this might increase the cost of the diet. This study has established that short-term nutritional supplementation with maize can be used as a management strategy to increase ovulation rate and potentially improve prolificacy in female goats in the tropics.

List of abbreviations

ANOVA	Analysis of variance
cAMP	Adenosine 3:5-cyclic monophosphate (cyclic AMP)
CIDR	Controlled Internal Drug Release
CL	Corpus luteum
CSIRO	Commonwealth Scientific and Industrial Research Organization
DMI	Dry matter intake
FSH	Follicle-stimulating hormone
GH	Growth hormone
GnRH	Gonadotrophin releasing hormone
i/m	Intramuscular
IGF-I	Insulin-like growth factor-I
JCU	James Cook University
LH	Luteinizing hormone
ME	Metabolic Energy
mmol/L	Millimoles per litre
mRNA	Messenger ribonucleic acid
NBS	Non-specific biding
NEFA	Non-esterified Fatty Acids
ng/mL	Nanogram per millilitre
P4	Progesterone
PBS	Phosphate buffered saline
PGF2α	Prostaglandin-F2α
QC	Quality controls
RIA	Radioimmunoassay
s/c	Subcutaneous
SD	Standard deviation
SEM	Standard error of the mean

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List of publications arising from this thesis

Nogueira DM, Parker AJ, Cavalieri J, Gummow B, Fitzpatrick LA, (2012) Effect of hormonal treatment and energy supplementation on reproductive performance in rangeland goats during the non-breeding season: preliminary results. Proceedings of the 29th Biennial Conference of the Australian Society of Animal Production (ASAP), Christchurch, New Zealand, **29**:49.

Nogueira DM, Gardiner CP, Gummow B, Cavalieri J, Fitzpatrick LA, Parker AJ (2015). A survey of the meat goat industry in Queensland and New South Wales. 1. General property information, goat and pasture management. ***Animal Production Science***. Online Early. doi: 10.1071/AN14793

Nogueira DM, Gardiner CP, Gummow B, Cavalieri J, Fitzpatrick LA, Parker AJ (2015). A survey of the meat Goat industry in Queensland and New South Wales. 2. Herd management, reproductive performance and animal health. ***Animal Production Science***. Online Early. doi: 10.1071/AN14794

Nogueira DM, Cavalieri J, Gummow B, Parker AJ (2015) Timing of the commencement of the breeding season in Boer and Rangeland goats raised in the tropics of Queensland, Australia. ***Small Ruminant Research***, **125**:101-105. doi: 10.1016/j.smallrumres.2015.02.013

Nogueira DM, Cavalieri J, Gummow B, Parker AJ (2015) Comparison of follicular dynamics and hormone profiles in Boer goats examined during the breeding and non-breeding seasons in the tropics of Queensland, Australia. ***Small Ruminant Research***, **125**:93-100. doi: 10.1016/j.smallrumres.2015.02.014

CHAPTER 1: General Introduction

In this general introduction, I am going to show the outline and aims of each research chapter of this thesis, and a review of the most important aspects that need further information. For a better understanding, I am presenting a brief outline of the meat goat industry, the seasonality of goat reproduction, the influence of nutritional supplementation on ovarian function and metabolic hormones, and I explain why I have used the supplementation with maize in the experimental studies. In addition to this general introduction, each research chapter of this thesis will be followed by a specific introduction and aims.

1.1 Outline and aims of this thesis

Australia is the largest exporter of goat meat in the world. However, little data is available regarding goat production systems of Australian commercial goat operations. The general aims of this thesis were to provide an overview of meat goat producing enterprises in Queensland and New South Wales, to understand the seasonality of the reproductive cycle in Boer and rangeland goats in the tropics and subtropics, and to gain further knowledge on the effect of nutrition on the development of ovarian follicles during the breeding and non-breeding seasons.

This thesis is divided into six research chapters **(Fig. 1.1**), which will be mentioned in the text as scientific studies by their cardinal numbers (1 to 6), as following:

Study 1: A Survey of the meat goat industry in Queensland and New South Wales: **1**. General property information, goat and pasture management.
Study 2: A Survey of the meat goat industry in Queensland and New South Wales: **2**. Herd management, reproductive performance and animal health.
Study 3: The timing of the commencement of the breeding season in Boer and rangeland goats raised in the tropics of Queensland, Australia.
Study 4: Comparison of follicular dynamic and hormonal profiles of Boer goats examined during the breeding season and non-breeding season in the tropics of Queensland, Australia.

Study 5: Effect of hormonal synchronization and/or short-term supplementation with maize on follicular dynamics and hormone profiles in goats during the non-breeding season.

Study 6: Short-term supplementation with maize increases ovulation rate in goats when total dietary energy provides requirements for both maintenance and 1.5 times maintenance.

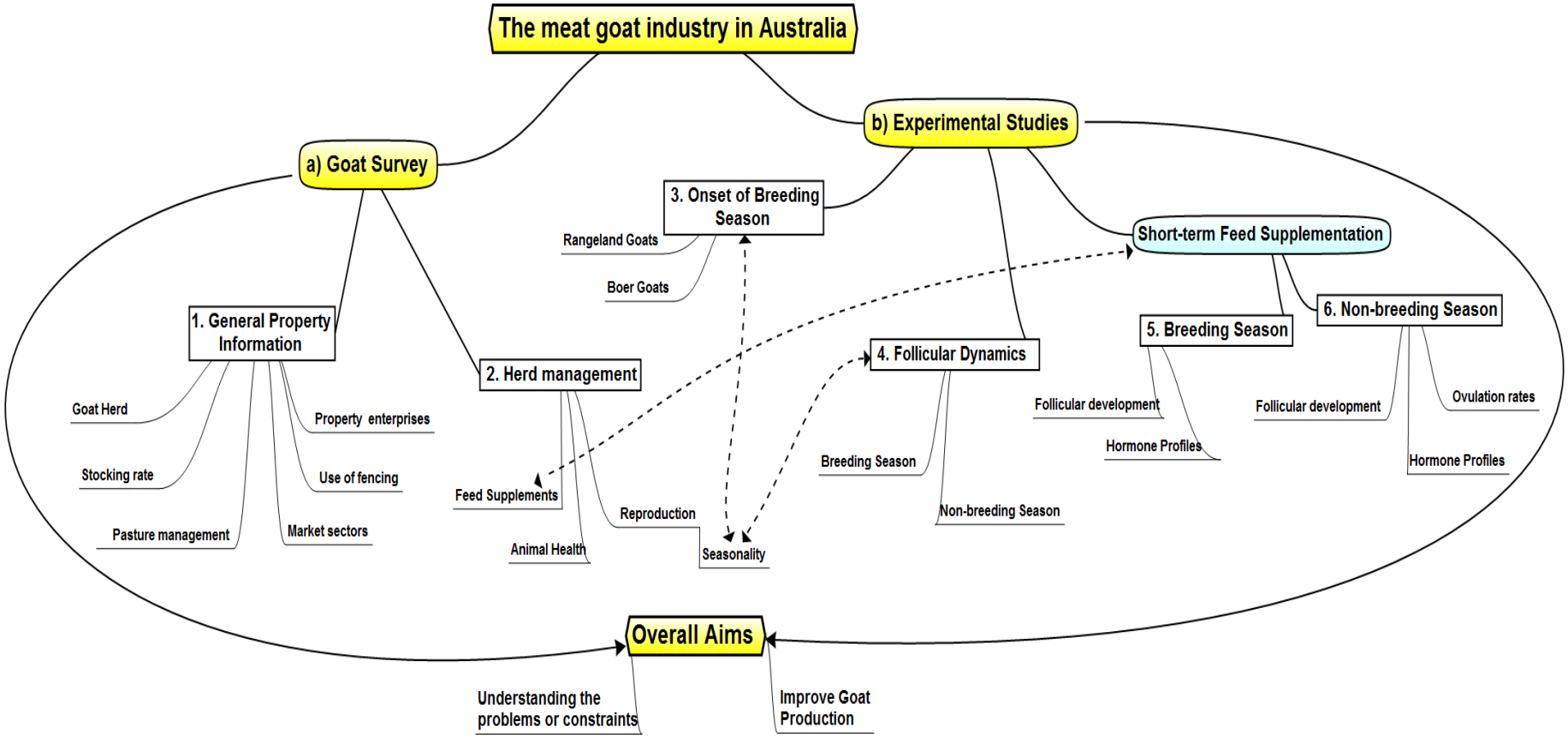


Fig. 1.1 Overview of the aims of this research entitled "The meat goat industry in Australia". The research is divided in two main studies a) Goat Survey and b) Experimental studies. Each scientific paper derived from the main studies is mentioned by cardinal numbers (1 to 6). The dash lines show the links between different studies.

Studies 1 and 2 present a survey of the meat goat industry conducted on properties located in Queensland and New South Wales that derived a significant proportion of their income from goats. These studies were designed to survey farmers' knowledge and practices on herd and property management, stocking rates, animal health, reproductive performance and markets of meat goat producing enterprises within Queensland and New South Wales. These studies will provide the first comprehensive overview of farming practices related to the management of Australian commercial meat goat operations. In order to improve the reproductive performance in goats, a thorough knowledge of the reproductive cycles of goats within the tropical regions of Australia is required. For instance, it is required the identification of the timing of onset of the breeding season in Boer and rangeland goats raised in the tropics of Queensland and the identification of the pattern and development of ovarian follicles in goats during the breeding and non-breeding seasons will be essential for understanding what is normal and how reproductive cycles of goats can change between seasons. This comprehension may also provide insights of how nutritional supplementation can affect the ovulation rate in goats during the breeding and non-breeding seasons.

The aim of **Study 3** was to determine the timing of the onset of the breeding season in Boer and rangeland goats raised in a tropical region of northern Queensland. As Boer and rangeland goats have adapted to dry climate conditions, we hypothesized that Boer and rangeland goats raised in the tropics of Queensland would exhibit a similar timing for the onset of the breeding season when fed above nutritional requirements for maintenance. Knowledge of the timing of the commencement of the breeding season in Boer and rangeland goats raised within northern Queensland could provide information on when interventions, such as strategic nutritional supplementation and/or hormonal treatments should be applied. In addition, understanding the patterns in follicular dynamics in female goats during the non-breeding and breeding seasons would help to illuminate physiological causes of differences in fertility and prolificacy when goats are bred at different times of the year. Therefore, the aim of **Study 4** was to describe the ovarian follicular dynamics in Boer goats during the non-breeding season and the following breeding season in the tropics of Queensland. To the author knowledge, this is the first report to describe follicular dynamics of the same Boer goats examined during both the non-breeding and breeding seasons.

The most common strategies to improve productivity in goats during the non-breeding season in the tropics are the use of hormonal synchronisation of oestrus and nutritional supplementation. Therefore, **Study 5** aimed to evaluate the reproductive response of seasonally anoestrus goats that were either hormonally treated and/or supplemented with maize to determine which treatment or combination of treatments was the most effective to stimulate follicular development, and whether these responses were associated with increases in circulating concentrations of glucose, insulin, leptin and LH in anoestrus goats. Numerical differences in ovulation rates suggested that supplementation with maize in combination with the synchronisation of oestrus did require further investigation as a mechanism of potentially increasing ovulation rate in goats with larger groups of animals. Furthermore, **Study 6** used double the number of animals per group than in **Study 5** to increase the statistical power. **Study 6**, therefore, aimed to evaluate the ovarian follicular development and changes in hormones and metabolites in goats, which were undergoing oestrus cycles supplemented with diets that differed in the composition of maize and the metabolisable energy content. **Study 6** indicates that the addition of maize in a diet to provide nutritional requirements for maintenance during nine days can be used as a management strategy to increase the ovulation rate and possibly improve prolificacy in female goats with synchronised oestrous cycles during the breeding season in the tropics.

1.2 The meat goat industry

Goats are widely distributed around the world and have been a source of human nutrition since the ancient civilization of Mesopotamia. Goats are an important source of milk, meat, skin and fibre throughout the world, while in parts of Australia they are also used as a means of controlling weeds. Many decision and policy makers, and heads of international organisations still appear to underestimate the capital role the goat has played since the early times of humanity (Boyazoglu *et al.* 2005). They are now faced with the impressive results of basic investigations, along with meaningful surveys, applied experimental data and breakthrough information that shows that goats can be a reference model for other farm livestock sectors (Boyazoglu *et al.* 2005). Goat production has been euphemistically declared to be of ‘third-world importance only’ or ‘goat is the cow of the poor’. However, goat production is clearly not synonymous with

under-development and poverty. In spite of the slow growth, the meat goat industry is increasing all over the world (**Table 1.1**).

Table 1.1 Total goat meat production (tonnes) in different countries from 2007 to 2012

Country	2007	2008	2009	2010	2011	2012
China	1,707,013	1,773,309	1,797,645	1,921,854	1,889,602	1,902,464
India	533,800	550,000	567,500	586,500	596,600	601,000
Pakistan	256,000	264,000	271,000	278,000	285,000	289,000
Mexico	42,873	43,128	43,242	43,867	43,839	41,492
South Africa	35,800	37,190	36,270	35,480	34,620	35,000
Brazil	29,440	29,050	28,450	28,900	29,150	29,500
Australia*	18,498	19,494	27,441	28,275	26,965	27,215
France	7,700	11,432	11,874	12,072	11,967	12,009
Spain	10,446	9,253	8,830	10,618	11,142	9,696
World	**4,723,978**	**4,905,903**	**5,043,858**	**5,211,907**	**5,262,747**	**5,300,336**

*Indigenous goats from rangeland production systems. Source: (FAOSTAT 2015).

Over the past 20 years the Australian meat goat industry has experienced continuous growth, largely supported by the sale of goats derived from rangeland production systems (Dubeuf *et al.* 2004; McRae and Thomas 2014). In Australia, there are approximately 3.6 million goats (FAOSTAT 2015), comprising 3.2 million rangeland goats and 400,000 domestic farmed goats, indicating that rangeland goats represent approximately 90% of the goat population in Australia. Rangeland goats in Australia are descended from the first European settlements and subsequent introductions. These goats were commonly kept by householders as a source of milk and were used as draught animals, some of which established permanent populations within sparsely populated areas of Australia (Restall et al. 1982).

Australia is the largest exporter of goat meat worldwide (**Table 1.2**), exporting 26,149 tonnes of meat in 2011 (FAOSTAT 2015). Furthermore, according to McRae and Thomas (2014) Australia slaughtered more than 2.0 million goats and produced 31,700 tonnes of goat meat in 2013-14. However, little data are available regarding goat production systems, animal health, reproductive performance and productivity of

Australian commercial goat operations and their capacity to meet export requirements (Brice *et al.* 2012).

In Australia, history reveals that rangeland goats are descended from the first European settlements in 1788 and subsequent introductions (Restall *et al.* 1982). These goats were commonly kept by householders as a source of milk and were used as draught animals, some of which established permanent populations within sparsely populated areas of Australia (Restall *et al.* 1982).

Table 1.2 World exports of goat meat (tonnes) in different countries from 2007 to 2011

Country	**2007**	**2008**	**2009**	**2010**	**2011**
Australia	15,988	17,528	24,758	26,221	26,149
China	9,124	8,262	5,428	6,733	4,660
Pakistan	3,505	2,466	2,342	3,938	4,290
France	2,668	2,531	2,486	2,580	2,684
Spain	332	257	335	471	736
India	152	27	7,234	40	129
USA	240	378	368	313	301
Mexico	7	13	49	61	59
South Africa	3	7	15	5	10
Brazil	6	6	0	0	0

Source: (FAOSTAT 2015)

Compared to the other meats, the consumption of mutton and goat meat in the world is very low. These days, pig meat (pork) is the most consumed meat worldwide, but similar consumption is observed to poultry (**Table 1.3**). Australia is also one of the greatest consumer of beef cattle and mutton, but the consumption of goat meat is low. Only about 5% of goats slaughtered enter the domestic market and this goat meat is sold through ethnic butchers in Melbourne and Sydney (Schuster 2006).

As almost 90% of the goat herd in Australia is derived from rangeland goats, improvements in the productivity and management of rangeland enterprises could have an important effect on the profitability of these enterprises (MLA 2013). In the **Studies**

1 and **2**, a survey was, therefore, designed to build a better understanding of the meat goat industry in Queensland and New South Wales.

Table 1.3 Latest data of meat consumption (kg/capita/year) of bovine, mutton+goat, pig meat and poultry in different countries

	Bovine	**Mutton + Goat**	**Pig meat**	**Poultry**
Australia	40.6	11.2	23.1	45.1
USA	37.0	0.4	27.9	51.4
Brazil	39.1	0.6	12.6	40.6
France	25.4	3.3	33.5	23.1
Mexico	16.0	0.9	13.8	29.5
South Africa	15.8	3.3	4.5	34.8
Spain	13.0	2.7	48.4	27.0
China	4.8	2.9	35.8	12.8
Malaysia	5.9	0.7	8.6	38.1
World (total)	**9.4**	**1.9**	**15.5**	**14.4**

Source: Food supply by (FAOSTAT 2015).

1.3 Reproductive cycle of goats

1.3.1 The oestrous cycle

The oestrous cycle is the period between two consecutive behavioral signs of oestrus (Fatet *et al.* 2011). The oestrous cycle in goats can be classified as short (lasting less than 17 days), normal (duration between 17 and 24 days) or long (longer than 24 days) (Chemineau *et al.* 1992a; Lopes Júnior *et al.* 2001). The changes in the ovaries are morphological (follicular recruitment and growth), biochemical (follicle maturation) and physiological (endocrine regulations) leading to the ovulation (Fatet *et al.* 2011).

The oestrous cycle is classically divided in two phases: the follicular phase and the luteal phase. The follicular phase is characterised by the stages of growth and development of the ovulatory follicle and involves maturation of gonadotrophin-dependent follicles until ovulation. The process leading to the formation of follicles takes place during foetal life. In ruminants, all current evidence is consistent with follicular formation being completed during foetal life and with a decline in the number

of remaining follicles throughout life (Garverick *et al.* 2010). The luteal phase starts from the time of ovulation and finishes with the regression of the corpus luteum (luteolysis). During this luteal phase, gonadotropin-dependant follicles continue to grow, but high concentrations of progesterone inhibit ovulation. The end of the luteal phase and beginning of a new follicular phase is marked by the luteolysis and decrease of progesterone secretion (Fatet *et al.* 2011).

1.3.2 Oestrus behaviour and ovulation

The oestrus is the period of the estrous cycle in which the female is receptive and accepts to be mounted by the male (standing oestrus). During oestrus, females may exhibit restlessness, tail movement, urinate and often scream, try to approach the male, have swollen and hyperemic vulva and vaginal discharge of mucus from the vagina, which may be watery at first, and dense, at the end of oestrus. In does, the mean duration of the oestrus is 36 hours, with a range of 24 to 48 hours (Fatet *et al.* 2011). Ovulation normally occurs at the end or after the standing oestrus. The mating occurs during standing oestrus, therefore, usually before ovulation.

1.3.3 Summary endocrinology of the oestrous cycle

The oestrous cycle is regulated by complex hormonal interactions among the hypothalamus and its secretion of GnRH, the pituitary gland and its secretion of LH and FSH, the ovarian follicles that secretes oestradiol and inhibin, the corpus luteum that secretes progesterone and oxytocin and the uterus that produces prostaglandin F2α. These hormones are linked by feed-forward processes (hypothalamus to pituitary gland to ovaries) and feedback processes (ovaries to hypothalamus and pituitary gland). The production of GnRH from the hypothalamus stimulates the secretion of LH from the anterior pituitary, which induces the ovulation (Day 0) of a large follicle and stimulates luteinisation of the follicular remnants. As the corpus luteum develops, concentrations of progesterone begin to rise and remains elevated during the luteal phase (Rubianes and Menchaca 2003). On Days 16-18 after the ovulation, prostaglandin F2α is secreted by the uterus and induces luteolysis, leading to a rapid decrease of progesterone concentration (McNeilly *et al.* 1991). Luteolysis marks the beginning of the follicular phase. During the follicular phase, the emergence, growth and development of follicles

is driven initially by LH pulse frequency. Both LH and FSH are involved in the development of the ovulatory follicle, which secretes oestradiol that, in turn, induces the behavioral signs of oestrus. The consequent increase in GnRH secretion induces the pre-ovulatory LH surge that induces ovulation 20–26 hours later and subsequently luteinisation of follicular cells (Scaramuzzi *et al.* 1993). At the end of the luteal phase, prostaglandin F2α secreted by the non-gravid uterus induces the luteolysis and decrease of progesterone secretion. The decrease of plasma concentrations of progesterone gradually removes the inhibition of gonadotropic hormones secretion and a new follicular phase then commences (Fatet *et al.* 2011).

1.4 Seasonality of reproduction

Goats are by nature seasonal breeders and this reproductive cyclicity is affected by variation in day length. In subtropical and temperate areas, the breeding season is stimulated by a reduction in the hours of daylight (negative photoperiod), with the largest percentage of conceptions occurring in autumn and winter (Fatet *et al.* 2011). Conception within autumn and winter results in kidding during spring, when feed supply and environmental conditions are usually most favourable (Scaramuzzi *et al.* 2006; Fatet *et al.* 2011).

The variation in day length depends on geographical location, and this influences the onset and duration of the breeding season. At latitudes greater than 35° in temperate zones, the variation in daylight are so great that goats and sheep tend to be strictly seasonal, with females showing behavioural signs of oestrus mostly during winter (Chemineau *et al.* 1992a; Rosa and Bryant 2003). In subtropical latitudes, seasonal variations in reproductive activity are also observed in most breeds of sheep and goats, and sexual activity can be affected by breed and/or food availability. However, in tropical areas, such as northern parts of Queensland where fluctuations in day length are not as extreme as in more southern parts of Australia (Timeanddate 2014), it is often hypothesized that food availability and socio-sexual interactions are the main factors controlling annual sexual activity in goats and sheep (**Table 1.4**).

Table 1.4 The influence of latitude and food availability on seasonality of reproduction in female goats

	Latitude	Cyclicity	Reference
Tropical (0 to 25º) Seasonality influenced by forage availability	3º & 9º South Brazil;	All year round	(Lopes Júnior *et al.* 2001); (Nogueira *et al.* 2012)
	16º 10' North Guadeloupe;	All year round	(Alexandre *et al.* 2001)
	20º & 25º North Mexico	Non-breeding season (low food availability)	(Mellado *et al.* 1991); (Galina *et al.* 1995)
Subtropical (>25º to 35º) Seasonality influenced by breed (genetic)	26º 23' North Mexico;	Non-breeding season (well nourished)	(Duarte *et al.* 2008)
	29º South Australia;	Non-breeding season (available pasture)	(Restall 1992)
	30º North Mexico	Non-breeding season (well nourished)	(Delgadillo *et al.* 2003)
Temperate (> 35º) Strictly seasonal	37º15' North Spain;	Non-breeding season (shorter by feed supply)	(Zarazaga *et al.* 2005)
	45º North France;	Non-breeding season (feed has no influence)	(Chemineau *et al.* 1992a)
	46º North Spain	Non-breeding season (feed has no influence)	(Valencia *et al.* 1990)

The response to photoperiod involves a complex process, including the detection of light by the retina, circadian rhythm control by the hypothalamus and secretion of melatonin by the pineal gland. Photoperiodic control of reproductive patterns is mediated through the secretion of melatonin by the pineal gland during darkness, which in turn influences the secretion of GnRH and hypothalamic-pituitary-gonadal feedback (Chemineau *et al.* 1992a; Fatet *et al.* 2011). In addition, the onset of the breeding season in sheep is primarily due to changes in the responsiveness of the hypothalamus to the negative feedback of oestradiol, which in turn is dictated by variations in the length of the daily photoperiod (Rosa and Bryant 2003).

Differences in seasonality and onset of breeding season between breeds of goats have been reported in the literature (Amoah *et al.* 1996; Freitas *et al.* 2004a), which highlights the influence of genotype on reproductive cyclicity in goats. In sheep, different responses between breeds to photoperiod could be due to different genetic abilities to secrete melatonin or differences in signal transmission within the brain or differences in responsiveness to circulating concentrations of oestradiol (Rosa and Bryant 2003).

1.4.1 Changes in day length

Variation in day length is shown for comparison between Townsville and different locations in more southern capital cities in Australia (**Fig. 1.2**). A progressive increase in day length occurs from June to December, which is followed by a decrease in day length from December to June (**Fig. 1.2a**). Greater differences between the maximum and minimum day lengths are evident for major metropolitan regions south of Townsville (**Fig. 1.2b**). These differences in day lengths are positively associated with the greater latitudes south from Townsville to Sydney.

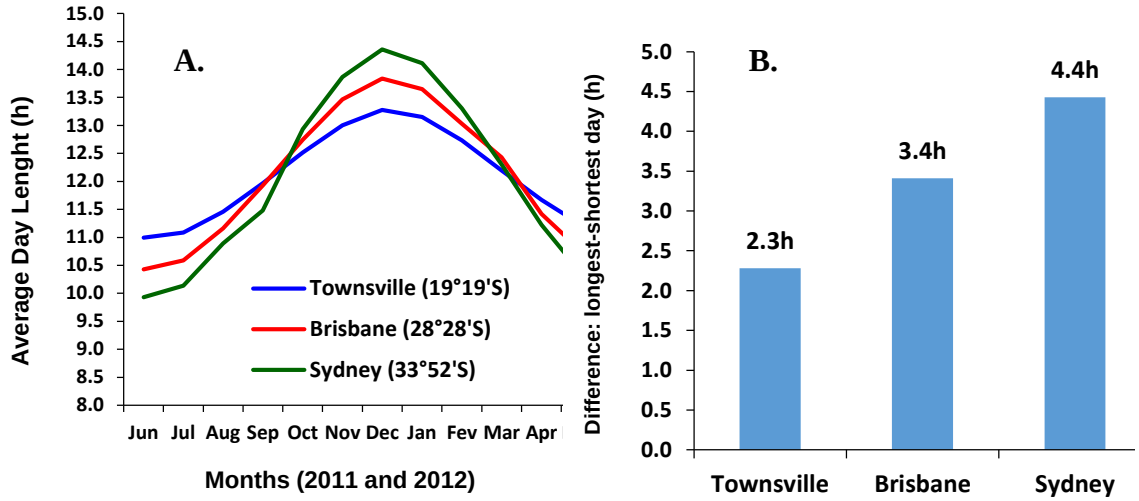


Fig. 1.2 (A) Day length in different cities of Australia, (B) Difference in day length between the longest and shortest day of the year (2011 to 2012). * Derived from Time and Date (2014).

At present, there is no information available about the timing of the commencement of the breeding season in Boer and rangeland goats raised in the tropics of Queensland. Determining the onset of the breeding season is critical when determining optimal times for commencement of breeding programs in extensively managed goat herds. In addition, variation among animals in the onset of reproductive cyclicity and seasonal anoestrus may provide insights into factors that may influence the timing of reproductive cyclicity in tropical regions of Queensland, Australia. Examination of potential means of manipulating of the breeding season of goats could also improve the productivity of goats by enabling goats to be bred and produce offspring throughout the year within tropical regions.

1.5 Follicular Dynamics

The use of ultrasound technology in sheep and goats has played a significant role in the collection of data regarding ovarian follicular dynamics. However, in sheep and goats, ultrasound imaging of ovarian follicles is technically challenging because of the small size of the animals, the size and position of the ovaries and the interpretation of data images, as goats and sheep normally have multiple ovulation.

Follicular dynamics involves the continual process of growth and regression of ovarian follicles that leads to the development of the preovulatory follicle. Follicular growth evolves in a wave-like manner throughout the cycle, with two or more follicles attaining 5 mm or more in diameter and growing approximately 1.0 mm per day (Ginther and Kot 1994; Medan *et al.* 2005; Simões *et al.* 2006). Studies using repeated ultrasonography suggest that there are between two and six waves of follicle development during oestrous cycles in goats with three or four waves being the most prevalent. Each follicular wave last approximately 5 to 10 days (Simões *et al.* 2006). Scaramuzzi *et al*. (1993) presented a model for folliculogenesis in the ewe (**Fig. 1.3**). The model illustrates five classes of follicles based on their dependency and sensitivity to gonadotrophins: i) Primordial follicles, ii) Committed follicles, iii) Gonadotrophin-responsive follicles, iv) Gonadotrophin-dependent follicles and v) Ovulatory follicles.

1.5.1 Primordial follicles

Primordial follicles constitute the resting stockpile of non-growing follicles found in the outermost regions of the ovarian cortex (Scaramuzzi *et al.* 1993). Primordial follicles are small (0.03 mm in diameter) and present in large numbers (40,000 to 300,000) in the ovaries (Scaramuzzi *et al.* 1993). In ruminants, all current evidence is consistent with follicular formation being completed during foetal life (Garverick *et al.* 2010), and these follicles are depleted throughout animal's reproductive life. In primordial follicles, there is very little evidence of atresia and cell turnover rates are extremely low. Primordial and committed follicles are largely independent of gonadotrophins. These classes of follicles can be affected by gonadotrophins, but they do not require gonadotrophins for their survival and continued development (Scaramuzzi *et al.* 2011).

1.5.2 Committed follicles

Follicles leave the primordial stage of development in an ordered sequence, and are committed to grow. The primary changes in this stage of development occur in the oocyte, with enlargement and development of the zona pellucida (Scaramuzzi *et al.* 1993). In addition, these follicles form two or three layers of granulosa cells and theca cells differentiate from surrounding stroma. In sheep, committed follicles range in diameter from 0.03 to 0.1 mm (Scaramuzzi *et al.* 1993). Similarly to the primordial follicles, committed follicles do not have the antral cavity and they are gonadotrophin-independent follicles (Scaramuzzi *et al.* 2011). However, receptors for FSH can be identified on granulosa cells and theca cells express receptors for LH.

1.5.3 Gonadotrophin-responsive follicles

Gonadotrophin-responsive follicles are large preantral follicles or small-medium antral follicles, ranging from 0.2 to 2.5 mm in diameter (Scaramuzzi *et al.* 1993; Scaramuzzi *et al.* 2011). The theca cells are LH-responsive, granulosa cells are FSH-responsive, and these follicles have an increasing rate of atresia without the presence of gonadotrophins (Scaramuzzi *et al.* 2011). As follicle development progresses, follicles gradually become more and more reliant to gonadotrophins, first as gonadotrophin-responsive follicles and then as gonadotrophin-dependent follicles.

1.5.4 Gonadotrophin-dependent follicles

For a follicle to progress from gonadotrophin-responsiveness to gonadotrophin-dependency there is an absolute requirement for FSH. During this stage, gonadotrophin-dependent follicles grow larger than 2.5 mm in diameter (Scaramuzzi *et al.* 1993) and they become atretic if concentrations of FSH are low before granulosa cells develop LH receptors (Scaramuzzi *et al.* 2011). With adequate FSH support, there is a further increase in aromatase activity and follicles secrete oestradiol in increasing amounts (Scaramuzzi and Campbell 1990). According to the same authors, without adequate FSH support, aromatase activity is not maintained and androgen accumulates within the follicle, leading to atresia. The number of follicles that passes from one stage of development to the next stage decreases with each step, and a high rate of atresia is associated with emergence of ovulatory follicles.

1.5.5 Ovulatory follicles

In goats, the ovulatory follicles usually reaches a diameter between 5.0 mm and 8.0 mm (Medan *et al.* 2005; Simões *et al.* 2006). Ovulatory follicles are those that are capable of ovulation, they have LH receptors on granulosa cells and they can survive in very low concentrations of FSH (Scaramuzzi *et al.* 2011). Ovulatory follicles have granulosa cells with a larger number of receptors for LH and FSH, and aromatase activity is maximal. For this reason, ovulatory follicles have the highest intra-follicular concentrations of oestradiol (Scaramuzzi *et al.* 1993). In addition, the increased secretion of oestradiol and inhibin suppresses FSH below the critical threshold required by gonadotrophin-dependent follicles. Due to the process of atresia, the number of follicles destined to ovulate and the number of follicles ovulating are strictly regulated (**Fig. 1.3**).

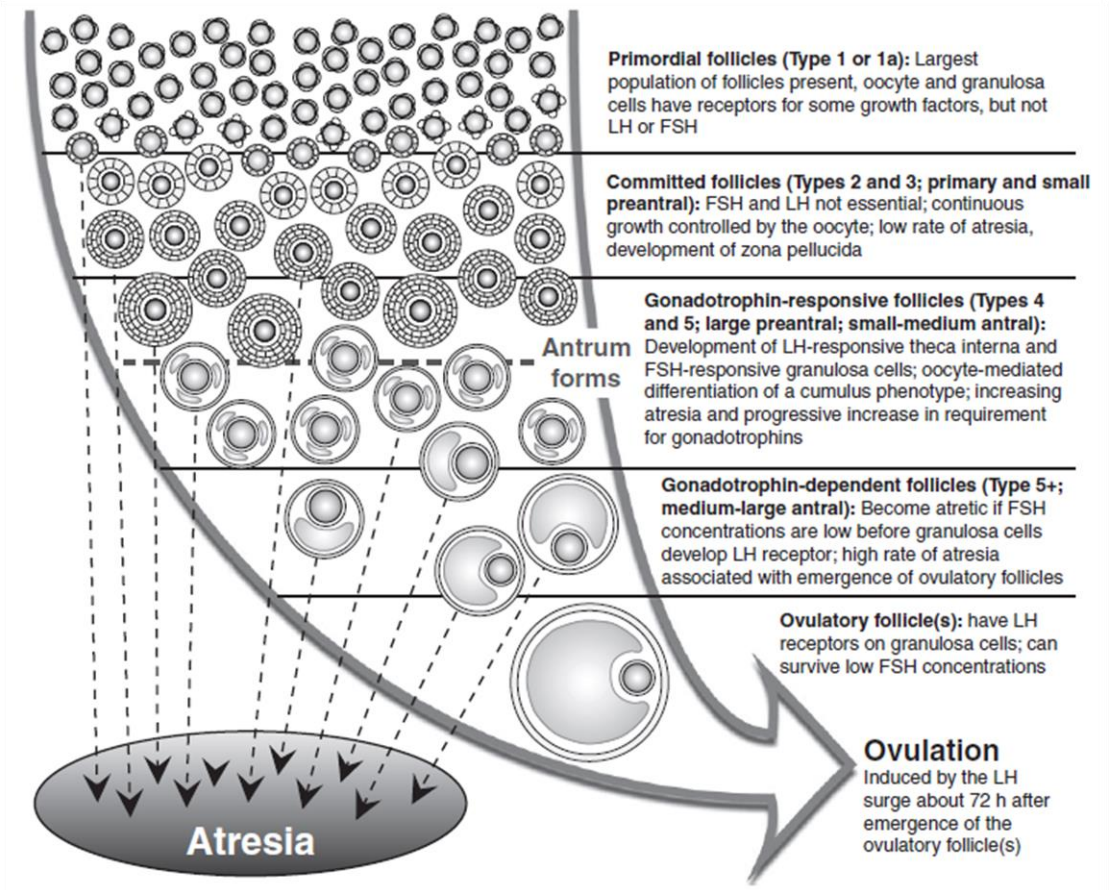


Fig. 1.3 The model for folliculogenesis in the ewe developed by Scaramuzzi *et al*. (1993) and updated by Scaramuzzi *et al*. (2011). A cohort of primordial follicles enter in a process of growth and development that is continuous and ends in either atresia or ovulation.

1.6 Follicular growth: Recruitment, Selection and Dominance

A follicular wave is defined as one or more antral follicles growing from 2 to ≥5 mm in diameter before subsequently regressing and being no longer detectable (Ginther and Kot 1994; Simões *et al.* 2006). A follicular wave is characterized by the sequence of three gonadotrophin events in follicular growth: i) recruitment, ii) selection and iii) dominance (Driancourt 2001).

1.6.1 Recruitment

Recruitment is term used to describe the growth of a cohort of gonadotrophin-responsive follicles from 2 to 3 mm in diameter. These follicles begin their initial growth phase under the influence of a small rise in FSH concentrations (Driancourt 2001). The number of follicles recruited into the cohort of emerging follicles is highly variable between species and appears to be affected by concentration of FSH (Driancourt 2001). The number of gonadotrophin-responsive follicles might also influence the number of follicles recruited by increasing the number of capable of responding to a given threshold stimulus of FSH. Evidence for this is provided in the Ramanov ewe that contain three times more growing follicles than those of non-prolific breeds (Scaramuzzi *et al.* 2011).

1.6.2 Selection

From the number of gonadotrophin-responsive follicles that were recruited as a cohort of growing follicles, one or more follicles are selected to a cohort of gonadotrophin-dependent follicles (Viñoles *et al.* 1999b). Follicles, once selected, are described as dominant as they can prevent the growth of other subordinate follicles (Driancourt 2001). The smaller, subordinate follicles will undergo atresia and fail to ovulate. The selected and growing follicles produce inhibin and oestradiol, which reduces the concentrations of FSH (Souza *et al.* 1998; Scaramuzzi *et al.* 2011). The fall in the concentrations of FSH plays an important role in limiting the number of follicles that eventually ovulate (Baird and Campbell 1998). The selected follicles are able to grow and mature more rapidly in low concentrations of FSH and transfer their gonadotrophic requirement from FSH to LH (Campbell *et al.* 1995). Therefore, the selected follicles, through the synergistic action of oestradiol and inhibin in causing a

negative feedback on FSH secretion are able to survive and continue to grow as concentrations of FSH decline, while other follicles from the cohort are suppressed.

1.6.3 Dominance

Dominance is defined as the process by which large follicles, potentially ovulatory follicles, escape from atresia (Webb and Campbell 2007). The concept of the dominant follicle has doubtful physiological relevance in small ruminants because the largest follicle is not necessarily the ovulatory follicle and may even be atretic (Viñoles *et al.* 1999a). The dominant follicle is a gonadotrophin-dependent follicle that is selected because it has molecular machinery that allows it to produce large amounts of oestradiol, to survive at low concentrations of FSH and to develop LH receptors (Scaramuzzi *et al.* 2011; Rosales-Torres and Guzmán-Sánchez 2012). It also secretes androstenedione and inhibin, reducing FSH concentrations to below the threshold needed to sustain the other gonadotrophin-dependent follicles (Scaramuzzi *et al.* 2011). Thus, the drop in FSH levels causes the atresia of subordinate follicles, whilst a dominant follicle avoids its own regression by shifting their absolute dependence on gonadotrophins from FSH to LH (Baird and Campbell 1998; Campbell *et al.* 1999; Meza-Herrera *et al.* 2008). In goats, follicles 5-9 mm in diameter reach the pre-ovulatory stage by developing LH receptors on their granulosa cells and becoming independent of FSH (Meza-Herrera *et al.* 2008; Fatet *et al.* 2011).

In the presence of a corpus luteum (a non-ovulatory wave), dominant follicles become atretic after 4–5 days, secreting less oestradiol and inhibin, therefore, FSH can increase and start a new follicular wave. If luteolysis occurs when dominant follicles are present, follicles will normally progress to ovulation (Scaramuzzi *et al.* 2011).

1.7 Codominant follicles and ovulations

Follicles are classified as codominant when two or more follicles $\geq$5 mm in diameter are present within the same follicular wave (Nogueira *et al.* 2015a). The number of codominant follicles is normally related to the number of ovulations. The presence of follicular waves with codominant follicles has been observed in does in different studies (Rubianes and Menchaca 2003; Gonzalez-Bulnes *et al.* 2005). When double ovulations occur, they are usually of codominant follicles derived from the same

follicular wave, but in a few cases they derive from two consecutive follicle waves (Ginther and Kot 1994). In our **Study 4** (Nogueira *et al.* 2015a), we found that 92.9% of Boer goats presented multiple ovulations from the same follicular wave, but 7.1% of does had double ovulations from different follicular waves. In this last example, a second ovulatory wave emerged a few days after the first ovulatory wave.

1.7.1 Mechanisms to increase the ovulation rate

There are three mechanisms of increasing ovulation rate: i) widening the gate through elevated FSH, ii) widening the gate by lowering the threshold of FSH and iii) increasing the number of gonadotrophin-dependent follicles (Baird and Campbell 1998; Scaramuzzi *et al.* 2011).

The "widened gate" represents the period of time when the concentration of FSH remains above the threshold and it regulates the number of gonadotrophin-dependent follicles that pass through it and avoid atresia to become ovulatory follicles. The three mechanisms to increase ovulation rate are:

1) Widening the gate through elevated FSH

Ovulation rate can be increased by decreasing the sensitivity of the hypothalamic-pituitary-ovarian axis to the negative effect of oestradiol to maintain the concentration of FSH above the threshold level for longer, thus allowing more time for follicles to pass through the "widened gate" (Baird and Campbell 1998; Hunter *et al.* 2004; Scaramuzzi *et al.* 2011). The "wider gate" and greater number of ovulations can be obtained by administration of exogenous hormones (FSH, eCG or oestradiol antiserum). With the administration of exogenous hormones, concentrations of FSH will remain above the threshold for longer periods of time before being suppressed by rising oestradiol and inhibin (Baird and McNeilly 1987).

2) Widening the gate by lowering the threshold of FSH

Ovulation rate can be increased by increasing the number of ovulatory follicles to pass through the gate before it is closed by suppression of FSH below its threshold level (Baird and Campbell 1998; Scaramuzzi *et al.* 2011). The gonadotrophin-dependent follicles may become more sensitive to FSH and hence develop precociously. This is the case of ewes carrying the Booroola gene that have been reported to select

and ovulate a large number of follicles (Souza *et al.* 2001). Both insulin and IGF-1 and some growth factors, particularly the vascular endothelial growth factor (VEGF) and fibroblast growth factor (FGF) can increase the sensitivity of granulosa cells to the low concentration of FSH (Hunter *et al.* 2004).

3)Increasing the number of gonadotrophin-dependent follicles

Finally, ovulation rate can be increased by reducing the size of follicles that become gonadotrophin-responsive and gonadotrophin-dependent that pass through the gate. This is also the case of ewes carrying the Booroola gene (Souza *et al.* 2001). Alternatively, the number of gonadotrophin-dependent follicles may be increased without changing the size of follicles as happens, for example, in the Romanov and Finnish Landrace breeds of sheep (Scaramuzzi *et al.* 2011). According to the same authors, these breeds of sheep have ovaries that contain three times more growing follicles than those of non-prolific breeds. The reports show that in Romanov and Finnish Landrace ewes, the hypothalamic-pituitary-ovarian axis is more resistant to the negative effect of oestradiol and, as a consequence, more gonadotrophin-dependent follicles pass through the widened gate. These three mechanisms of increasing ovulation rate may operate simultaneously in some highly prolific breeds of sheep.

1.8 Influence of nutrition on ovarian function

The effects of nutrition on reproduction, mainly from sheep studies, are well known and widely reported. Nutrition exerts a significant influence on reproductive function through changes in body weight and body condition affecting processes of follicular development and ovulation rate (Lindsay *et al.* 1993; Scaramuzzi *et al.* 2006; Scaramuzzi and Martin 2008). Nutritional supplementation affects most of the stages of folliculogenesis to some extent; influencing in the selection of dominant follicles, increasing the diameter and follicular growth, and improving the quality of oocytes (Lucy 2000; Webb *et al.* 2004; Scaramuzzi *et al.* 2011). These changes in follicular development are enhanced through supplementation with high-energy and/or high-protein diets (Teleni *et al.* 1989).

The chemical nutrient of most significance for ovarian function is probably energy, particularly when derived from glucose (Teleni *et al.* 1989; Downing *et al.* 1995b; Viñoles *et al.* 2005), however, the evidence in favour for any particular nutrient

is still controversial and the precise interrelations between ovarian function and the components of the diet remain obscure (Scaramuzzi and Martin 2008). Because reproduction is very energetically demanding, energy balance is arguably the most powerful regulator of reproductive function (Blache *et al.* 2008).

1.8.1 Long-term and short-term nutritional supplementation

Several explanations of the effect of nutrition on ovulation rate have been formulated. These include the "static or dynamic effect" and the "acute effect". The "static or dynamic effect" refers to the effect, respectively, of body condition or body weight gain during 3 to 6 weeks (long-term) of nutritional supplementation (Lindsay *et al.* 1993; Viñoles *et al.* 2005). The "acute effect" refers to the short-term nutritional supplementation for 4 to 11 days, which affects the ovarian activity without changes in body weight or body condition (Viñoles *et al.* 2005; Scaramuzzi *et al.* 2006). After these studies, the period for nutritional supplementation could was reduced from 42 days (6 weeks) to up to 11 days. This breakthrough in research led to a reduction in the cost of feed supplementation.

The effects of long-term nutritional supplementation in sheep and goats were initially embodied in the concept of 'flushing' for a period of 3 to 6 weeks before mating, leading to an increase in body weight and body condition and greater ovulation rate (Rhind *et al.* 1989; Viñoles *et al.* 2002; Meza-Herrera *et al.* 2008). This greater ovulation rate was associated (Rhind *et al.* 1989; Viñoles *et al.* 2002) or not associated (Meza-Herrera *et al.* 2008) with greater concentrations of LH.

Over the last 30 years (1985 to 2015), a few studies have shown that a short-term nutritional supplementation can promote an increase in the ovulation rate of sheep during five to seven days (Stewart and Oldham 1986; Nottle *et al.* 1990), for 11 days (Downing *et al.* 1995a) or for 14 days (Nottle *et al.* 1997). In contrast, other studies have demonstrated that short-term nutritional supplementation can increase the ovarian follicular development in sheep (Viñoles *et al.* 2005; Letelier *et al.* 2008; Viñoles *et al.* 2010; Ying *et al.* 2011) and in goats (Haruna *et al.* 2009) without increasing the ovulation rate. This inconsistent effect of short-term nutrient supplementation on ovulation rates suggests that ovulation rate may depend on the follicular development at the beginning of the nutritional supplementation. To be effective, short-term supplements have to be fed on days 9 to 13 of oestrus cycle or 6 days before luteolysis

(Stewart and Oldham 1986; Nottle *et al.* 1990; Downing *et al.* 1995b). However, at that time, it was not possible to associate daily follicular growth with the endocrine and metabolic responses to the nutritional supplementation. A decade later, with the use of ultrasound evaluations of the ovaries, Viñoles *et al*. (2005) described that feed supplementation may need to begin at the time of the emergence of the ovulatory wave, from day 4 to 8 days before ovulation. In addition, a single synchronized follicular wave, called as 'the first-wave model', could be induced in all females during the beginning of the nutritional treatment (Viñoles *et al.* 2010).

Viñoles *et al*. (2005) suggested that the effect of short-term supplementation on ovulation rate may depend on three factors: i) the status of follicular development at the beginning of the nutritional treatment, ii) the concentrations of glucose, insulin, leptin and IGF-1, and iii) the pool of follicles available for the action of these metabolic hormones at the time nutritional supplementation is introduced. In order to control this follicular status, Viñoles *et al*. (2010) used a series of three cloprostenol injections (prostaglandin analogue) administered at 7-day intervals to align the emergence of follicular waves. The 6-day period of supplementation started after the second injection of cloprostenol, and the third injection of cloprostenol was given at the end of supplementation, used to induce the ovulation of the follicular wave. By using this protocol, Viñoles *et al*. (2010) could synchronise the growing phase of the follicles with the commencement of the nutritional supplementation.

1.8.2 Hormonal and metabolic response to nutrition

Nutritional supplementation influences either directly through dietary nutrients or through metabolic intermediates, and affects folliculogenesis at multiple levels of the hypothalamic-pituitary-ovarian axis (Scaramuzzi *et al.* 2006). The effect of nutrition on the blood concentration of FSH and LH remains unclear and difficult to demonstrate, with reports for and against the induction of a change in gonadotrophin secretion (Viñoles *et al.* 2010). The pattern of gonadotrophin secretion can be altered through nutritional supplementation, but it is unlikely to be the main driver of a change in ovulation rate (Downing *et al.* 1995b). It is likely that nutritional supplementation affects the sensitivity of granulosa cells of large follicles to the action of FSH (Viñoles *et al.* 2005; Scaramuzzi *et al.* 2011).

The action of nutrition on folliculogenesis is thought to be mediated by different physiological pathways. Viñoles *et al*. (2005) suggested that the effect of short-term 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, which can then promote increased follicular steroidogenesis and increased ovulation rate. Recent evidence suggests that the stimulatory effects of short-term supplementation on folliculogenesis are mediated directly at an ovarian level, and glucose, fatty acids and several metabolic hormones have all been shown to have direct actions on the follicle (Scaramuzzi *et al.* 2006; Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011).

The list of hormones and metabolites that have direct influence on follicular development is extensive. The most studied of the intra-follicular mediators of nutritional influences on folliculogenesis are glucose, insulin, leptin, IGF-1 and GH. Insulin is involved in stimulating uptake of glucose by follicular cells (Scaramuzzi *et al.* 2011). The insulin receptor is a tyrosine kinase class that auto-phosphorylates on insulin binding, activating the phosphatidylinositol-3 kinase (PI3K) pathway to translocate the glucose transporter 4 (GLUT4) to the cell membrane to mediate the uptake of glucose into granulosa and theca cells (Scaramuzzi *et al.* 2010). The insulin-glucose system stimulates folliculogenesis by increasing the number of medium follicles (gonadotrophin-responsive follicles) and increasing the ovulation rate (Downing *et al.* 1995b). However, without any effect on the number of small follicles (Viñoles *et al.* 2005). In addition, insulin enhances the synthesis of IGF-1 in the liver to increase oestradiol production by the dominant follicle, resulting in increased LH receptors (Lucy 2000; Webb *et al.* 2004), and insulin has a direct effect on adipocytes to stimulate secretion of leptin (Marie *et al.* 2001).

Leptin is a neuropeptide produced primarily by adipose tissue and is involved in the regulation of appetite, being sensitive to short-term supplementation in sheep, as well as sensitive to long-term changes in food intake and is positively correlated with body condition and fat stores (Marie *et al.* 2001; Muñoz-Gutiérrez *et al.* 2002). Concentrations of leptin may increase to a maximum at 24 hours after the start of feeding and remains high for another 72 hours, after which return to basal concentrations (Muñoz-Gutiérrez *et al.* 2002). Leptin does not act alone; leptin is a member of a cohort of humoral and neural factors that influences homeostasis of glucose and the activity of the GnRH-LH pulse secretion (Blache *et al.* 2000a; Zhang *et*

al. 2004). Kendall *et al*. (2004) reported that leptin inhibits the secretion of oestradiol and stimulates folliculogenesis during the follicular phase of the oestrous cycle and, furthermore, that passive immunisation against leptin resulted in an acute increase in follicular secretion of oestradiol, but had no effect on concentrations of gonadotrophin or ovulation rate.

A better response to nutritional supplementation has been described in ewes that were in high body condition compared to those ewes in low body condition (Viñoles *et al.* 2002; Viñoles *et al.* 2005). In animals with a low feed intake and low levels of leptin, ovarian function is dictated primarily by gonadotrophins and insulin/IGF-1. Insulin-like growth factor I (IGF-1) stimulates proliferation of granulosa cells and synergizes with FSH in granulosa cell differentiation (Monget and Monniaux 1995). The IGF-1 is not required for recruitment of primordial follicles or growth of gonadotrophin-independent follicles (Mazerbourg *et al.* 2003; Scaramuzzi *et al.* 2011). These studies show that IGF-1 increases the sensitivity of small follicles (>2 mm in the sheep) to gonadotrophin stimulation and simulates their transition from the gonadotrophin-responsive to the gonadotrophin-dependent stages (Mazerbourg *et al.* 2003). Therefore, it seems that IGF-1 can stimulate either the proliferation or differentiation of granulosa cells to secretion of oestradiol in most species (Scaramuzzi *et al.* 2011). The IGF-1 and IGF-2 are bound to at least six different binding proteins (IGFBP). Each binding protein has its own unique physiology. For instance, in the bovine ovary, IGFBP-2 is a stimulator of follicular growth and maturation, but IGFBP-4 is an inhibitor (Mazerbourg *et al.* 2003). Insulin and IGF-1 are positively correlated, they have a synergistic relationship, and both can promote gonadotropin action by potentiating gonadotropin receptor function (Lucy 2000; Webb *et al.* 2004; Scaramuzzi *et al.* 2006).

Growth hormone (GH), insulin, IGF-1 are important mediators for the effect of the energy balance. The GH interacts with insulin to control hepatic production of IGF-1. In adipose tissue, GH promotes lipolysis while antagonizing lipogenesis and blocking insulin-dependent glucose uptake. Perhaps the most widely understood action of GH in liver is the increase in the synthesis and secretion of IGF-1 (Lucy 2008; Scaramuzzi *et al.* 2011).

1.8.3 Mechanisms of how nutrition increases ovulation rate

It is reasonable to conclude that the mechanism of how nutritional supplementation increases ovulation rate is included in the general mechanisms for the control of ovulation rate. According to Scaramuzzi *et al.* (2011) there are two evidences of how nutrition affects ovulation rate: i) nutrition increases the number of small and medium-sized gonadotrophin-responsive follicles; ii) nutrition reduces atresia among large gonadotrophin-dependent follicles, increasing the number of ovulatory follicles. The reduced atresia amongst the gonadotrophin-dependent follicles can be explained by the "widened gate" associated with low FSH threshold rather than an increase in FSH concentration. Finally, the effect of nutritional supplementation on ovulation rate is not totally understood, but it is incontestable that nutrition stimulates folliculogenesis in ruminants.

1.9 The supplementation with Maize

In this general introduction, I suggest that energy is arguably the most important regulator of ovarian function (Blache *et al.* 2008). The supplementation of high-energy diets with carbohydrate content, such as starch from maize, may provide a rapidly available source of energy to rumen microbes (Landau *et al.* 1995). Previous studies have tried to address changes in ovarian function by changes in the levels of energy of the diet and it has been shown that the efficiency of utilization of energy for maintenance increases when supplementation with maize is given to feed sheep and cattle (Blaxter and Wainman 1964).

Maize has been reported to be partially undegradable in the rumen of sheep (Nocek and Tamminga 1991; Landau *et al.* 1995). The average rumen degradability of starch from cracked maize is 65% which generates ruminal propionate (Nocek and Tamminga 1991). But still, good amounts of non-degradable starch may pass into the small intestine 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 (Landau *et al.* 1997; Banchero *et al.* 2007). According to these authors, this may promote the uptake of glucose by the ovaries and enhances the follicular development.

However, according to the same authors, high feed intake of rapidly fermentable starch can decrease rumen pH, resulting in a lower rate of forage digestion, which in turn can restrict feed intake. Fine grinding may accelerate fermentation of starch and this may be reduced by feeding the whole maize grain or cracked maize grain. For this reason, in our last two experimental studies, we chose to use a small amount (220 g/goat/day) of cracked maize grain to feed the animals (**Studies 5** and **6**).

Although lupin grains has become a valuable model for investigating the process that mediate the reproductive responses to short-term supplementation in sheep in Australia (Martin and Walkden-Brown 1995; Scaramuzzi *et al.* 2006), lupins are not commonly available worldwide. In addition, maize is one of the most widely grown grain crops in Brazil and throughout the Americas, and, in the near future, I am going to be able to apply and adopt the results from this research in the goat production systems in Brazil.

To the author knowledge, there are limited published data on the effect of a short-term supplementation with maize and lucerne on follicular development, ovulation rate and metabolic hormones in goats. A few publications have evaluated the effect of supplementation with maize on ovarian function in sheep (Letelier *et al.* 2008) and in goats (Fasanya *et al.* 1992; De Santiago-Miramontes *et al.* 2008). Furthermore, lucerne (*Medicago sativa*) is a predominant legume used to feed many classes of livestock worldwide and lucerne hay is often used to supply crude protein in finishing diets for small ruminants. Finally, most of forage diets for ruminants are often limiting in energy for optimal performance, and strategic energy supplementation with maize is usually done to increase digestible energy intake to improve animal performance (Letelier *et al.* 2008).

CHAPTER 2: A survey of the meat goat industry in Queensland and New South Wales. 1. General property information, goat and pasture management

Study 1: *Animal Production Science*, 2015. Online Early. doi: 10.1071/AN14793

Abstract. This study aimed to survey farmers' knowledge and practices on the management of pastures, stocking rates and markets of meat goat producing enterprises within New South Wales and Queensland, Australia. An interview based questionnaire was conducted on properties that derived a significant proportion of their income from goats. The survey covered 31 landholders with a total land area of 567,177 ha and a reported total of 160,010 goats. A total of 55% (17/31) of producers were involved in both 'opportunistic harvesting' and commercial goat operations, and 45% (14/31) were specialized seedstock producers. Goats were the most important livestock enterprise on 55% (17/31) of surveyed properties. Stocking rate varied considerably (0.3 to 9.3 goats/ha) within and across surveyed properties and was found to be negatively associated with property size and positively associated with rainfall. Overall, 81% (25/31) of producers reported that the purpose of running goats on their properties was to target international markets. Producers also cited the importance of targeting markets as a way to increase profitability. Fifty-three percent of producers were located over 600 km from a processing plant and the high cost of freight can limit the continuity of goats supplied to abattoirs. Fencing was an important issue for goat farmers, with many producers acknowledging this could potentially add to capital costs associated with better goat management and production. Producers in the pastoral regions appear to have a low investment in pasture development and opportunistic goat harvesting appears to be an important source of income.

Additional keywords: feral goats, market, rangeland, seedstock producer.

2.1 Introduction

Over the past 20 years the Australian meat goat industry has experienced continuous growth, largely supported by the sale of goats derived from rangeland production systems (Dubeuf *et al.* 2004; McRae and Thomas 2014). In Australia there

are approximately 3.6 million goats (FAOSTAT 2015), comprising 3.2 million rangeland goats and 400,000 domestic farmed goats, indicating that rangeland goats represent almost 90% of the goat population in Australia. Australia is the largest exporter of goat meat worldwide, slaughtering more than 2.0 million goats, exporting 75,100 live goats and producing 31,700 tonnes of meat in 2013-14 (McRae and Thomas 2014). However, little data are available regarding goat production systems, goat enterprises and productivity of Australian commercial goat operations and their capacity to meet export requirements (Brice *et al.* 2012). Rangeland goats in Australia are descended from the first European settlements and subsequent introductions. These goats were commonly kept by householders as a source of milk and were used as draught animals, some of which established permanent populations within sparsely populated areas of Australia (Restall *et al.* 1982). Rangeland goats are now declared as a pest in every state and territory in Australia with the exception of the state of New South Wales (Parkes *et al*. 1996; Environment Australia, 1999). Inadequate management of rangeland goats can cause environmental degradation (Bayne *et al.* 2004; Brice *et al.* 2012; Khairo *et al.* 2013). Thus most State governments in Australia view rangeland goats as detrimental to the environment and favour eradication rather than seeing the goats as a potential source of income (Khairo *et al.* 2013). Others view goats as an aid for the control of woody weeds and pasture manipulation (Silanikove 2000; McGregor 2010a), a potential source of supplementary income for pastoral industries, an emerging commodity for organically produced products and as a strategy for complementary pasture management associated with cattle production (Boyazoglu *et al.* 2005).

As almost 90% of the goat herd in Australia is derived from rangeland goats, improvements in the productivity and management of rangeland enterprises could have an important effect on the profitability of these enterprises (MLA 2013). A survey was, therefore, designed to build a better understanding of the goat industry in New South Wales and Queensland. The aim of this study was to survey farmers' knowledge and practices on the management of pastures, stocking rates and markets utilised by meat goat producing enterprises within New South Wales and Queensland. A companion paper to this publication will discuss herd management, reproductive performance and animal health (Nogueira *et al.* 2015d).

2.2 Material and Methods

Survey design and structure

An interview based questionnaire was developed to survey meat goat properties located in Queensland (QLD) and New South Wales (NSW) during 2013. The questionnaire covered the period from 2012 to 2013 and consisted of 106 questions and was designed to take an average of 2.5 hours to be completed. The majority of the questions were in a multiple tick-a-box format and were based on a previous beef industry survey reported by Bortolussi *et al.* (2005a).

The survey was conducted face to face where one or two interviewers visited the meat goat producers and completed the questionnaire with them. Goat producers were the owners of properties that derived income from goats. Face to face interviews were used to ensure a consistent approach and interpretation of the questions and answers, as well to ensure a high return rate. The template questionnaire was approved by the Human Ethics Committee of James Cook University (approval number: ID H4415).

Information was collected on property location, property area, herd size, rainfall, soils, vegetation, pasture management practices, stocking rate, infrastructure development, use of fire and woody weeds, types of production activities and goat meat markets, market aspiration and whether or not market specifications are met. Further information was also collected on herd management, reproductive performance and animal health, and is presented in Nogueira *et al*. (2015d).

Survey validation

To manage the quality of data collected, most survey questions were cross-referenced where responses to a particular question could be cross-checked and/or validated by the response to a previous or subsequent question (Bortolussi *et al.* 2005b). In addition, there were some follow-up calls or emails after the survey for clarification of responses. The questionnaire was tested with four producers prior to the survey and a revised questionnaire was then used with the wider survey group. On most properties, an inspection of pasture and herd management was conducted with the authorization and presence of the owner. Inspecting the pasture and the herd was to confirm the information obtained in the questionnaire.

Survey population

The Survey was carried out in Queensland and New South Wales, and involved owners of 31 properties that derived income from goats. A goat producer was defined as an entity that obtained a significant proportion of income from meat goats. Meat goat producers were recruited non-randomly through a direct approach. The sample frame comprised farmers who were members of Meat and Livestock Australia (MLA) and the Boer Goat Breeders Association. The producers were screened to include only commercial private goat producers and corporate companies, and those willing to participate in the survey were then included. The first contact with producers was done either by telephone or email, when the purpose of the survey was explained. Seventy-four percent (31/42) of goat producers approached were willing to participate in the survey. They formed six clusters representing the major goat producing areas in Queensland and New South Wales (Fig. 2.1). The properties were clustered according to proximity and labelled as regions 1 to 6 (Table 2.1).

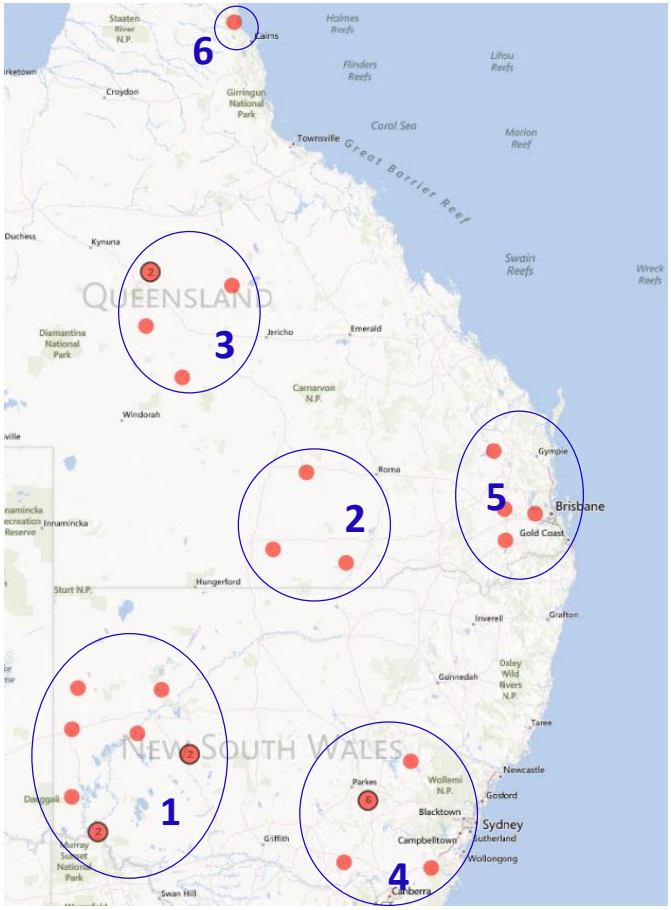


Fig. 2.1 Location of properties included in the survey, which were clustered in three pastoral regions (1, 2 and 3) and three high rainfall regions (4, 5 and 6) of Queensland and New South Wales.

Table 2.1 Brief description of the surveyed regions in Queensland and New South Wales adapted from the Interim Biogeographic Regionalisation for Australia

Region	Bioregion (predominant)	Towns closest to survey sites	Annual Rainfall (range)	Temperature (average max and min)	Altitude (sea level)	Climate (Köppen)
1. Western NSW	Broken Hill Complex	Broken Hill, Mildura, Wilcannia	130 mm to 250 mm.	Summer: 34ºC Winter: 5ºC	94 m to 315 m	Hot desert climate.
2. South-western QLD	Mulga Lands	Dirranbandi, Morven, Charleville	500 mm.	Summer: 35°C Winter: 18°C	170 m to 290 m	Hot, dry, semi-arid climate
3. Central-western QLD	Mitchell Grass Downs	Corfield, Longreach, Isisford	250 mm to 500 mm	Summer: 38ºC Winter: 12ºC.	191 m to 203 m	Dry monsoonal to semi-arid climate
4. Eastern NSW	South-western Slopes	Forbes, Mudgee, Cootamundra	600 mm to 750 mm.	Summer: 28ºC Winter: 2 ºC	240 m to 320 m	Humid, high rainfall, temperate climate and hot summers
5. South-eastern QLD	South-eastern	Wivenhoe Pocket, Toowoomba, Proston	700 mm to 944 mm	Summer: 23ºC Winter: 9 ºC	458 m to 691 m	Subtropical highland with warm summers and cool winters
6. Far North QLD	Wet Tropics	Mossman	2,010 mm	Summer: 28ºC Winter: 20ºC	4 m	Tropical monsoon climate with summer wet season

Source: Adapted from the Interim Biogeographic Regionalisation for Australia (IBRA 2014).

Definition of terms and parameters evaluated:

'*Pastoral regions*' refers to properties located in the western NSW and western QLD (Regions 1, 2 and 3). They are characterised as an arid environment (130 mm to 500 mm rainfall) and span various climatic zones from summer dominant rainfall in the north to winter dominant rainfall in the south, with wide variation in soil types and vegetation species. Livestock production from pasture (extensive grazing) is the main source of farm income. '*High rainfall regions*' refers to properties located in the eastern NSW, eastern QLD and far north QLD (Regions 4, 5, and 6), with an annual rainfall of more than 600 mm. These properties are smaller and livestock are raised under an intensive grazing management system. '*Domestic market*' was considered as the commercialization of goat meat to restaurants, store operations, and goats sold to depots from dealer operations or goats sold to another property. '*International market*' was considered as live animals or goat meat sold for use outside the country, including live export and carcass export. '*Live export*' refers to live goats that were sold either unfinished or finished for use in markets overseas. '*Seedstock*' refers to goat stock sold for use in herd breeding programs from registered studs. '*Store*' refers to goats sold in an unfinished condition to be grown and/or fattened or used for breeding elsewhere within Australia.

The '*stocking rates (goats/ha)*' was reported firstly by respondents stating their perceived stocking rate for the area on their property dedicated to goat production. Secondly, the stocking rate was calculated by taking the total number of goats run on the property and dividing by the area (ha) on the property dedicated to goat production. The unit '*goats/ha*' is equivalent to one non-breeding doe per ha which is equal to 1.2 DSE (McGregor 2010b). '*Scrub soils*' were reported by producers to describe an association with many other soils, as shallow dense loam soils, sand spreads or dark cracking clays often dominated by shrubs, including grasses and herbs. '*Clay Soils*' were classified as vertosols which are defined by shrink-swell soils that exhibit strong cracking when dry and at depth have slicken sides and/or lenticular structural aggregates. '*Rocky/skeletal soils*' were shallow porous loam soils, associated with stones, gravels or rock walls, with neutral and alkaline yellow mottled soils. '*Paddock spelling*' is a strategy of removing the stock from pasture to promote recovery and regeneration of vegetation.

Data analysis

Descriptive statistical procedures were used to compare surveyed regions. The data analyses are presented as means and standard deviations, frequencies and cross-tabulation tables. Stocking rate was calculated by taking the total number of goats run on a given property and dividing by the area (ha) on the property dedicated to goat production. Overall percentages were calculated by the number of properties in both pastoral and high rainfall regions showing the characteristics divided by total number of properties (n = 31) and multiplied by 100. Correlation among number of goats in a herd, stocking rate, rainfall and property size were obtained by the Pearson and Spearman tests. Data expressed as percentages were compared using the Chi-square test. Data were analyzed using Epi Info software (Epi Info™ 7.1.1.14, USA, 2013). Differences were considered significant when $P < 0.05$.

2.3 Results

Scope of the survey and goat herd

The survey covered 31 landholders with a total land area of 567,177 ha and a reported total of 160,010 goats (Table 2.2). The properties in NSW constituted 58% (18/31) and those in QLD constituted 42% (13/31) of the surveyed properties. The properties located in the pastoral region (western NSW, south-western QLD and central-western QLD) covered larger areas and the greatest number of goats per property, and represented 55% (17/31) of producers. These pastoral area producers were predominately involved in 'opportunistic harvesting' and commercial goat operations. In contrast, the properties located in the high rainfall regions (eastern NSW, south-eastern QLD and far north QLD) covered smaller areas with fewer numbers of goats, and represented 45% (14/31) of producers specialized in seedstock breeding. In addition, the properties located in the pastoral regions covered 99% of the land area of the surveyed properties and the rangeland goats from these properties comprised 97% of the goat herd covered in this survey. Hence, the domestic farmed goats of seedstock producers from high rainfall regions only made up 3% of the goat herd covered in this survey (Table 2.2).

Table 2.2 The number of properties, total land area and total goat herd size reported from surveyed regions of New South Wales and Queensland from 2012 to 2013

Characteristics	Pastoral regions			Subtotal	High rainfall regions			Subtotal	Total
	West NSW	S.West QLD	C.West QLD		East NSW	S.East QLD	North QLD		
Number of properties	9	3	5	17	9	4	1	14	31
Property area (ha)									
Total area covered (ha)	391,917	96,146	74,601	562,664	3,869	482	162	4,513	567,177
Total area (%)	69.1	17.0	13.2	99%	0.7	0.1	0.03	1%	100
Mean property size (ha)	43,546	32,049	14,920	33,098	430	121	162	322	18,296
Mean area utilized for goats (%)	72	45	28	54	68	70	15	64	.
*Rainfall (mm)**									
<250	5	0	0	5	0	0	0		5 (16)
250 to 500	4	3	4	11	0	1	0	1	12 (39)
501 to 750	0	0	1	1	9	3	0	12	13 (42)
>751	0	0	0	0	0	0	1	1	1 (3)
Stocking rate (goat/ha, mean±SD)									
Reported (goats/ha)	0.3±0.2	0.7±0.5	0.6±0.2	0.4±0.3	5.0±3.2	3.2±2.0	5.1	4.5±2.8	.
Calculated (goats/ha)	0.6±0.4	0.5±0.2	1.0±0.7	0.7±0.5	4.1±2.4	2.6±1.7	6.2	4.3±2.3	.
Goat herd (head)									
Total goat herd in 2013	110,100	30,500	14,300	154,900	4,320	640	150	5,110	160,010
Goat herd in 2013 (%)	68.8	19.1	8.9	97%	2.7	0.4	0.1	3%	100
Total goat sold in 2012	86,059	14,425	18,460	118,944	1,463	386	50	1,899	120,843

* Reported rainfall from the last 3 years.

General property information

Overall, 32% (10/31) of surveyed properties were run in conjunction with another property and 100% of surveyed properties were managed by family members. Daily rainfall records were recorded by 77% (24/31) of the surveyed properties and 50% (12/24) of these properties showed a rainfall of less than 500 mm/year. The only extreme was a property located in far north QLD, which recorded the highest rainfall (2,500 mm/year). The properties located in western NSW had greater areas allocated to goat production and reported the lowest annual average rainfalls. Figure 2.2a shows that the greatest numbers of goats were found on the largest properties ($y = 0.3x + 159.5$; $r^2 = 0.7$; $P < 0.05$).

Stocking rate and carcass weight

A majority of producers surveyed stated that they determined stocking rate by 'eye and experience'. Figure 2.2b shows that the stocking rates increased on the smaller size properties, presenting a negative association ($y = -0.5 \ln(x) + 6.3$; $r^2 = 0.6$; $P < 0.05$). The mean stocking rates reported in the pastoral regions varied from 0.3 to 1.2 goats/ha and the stocking rates in the high rainfall regions varied from 3.2 to 9.3 goats/ha (Table 2.2).

A total of 42% (13/31) of the surveyed properties occupied land areas greater than 15,000 ha (Fig. 2.2). In general, the producer's reported stocking rates were similar and followed the same trend as the calculated stocking rates ($r^2 = 0.57$; $P < 0.05$); however, producers in western NSW and central-western QLD reported lower average stocking rate (Table 2.2, Fig.2.2b).

A negative association was found between rainfall and property size, with lesser rainfall regions associated with greater property sizes (Fig. 2.2c). Producers were asked if the number of goats carried would vary according to the seasonal conditions. The results showed that during a 'good season', the number of goats would increase up to 147% (Table 2.3). Only the properties in the pastoral regions reported that the number of goats varied significantly with times of the year due to changes in seasonal conditions. During a 'poor season' the number of goats would be reduced to 27% of the 2012 herd population (Table 2.3). The percentage of animals in the high rainfall regions varied little between the seasonal conditions.

The carcass weight varied from 14 kg to 25 kg, reported by ten properties in the pastoral regions and two properties in the high rainfall regions (Fig. 2.3). Positive

associations were found between stocking rate and carcass weight ($r^2 = 0.62$; $P < 0.05$), and between rainfall and carcass weight ($r^2 = 0.37$; $P < 0.05$). Carcass weight was greater in the higher rainfall regions (Fig. 2.3a) and greater in the properties with higher stocking rates (Fig. 2.3b).

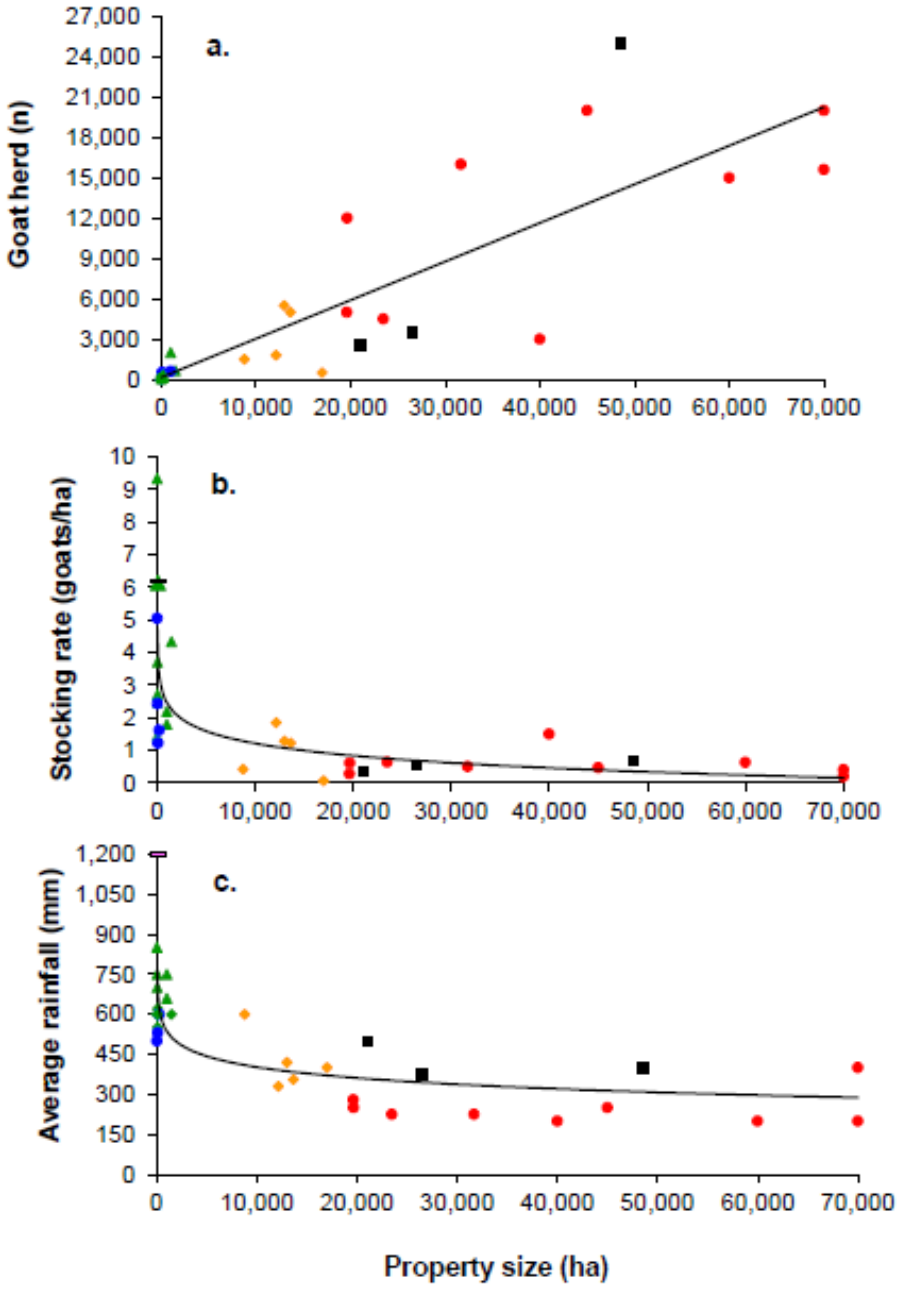


Fig. 2.2 Association between the property size and goat herd **(a)** ($y = 0.3x + 159.5$; $r^2 = 0.7$; $P<0.05$), property size and stocking rate **(b)** ($y = - 0.5 \ln(x) + 6.3$, $r^2 = 0.6$; $P < 0.05$) and property size and rainfall **(c)** ($y = - 57.3 \ln(x) + 931.8$, $r^2 = 0.6$; $P<0.05$) for the bioregions of Western NSW (●), South-western QLD (■), Central-western QLD (♦), Eastern NSW (▲), South-eastern QLD (●) and North QLD (-).

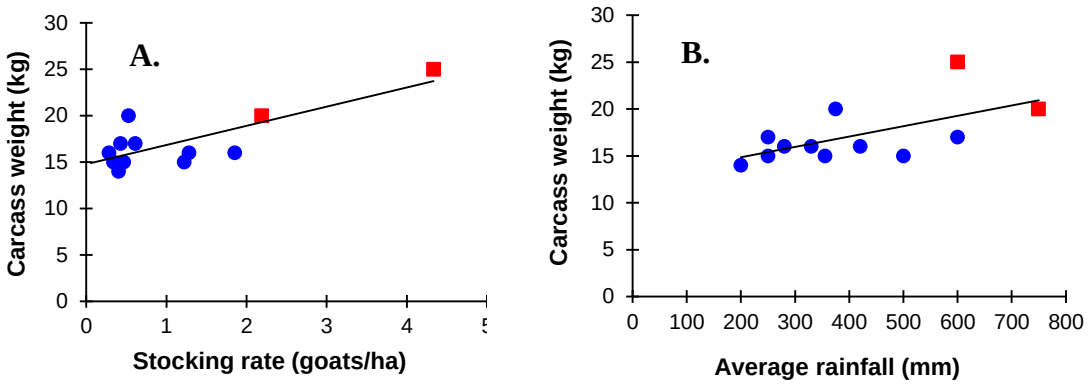


Fig. 2.3 Associations between carcass weight and stocking rate **(a)** ($y = 2.1x + 14.7$, $r^2 = 0.62$; $P<0.05$, and carcass weight and rainfall **(b)** ($y = 0.01x + 12.6$, $r^2 = 0.37$; $P<0.05$) for pastoral regions (●, n=10) and high rainfall regions (■, n=2).

Table 2.3 Relative carrying capacity of goats according to producer's assessment of pastoral conditions (poor, average and good) compared to the year of 2012*

	Pastoral regions				High rainfall regions			
Pastoral condition	West NSW	S.West QLD	C.West QLD	Subtotal *mean±SD*	East NSW	S.East QLD	North QLD	Subtotal *mean±SD*
Poor (%)	50	34	60	51 ± 24	77	91	80	82 ± 18
Average (%)	82	72	78	79 ± 13	99	96	80	97 ± 7
Good (%)	116	115	122	117 ± 30	105	104	100	105 ± 14

*100% was the percentage of goats in 2012.

Goat as the main livestock enterprise and the goat meat markets

Most of the properties were involved in more than one livestock enterprise, usually goats, sheep and cattle. The producers indicated the main livestock enterprise in order of importance to their property. Goats were the most important livestock enterprise on 55% (17/31) of surveyed properties, 32% (10/31) of producers reported that sheep production was the main enterprise and only 13% (4/31) reported cattle production as the main enterprise. None of the properties located in central-western QLD reported that goats were the main livestock enterprise. However, 67% (6/9) of the properties located in western NSW and 78% (7/9) in eastern NSW reported that goats were the most important livestock enterprise on the surveyed properties.

Overall, when the producers were asked what was the purpose of running goats on their property (Table 2.4), 81% (25/31) reported targeting international markets, 58% (18/31) reported targeting the domestic market and 29% (9/31) reported that the goat

herd was used for weed control. Overall, there was no difference ($P > 0.05$) between numbers of producers that reported targeting the international and domestic market. However, the percentage of producers that targeted meat markets as a primary consideration for running goats was significantly greater ($P < 0.05$) than producers who used goats for weed control. The producers that considered goats as the main livestock enterprise reported the following hierarchical preference for markets: international market (100%), domestic market (65%) and weed control (18%; $P < 0.05$; Table 2.4).

Table 2.4. Cross tabulation between main livestock enterprise and the reason for running goats on properties surveyed in NSW and QLD, Australia

		Reasons for running goats %, (n*)		
Main Livestock	% (n*)	International market	Domestic market	Weed control
Goats	55 (17/31)	100 (17/17) [a]	65 (11/17) [b]	18 (3/17) [c]
Sheep	32 (10/31)	50 (5/10)	50 (5/10)	50 (5/10)
Cattle	13 (4/31)	75 (3/4)	50 (2/4)	25 (1/4)
Overall %, (n)	100 (31/31)	81 (25/31) [a]	58 (18/31) [a]	29 (9/31) [c]

*Number of properties. Values with different letters in the same row are significantly different with a Chi-square test ($P < 0.05$).

All producers reported more than one goat enterprise activity on their property (Table 2.5). The majority of producers in NSW and QLD (68%; 21/31) reported breeding stores and replacements as the most common activity on goat properties. Opportunistic harvesting was the first most common activity reported by 88% (15/17) of producers in the pastoral regions (Table 2.5). All of the surveyed properties located in western NSW carried out opportunistic harvesting of goats and 100% of properties in central-western QLD carried out breeding-finishing of goats on native pasture. In addition, all the properties located in the high rainfall regions were Boer goat seedstock producers (Table 2.5).

Overall, the first three market sectors reported by producers in order of importance were: domestic market with 81% (25/31), live export with 68% (21/31), carcass export with 61% (19/31) and 13% (4/31) for restaurants (Table 2.6). The carcass export market was mentioned as the dominant market sector by 100% of producers located in western NSW, south-western QLD and central-western QLD (Table 2.6). A total of 81% (25/31) of the producers reported they had sold goats to the international market. When producers were asked to identify international markets that they supplied, Asia was identified by 52% (16/31) of producers, 29% (9/31) identified sales to the

USA and 13% (4/31) to the Middle East. Exports of carcasses were reportedly sold to the USA and the live goat export trade was directed towards Asia and the Middle East. Live goat exports to Malaysia was the most cited country by the producers located in central-western QLD. The range reported export carcass weight varied from 15.5 kg to 22.5 kg (Table 2.6).

One of the biggest concerns reported by the majority of producers located in the pastoral regions (53%; 9/17) was the distance from their property to the abattoir. Distances greater than 700 km were reported by producers from western NSW (Table 2.6). Overall, 84% (26/31) of producers reported a willingness to change the management of their enterprises over the next 5 years to increase profitability and 16% (5/31) of respondents said that no changes would be made (Table 2.7). The producers willing to increase their profitability reported adopting the following strategies: 48% (15/31) reported focusing on target markets, 45% (14/31) improving pasture management, 35% (11/31) introducing better quality bucks and the minority were associated with herd management issues, such as reducing the death rate, increasing weight at turn-off and increasing marking percentage (Table 2.7). A total of 71% (22/31) of producers of all regions reported they needed additional help in the promotion and advertisement of goat meat for consumption in Australian and international markets.

Table 2.5 The number of properties in New South Wales and Queensland conducting various goat enterprises

	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31(100)
Number of properties by enterprise									
1 enterprises	2	1	1	4	0	2	1	3	7 (23)
2 enterprises	6	1	1	8	3	1	0	4	12 (39)
3 or 4 enterprises	1	1	3	5	6	1	0	7	12 (39)
Enterprises carried out									
Breeding stores/replacements	4	2	2	8	9	3	1	13	21 (68)
Opportunistic harvesting	9	2	4	15	0	0	0	0	15 (48)
Seedstock producer	0	0	0	0	9	4	1	14	14 (45)
Breeding-finishing on pasture	3	1	5	9	4	1	0	5	14 (45)
Breeding-finishing on crop	0	1	0	1	4	1	0	5	6 (19)
Buying-finishing on pasture	2	1	2	5	0	0	0	0	5 (16)

Table 2.6 Number of properties targeting goat meat market sectors, typical export market weight and the shortest distance from surveyed properties in to the closest abattoir

	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31 (100)
Number of sectors selected									
1 sector	5	0	1	6	0	2	0	2	8 (26)
2 sectors	1	1	1	3	5	2	1	8	11 (35)
3 sectors	1	2	3	6	3	0	0	3	9 (29)
4 sectors	2	0	0	2	1	0	0	1	3 (10)
Markets sectors for goat meat									
Domestic market	5	3	4	12	9	3	1	13	25 (81)
Live export	3	2	3	8	9	3	1	13	21 (68)
Carcass export	9	3	5	17	2	0	0	2	19 (61)
Restaurant	1	0	0	1	3	0	0	3	4 (13)
Records available for carcass weight (n)	4	2	4	10	2	0	0	0	12 (39)
Carcass weight (kg)	15.5±1.3	17.5±3.5	16.0±0.8	16.1±1.7	22.5±3.5	*	*	22.5±3.5	17.2 ± 3.1
Closest abattoir (km)	720±80	425±177	574±64	637±134	242±200	75±84	120	176±190	

* Producers from south-eastern QLD and north QLD only sold breeding animals.

Table 2.7 Proposed changes over the next 5 years to increase profitability on the properties of New South Wales and Queensland

Increase profitability	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%[1])
Make no changes	2	1	2	5	0	0	0	0	5 (16)
Target markets	3	0	2	5	6	3	1	10	15 (48)
Better pasture management	1	1	2	4	8	1	1	10	14 (45)
Better quality bucks	0	0	1	1	5	4	1	10	11 (35)
Reduce turn-off age	3	0	1	4	1	0	1	2	6 (19)
Increase herd size	0	1	1	2	2	2	0	4	6 (19)
Reduce herd size	1	0	1	2	1	2	0	3	5 (16)
Reduce death rate	1	1	1	3	1	0	1	2	5 (16)
Increase turn-off weight	1	1	0	2	2	0	1	3	5 (16)
Increase marking rate	2	0	0	2	2	0	1	3	5 (16)

[1] From the total number of properties (n = 31).

Land and soil

A total of 55% (17/31) of producers reported they had very good or good land condition, although 42% (13/31) of producers in any region reported some land erosion (Table 2.8). In contrast to the reported good land condition, 61% (19/31) of producers reported they had an average or poor pasture condition. Paddock spelling was practiced by 90% (28/31) of producers in all regions. The same majority of producers (90%) indicated that land management issues influenced their property management decisions. Clay soil and its derivatives were the major soil type reported by 68% (21/31) of producers (Table 2.8). Clay soils existed in all of the surveyed properties, but mainly in eastern NSW (88%; 8/9) and central-western QLD (80%, 4/5). Scrub soils could be found in western NSW, south-eastern and far north QLD. Yellow, red or black loam and sandy soils were most commonly reported in western (55%; 5/9) and eastern NSW (22%; 2/9) (Table 2.8).

In the high rainfall regions, the most common nutrient deficiencies reported were iodine (50%; 7/14), calcium and/or magnesium (50%; 7/14), selenium (43%; 6/14), phosphorus (23%; 4/17) and copper (23%; 4/17). In the pastoral regions, the common nutrient deficiencies were protein/nitrogen and energy, both reported by 29% (5/17) of producers, followed by phosphorus (18%; 3/17). Producers reporting nutrient deficiencies were based on previous soil analysis or they were based on the historical background for their properties. Overall, 26% (8/31) of producers did not report any nutrient deficiencies because they considered that soils on their properties did not have a nutrient deficiency or they did not have sufficient information to comment.

Pasture and weeds

In all regions, the most reported browse species were Wattles (other than Mulga and Gidgee) at 42% (13/31), followed by 35% (11/31) of Box/Gum trees. Mulga was only reported by 23% (7/31) of producers from pastoral regions (Table 2.9). In some cases, the presence of three or more browse species was reported on the same property. Belah (23%; 4/17), Black oak (12%; 2/17) and Rosewood (12%; 2/17) were only recorded in the pastoral region of western NSW. Black berry (14%; 2/14), Chicory (14%; 2/14) and Pine trees (7%; 1/14) were only reported in the high rainfall region of eastern NSW (Table 2.9).

Spear grass (*Stipa variabilis*) was the most important pasture community in both western and eastern NSW and it was reported by 32% (10/31) of surveyed producers

(Table 2.9). Mitchell (47%; 8/17), Buffel (35%; 6/17) and Flinders grass (35%; 6/17) were the most commonly reported by producers in the pastoral regions. The presence of Phalaris (43%; 6/14), Kikuyu (43%; 6/14), annual Ryegrass (36%; 5/14) and Rhodes grass (29%; 4/14) was only reported in the high rainfall regions of eastern NSW and south-eastern QLD (Table 2.9).

When producers were asked if there were any weed species occurring on their property, 81% (25/31) responded positively. Thistles (*Carduus sp.*) were the most common weeds reported by producers from eastern NSW (78%; 7/9), south-western QLD (67%; 2/3) and western NSW (11%; 1/9). Gidgee/bore (*A. cambagei* and *A. tephrina*) and other Acacia species were the second most noted weed species reported by 26% (8/31) of the surveyed producers. Patterson curse (*E. plantageneum*) and Black berry (*Rubus fruiticosus*) were reported, respectively, by 78% (7/9) and 44% (4/9) of producers from eastern NSW.

Overall, 19% (6/31) of producers reported that toxic plants were reducing the performance of their herds. Copper burr (*Bassia convexula*) was reported by 33% (3/9) of producers from western NSW and by 11% (1/9) of producers from eastern NSW. Pimelea (*Pimelea* spp.) was reported by 67% (2/3) of producers from south-western QLD and by 20% (1/5) of producers from central-western QLD. Turpentine (*Eremophilia* sp.) was reported by 22% (2/9) of producers from western NSW. Bracken Fern (*Pteridium aquilinum*) and Rock Fern (*Cheilanthes sieberi*) were reported equally by 22% (2/9) of producers from eastern NSW. Producers reported controlling toxic plants by using physical removal, herbicides and/or densely stocking the infested area with goats.

Use of fencing

Ninety-seven percent (30/31) of producers in all regions carried out some fencing activity over the last 5 years (Table 2.10). From this total, the most frequent reasons for fencing activities were associated with installing new watering points (47%; 14/30), establishing goat management paddocks (87%; 26/30) and to create a new paddock (73%; 22/30). In south-eastern QLD, 100% (4/4) of producers reported dog control as the main reason for building new fences (Table 2.10). In all regions, 81% (25/31) of producers reported that they were planning fencing during the next 5 years (2013 to 2018), although this could potentially add to capital costs associated with better goat management and production. The two most important reasons for fencing in

the future were to replace old fences (55%; 17/31) and to create new holding paddocks (45%; 14/31). The most common types of fences were hinge joint (84%; 26/31) and plain wire (52%; 16/31). Producers mentioned that the hinge joint fence was normally associated with a plain wire on the top. Producers also reported that they needed 11 lines of plain wire to hold goats in a paddock, and they mentioned that if the rectangular area in the hinge joint fence was too small, goats could be caught and may die as a result.

Table 2.8 Land and pasture condition and major soil types in New South Wales and Queensland

	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31 (100)
Land condition									
Very good	1	1	2	4	1	1	0	2	6 (19)
Good	2	2	3	7	2	2	0	4	11 (35)
Average	4	0	0	4	6	0	1	7	11 (35)
Poor	2	0	0	2	0	1	0	1	3 (10)
Land Erosion									
Yes	4	2	2	8	3	1	1	5	13 (42)
No	5	1	3	9	6	3	0	9	18 (58)
Pasture condition									
Very good	0	0	2	2	1	1	0	2	4 (13)
Good	3	2	2	7	0	1	0	1	8 (26)
Average	4	1	1	6	4	2	1	7	13 (42)
Poor	2	0	0	2	4	0	0	4	6 (19)
Pasture spelling									
Yes	7	3	4	14	9	4	1	14	28 (90)
No	2	0	1	3	0	0	0	0	3 (10)
Major Soil types									
Clay soils (Vertosols)	4	3	4	11	8	1	1	10	21 (68)
Yellow/ Red/ Black loam	5	3	1	9	2	1	1	4	13 (42)
Sandy and Alluvial soils	4	1	1	6	4	1	0	5	11 (35)
Scrub soils	2	0	0	2	0	1	1	2	4 (13)
Rocky/skeletal soils	0	0	0	0	3	0	1	4	3 (10)

Table 2.9 Major browse and natural pasture species reported in the pastoral and high rainfall regions of New South Wales and Queensland

	Pastoral Regions	High rainfall regions	Overall Browse species		Pastoral Regions	High rainfall regions	Overall Pasture species
Major browse species	n	n	n (%[1])	***Major natural pasture species***	n	n	n (%[1])
Wattle (*Acacia* spp.)	4	9	13 (42)	Spear grass (*Stipa variabilis*)	6	4	10 (32)
Box/Gum trees (*Eucalyptus* spp.)	5	6	11 (35)	Mitchell (*Astrebla sp.*)	8	0	8 (26)
Mulga (*Acacia aneura*)	7	0	7 (23)	Buffel grass (*Cenchrus ciliaris*)	6	2	8 (26)
Blue bush (*Chenopodium* sp.)	4	1	5 (16)	Summer grass (*Digitaria* sp.)	3	3	6 (19)
Gidgee (*Acacia cambagei*)	4	1	5 (16)	Flinders (*Iseilema macratherum*)	6	0	6 (19)
Salt bush *(Atriplex* sp.)	5	0	5 (16)	Phalaris (*Phalaris aquatica*)	0	6	6 (19)
Belah (*Casuarina cristata*)	4	0	4 (13)	Kikuyu (*Pennisetum clandestinum*)	0	6	6 (19)
Black oak (*Casurina* spp.)	2	0	2 (6)	Ryegrass (*Lolium rigidum*)	0	5	5 (16)
Rosewood (*Heterodendrum* sp.)	2	0	2 (6)	Wiregrass *(Aristida latifolia)*	4	1	5 (16)
Turkey bush (*Eremophila* spp.)	2	0	2 (6)	Barley grass (*Hordeum leporinum*)	0	4	4 (13)
Prickly acacia (*Acacia nilotica*)	2	0	2 (6)	Cocksfoot (*Dactylis glomerata*)	0	4	4 (13)
Burr medic (*Medicago* sp.)	1	1	2 (6)	Rhodes grass (*Chloris gayana*)	0	4	4 (13)
Brigalow (*A. harpophyla*)	1	1	2 (6)	Spear grass (*Heteropogon contortus*)	2	1	3 (10)
Black berry (*Rubus fruiticosus*)	0	2	2 (6)	Couch grass (*Cynodon* sp.)	0	3	3 (10)
Chicory (*Cichorium* sp.)	0	2	2 (6)	Bluegrass (*Dichanthium sericium)*	0	3	3 (10)
Pines (*Pinus* sp.)	0	1	1 (3)	Copper Burr (*Bassia* spp.)	3	0	3 (10)
Geebung (*Persoonia acerosa*)	0	1	1 (3)	Clovers (*Trifolium sp.)*	0	2	2 (6)

[1] From the total number of properties (n = 31).

Table 2.10 Characteristics of fencing undertaken on surveyed properties and its reported purpose

Characteristics	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31 (100)
Fencing over the last 5 years									
No	0	0	1	1	0	0	0	0	1 (3)
Yes, associated with waters	6	1	3	10	2	1	1	4	14 (45)
Yes, not associated with waters	3	2	1	6	7	3	0	10	16 (52)
Reasons for the use of fence									
Goat management paddock	8	2	3	13	9	3	1	13	26 (84)
Create new paddock	6	3	2	11	7	3	1	11	22 (71)
Build a new lane	0	1	3	4	4	2	0	6	10 (32)
Fence for dog control	0	0	1	1	0	4	1	5	6 (19)
Fence out a problem area	1	0	1	2	2	2	0	4	6 (19)
Plan fencing for the future									
Yes	7	3	4	14	7	3	1	11	25 (81)
No	2	0	1	3	2	1	0	3	6 (19)
Reasons for fencing in future									
Replace old fence	5	1	4	10	5	2	0	7	17 (55)
Create new holding paddock	4	1	1	6	7	1	0	8	14 (45)
Build lane ways	0	2	2	4	3	1	1	5	9 (29)
Create a new main paddock	0	1	0	1	5	0	1	6	7 (23)
Fence out country types	1	0	0	1	2	0	0	2	3 (10)
Fence out a problem areas	1	0	0	1	1	0	0	1	2 (6)
Kind of fence used									
Hinge joint	6	3	3	12	9	4	1	14	26 (84)
Plain wire	9	1	3	13	2	0	1	3	16 (52)
Electric fence	0	2	2	4	5	3	0	8	12 (39)
Barbed wire	2	1	4	7	0	1	0	1	8 (26)

Use of pasture development strategies

Seventy-seven percent (24/31) of producers interviewed had undertaken some pasture development activity in the past five years and 58% (18/31) of producers had undertaken these activities in 2012 or 2013. Only 23% (7/31) of surveyed producers did not engage in pasture development in the previous five years to 2012. The types of pasture development strategies employed by 78% (7/9) of producers surveyed from eastern NSW were the use of fertilizer, sowing improved grasses and sowing improved legumes. 'Crash grazing' with goats was the most common pasture development strategy mentioned by 19% (6/31) of producers. This involved putting goats in a paddock at a high stocking rate to promote the reduction of undesirable shrubs or weedy species. The pasture strategy of broadcasting seeds into grassland was exclusively mentioned by producers from eastern NSW (22%; 2/9) and south-eastern QLD (75%; 3/4). Pulling trees/vegetation and sowing improved grasses or sowing native pasture was widely used in south-western QLD (100%; 3/3) and central-western QLD (60%; 3/5). The pasture development strategies of adding limestone and/or diatomaceous earth (33%; 3/9), blade ploughing of woody weeds (22%; 2/9) and direct-drill disc seeding (22%; 2/9) were reported exclusively by the producers from western and eastern NSW.

Overall, 48% (15/31) of producers used fire on their properties. The reasons for using fire included reducing fire risk (23%; 7/31), grazing management (i.e. increasing the number of goats in certain areas, 23%; 7/31), controlling woody weeds (19%; 6/31) and encouraging growth of pasture species (16%; 5/31).

Pasture improvement with legumes was reported by 29% (9/31) of producers and the pasture improvement with grasses was reported by 32% (10/31) of producers. The two most important legumes reported by producers from eastern NSW were lucerne (*Medicago sativa*) by 67% (6/9) and clovers (*Trifolium sp.*) by 33% (3/9). Thirty-three percent (3/9) of producers from eastern NSW reported using improved grasses such as phalaris (*Phalaris aquatic*), cocksfoot (*Dactylis glomerata*) and annual ryegrass (*Lolium rigidum*). Sixteen percent (5/31) of surveyed producers reported using forage crops such as oats (*Avena sativa*). Very limited pasture development/sowing of improved grasses or legumes were reported from central-western QLD, south-eastern QLD and northern QLD.

2.4 Discussion

This study represents the first comprehensive survey of farming practices related to the management of meat goat producing enterprises within New South Wales and Queensland. Goats were the most important livestock enterprise on 55% of surveyed properties, but goats were farmed in conjunction with cattle and or sheep. Goats, when grazed with sheep and cattle, have been shown to have a beneficial influence on pasture management (McGregor 2010a; Rosa García *et al.* 2012). A positive association existed between the number of goats in the herds and property size (Fig. 2.2a) and a negative association between stocking rate and property size (Fig. 2.2b). The explanation for these associations is that dry matter production is limited by rainfall and therefore lower rainfall regions are associated with large property sizes (Fig. 2.2c) that are required to maintain a sustainable living area for producers.

The survey revealed similarities of issues and factors between properties located in the pastoral regions, and some other similarities between properties located in the high rainfall regions. In the following discussion, the authors have attempted to deal with this complexity by discussing the results under sub-headings to build a better understanding of the goat industry.

Goat meat markets

The export carcass market was the most important sector in 100% of the properties in pastoral regions (Table 2.6). This represented 97% of the goat herd in this survey. These results are in agreement with the Australian Bureau of Statistics which reported that the export carcass market represents around 96.5% of the goat industry, whereas live export only represents 3.5% (McRae and Thomas 2014). Carcass weight was positively associated with stocking rates and rainfall (Fig. 2.3). The heavier carcasses associated with higher stocking rates were confounded by the supplementary feeding practices of producers in the high rainfall regions (Nogueira *et al.* 2015d).

In this survey, the domestic market was used by 81% of producers. This is probably because a large number of properties were selling goats to store operations, dealer depots, other properties and, to a lesser extent, selling goat meat to restaurants. However, the amount of goat meat sold to restaurants in Australia is very low. Schuster (2006) reported that only about 5% of goats slaughtered enter the domestic market and this goat meat is sold through ethnic butchers in Melbourne and Sydney.

A constraint identified by 53% of goat producers in the pastoral regions that limited the continuity of supply was the long distances from their property to an abattoir (>600 km; Table 2.6) and as a consequence the greater cost of freight. Distances to abattoirs longer than 300 km require an 8 deck lot of animals (approximately 700-800 goats) to reduce the freight cost per animal. Furthermore, management decisions in the pastoral regions take into account the price received per kilogram on farm. If the price offered is not considered adequate to make a profit then no harvest takes place (Forsyth *et al.* 2009), although goats are available to enter the supply chain. According to Brice *et al.* (2012), one of the greatest challenges facing the Australian goat meat industry is the inconsistent supply of product throughout the year.

In an attempt to fulfil market demand, high prices will be offered for product supplied outside the normal production cycle (McRae and Thomas 2014), although other authors have recommended that producers prepare their goats to meet market specifications for age, liveweight or carcass weight and condition score in order to maximise the price received to producers (McGregor 2012). Historically, prices for rangeland and Boer goat cross breeds have been quite volatile. Goat meat prices are subject to fluctuations in response to supply and demand, exchange rates and affordability to consumers (Clarke and Ronning 2013).

Land, pasture and stocking rate

The reported stocking rate in this survey varied from 0.3 goats/ha to 9.3 goats/ha. This is similar to what has been previously reported by Ferrier and McGregor (2002) who found a stocking rate varying from 0.2 goats/ha to 4.2 goats/ha in Victoria. These authors suggested that producers were underestimating their stocking rates, especially when mixed with other grazing species. In this survey, producers from western NSW and central-western QLD also tended to underestimate their stocking rates, highlighted by inconsistencies between the reported and calculated stocking rates (Table 2.2). Underestimation of stocking rates can be a problem, as high stocking rates can cause overgrazing, degradation of rangeland vegetation, reduced groundcover, and increased soil erosion (Bayne *et al.* 2004; Brice *et al.* 2012; Hacker and Alemseged 2014). High stocking rates of 7.5 goats/ha has been reported as possible in 500 mm rainfall region of Victoria without negatively affecting the botanical composition or ground cover (McGregor 2010a). However, careful management of the goat herd was

required to achieve this stocking rate, inclusive of supplementary feeding and containment areas during periods of drought.

Fifty-five percent (17/31) of producers reported very good or good land conditions, but only 39% (12/31) reported very good or good pasture conditions (Table 2.8). These results imply that the pasture is not totally expressing the quality of the land on which it is grown or that producers are measuring incorrectly their land and pasture conditions. This could be due to pasture management or other limiting factors, such as rainfall or inadequate fencing activities.

Producers in the pastoral regions reported changes in stocking rate to match seasonal conditions (Table 2.3). It is unknown if the changes in stocking rates occur naturally due to fluctuations in reproduction consequent upon seasonal conditions or if it is managed by producers. For instance, during a 'poor season' kidding rates can be lower and mortality rates can be higher and as a consequence the number of goats on a property can decline. In contrast, in a 'good season' reproductive rates and survival rates may increase and stocking rates would naturally increase. Producers in the high rainfall regions, however, reported an unwillingness to modify stocking rate according to seasonal conditions because of limited property area and pasture shortages. Furthermore, the highest stocking rates reported in the present survey (>3 goats/ha) on these properties can be explained by the higher rainfall and by supplementary feeding of animals (Nogueira *et al.* 2015d).

In the pastoral regions of western NSW, the stocking rates of 0.5 goats/ha within the Mulga may be optimal for achieving a balance between weed control and regrowth of herbage, although a stocking rate of 2 goats/ha, resulted in hopbushes being rapidly killed and mulga being defoliated (Downing 1986). It is recommended that in dry seasons, where palatable plant species are in short supply, a stocking rate below that considered to be appropriate for the area should be applied and plant species monitored to avoid eradicating the species and increasing soil erosion by removal of pasture litter (Harrington 1986). Setting and adjusting the stocking rate is a critical management practice that is required for maintaining sustainability (McGregor 2010a; Hacker and Alemseged 2014).

Browse and pasture species

The meat goat industry in the pastoral regions is largely based on the utilization of natural pastures and browse species. A similar observation was made by Bortolussi *et*

al. (2005c) with respect to the cattle industry. This survey shows that goats in Australia are adapted to eat a variety of plants including wattle, gum trees, mulga and prickly acacias (Table 2.9). According to Squires (1980), shrubs, specifically mulga (*Acacia aneura*), hopbush (*Dodonea viscose*) and broom brush (*Apophyllum anomalum*) contributed more than 50% to the diet of goats in north-western NSW. In the present study, mulga was reported by 23% of producers (Table 2.9), but no producers in any region mentioned hopbush or broom brush. Producers reported that goats browsed belah and rosewood species, and goats also ate spear grass and copper burr. Similar results were found by Wilson *et al.* (1975) who reported that goats ate a large amount of rosewood and belah, in comparison to sheep, but sheep preferred to eat mainly spear grass and copper burr.

The results of the present survey suggest that some of the woody weeds that are not readily utilised by cattle and sheep can be utilized for goat production (Simmonds *et al.* 2000). This is because goats are more selective compared to sheep and goats have the flexibility of browsing and grazing different plants (Silanikove 2000; McGregor 2005b, 2010a).

The most commonly reported pasture species present on surveyed properties were spear grass, mitchell, buffel and flinders grass (Table 2.9), and these pasture species were normally found in dry environments. Therefore, there is opportunity to capitalise on the ability of goats to better utilise pasture in summer, suggesting that goats have an advantage over sheep in either selecting and/or digesting low quality pasture. This advantage can result in increased gains in goats compared to sheep during seasonally dry periods and reductions in supplementary feed required during period of drought (McGregor 2010b).

Weeds and toxic plants

To the producers in the pastoral regions, an important benefit of having goats on their properties is the control of weeds and undesirable browse species. This supports the argument that goats act as biological control agents and have an advantage over other control methods such as mechanical cutting and herbicide application, which are expensive and have a negative impact on the environment (Magadlela *et al.* 1995; Simmonds *et al.* 2000).

While it is thought that goats are able to develop a tolerance to some toxic plants (Downing 1986), 19% of producers reported that toxic plants were reducing the

performance of their herd. For instance, turpentine was mentioned as a toxic plant by 22% of producers from western NSW, however, in previous studies, turpentine was reported to be unpalatable or rarely eaten by goats (Wilson *et al.* 1975; Squires 1980), which may explain the drop in performance seen by producers.

Pasture development strategies and use of fencing

The lowest incidence of pasture development strategies was reported by producers in western NSW and central-western QLD, which reflects a majority of properties with rainfall below 500 mm and the overall presence of heavy clay soils (68%). These regions rely almost entirely on native grass, such as mitchell, flinders and spear grasses, which could reduce animal productivity. Productivity of goats in the semi-arid regions could potentially be raised by improving the feed base with grasses and legumes where appropriate. In subtropical semi-arid regions, for example, where native or woody weeds (gidgee) have been cleared, buffel grass with the addition of an adapted legume such as *Desmanthus spp.* may enhance pasture quantity and quality, thereby increasing goat productivity and the sustainability of the enterprise (Gardiner *et al.* 2013). Moreover, *Desmanthus* spp. is one of few legumes species adapted to grazing in that particular semi-arid clay soil environment.

Use of fencing was a constraint for producers in all regions. Ninety seven percent of producers carried out fencing activities in the previous five years to 2012-2013, and 81% of producers reported they were planning fencing during 2013 to 2018. Inadequate fencing negatively influences pasture and animal management (McGregor 2005b). This is particularly important in the case of supplementary feeding during a drought, and with feeding and exit schedules for goats in paddocks (McGregor 2005b). Fencing in pastoral regions, where vast areas are grazed, were primarily perceived by producers as an important activity, but challenging due to the high inherent costs.

2.5 Conclusions

This study provides an overview of meat goat producing enterprises in New South Wales and Queensland, Australia. Some of the important findings of the survey are that 48% producers rely on opportunistic harvesting. Rangeland goats in pastoral regions are an important source of income. Stocking rate varied considerably within pastoral regions and high rainfall regions, and was found to be negatively associated

with property size and positively associated with rainfall. The results have confirmed the importance of the international market as a source of income and the utilisation of goats to control weeds on many properties. Many producers are located over 600 km from a processing plant and the high cost of freight can limit the continuity of goat supply to the market. The reasons for use of fencing appeared to be an important issue for goat farmers, and this could potentially add to capital costs associated with better goat management and production. Improved pasture management, strategic management of stocking rates and nutrition to meet market specifications and regional location of processing plants within 600 km of major areas of production could improve the utilisation and production of rangeland goats in New South Wales and Queensland.

CHAPTER 3: A Survey of the meat goat industry in Queensland and New South Wales. 2. Herd management, reproductive performance and animal health

Study 2: *Animal Production Science*, 2015. Online Early. doi: 10.1071/AN14794

Abstract. An interview based questionnaire survey was conducted on 31 goat properties in New South Wales (NSW) and Queensland (QLD) in 2013. This study has gathered information on goat herd management, reproductive performance and animal health, and has identified constraints that may limit goat productivity. Producers from high rainfall regions reported having full blood Boer goats for stud breeding. In contrast, producers from pastoral regions had rangeland goats and Boer-cross goats. Overall, 87% of the producers identified a natural breeding season in goats and 61% separated kids from their mothers at weaning. The weaning age varied between 3.0 to 6.0 months. A total of 52% of producers castrated male kids. Only 10% of producers used ultrasound to conduct pregnancy diagnosis on their goats. The reported pregnancy rate was 60% for the Pastoral regions and 94% for the High rain fall regions. The average prolificacy was 1.4 kids/doe and the kidding interval was 12 months. Overall, 68% of producers fed their goat herd with supplements, with the exception that most producers from western NSW and south-western QLD did not use supplements. Producers considered gastrointestinal parasites (61%) and body lice (48%) as the main diseases associated with their goat herds, although only 52% mentioned drenching the animals with anthelmintics. In general, properties in the pastoral regions showed low pregnancy and kidding rates, early age at first mating, high mortality rates, poor performance of Boer bucks and lower weights and weight gain compared with properties in the high rainfall regions. The survey has highlighted areas that require further study to validate the observations of producers, for instance, factors that may be limiting the fertility of Boer goats in rangeland environments, the incidence of diseases, the use of Kidplan® and management activities to improve goat productivity.

Additional keywords: goatmeat, diseases, feral goats, rangeland.

3.1 Introduction

The economic importance of the goat industry is increasing around the world and this dynamic sector may prove to be a new lever for agricultural development in the 21st century (Boyazoglu *et al.* 2005). Australia is the largest exporter of goat meat worldwide, exporting 31,700 tonnes of meat and 75,100 live goats in 2013-14 (McRae and Thomas 2014). Meat goat exports from Australia were initiated in 1952 (Restall *et al.* 1982), but producers in the pastoral regions are still conducting opportunist harvesting of goats and they keep few records related to their property (Nogueira *et al.* 2015c). According to Brice *et al*. (2012) little is known about goat production systems and productivity of rangeland goat meat enterprises in Australia.

The goat herd in Queensland is estimated to represent 12.3% of the national goat herd while the New South Wales herd represents 73.8%, and together these two states represent 86.1% of the national goat herd in Australia, with other states and territories making up the remaining goat numbers (Pople and Froese 2012). A survey of the meat goat industry in Victoria, Australia, showed that the three main animal health issues identified by commercial goat producers were: internal parasitism, low fertility and Johnes disease; and the three main animal husbandry issues identified were: kid predation, fencing security and kid growth rates (Ferrier and McGregor 2002).

Previous studies on goat heath showed that the prevalence of lymphadenitis in Western Australia was 7.8% (Batey *et al.* 1986); enterotoxaemia throughout Australia was 1.4% (Uzal *et al.* 1998), caprine arthritis encephalitis in New South Wales was 59.7% (Greenwood *et al.* 1995) and coccidiosis in South Australia was 97% for the domestic goats and 3% for feral goats (O'Callaghan 1989). However, few data appear to be available regarding goat enterprises, animal health and reproductive performance within Queensland and New South Wales. For this reason, a study was designed to survey farmers' knowledge and practices on the herd management, which includes timing of the breeding season, kidding, weaning, culling and selection, animal health, nutrition and genotypes utilised by meat goat producing enterprises within Queensland and New South Wales. A companion study (Chapter 2) to this publication has discussed the management of pastures, stocking rates and markets of meat goat producing enterprises (Nogueira *et al.*, 2015c).

3.2 Material and Methods

Survey design and structure

An interview based questionnaire survey was conducted on goat properties located in Queensland (QLD) and New South Wales (NSW) during 2013. The questions were related to the period 2012 to 2013. The questionnaire consisted of 106 questions and was designed to take an average of 2.5 hours to be completed. The majority of the questions were in a multiple tick-a-box format, which were modified from a previous beef industry survey reported by Bortolussi *et al.* (2005a).

The survey was conducted via face to face interviews where one or two authors visited meat goat producers and completed the questionnaire with them. Goat producers were the owners of properties that derived substantial income from meat goats. Face to face interviews ensured a consistent approach and interpretation of the questions and high response rate. The template questionnaire and methodology for this survey was approved by the Human Ethics Committee of James Cook University (approval number: ID H4415).

Survey validation

To manage the quality of data collected, most survey questions were cross-referenced where responses to a particular question could be cross-checked and/or validated by the response to a previous or subsequent question (Bortolussi *et al.* 2005b). In addition, there were some follow up calls or emails after the survey was conducted for clarification of responses. The questionnaire was tested with four producers prior to the survey and a revised questionnaire was then used with the wider survey group. On most properties, an inspection of pasture and herd management was conducted with the authorization and presence of the owner. Inspection of the pastures and herd validated some the responses provided in the questionnaire.

Survey population

The survey was carried out in Queensland and New South Wales, and involved owners of 31 properties that derived income from goats. Meat goat producers were recruited non-randomly through direct approach and local networks. The sample frame comprised farmers listed by the respective state government extension personnel, the investigators personal contacts and the Australian Boer Goats Breeders Association.

The producers were screened to include only commercial private goat producers and corporate companies. Those willing to participate in the survey were then included. The first contact with producers was done either by telephone or email when the purpose of the survey was explained. Seventy-four percent (31/42) of goat producers approached were willing to participate in the survey. Taking part in the survey was voluntary. They formed six clusters representing the major goat producing areas in Queensland and New South Wales (Fig. 3.1). The properties were clustered according to proximity and labelled as regions 1 to 6 (Table 3.1).

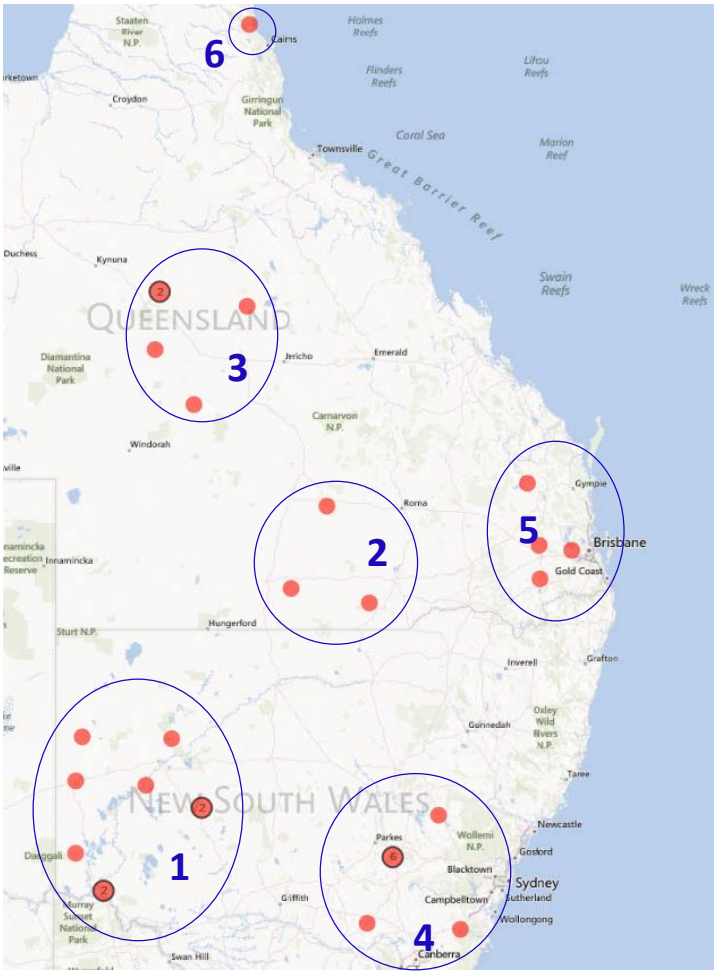


Fig. 3.1 Location of properties included in the survey, which were clustered in three pastoral regions (1, 2 and 3) and three high rainfall regions (4, 5 and 6) of Queensland and New South Wales.

Table 3.1 Brief description of the surveyed regions in Queensland and New South Wales adapted from the Interim Biogeographic Regionalisation for Australia

Region	Bioregion (predominant)	Towns closest to survey sites	Annual Rainfall (range)	Temperature (average max and min)	Altitude (above sea level)	Climate (Köppen)
1. Western NSW	Broken Hill Complex	Broken Hill, Mildura, Wilcannia	130 mm to 250 mm.	Summer: 34ºC Winter: 5ºC	94 m to 315 m	Hot desert climate.
2. South-western QLD	Mulga Lands	Dirranbandi, Morven, Charleville	500 mm.	Summer: 35°C Winter: 18°C	170 m to 290 m	Hot, dry, semi-arid climate
3. Central-western QLD	Mitchell Grass Downs	Corfield, Longreach, Isisford	250 mm to 500 mm	Summer: 38ºC Winter: 12ºC.	191 m to 203 m	Dry monsoonal to semi-arid climate
4. Eastern NSW	South-western Slopes	Forbes, Mudgee, Cootamundra	600 mm to 750 mm.	Summer: 28ºC Winter: 2 ºC	240 m to 320 m	Humid, high rainfall, temperate climate and hot summers
5. South-eastern QLD	South-eastern	Wivenhoe Pocket, Toowoomba, Proston	700 mm to 944 mm	Summer: 23ºC Winter: 9 ºC	458 m to 691 m	Subtropical highland with warm summers and cool winters
6. Far North QLD	Wet Tropics	Mossman	2,010 mm	Summer: 28ºC Winter: 20ºC	4 m	Tropical monsoon climate with summer wet season

Source: Adapted from the Interim Biogeographic Regionalisation for Australia (IBRA 2014).

Definition of terms and parameters evaluated

'*Pastoral regions'* refers to properties located in western NSW and western QLD (Regions 1, 2 and 3), characterised as an arid environment (130 mm to 500 mm rainfall). Livestock production from pasture (extensive grazing) is the main source of farm income. '*High rainfall regions*' refers to properties located in the eastern NSW, eastern QLD and far north QLD (Regions 4, 5, and 6), with an annual rainfall of more

than 600 mm. These properties are smaller, and livestock is raised under an intensive grazing management system. '*Does*' refers to female goats; '*bucks*' are male goats; '*kids*' are newborns or young goats; '*maidens*' are young female goats and '*wethers*' are castrated male goats. '*Pregnancy rate*' was defined as the number of does that were pregnant/ total number of exposed does; '*kidding interval*' was the period between two parturitions; '*prolificacy*' was calculated as the number of kids born/ number of kidding does. The '*kidding rate*' was calculated by (number of kids in the herd/ number of exposed does) x 100. '*Breeding season*' was considered as the natural period where does regularly enter oestrus and are mated with bucks. '*Mortality rate*' was the number of dead goats/ number of goats born. '*Full Blood*' refers to Boer goats originated from fully imported bloodlines and pedigrees can be traced back to South Africa herd books. '*Kidplan®' is* an Australian database developed to select animals using estimated breeding values (EBVs) and customised selection indices that help producers and breeders assess their genetic potential (Ball *et al.* 2001). '*Estimated weight gain at weaning (g/day)*' was calculated by subtracting the bodyweight at birth from that at weaning and then dividing by the age at weaning (days).

Data analysis

Data were analyzed using Epi Info software (Epi Info™ 7.1.1.14, USA, 2013). Descriptive statistical procedures were used to compare surveyed regions. Data is presented as mean and standard deviation, frequencies and cross-tabulation tables. Overall percentages were calculated by the number of properties in both pastoral and high rainfall regions showing the characteristics divided by total number of properties (n = 31) and multiplied by 100. The data expressed as percentages were compared using the Chi-square test. Analysis of variance (ANOVA) was used to compare the values from subtotals between pastoral and high rainfall regions. Fisher's protected least significant difference (LSD) was used as a Post-Hoc to determine differences in subtotals, between pastoral and high rainfall regions. Differences were considered significant when $P < 0.05$.

3.3 Results

Records from goat production

The questionnaire survey found that properties located in the pastoral regions had few records on goat births, deaths and production. In general, only seedstock producers and commercial breeders kept records on goat production and information about goat management. Overall, 97% (30/31) of producers reported keeping stock records. However, the two records they kept were the 'stock numbers' (97%; 30/31) and records from 'sales or kill sheets' (87%; 27/31; Table 3.2).

Goat breeds and body weight

Producers reported the existence of the following breeds: Australian rangeland goats, Boer (White and Red), Anglo-Nubian, Toggenburg, Saanen and Savannah. All the properties located in the pastoral regions had rangeland goats and Boer-cross goats, while properties located in the high rainfall regions had full blood Boer goats for stud breeding. Breeds other than rangeland and Boer goats were kept by 35% (11/31) of producers interviewed. Producers reported introducing Boer goats into the rangeland goat herd to improve body and carcass weights. However, some goat producers from rangeland environments reported a lack of satisfaction with the use of Boer bucks on their properties. These producers stated that full blood male Boer goats had a poor reproductive performance when crossed with their rangeland doe herds. Only 35% of producers evaluated the body condition score of the animals and this was usually a casual evaluation as "Good" or "Bad". Live weights were lower for mature (3-year-old) breeding does ($P < 0.05$) and bucks ($P < 0.05$) in the pastoral regions compared to the high rainfall regions (Table 3.3).

Table 3.2 Records kept by goat producers in New South Wales and Queensland from 2012 to 2013

Stock records	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31(100)
Kept records and stock numbers	8	3	5	16	9	4	1	14	30 (97)
Sales or kill sheets	8	3	4	15	8	3	1	12	27 (87)
Date of kidding	1	2	3	6	9	4	1	14	20 (65)
Paddocks record*	5	1	4	10	4	3	1	8	18 (58)
Deaths	0	1	2	3	9	4	1	14	17 (55)
Supplementary feeding	0	1	1	2	5	4	1	10	12 (39)
Pregnancy status	0	0	0	0	6	0	2	8	8 (26)
Treatment to diseases	0	0	0	0	5	2	1	8	8 (26)

* Use of fertilizer, sowing grasses or legumes or pulling trees.

Table 3.3 Recorded liveweight (mean ± SD) of mature (3-year old) male and female goats in New South Wales and Queensland from 2012 to 2013

	Pastoral regions				High rainfall regions			
	West NSW	S.West QLD	C.West QLD	Subtotal	East NSW	S.East QLD	North QLD	Subtotal
Number of properties	9	3	5	17	9	4	1	14
Records available	2	1	3	6	9	2	1	12
Liveweight for male (kg)	61±41	50	60±28	58.7±25.8[b]	104±13	100±28	80	101.6±15.7[a]
Liveweight for female (kg)	42±17	40	50±14	45.0±12.2[b]	73±9	65±21	60	71.2±10.8[a]

Values in subtotals with different letters in the same row are significantly different ($P < 0.05$).

Breeding season

Goat producers were asked if they saw a natural breeding season in the goat herd. Most of the producers (87%, 27/31) identified a natural breeding season in goats to occur between December and May, and the non-breeding season between June and December (Fig. 3.2). The landholders also reported that does start showing oestrus and conceiving within a short interval after rainfall that is sufficient to facilitate pasture growth in October and November. One producer also mentioned that his goats did not have a breeding season on his property.

Only the stud breeders (45%; 14/31) reported a controlled mating season. These producers segregated female goats from bucks during the non-breeding season. A total of 71% (22/31) of producers reported that some animals within the herd (bucks, does or kids) were segregated from the rest of the herd, but did not specify the time of year when segregation occurred.

Liveweight and weight gain at weaning

Birth weights of kids were lower ($P < 0.05$) in the pastoral regions than the birth weights of kids in the high rainfall regions (Table 3.4). Overall, 61% (19/31) of the surveyed producers weaned their goat kids. Although all the producers from high rainfall regions weaned the kids, none of the producers from south-western QLD and only 22% (2/9) of producers from western NSW weaned their kids. A total of 52% (16/31) of producers castrated male kids between three and four months of age (Table 3.4). On average, the reported weaning age varied from three to six months and weaning weight varied from 17 kg to 25 kg. Although weaning weights were similar ($P > 0.05$) between regions, the age of the kids at weaning was greater ($P < 0.05$) for the pastoral regions at 4.5 months compared to the high rainfall regions of 3.2 months (Table 3.4). The pastoral and high rainfall regions targeted similar ($P > 0.05$) weaning live weights for kids at approximately 25 kg. The calculated weight gain at weaning varied between regions, from 105 g/day in central-western QLD to 204 g/day in eastern NSW (Table 3.4).

Survey regions	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Far North, QLD												
Central-western, QLD												
South-western, QLD												
South-eastern, QLD												
Western, NSW												
Eastern, NSW												

Fig. 3.2 Schematic distribution of the breeding season (gray squares) and non-breeding season (white squares) according to producer's perception.

Table 3.4 Mean (± SD) reported birth weight of kids, weaning weight, age at weaning, calculated and targeted weaning weights and age for castration of male goats in New South Wales and Queensland from 2012 to 2013

	Pastoral regions				High rainfall regions			
	West NSW	S.West QLD*	C.West QLD	Subtotal	East NSW	S.East QLD	North QLD	Subtotal
Number of properties	9	3	5	17	9	4	1	14
Reported to wean the kids	2	0	3	5	9	4	1	14
Records available (n)	3	0	2	5	9	4	1	14
Birth weight (kg)	2.4±0.2	.	2.3±0.3	2.3±0.2[b]	3.5±0.5	3.6±0.3	3.5	3.5±0.4[a]
Liveweight at wean (kg)	20.5±4.9	.	18.3±2.8	19.6±3.2	23.5±5.7	20.7±6.5	17.0	22.2±5.8
Age at wean (month)	4.2±1.4	.	5.1±1.4	4.5±1.3[b]	3.3±0.2	3.4±0.2	3.0	3.2±0.2[a]
Calculated weight gain at weaning (g/day)	143.7	.	104.6	128.1	204.0	167.6	150.0	191.4
Target weaning weight (kg)	20.5±4.9	.	27.5±5.6	24.0±7.8	28.1±4.1	20.8±6.5	20.0	25.0±6.1
Producers who castrate (n)	2	.	2	4	8	3	1	12
Castration age (month)	3.5±0.7	.	4.1±1.0	3.3±1.3	2.1±0.5	3.5±2.5	3.0	2.6±1.3

* There was no information available from producers from south-western QLD. Values in subtotals with different letters in the same row are significantly different ($P < 0.05$).

Reproductive performance

Only 10% (3/31) of producers reported that pregnancy diagnosis of their females was carried out by ultrasonography. The other 90% of producers either assessed the pregnancy status of a doe, usually in late pregnancy, by visual observation or did not assess the pregnancy status of their doe herd. Overall, 48% (15/31) of producers mentioned they kept some form of reproductive performance records such as pregnancy rates, kidding rates, prolificacy and kidding interval. All the seedstock producers from high rainfall regions recorded reproductive data; in contrast, none of the producers from western NSW and south-western QLD recorded reproductive data (Table 3.5). The reported pregnancy rate was higher than 93%, except for the producers from central-western QLD who reported a pregnancy rate of 60% and western NSW and south-western QLD who failed to report the pregnancy rate of their doe herd. Overall, producers reported that the kidding rate increased between a poor season and a good season. However, regardless of the seasonal conditions, the kidding rate and prolificacy was less in central-western QLD compared to the high rainfall regions. The average prolificacy was 0.9 kids/doe in central-western QLD compared to 1.6 kids/doe in the high rainfall regions. Most of producers reported a kidding interval of 12 months (Table 3.5). In addition, producers indicated that goats were very prolific, reporting the mean (± SD) prolificacy rate for doe herds to be 65 ± 14% twins, 13 ± 8% triplets and 22 ± 14% single bearing does.

Age at first mating for maidens ($P < 0.05$) and the age at first kidding ($P < 0.05$) was significantly greater in the pastoral regions compared to the high rainfall regions (Table 3.6). Forty-seven percent (8/17) of properties in the pastoral regions reported to retain an average of 50% of young does in the breeding herd compared to 34.6% of young does retained in the high rainfall regions (Table 3.6).

Criteria for selecting bucks

Goat producers in the high rainfall regions selected bucks based on two or more criteria. In contrast, the majority of producers in the pastoral regions selected bucks for two or less criteria (Table 3.7). The most common criterion for selecting bucks was conformation or absence of physical defects, reported by 80% (25/31) of surveyed producers. The selection criteria of weight for age, temperament and colour were used by 32% (10/31) of respondents when selecting bucks. Only two seedstock producers in the high rainfall regions used Kidplan® as a selection criterion for bucks (Table 3.7).

Reasons for culling bucks and does

Mature does and bucks were culled when they were unproductive or over seven years old on 58% (18/31) of surveyed properties. Bucks were most likely to be culled because of physical defects (71%) such as angulations of legs and dentition defects, old age (58%), reproductive problems (55%) and temperament (45%). The main criteria for culling does were failure to become pregnant and deliver a kid (65%), old age (58%), mastitis (48%) and failure to rear a kid (39%).

Seedstock producers routinely culled their animals and they appeared to place emphasis on conformational traits (93%, 13/14). For instance, in full blood Boer goats, the presence of two individual teats on each udder was acceptable; more than two teats on each udder was a major fault and the doe would be culled. However, producers dealing with opportunistic harvesting enterprises reported that they did not routinely cull their animals. They sold their animals in accordance with the international market specifications, usually when animals reached the minimum dressed carcass weight of 12 kg. In contrast, seedstock producers normally culled Bucks and Does before 12 months-of-age when animals presented with major physical defects or conformational faults. If young females (maidens) or does less than 2 years-of-age fail to deliver a kid, producers mentioned they normally rebred these animals, but if an adult doe, older than 2 years old, failed to deliver a kid, producers reported they were culled. In addition, they mentioned that wethers were culled between four and 12 months of age or when wethers achieved the best body weight for sale.

Supplementary feeding

All producers in the high rainfall regions reported using supplements in their goat herds compared to 41% (7/17) of producers from pastoral regions. A majority of producers from western NSW (89%, 8/9) and south-western QLD (67%, 2/3) did not use any supplements (Table 3.8). The most commonly used supplements were mixes or formulated rations (48%; 15/31) and feed blocks (45%; 14/31). Only producers in the high rainfall regions reported to use grain (57%, 8/14) and crops (36%; 5/14). Only 13% (4/31) of producers reported the use of rumen modifiers for their goat herd (Table 3.8). The classes of goats fed with supplements in order of frequency were: does (68%), kids (61%) and bucks (55%).

Table 3.5 Mean (± SD) for reported pregnancy and kidding rates, doe prolificacy and kidding interval in New South Wales and Queensland from 2012 to 2013

	Pastoral regions				High rainfall regions			
	West NSW*	S.West QLD*	C.West QLD	Subtotal	East NSW	S.East QLD	North QLD	Subtotal
Number of properties	9	3	5	17	9	4	1	14
Records available	0	0	1	1	9	4	1	14
Pregnancy rate (%)	.	.	60	60	93±4	95±4	96	94.2±3.6
Kidding rate:								
Poor season (%)	.	.	60	60	153±58	127±38	100	142±52
Average season (%)	.	.	85	85	171±66	160±34	150	166±55
Good season (%)	.	.	120	120	186±74	202±33	200	191±61
Prolificacy (kids/doe)	.	.	0.9	0.9	1.7±0.3	1.6±0.4	1.5	1.6±0.2
Kidding interval (months)	.	.	12	12	11.5±1.3	12.0	12.0	11.7±1.1

* There was no information available from producers from western NSW and south-western QLD.

Table 3.6 Mean (± SD) Age that young does enter the breeding season and age at first kidding in New South Wales and Queensland from 2012 to 2013

	Pastoral regions				High rainfall regions			
	West NSW	S.West QLD	C.West QLD	Subtotal	East NSW	S.East QLD	North QLD	Subtotal
Number of properties	9	3	5	17	9	4	1	14
Records available	3	2	3	8	9	4	1	14
Age at first mating (month)	6±0.0	8±2.8	11.5±4.9	8.5±3.5[b]	15±3.3	16.5±3.0	.	15.5±3.1[a]
Age at first kid (month)	11±0.0	13±2.8	16.5±2.5	14.7±3.4[b]	20.3±3.4	21.5±3.0	.	21.0±3.4[a]
Retained young does (%)	33.3±15.3	50.0±3	62.5±18	50.0±20	42.7±33	20±4.1	20.0	34.6±28.0

*There was partial information available from North QLD. Values in subtotals with different letters in the same row are significantly different ($P < 0.05$).

Table 3.7 Criteria for selecting bucks for breeding in New South Wales and Queensland from 2012 to 2013

	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31(100)
				Number of criteria selected					
0 criteria	4	1	0	5	0	0	0	0	5
1 type	2	2	1	5	0	0	0	0	5
2 types	3	0	3	6	3	1	1	5	11
$\geq$ 3 types	0	0	1	1	6	3	0	9	10
				Criteria for selection					
Conformation	5	2	4	11	9	4	1	14	25 (80)
Weight for age	2	0	2	4	5	1	0	6	10 (32)
Temperament	1	0	2	3	4	2	1	7	10 (32)
Colour	0	0	2	2	5	3	0	8	10 (32)
Kidplan®	0	0	0	0	1	1	0	2	2 (6)

Table 3.8 Use of supplements and/or rumen modifiers associated with goat production reported from New South Wales and Queensland

	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31(100)
Producers using supplements	1	1	5	7	9	4	1	14	21 (68)
Producers using rumen modifiers	0	0	1	1	2	1	0	3	4 (13)
Type of supplements									
Mixes (formulated ration)	0	1	3	4	8	2	1	11	15 (48)
Feed blocks	1	1	3	5	6	3	0	9	14 (45)
Grain	0	0	0	0	6	2	0	8	8 (26)
Urea and associations	0	0	2	2	0	2	2	4	6 (19)
Crops	0	0	0	0	3	2	0	5	5 (16)
Whole cottonseed	0	0	2	2	0	1	0	1	3 (10)
Protein meal (Copra)	0	0	0	0	2	1	0	3	3 (10)
Phosphorus (P) only	1	0	1	2	1	0	0	1	3 (10)
Protein meal (Soy bean)	0	0	0	0	0	0	1	1	1 (3)

Animal Health

In general, producers had limited data about goat herd health. They rarely used any diagnostic tests or any professional help to diagnose diseases. The producers who reported using faecal egg counts (FEC) as a tool to monitor the incidence and severity of gastrointestinal nematodes were predominately from high rainfall regions, accounting for 42% (13/31) of surveyed producers.

Gastrointestinal parasites were reported as a disease of concern by 100% of producers located in the high rainfall regions and by 29% (5/17) of producers in the pastoral regions. Producers from all regions reported the following diseases associated with their goat herds in order of importance: external parasites such as body lice (48%, 15/31), caseous lymphadenitis (26%, 8/31), contagious ecthyma (10%, 3/31) and caprine arthritis encephalitis virus (6%, 2/31). Only producers from high rainfall regions reported the occurrence of coccidiosis (64%, 9/14) and enterotoxaemia (43%, 6/14).

Although producers ranked gastrointestinal parasites and body lice as the most important diseases, only 52% (16/31) of producers reported drenching the animals with anthelmintics and only 48% (15/31) were controlling lice. Half of the properties (7/14) from the high rainfall regions reported using greater than seven anthelmintic drugs (Table 3.9). However, producers from western NSW and south-western QLD reportedly had not used any anthelmintics in the previous three years to 2013 (Table 3.9). During inspection of the goat herd of three properties (27%, 3/11) located in western NSW and south-western QLD, the authors observed varying degrees of anaemia. These producers reported the anaemia to be caused by malnutrition rather than by internal parasite burden.

The chemical group macrocyclic lactones was the most commonly reported (52%, 16/31) anthelmintic group used to treat goats for intestinal parasites (Table 3.9). To reduce the frequency of anthelmintic administration, 22% (7/31) of producers were using the FAMACHA© system to monitor the colour of the eyelid for signs of anaemia.

Table 3.9 Type of drenches (deworming products) used in New South Wales and Queensland in the previous three years to 2013

	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5		9	4	1		31 (100)
Number of chemicals used									
0 chemical	9	3	3	15	0	0	0	0	15
1 or 2 types	0	0	1	1	0	0	0	0	1
3 or 4 types	0	0	1	1	1	2	0	3	4
5 or 6 types	0	0	0	0	3	1	0	4	4
≥ 7 types	0	0	0	0	5	1	1	7	7
Anthelmintic groups used									
Macrocyclic lactones [1]	0	0	2	2	9	4	1	14	16 (52)
Benzimidazoles [2]	0	0	1	1	9	3	1	13	14 (45)
Nicotinic [3]	0	0	1	1	9	4	0	13	14 (45)
Salicylanilides [4]	0	0	0	0	8	2	1	11	11 (35)
Amino acetonitrile [5]	0	0	0	0	5	1	1	7	7 (23)
Organophosphate	0	0	0	0	0	0	1	1	1 (3)

[1] Abemectin, ivermectin, doramectin and moxidectin

[2] Albendazole, fenbendazole and oxfendazole

[3] Levamisole and Morantel

[4] Closantel

[5] Monepantel

A total of 65% (20/31) of producers reported that they isolated sick animals and 45% (14/31) had a quarantine period for new animals. Seedstock producers from south-eastern QLD and northern QLD said they did not have a quarantine period because they seldom introduce new animals, but they were willing to segregate new animals before introduction to the goat herd.

The vaccinations used in the goat herd were against clostridial diseases, being used by 52% (16/31) of producers, and vaccination against caseous lymphadenitis (13%), normally, included with the clostridial vaccination pack (5 in 1). All the seedstock producers from high rainfall regions vaccinated their goat herd, but only two producers from pastoral regions vaccinated their goats.

Mortality rates for kids (0 to 3 months), young goats (4 to 12 months) and adults (> 12 months) are reported in Table 3.10. The mortality rate of the kids for western NSW and south-western QLD were unknown to producers interviewed. Central-western QLD presented greater mortality rate for kids at 33%/year than the high rainfall regions at 12%/year. Mortality rates were also greater in young goats and adults in the pastoral regions compared to the high rainfall regions (Table 3.10). Producers from pastoral regions reported that the most common causes for mortality in goat herds were: starvation (malnutrition), dehydration, predators and old age.

When producers were asked about problems caused by feral animals and/or predators, the majority indicated that foxes (65%), kangaroos (52%), wild dogs (48%) and feral pigs (48%) were the biggest problem (Table 3.11). Wild dogs (including dingoes and dingo-crosses) were mentioned by properties in all regions, except for eastern NSW. The use of Maremma guardian dogs or traps to protect goat herds against wild dogs was reported by 48% (15/31) of producers.

Table 3.10 Mean (±SD) reported annual mortality rates for kids (0 to 3 months), young goats (4 to 12 months) and adult goats (>12 months) in New South Wales and Queensland from 2012 to 2013

	Pastoral regions				High rainfall regions			
	West NSW*	S.West QLD*	C.West QLD	Subtotal	East NSW	S.East QLD	North QLD	Subtotal
Number of properties	9	3	5	17	9	4	1	14
Records available	0	0	3	3	9	3	1	14
Mortality for kids (%)	.	.	33.3±23	33.3±23	12.5±11	10.3±5	5.0	11.6±9.9
Mortality for young (%)	.	.	15.7±17	15.7±17	4±3	9.0±7	15.0	6.0±5.1
Mortality for adults (%)	.	.	8.3±3	8.3±3	1.2±0.4	7.0±7	1.0	2.5±3.8

* There was no information on mortality in western NSW and south-western QLD.

Table 3.11 Number of properties that reported a problem caused by pests and/or predators in New South Wales and Queensland

Pest or Predators	Pastoral regions				High rainfall regions				
	West NSW	S.West QLD	C.West QLD	Subtotal n	East NSW	S.East QLD	North QLD	Subtotal n	Overall n (%)
Number of properties	9	3	5	17	9	4	1	14	31 (100)
Predators									
Foxes	5	1	2	8	9	3	0	12	20 (65)
Wild dogs	2	3	5	10	0	4	1	5	15 (48)
Feral Pigs	6	3	5	14	0	0	1	1	15 (48)
Eagles	2	0	2	4	2	0	0	2	6 (19)
Non-predators									
Kangaroos	9	2	4	15	1	0	0	1	16 (52)
Rabbits	3	0	0	3	7	4	0	11	14 (45)
Feral cats	1	1	2	4	0	1	0	1	5 (16)

3.4 Discussion

The properties located in the pastoral regions covered larger areas and the greatest number of goats per property, and represented 55% of producers involved in 'opportunistic harvesting' and commercial goat operations. On the other hand, 45% of properties were located in the high rainfall regions and were represented by specialized seedstock producers (Nogueira *et al.* 2015c). The survey revealed that most producers do not record detailed data relating to herd health and performance. This failure to record data was more common among opportunistic harvesters who managed large properties in excess of 10,000 ha. Only seedstock producers who farmed smaller land areas were more commonly able to provide detailed herd performance data. Overall, 13% of producers did not keep records from the 'kill sheets' from the abattoirs.

Breeding season

Only seedstock producers (45%) from high rainfall regions were using a controlled mating season. These producers had smaller properties and goat herd size. In addition, they had better infrastructure, with holding paddocks, facilities to castrate wethers and the ability to segregate bucks during the non-breeding season.

In general, producers perceived that a natural breeding season in goats occurred from December to May (Fig. 3.2) and this is contrary to what Restall (1992) found in north-eastern NSW (29ºS, 154ºE) where only 30% of rangeland does began to ovulate between March-May. According to the same author, the highest incidence of ovulatory activity was detected between June-July with 60% of does ovulating during that period. The difference in the distribution of breeding season between our survey and Restall's (1992) findings may be due to differences in day length, temperature, rainfall, feed supply and the presence or absence of males (Mellado *et al.* 1991; Chemineau *et al.* 1992a; Walkden-Brown and Bocquier 2000; Scaramuzzi and Martin 2008). Producers from central-western QLD and south-western QLD reported that goats started showing behavioural signs of oestrus in October and November (Fig. 3.2), after the onset of a period of rainfall. The natural increase in the plane of nutrition that occurs with the onset of rainfall and new pasture growth towards the end of the non-breeding season has been reported to stimulate the early onset of the breeding season in goats in Mexico and Australia (Mellado *et al.* 1991; Scaramuzzi and Martin 2008). The length of the breeding season was reported to be shortest in far north QLD which has the least

variation in photoperiod. Freitas et al. (2004b) reported that the duration of the breeding season is longer in tropical areas compared to more temperate regions of the world. This is in contrast to the findings of our survey, suggesting that there are local influences, including farmers' practices that result in variation in the breeding season.

Goat breed

Boer goats are used in many parts of the world to improve carcass weight (Van Niekerk and Casey 1988). However, producers from pastoral regions cited poor pregnancy rates and survival of Boer bucks as low in their environment. The reasons for the low pregnancy rates with Boer genotypes in some rangeland environments remain unclear from this survey. However, a number of reasons may be suggested. Firstly, there may be an underestimation of the ratio of Boer bucks to rangeland does and as a consequence competition from feral bucks for females may be greater than expected. Secondly, acclimatisation of Boer genotypes to pastoral browsing and climatic conditions may not have occurred, especially if death was the reported end result. Thirdly, insufficient supplementation and nutritional regimens of Boer goats in rangelands may be limiting their reproductive performance in the pastoral regions (MLA 2013).

Liveweight and weight gain at weaning

The greater liveweight of adult male and female goats in high rainfall regions can be explained firstly by basal diet and supplementary feeding practices established by producers and secondly by the genetic type of the individual goat herds. The pastoral regions rely heavily upon its natural resources as a feed base for livestock, including browse and native pasture species (Nogueira *et al*., 2015c). In contrast, the high rainfall regions rely on improved pastures and supplementary feed (Table 3.8).

Breed and mature liveweight of goats have a major influence on other productive traits such as birth weight and weaning weight of the offspring, causing important impacts on animal production (McGregor and Butler 2010). Producers from the pastoral regions reported birth weights that were 1.2 kg less than those reported by producers in the high rainfall regions (Table 3.4). Eady and Rose (1988) reported similar birth weights to those given by producers in the pastoral regions for male (2.76 kg) and female (2.54 kg) cashmere kids in south-western QLD.

The results of weight gain at weaning varied from 104 g/day to 204 g/day (Table 3.4). These variations can be explained by breed, sex, mature liveweight of does, production system (extensive or intensive) and the period of the year when kids were born (McGregor 2005a). For instance, Boer goats raised in semi-intensive conditions can achieve a weaning weight gain of 169 g/day (Montaldo *et al.* 2010) and Boer goats crossed with rangeland goats in Australia achieved 148 g/day (Dhanda *et al.* 2003; McGregor 2005a). Furthermore, the reported growth rate at weaning of rangeland goats varied from 15 g/day to 82 g/day (McGregor *et al.* 1988) and the growth rate of Saanen wether goats fed with cows' milk ad libitum prior to weaning varied from 154 to 216 g/day (McGregor 1980), which is in accordance to the results from this survey.

Only 29% (5/17) of producers from pastoral regions reported to wean their kids (Table 3.4). One important explanation for the lack of strategic weaning is the lack of fencing or no fencing plans to create holding paddocks and to segregate the goat herd (Nogueira *et al*., 2015c). Strategic weaning may confer production advantages to rangeland systems, with improvement in weaning weights and survival rates (McGregor and Butler 2010). Furthermore, strategic weaning can be used to reduce the loss of body condition in lactating does and to reduce the post-partum anoestrus interval (Freitas *et al.* 2004b). By practicing early weaning producers can enter the premium domestic market in Australia, which requires goats to be sold at a dressed carcass weight of 6-12 kg, known as Capretto (Dhanda *et al.* 2003).

Reproductive performance

Little information was recorded by producers in the pastoral regions on reproductive parameters of their doe herds. In this survey, pregnancy rates were less in the pastoral region of central-western QLD (60%) compared to the mean of the high rainfall regions (94%; Table 3.5). The reported pregnancy rate from the pastoral region was represented by one producer and, therefore, caution should be taken in any interpretation of this difference. The lack of record keeping and herd management in the pastoral regions has cast a shadow over the true regional reproductive performance of the rangeland goat herd in Australia. However, better reproductive performance is possible in the pastoral zone. The current findings are different to Eady and Rose (1988) who reported a pregnancy rate of 89% in a controlled experimental goat herd in the pastoral region of south-western QLD. Similarly, Restall (1992) in north-eastern NSW observed a pregnancy rate of 88% on rangeland goats after an April joining. The ability

of the animal to meet their nutrient requirements before and after mating, differences in day length, temperature, rainfall and the presence of fertile bucks are also important factors that affect ovulation and pregnancy rates in goats (Mellado *et al.* 1991; Chemineau *et al.* 1992a; Walkden-Brown and Bocquier 2000; Martin *et al.* 2004; Scaramuzzi and Martin 2008). The reported kidding rates varied by season. For all producers the kidding rates increased in a good season and decreased in a poor season (Table 3.5). Seasonal conditions and the quality of pasture can have significant impacts on liveweight and thus on pregnancy rate. In the rainy season the quality of pasture is better and as a consequence the goat herds have better reproductive performance (Nogueira *et al.* 2012). Prolificacy also varied between regions; for instance, the herd from the pastoral region of central-western QLD presented half of the prolificacy (0.9 kids/doe) of the herds in the high rainfall regions (1.6 kids/doe). These results may be explained by the feed base and the extensive management system of the pastoral regions, as Eady and Rose (1988) also reported a prolificacy of 1.6 kids per doe joined under a controlled experimental system.

The age at which maiden does are mated was reported to be less for the pastoral region (8.5 months) compared to the high rainfall region (15.2 months; Table 3.6). This may be explained by the lack of fencing and, therefore, this suggest a lack of control in the age at first mating for maiden does in the pastoral regions. Opportunistic harvesting operations will sell mature dry does to make up a consignment of animals that will meet a carcass weight specification (Nogueira *et al.* 2015c). As a result, the remaining females available for breeding will have a lower body weight and, probably, lower reproductive performance. The practice of selling breeding animals may be why a greater percentage of young does are retained in the herds from the pastoral regions compared to the high rainfall regions (Table 3.6).

Criteria for selecting and reasons for culling bucks and does

Only 6% of all producers reported using Kidplan® for the selection of breeding bucks (Table 3.7). Producers appeared to be unaware of the evaluations and positive outcomes from the use of Kidplan® as a selection tool (Ball *et al.* 2001). These results may also suggest that producers may be unwilling to use Kidplan® or that they do not see it as being economically worthwhile or necessary for the selection of bucks.

Seedstock producers routinely culled their animals and they appeared to place emphasis on conformational traits (80%). In contrast, producers from pastoral regions

did not routinely cull their animals, but they sold when animals achieved a target sale liveweight. Opportunistic harvesters removed their animals when they reach minimum dressed carcass weight of 12 kg and producers appeared to place little if any emphasis on other traits. If producers keep harvesting the mature or the fastest growing goats to meet the carcass weight specification, these animals are effectively being culled from the herd. Thus, the goat herd remaining for breeding are the less productive performers, which indicates that a negative selection for performance is being practiced. This suggests that there is potential amongst opportunistic harvesters to improve productivity per head by applying selection criteria that remove unproductive or less productive animals from herds. It is known that regularly culling goats saves double handling and helps improve the productivity of the enterprise (MLA 2013).

Supplementary feeding

Feed availability and supplementary feeding in organized goat production may be one of the most important single factors that affect total productivity (Copland *et al.* 1984). Supplementary feeding was used by 100% of producers from high rainfall regions, but only 41% of producers from pastoral regions have used supplements to feed their goat herds (Table 3.8). These results can be explained by the difference in the animal production system (extensive or intensive). Supplementary feeding may not be available, difficult to provide or too expensive for goat producers in pastoral regions.

Furthermore, only 35% of producers evaluated body condition scores. This may suggest a lack of understanding on when supplementation may be required in the herds, as the use of body condition scoring accounts for 60-67% of the variation in liveweight change, carcass weight and fat reserves of goats (McGregor 2012). McGregor (2005b) reported that supplementation of goats is generally required during drought, and if this option is pursued, the best strategy is to provide supplementation early in a drought to finish and sell goats rather than holding them for an unknown period.

Animal Heath

The majority of producers from pastoral regions reported that gastrointestinal parasites were not a problem and that they never use any anthelmintic products. However, the authors observed varying degrees of anaemia in 27% of the goat herds inspected when undertaking this survey, suggesting that producers are unaware of the effect of gastrointestinal parasites. Further study is required to determine whether the

anaemia in some animals was caused by malnutrition or caused by internal parasite burden with, for example, *Haemonchus contortus*.

Previous research has demonstrated that the FAMACHA© system can be used to reduce indiscriminate use of drenches within sheep and goats (Kaplan *et al.* 2004; Reynecke *et al.* 2011). However, only 22% of respondents reported that they used the FAMACHA© system and 42% reported that they used FEC to monitor gastrointestinal parasite burdens. This may suggest that there is a greater need for goat herd managers to use monitoring tools when considering therapeutic treatments for gastrointestinal parasites. It may also suggest that producers are unaware of these tools or they do not see them as being necessary for management decisions.

A total of 13 anthelmintic products were reported by producers (Table 3.9). In Australia, most of the commercial anthelmintic products are not registered for goats and this is a problem mentioned by all surveyed producers. Chemicals that are widely used on sheep may be suitable for goats, but they need to go through the Australian processes of registration before dose rates and effectiveness can be verified for goats (Brice *et al.* 2012).

Coccidiosis, caseous lymphadenitis, enterotoxaemia, contagious ecthyma and caprine arthritis encephalitis appeared to be diseases more important in the high rainfall regions. This may be due to higher quality pastures associated with high stocking rates in the high rainfall regions (Nogueira *et al.* 2015c), and high stocking rates may significantly increase the level of nematode infections (McGregor *et al.* 2014). The heavy reliance upon opportunistic goat harvesting operations in the pastoral regions may limit animal health monitoring and interventions. Further study will be needed to assess the true impact of these diseases in goat herds and whether implementing control measures is economically worthwhile and able to reduce the prevalence of these diseases, as well as, determining reasons for any perceived or real regional differences.

Mortality rate and predators

In the pastoral region of central-western QLD, the reported mortality rates for goat kids pre-weaning (33%) and adults (8%) were high (Table 3.10). It is likely that the mortality rate of kids may be greater than this as the western NSW and south-western QLD producers did not know the mortality rate of their kids. The mortality rate of goat kids from birth to weaning has been reported to be 15% in a controlled experimental herd in the pastoral region of south-western QLD (Eady and Rose 1988). Under a semi-

extensive production system in Brazil, it was found that the mortality rate of crossbred Anglo-Nubian goats varied from 12% to 23% for kids up to weaning and 5% to 13% for young goats (Nogueira *et al.* 2012). In high rainfall regions, the mortality rate for kids (11%), young (6%) and adult animals (2%) was low, probably due to the better nutrition, animal health and less predators (Table 3.11). However, on temperate pastures, mortality rate caused by internal parasitism can be increased by stocking rates equal or greater than 10 goat/ha (McGregor 2010b).

Predation of kids by wild dogs, foxes, wild pigs and wedge tailed eagles were reported as a significant source of losses for young goats from all producers. However, the numbers of kids that were predated upon in a year was unknown. Brice *et al.* (2012) reported that predators can affect a goat enterprise at any stage in the production cycle, but kids are the most vulnerable animals.

3.5 Conclusions

Rangeland goats represented 97% of the goat population covered in this survey. Producers who engage in opportunistic goat harvesting maintain few records related to herd management and animal health. On the other hand, commercial and seedstock producers generally keep more detailed records and are trying to improve the productivity of their goat herds. In general, properties in the pastoral regions showed low pregnancy and kidding rates, early age at first mating, high mortality rates, poor performance of Boer bucks and lower weights and weight gain than properties in the high rainfall regions. Few registered veterinary chemicals are available to control parasites of goats, and goat producers are using chemicals that are registered for use in sheep. The survey has highlighted areas that require further study to validate the observations of producers, for instance, factors that may be limiting the fertility of Boer goats in rangeland environments, the incidence of gastrointestinal parasites and infectious diseases, the use of Kidplan® and management strategies to improve goat productivity.

CHAPTER 4: The timing of the commencement of the breeding season in Boer and rangeland goats raised in the tropics of Queensland, Australia

Study 3: *Small Ruminant Research* 125 (2015):101-105. doi:10.1016/j.smallrumres.2015.02.013

Abstract. This study aimed to determine the timing of the onset of the breeding season in Boer and rangeland goats raised in a tropical region of northern Queensland. The experiment was carried out using 25 Boer and 20 rangeland female goats. Boer and rangeland goats were kept on the same pasture in the absence of males and supplemented to provide nutritional requirements above maintenance. Blood samples were collected once weekly from December 2011 to May 2012 and analyzed for concentrations of progesterone. The mean time to first ovulation was found to occur earlier in Boer compared to rangeland goats (64.7 ± 5.0 days vs 87.7 ± 5.6 days, respectively; $P < 0.05$). Differences in survival curves ($P < 0.05$) for the timing of onset of first ovulation between breeds were also detected. Boer goats started ovulating in December (8.3%) and had all ovulated by March while most rangeland goats started ovulating in March (84%) and had all ovulated by the end of April. These results demonstrate that in a tropical region of north Queensland Boer goats commence ovulatory cycles earlier than rangeland goats which may be beneficial if an earlier start to the breeding season is preferred.

Keywords: goat, progesterone, reproduction, seasonality, photoperiod.

4.1 Introduction

In Australia there are approximately 3.6 million goats (FAOSTAT 2015), comprising 3.2 million rangeland goats and 400,000 domestically farmed goats (Pople and Froese 2012). Thus rangeland goats represent more than 90% of goats thought to be present in Australia. Australia is the largest exporter of goat meat worldwide, slaughtering more than 2 million goats and producing 31,700 tonnes of meat in 2013-2014 (McRae and Thomas 2014). While goat meat exports from Australia commenced in 1952 (Restall *et al.* 1982), the Australian goat industry remains relatively small and little is known about the production and reproduction of goats raised within tropical

regions of Queensland (Brice *et al.* 2012) in which 12% of the goat population in Australia is estimated to be located (Pople and Froese 2012).

A seasonal distribution in breeding activity is common of sheep and goats living outside the tropics. In subtropical and temperate areas, the breeding season is stimulated by a reduction in the hours of daylight (negative photoperiod), with the largest percentage of conceptions occurring in autumn and winter (Fatet *et al.* 2011). However, in tropical areas, such as northern parts of Queensland where fluctuations in day length are not as extreme as in more southern parts of Australia (Timeanddate 2014), it is often hypothesized that food availability is the main factor controlling annual sexual activity within sheep and goats maintained in tropical environments (Mellado *et al.* 1991; Scaramuzzi *et al.* 2006; Scaramuzzi and Martin 2008). At present, there is no information available about the timing of the commencement of the breeding season in Boer and rangeland goats raised in the tropics of Queensland. Determining the onset of the breeding season is critical when determining optimal times for commencement of breeding programs in extensively managed goat herds.

Boer goats are regarded as very adaptable under all environmental conditions of Southern Africa, including mediterranean, tropical and subtropical, and in semi-desert regions (Casey and Van Niekerk 1988; Greyling 2000). Rangeland goats in Australia are descended from the first European settlements and subsequent introductions. These goats were commonly kept by householders as a source of milk and were used as draught animals, some of which established permanent populations within sparsely populated areas of Australia (Restall *et al.* 1982). Rangeland goats can survive long dry periods, in areas where average annual rainfall ranges from 150 mm to 450 mm and temperatures exceed 40°C in summer (Restall *et al.* 1982; Thompson *et al.* 2002). Rangeland goats have therefore adapted over the past 200 years in Australia to the prevailing climatic conditions which could have altered their annual reproductive cycle in comparison to other breeds of goats and fostering natural selection for survival rather than reproductive traits.

As Boer and rangeland goats have adapted to dry climate conditions, we hypothesized that Boer and rangeland goats raised in the tropics of Queensland would exhibit a similar timing for the onset of the breeding season when fed above nutritional requirements for maintenance. Knowledge of the timing of the commencement of the breeding season in Boer and rangeland goats raised within northern Queensland will provide information on when interventions, such as strategic nutritional

supplementation and/or hormonal treatments should be applied. The aim of this study was, therefore, to determine the timing of the onset of the breeding season in Boer and rangeland goats raised in the tropics of Queensland, Australia.

4.2 Material and Methods

Location, animals and evaluation period

This experiment was carried out at James Cook University, Townsville (19°19'30" S; 146°45'44" E) which is located within a tropical region in Queensland. The experiment was conducted between December 2011 and May 2012, during what was estimated to be the transition from the non-breeding season to the breeding season for goats. A total of 25 Boer and 20 rangeland nulliparous, anoestrous does, were enrolled in the study. In November, every goat was classified as being in anoestrous when no corpora lutea were observed in the ovaries when examined twice 14 days apart using transrectal ultrasonography.

At the start of the experiment, the mean (± SEM) age and body weights of the does were 1.5 ± 0.1 years and 43.8 ± 0.9 kg for Boer goats, and 1.4 ± 0.2 years and 35.6 ± 1.0 kg for rangeland goats, respectively. Experimental procedures for the study were approved by the James Cook University Animal Ethics Committee (approval number: A1695).

Animal management

Female Boer and rangeland goats were maintained on the same pasture in the absence of male goats and supplemented daily with a base ration consisting of lucerne hay. In addition, does had *ad libitum* access to a pasture of annual ryegrass (*Lolium multiflorum)* in order to provide nutritional requirements above maintenance (7.6 MJ ME/day) for a goat weighing 40 kg (NRC 2007). The body weights of all animals were monitored every two weeks from November 2011 to May 2012.

Blood samples and Progesterone assays

Blood samples were collected once weekly (weeks 0 to 18) from the jugular vein using evacuated tubes (BD Vacutainer®, Plymouth, UK) containing lithium heparin. Samples were stored on ice then centrifuged (2500 g for 15 minutes) within two hours of collection. Plasma was then isolated and frozen (-20°C) until the time of assay. The

onset of the breeding season was recorded when concentrations of progesterone were determined to be greater than 1 ng/mL in two successive blood samples collected one week apart. The mean time to first ovulation was defined as the interval between the day that goats were first classified as being in anoestrus (Day 0) and the first day when concentration of progesterone exceeded 1 ng/mL (Thimonier 2000).

Concentrations of progesterone in plasma were measured using a competitive binding enzyme-linked immunosorbent assay (Access Progesterone 33550, Beckman Coulter Australia Pty Ltd, Lane Cove, NSW). The sensitivity of the assay was 0.10 ng/mL. The intra-assay coefficients of variation for low (0.62 ng/mL) and high (5.81 ng/mL) controls were 9.5% and 6.8%, respectively. The corresponding inter-assay coefficients of variation were 17.3% and 14.5%. The ratios for observed/expected values for dilution parallelism using the ELISA assay was assessed using nine serial dilutions of three plasma samples collected from goats in which a CL was observed between days 12 and 15 of oestrous cycle. The average (mean ± SEM) of the observed/expected ratios (efficacy) was 110 ± 2.6%.

Statistical analysis

Statistical analyses were conducted using the statistical software package IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp. Armonk, NY, 2013). Repeated measures analysis of variance was used to compare the variation in body weight between Boer and rangeland goats. The distribution of the timing of the first ovulation (P4 >1ng/mL) between breeds was determined with the log-rank test (Mantel-Cox), using Kaplan-Meier survival curves. A multivariate Cox proportional model was used to analyse the effect of the initial body weight, breed and their interaction on the interval to first ovulation. In addition, ANOVA was used to determine the difference in the mean interval in days to the first ovulation between breeds and Levene's test was used to assess homogeneity of variance in the mean interval to the onset of first ovulation. The proportion of goats ovulating every month was compared with a Chi-square test. Results are presented as mean ± SEM and differences were considered significant when $P < 0.05$.

4.3 Results

The mean time to first ovulation was significantly less in Boer goats compared to rangeland goats (64.7 ± 5.0 days vs. 87.7 ± 5.6 days, respectively; P = 0.004). In addition, the variability for the onset of the first ovulation was greater in Boer goats than in rangeland goats (P = 0.010; Fig. 4.1). Eight percent of Boer goats started ovulating in December, two months before any rangeland goats had started ovulating. Most ovulations in rangeland goats were detected in March (84%), (Fig. 4.1).

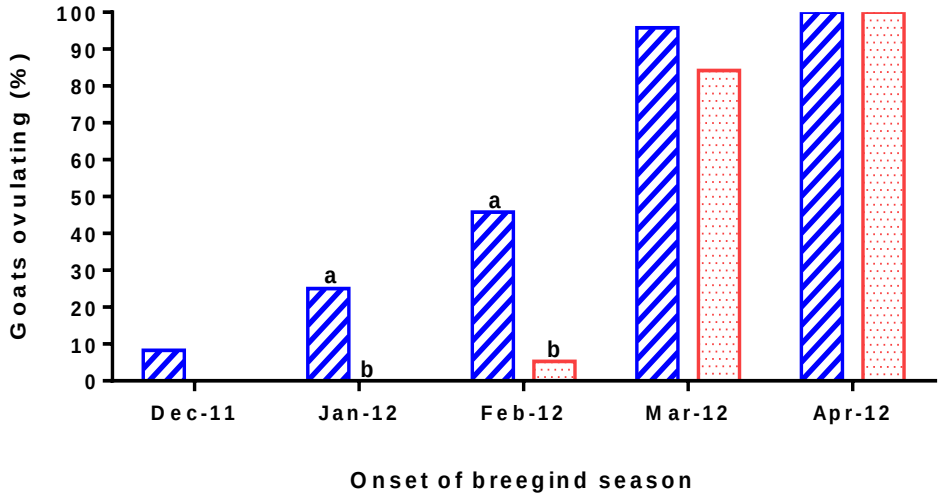


Fig. 4.1 Cumulative percentage of Boer ( ) and rangeland ( ) goats ovulating between December and April (ab: within months differ; P < 0.05).

The difference between breeds for the distribution of the timing of the first ovulation was also supported by differences in the Kaplan-Meier survival curves between breeds (P = 0.038). The timing of first ovulation in Boer goats occurred gradually over the period of 18 weeks, in contrast to rangeland goats, in which the timing of first ovulation happened suddenly between weeks 10 and 12 (Fig. 4.2).

Analysis of body weights between the two breeds over time indicated that there were differences between breeds (P = 0.001). The mean weights of Boer and rangeland goats throughout the study were 43.0 ± 0.9 and 36.3 ± 0.9, respectively (Fig. 4.3). While the initial body weight of both breeds was similar to their final body weight, the magnitude of the difference in body weight between breeds varied over time although Boer goats were always at least 5.6 kg on average heavier than rangeland goats throughout the study. Body weight was included in the model as a covariate, but the

Cox regression analysis did not show any effect (P = 0.537) of the body weight on the time to first ovulation.

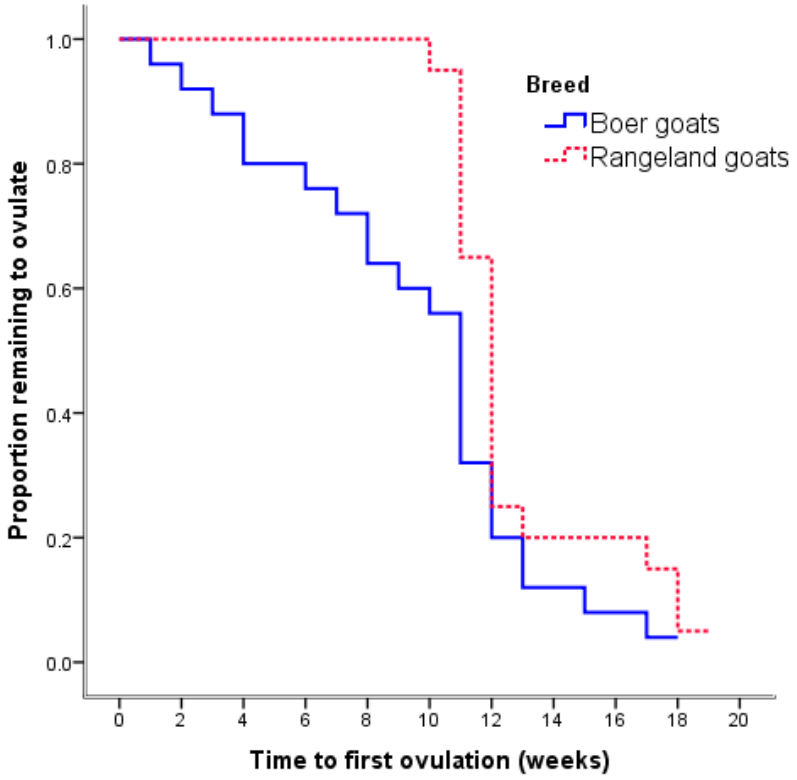


Fig. 4.2 Kaplan-Meier survival plot of the onset of the first ovulation in Boer and rangeland goats.

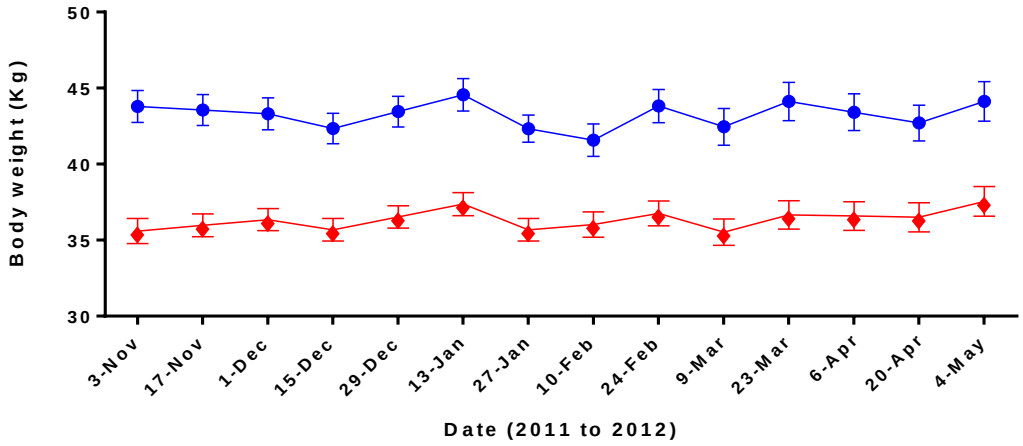


Fig. 4.3 Variation of body weight of Boer (●) and rangeland (♦) goats from November 2011 to May 2012.

4.4 Discussion

Determining the onset of the breeding season is critical when determining optimal times for commencement of breeding programs in extensively managed goat herds in order to condense the kidding season and improve annual production (Freitas *et al.* 2004a). In this study, when we compared the onset of first ovulation in anoestrous does, we found a different pattern in the timing of onset and an earlier mean time interval to a first ovulation in Boer goats. We, therefore, reject our hypothesis that Boer and rangeland goats located in the tropics of Queensland exhibit similar timing for the onset of the breeding season. Boer goats started the breeding season two months earlier than rangeland goats. This may have practical consequences for when the breeding season should commence and when managing the different breeds in tropical environments.

The results from this study indicate that rangeland goats in a tropical environment located closer to the equator started ovulating earlier compared with what has previously been reported for the same breed located in a more southern location of Australia. For instance, in a study conducted in north-eastern NSW (29ºS, 154ºE), Restall (1992) observed that rangeland does, separated from males, began to ovulate between April-May, with 30% of does ovulating during this period. In addition, the highest incidence of ovulatory activity in rangeland does was detected between June-July, with 60% of does ovulating during that period. In this study, over 84% of rangeland does had ovulated by March and 100% by April (Fig. 4.1). The difference in the timing of the commencement in the breeding season between different studies is likely to be due to differences in day length (Fatet *et al.* 2011). In addition, other factors like temperature, humidity, rainfall, food supply, body condition and the method to detect ovulation might be affecting the timing of the first ovulation between experimental sites (Chemineau *et al.* 1992a; Duarte *et al.* 2008).

Zarazaga *et al.* (2005) studied the effect of nutrition on the seasonal pattern of sexual activity in Payoya goats kept under a natural photoperiod (37º15'N) for 20 months. They reported that the duration of breeding season was increased by about one month when does received 1.5 times maintenance compared with those that received only a maintenance diet. Thus differences in nutritional supplementation or variations in feed intakes between studies could also contribute to differences in the pattern of onset of first ovulation observed in goats. On the other hand, according to Duarte *et al.* (2008)

reproductive seasonality in goats in a subtropical environment (26º23'N) persisted independently of food availability and they reported that photoperiod is the key factor regulating seasonality in subtropical latitudes. In this study, both breeds were supplemented to above maintenance requirements and still varied in their interval to first ovulation. The results therefore suggest that while the onset of cyclicity may be affected by factors such as body condition, food availability and the presence or absence of male animals, genetic factors interacting with photoperiod can significantly modulate the onset of the breeding season in goats within subtropical environments (Mellado *et al.* 1991; Chemineau *et al.* 1992a; Duarte *et al.* 2008).

The reasons why Boer goats started the breeding season earlier than rangeland goats are unclear from the results of this study. However, possible reasons may be suggested. First, Boer goats have been selected over a long period as a precocious breed for red meat production with greater selection pressure for reproductive traits (Casey and Van Niekerk 1988; Malan 2000), while rangeland goats have existed mainly in the wild with only natural selection for a reproductive capacity that favours their survival within a rangeland environment. Second, even though goats within each breed were of similar age groups, the heavier weight of Boer goats compared to the rangeland goats may have encouraged the resumption of the ovarian activity earlier in Boer goats, although this is not supported by our finding that body weight was not significantly associated with the interval to first ovulation with survival analysis. The results of this study agree with previous studies with Boer goats, in which the body weight could not be correlated to the annual oestrous activity (Greyling 2000). The same author reported that sexual activity in Boer goats and daylight length was recorded to have a significant negative correlation ($r^2 = -0.654$). This may suggest that genetic sensitivity to photoperiod is a more important driver of the timing of the onset of ovulation than absolute body weight when nutritional requirements are being met. Finally, we also speculate that the difference in temperament between Boer and rangeland goats may contribute to the longer timing for the onset of the breeding season. In this study, we observed a greater flight zone for the rangeland goats compared to the Boer goats. The greater flight zone and other stressors are associated with activation of the hypothalamus-pituitary-adrenal axis to increase concentrations of cortisol in goats (Kannan *et al.* 2000). Furthermore, the circadian rhythm also influences cortisol production and is associated with changes in photoperiod (Alila-Johansson *et al.* 2003).

Although unmeasured in this study, it is possible that concentrations of cortisol may have contributed to the delay in the onset of the breeding season in rangeland goats.

Differences in seasonality and onset of puberty between breeds of goats have been reported in the literature, which highlights the influence of genotype on reproductive cyclicity in goats. For instance, Amoah *et al*. (1996) reported that Nubian and Pygmy female goats (breeds of tropical ancestry) when raised in temperate region have an extended breeding season when compared to Saanen, Toggenburg and American Alpine does. This could be due to reduced sensitivity of Nubian and Pygmy goats to changes in photoperiod during the year. In tropical regions, Saanen female kids achieved puberty earlier than Anglo-Nubian goats when raised in the same environment (Freitas *et al.* 2004a). These same authors reported that the precocity of Saanen goats was due to a faster growth rate in Saanen than Anglo-Nubian goats, which suggests that nutrtion may interact with photoperiod to influence reproductive function. In this study, goats remained relatively stable in body weight and were fed with a diet which provided above maintenance nutritional requirements.

Different responses between breeds to photoperiod could be due to different genetic abilities to secrete melatonin or differences in signal transmission within the brain or differences in responsiveness to circulating concentrations of oestradiol (Rosa and Bryant 2003). Photoperiodic control of reproductive patterns is mediated through secretion of melatonin by the pineal gland during darkness, which in turn influences the secretion of GnRH and hypothalamic-pituitary-gonadal feedback (Chemineau *et al.* 1992a; Fatet *et al.* 2011). As Boer and rangeland goats have different genetic backgrounds, it could be that they have different abilities to translate the signal of melatonin in the pituitary gland and hypothalamus. The seasonality of reproduction in sheep is primarily due to changes in the responsiveness of the hypothalamus to the negative feedback of oestradiol, which in turn is dictated by variations in the length of the daily photoperiod (Rosa and Bryant 2003). Reproductive function in male sheep is also less responsive than in females to changes in photoperiod and this has in part been attributed to males having a lower sensitivity to oestradiol than females (Lubbers and Jackson 1993). According to the same authors, this is explained by the finding of lower concentrations of mRNA oestrogen receptors in the hypothalamus of males than in females, which could explain the greater suppression of LH secretion in females than in male sheep during the non-breeding season (Lubbers and Jackson 1993).

Similarly, Boer goats may have a lower sensitivity to oestradiol than rangeland goats and, as a consequence, concentrations of LH are greater in Boer goats than rangeland goats during transition from anoestrous to the breeding season. In summary, the earlier onset to the breeding season in Boer goats than rangeland goats could be explained by a combination of different responsiveness to photoperiod and different sensitivity to oestradiol in the hypothalamus.

4.5 Conclusion

Goats fed above nutritional maintenance requirements, in a tropical region of Australia commenced their breeding season from December to April, although the pattern of onset of ovulation was affected by breed. In this study, onset to the first ovulation, determined by the concentrations of progesterone, in Boer goats was more precocious than rangeland goats, which indicates that there are likely genetically driven differences in sensitivity to photoperiod between these breeds. Managing the timing of the start of the breeding season for goats on commercial farms in tropical regions should take into consideration not only the seasonality of reproduction, but also potential differences between genotypes in the onset of the breeding season. In addition, for an earlier start of the breeding programs, we suggest that Boer goats may be a better commercial option than rangeland goats.

CHAPTER 5: Comparison of follicular dynamics and hormone profiles in Boer goats examined during the breeding and non-breeding seasons in the tropics of Queensland, Australia

Study 4: *Small Ruminant Research* 125(2015): 93-100. doi:10.1016/j.smallrumres.2015.02.014

Abstract. This study aimed to describe ovarian follicular dynamics in Boer goats (n = 14) during the breeding and non-breeding seasons in the tropics of Queensland. Progesterone profiles and follicular dynamics were compared over a 21-day period in the non-breeding season and one oestrous cycle in the breeding season. Between September and October, 100% of goats were in anoestrus while between April and May they were all undergoing ovulatory cycles. The number of follicular waves during a 3-week period of monitoring was greater during the non-breeding compared to the breeding season (4.8 ± 0.1 vs 4.1 ± 0.1, respectively; $P < 0.05$), while the number of codominant follicles (5.6 ± 0.3 vs 6.8 ± 0.3, respectively; $P < 0.05$), growth rate (0.61 ± 0.05 mm/day vs 0.81 ± 0.05 mm/day, respectively; $P < 0.05$) and the diameter of the largest follicle measured within follicular waves (6.7 ± 0.1 mm vs 7.8 ± 01 mm, respectively; $P < 0.05$) were less in the non-breeding compared to the breeding season. During the breeding season the interovulatory interval was 19.7 ± 0.2 days. Total number of small follicles (2 to 3 mm) and the total number of follicles ≥3 mm from Days 2 to 14 of the period of examination were greater ($P < 0.05$) during the non-breeding compared to the breeding season. In the breeding season, 35.7% of cycling goats showed large anovulatory follicles, which persisted and became luteinized. Ovulatory follicles were derived from the fourth follicular wave in 71% of goats. These results have described differences in characteristics of follicular development in the same Boer goats examined during the breeding and non-breeding seasons. In the non-breeding season, the ovaries remained active and follicles continued to grow to reach the equivalent size of preovulatory follicles. Follicular dynamics in the breeding season was characterised by the development of larger follicles and greater follicular growth rates. Short oestrous cycles and follicular cysts may reduce ovulation rate in Boer goats in the breeding season.

Keywords: Anoestrus, goats, oestrous cycle, progesterone, reproduction, seasonality.

5.1 Introduction

Goats are by nature seasonal breeders. This seasonality of reproductive cyclicity is related to the annual variations in photoperiod (Fatet *et al.* 2011). The breeding season is stimulated by a reduction in the hours of daylight (negative photoperiod), with the largest percentage of conceptions occurring in autumn and winter. Conception within autumn and winter results in kidding during spring, when feed supply and environmental conditions are usually most favourable (Scaramuzzi *et al.* 2006; Fatet *et al.* 2011).

Some authors have claimed that Boer goats are not seasonal breeders (Malan 2000) and that a complete period of seasonal anoestrus has never been observed in Boer goats (Greyling 2000). In Townsville (19°19' S), which is located within a tropical region of north QLD, Boer goats fed with an above maintenance diet were recorded to be in anoestrus in November and the timing of the commencement of the breeding season was distributed from December to April; with most goats starting to ovulate in March (Nogueira *et al.* 2015b).

There are a limited number of reports that have studied follicular dynamics in anoestrous goats with most studies reporting on follicular dynamics in does that are undergoing oestrous cycles (Ginther and Kot 1994; Menchaca and Rubianes 2002; Medan *et al.* 2005). Previous studies in cyclic goats indicated that ovarian follicles throughout the oestrous cycle exhibited a wave-like pattern, with two or more follicles attaining 5 mm or more in diameter and growing approximately 1.0 mm per day (Ginther and Kot 1994; Medan *et al.* 2003; Simões *et al.* 2006). In anoestrus Anglo-Nubian and Saanen goats, the ovaries remained active and antral follicles continued to grow in a wave-like pattern with the largest follicles within follicular waves reaching the equivalent size of preovulatory follicles (Cruz *et al.* 2005). No information, however, appears to be available regarding follicular dynamics in Boer goats maintained in the tropics of Australia, and there are no reports that have compared follicular dynamics in the same goats when they are seasonally anoestrous and when they are undergoing oestrous cycles.

Understanding the patterns in follicular dynamics in does between the non-breeding and breeding season may help to illuminate physiological causes of differences in fertility and prolificacy when goats are bred at different times of the year. The aim of

this study was to describe the ovarian follicular dynamics in Boer goats during non-breeding season and the following breeding season in the tropics of Queensland.

5.2 Material and Methods

Location, animals and evaluation period

The experiment was carried out at James Cook University, Townsville (19°19'30" S; 146°45'44" E) between August 2011 and May 2012. A total of 14 nulliparous and non-pregnant Boer does were used in this study. Animals were evaluated during two consecutive periods: the non-breeding season (September to October; mean dark:light hours, 11.5:12.5) and the following breeding season (April to May; mean dark:light hours, 13:11; Timeanddate, 2014). In the non-breeding season, the mean (± SEM) age and bodyweight of the does were 1.5 ± 0.4 years and 41.3 ± 0.7 kg, respectively. In the breeding season, the mean (± SEM) age and bodyweight of the does were 2.1 ± 0.4 years and 45.7 ± 0.7 kg, respectively. During each period, animals were monitored for four weeks with the aim of documenting and comparing concentrations of progesterone and follicular dynamics over a 21-day period in the non-breeding season and one oestrous cycle during the breeding season. The same 14 does were used in the non-breeding and breeding seasons. All experimental procedures for this study were approved by the Animal Ethics Committee of James Cook University (approval number: A1695).

Animal management

All female goats were maintained on a ryegrass (*Lolium multiflorum*) dominated pasture in the absence of male goats and supplemented daily with lucerne hay in order to provide nutritional requirements above maintenance (7.6 MJ ME/day) for a goat weighing 40 kg (NRC 2007). Does were observed twice daily for behavioural signs of oestrus with one mature buck for 30 min. Does that allowed the buck to mount were classified as being in oestrus. Intromission by the buck during mounting was prevented by manual withdrawal of the buck from the doe before mating occurred. The bodyweights of all animals were monitored once every two weeks from August 2011 to May 2012 (Fig. 5.3).

Blood samples and hormonal assay

Blood samples were collected once weekly from August 2011 to May 2012 from the jugular vein into evacuated tubes (BD Vacutainer®, Plymouth, UK) containing lithium heparin. During the 21-day periods in which follicular dynamics were being monitored in the non-breeding and breeding season, blood samples were collected once every second day. After collection, blood samples were centrifuged at 2500 g for 15 minutes, then plasma was isolated and frozen (-20^{o}C) until the time of assay.

Concentrations of progesterone in plasma were determined by Radioimmunoassay (RIA) using anti-progesterone antibody-coated tubes (RIA Progesterone IM1188, Beckman Coulter Australia Pty Ltd, Yeerongpilly, QLD). The sensitivity of the assay was 0.05 ng/mL. The intra-assay coefficients of variation for low (0.80 ng/mL) and high (4.55 ng/mL) quality controls were 4.1% and 3.5%, respectively. The corresponding inter-assay coefficients of variation were 13.8% and 9.7%, respectively. Concentrations of progesterone above 1 ng/mL was used as an indication of ovulation (Thimonier 2000).

Synchronization of oestrus and ultrasonography

During the breeding season Boer goats had their oestrous cycles synchronized with two injections of cloprostenol (125 µg IM; EstroPlan®, Parnell Australia Pty Ltd, Alexandria, NSW), given seven days apart. During the breeding season goats were monitored with transrectal ultrasound evaluations using a 6.6 MHz transducer (MyLab^{TM} FiveVET, Medical Plus Australia Pty Ltd, Tullamarine, Vic) once daily after administration of the last dose of cloprostenol to detect ovulation with examinations continuing until the next ovulation was recorded. During the non-breeding season data were recorded over a 21-day period following the retrospective identification of follicular wave emergence.

Video recordings of each ultrasound examination were made. All follicles $\geq$2 mm in diameter and corpora lutea were measured using electronic calipers and ovarian maps were drawn. A follicular wave was defined as one or more antral follicles growing from 3 to $\geq$5 mm in diameter before subsequently regressing and being no longer detectable. The day of emergence of follicles was identified as the day on which the dominant follicle within a given follicular wave was retrospectively first observed to be $\geq$3 mm in diameter. The end of a follicular wave was recorded when dominant follicle(s) associated with a follicular wave could no longer be identified. Individual

follicles emerging within a 48-hour period of the day of emergence of the dominant follicle were regarded as belonging to the same follicular wave. The duration of a follicular wave was defined as the interval between the day of emergence and the day this follicular wave could no longer be identified. The interwave interval was recorded as the number of days between the start of two sequential follicular waves. Follicular growth rate (mm/day) was the time taken by a follicle to grow from the first time it was observed (≥2 mm in diameter) to its maximum diameter. The day of maximum follicular diameter was the first day in each wave when dominant follicles reached a maximum diameter ≥5 mm. Follicles were classified as codominant when two or more follicles ≥5 mm were present within the same follicular wave. When codominant follicles were observed only data related to the largest follicle was used for the purposes of analyses related to the assessment of follicular waves. The day of ovulation was defined by the sudden loss of a follicle ≥5 mm in diameter followed by the development of a corpus luteum within same ovary. During the breeding season the day of ovulation was defined as Day 0. During the non-breeding season, Day 0 was the day of emergence of a new follicular wave. The interoestrus and interovulatory intervals were defined as the interval between the detection of two successive periods of oestrus and ovulations, respectively. The total number of corpora lutea observed in the ovaries of each doe was recorded as the ovulation rate for each doe. During the present study, all ultrasound examinations were performed by the same operator.

Statistical analysis

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 season on the number of follicular waves, number of codominant follicles, the maximum diameter of the largest follicle in each wave, duration of a wave, the interwave interval, growth rate of follicles, number of ovulations, and number of small (2 to 3 mm), medium (>3 and <5 mm) and large follicles (≥5 mm). Interactions included in the ANOVA model were between the effects of the non-breeding and breeding season and between each season and the order in which follicular waves (1^{st}, 2^{nd}, 3^{rd} or 4^{th} waves) were recorded during the period of observation. Differences in means between the non-breeding and breeding seasons were compared using a paired t-test. Repeated measures analysis of variance was used to compare the mean total number of small, medium and large follicles, and

plasma concentrations of progesterone from Days 1 to 21 between goats in the breeding and non-breeding season. 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 $P < 0.05$.

5.3 Results

Timing of the breeding and non-breeding season

Weekly assessment of concentrations of progesterone indicated that during August 43% (6/14) of does were in anoestrus, and between September and October 100% of does were in anoestrus. A small percentage of goats (7.1%; 1/14) commenced cycling in November and by April 100% of does were cycling (Fig. 5.1).

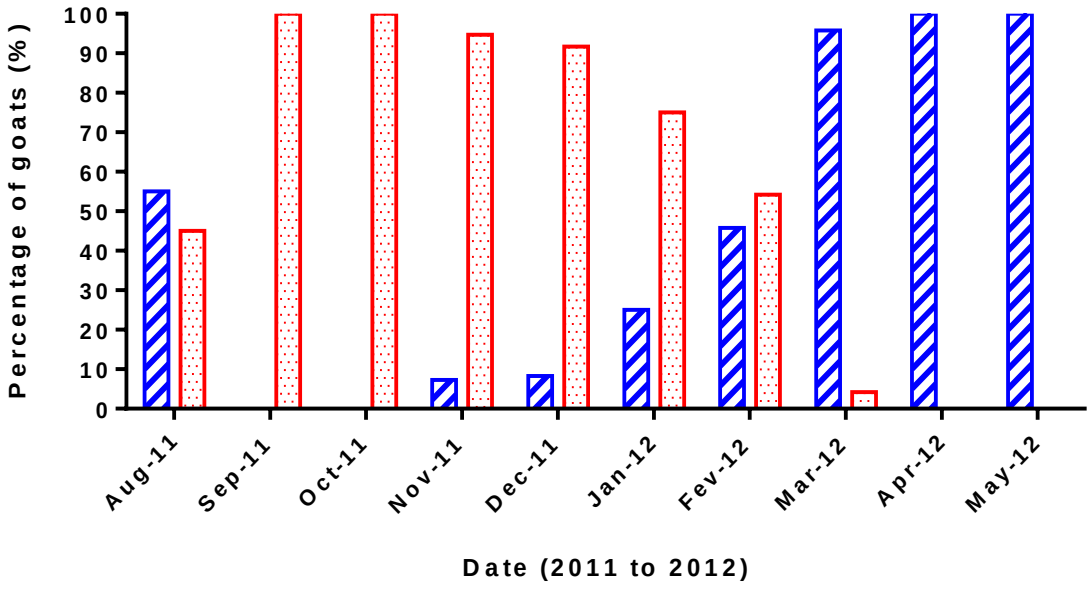


Fig. 5.1 Percentage of Boer goats ovulating ( ) and in anoestrus ( ) during the experimental period.

In the non-breeding season (September and October), oestrous behaviour was not observed and ovulation was not detected. Concentrations of progesterone were always less than 0.65 ng/mL when does were sampled in the non-breeding season (Fig. 5.2).

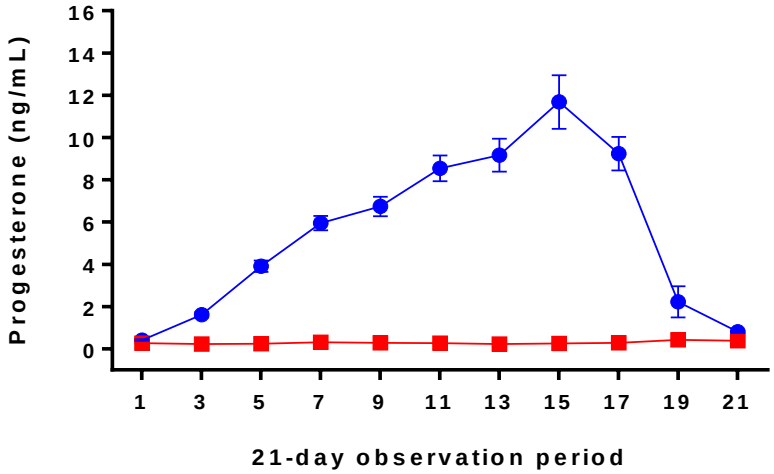


Fig. 5.2 Concentrations of progesterone in Boer goats during the breeding (●) and non-breeding (■) seasons.

Body weight

The bodyweights of all animals increased ($P < 0.05$) throughout the experimental period (Fig. 5.3).

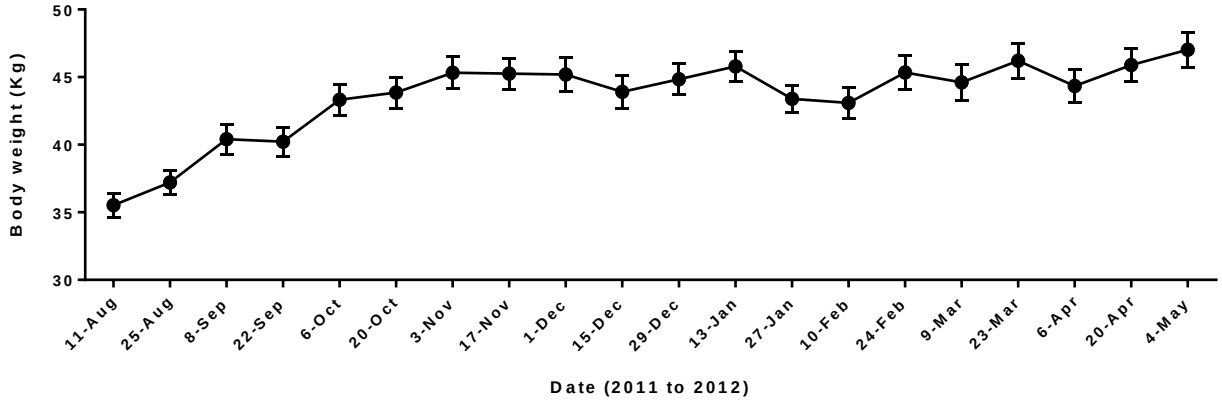


Fig. 5.3 Variation of bodyweight of Boer goats during the experimental period.

Follicular dynamics

The mean number of follicular waves during the 21-day recording period was greater ($P < 0.05$) during the non-breeding compared to the breeding season, while the mean number of codominant follicles was greater ($P < 0.05$) in the breeding season (Table 5.1). In the non-breeding season, 64% (9/14) of goats had five follicular waves, while in the breeding season 71% (10/14) of goats had four waves (Table 5.1).

Table 5.1 The number of follicular waves found in Boer goats during a 21-day period of observation conducted in the breeding and non-breeding season

	Non-breeding season (n = 14)	Breeding Season (n = 14)
Follicular waves (n)	4.8 ± 0.1^{a}	4.1 ± 0.1^{b}
Codominant follicles (n)	5.6 ± 0.3^{a}	6.8 ± 0.3^{b}
Goats with 3 waves, % (n)	0.0^{C}	$7.1\ (1/14)^{C}$
Goats with 4 waves, % (n)	$28.6\ (4/14)^{aC}$	$71.4\ (10/14)^{bD}$
Goats with 5 waves, % (n)	$64.3\ (9/14)^{aD}$	$21.4\ (3/14)^{bC}$
Goats with 6 waves, % (n)	$7.1\ (1/14)^{C}$	0.0^{C}

[ab] Values between seasons differ ($P < 0.05$).

[CD] Values within the same season differ ($P < 0.05$).

Significant differences in characteristics of follicular development were found between the non-breeding and breeding seasons, and significant interactions were observed between the diameter of the largest follicle and the order of follicular waves, and the duration of waves and order of follicular waves during the breeding season (Table 5.2). The mean diameter of the largest follicle that was recorded during the period of observation in each season was greatest during the breeding season. The diameter of largest follicles recorded in Waves 2 and 3 were similar ($P > 0.05$) between the non-breeding and breeding season. However, the diameter of the largest follicle in Waves 1 and 4 during the breeding season was greater ($P < 0.05$) compared to the largest follicle in comparable waves during the non-breeding season (Table 5.2).

In the breeding season, the duration of a follicular wave was greatest for Wave 1 and shortest for Wave 4 (Table 5.2; $P < 0.05$). The mean duration of follicular waves was similar between the non-breeding and breeding season. However, duration of Wave 4 in the breeding season was shorter ($P < 0.05$) than that in the non-breeding season (Table 5.2). Overall, the growth rates of follicular waves were greater ($P < 0.05$) in the breeding season compared to the non-breeding season. The mean interwave interval between the non-breeding and breeding season were similar (Table 5.2).

Table 5.2 Mean ± SEM characteristics of follicular development during a 21-day period of observation during the non-breeding and breeding season in Boer goats

Parameters	Non-breeding season (n = 14)	Breeding Season (n = 14)
Largest follicle of wave 1 (mm)	6.2 ± 0.2^{a}	7.2 ± 0.2^{bC}
Largest follicle of wave 2 (mm)	6.3 ± 0.1	6.5 ± 0.1^{D}
Largest follicle of wave 3 (mm)	6.3 ± 0.2	6.6 ± 0.2^{DE}
Largest follicle of wave 4 (mm)	6.2 ± 0.2^{a}	7.1 ± 0.2^{bCE}
Duration of wave 1 (days)	8.5 ± 0.4^{a}	9.6 ± 0.4^{bC}
Duration of wave 2 (days)	8.3 ± 0.3	8.3 ± 0.3^{CD}
Duration of wave 3 (days)	8.5 ± 0.4	7.4 ± 0.4^{D}
Duration of wave 4 (days)	8.4 ± 0.4^{a}	5.9 ± 0.4^{bE}
Largest follicle of all (mm)	6.7 ± 0.1^{a}	7.8 ± 0.1^{b}
Duration of all waves (days)	8.4 ± 0.2	7.8 ± 0.2
Interwave interval (days)	4.4 ± 0.2	4.2 ± 0.4
Growth rate (mm/days)	0.61 ± 0.05^{a}	0.81 ± 0.05^{b}

[ab] Values between seasons differ ($P < 0.05$).

[CDE] For similar parameters, values within the same season differ ($P < 0.05$).

The number of small, medium and large follicles and the total number of follicles during 21 days of ultrasound evaluations are shown in Figure 5.4. The mean number of medium and large follicles during the examination periods did not differ ($P > 0.05$) between the breeding and non-breeding seasons and no significant interactions between day and season were detected for these variables (Fig. 5.4b and Fig. 5.4c). Significant interactions between day and season were detected for the number of small follicles (Fig. 5.4a) and the total number of follicles (Fig. 5.4d). On Day 1, the number of small follicles was greater ($P < 0.05$) in the breeding season compared to the non-breeding season; however, between Days 2 and 14 the number of small follicles and the total number of follicles were greater ($P < 0.05$) during the non-breeding season.

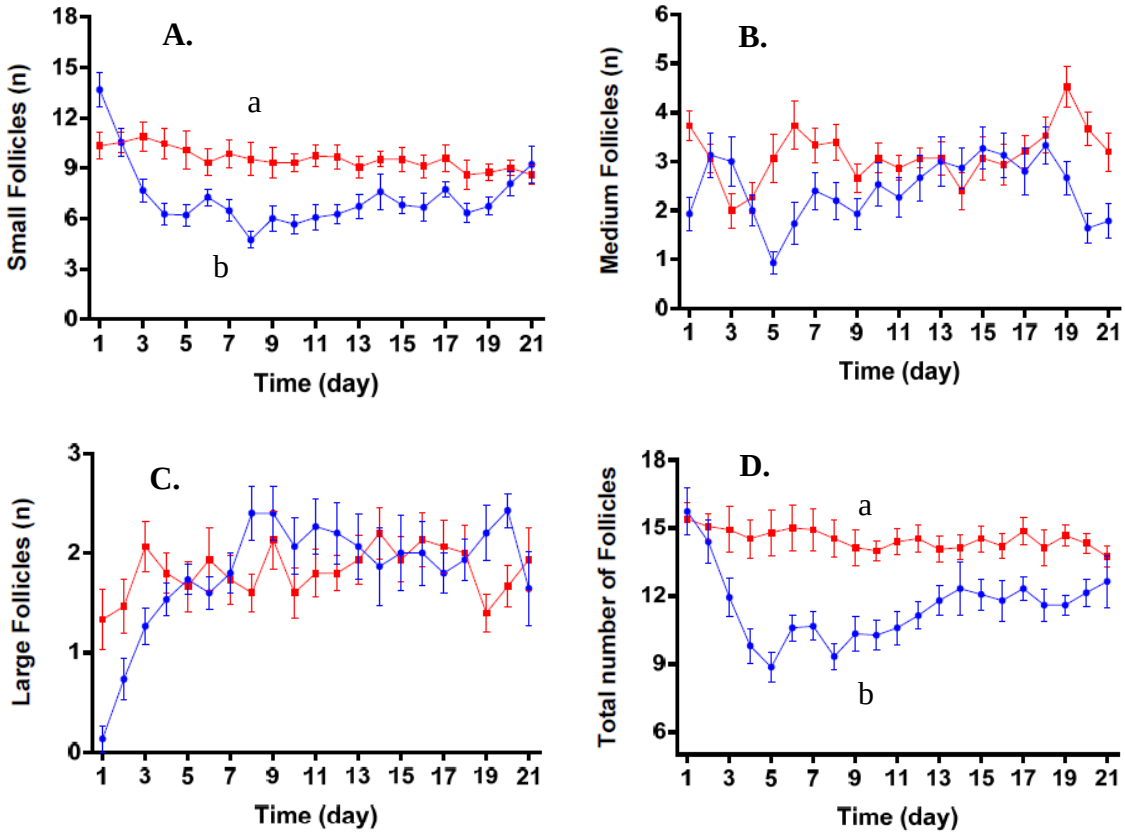


Fig 5.4 Number of (A) small (2 to 3 mm), (B) medium (>3 and <5 mm), (C) large (>5mm), and (D) total number of follicles ≥ 3 mm during 21 days of ultrasound evaluations of Boer goats during the non-breeding (■) and breeding seasons (●). (ab: within seasons differ; P<0.05).

Characteristics of the oestrous cycle in the breeding season are listed in Table 5.3. The number of ovulations recorded following the synchronized oestrus was similar (P > 0.05) to the number that occurred following a non-synchronized oestrus. The interovulatory interval observed by ultrasound was one day shorter (P > 0.05) than the interoestrus interval (Table 5.3). After the synchronized oestrus with cloprostenol, 14.3% (2/14) of does had short cycles. In these animals, a second ovulation was observed six days after the first ovulation.

Table 5.3 Overall characteristics of oestrus cycle of Boer goats during the breeding season in the tropics of QLD, Australia

Variables	mean ± SEM
Ovulations after a synchronized oestrus with cloprostenol (n)	1.8 ± 0.2
Ovulations after a natural oestrus (n)	2.1 ± 0.1
Interovulatory interval (days)	19.7 ± 0.2
Interoestrus interval (days)	20.7 ± 0.2
Max diameter of preovulatory follicle (mm)	7.4 ± 0.3
Emergence to ovulation of the ovulatory follicle (days)	5.3 ± 0.4
Growth rate of ovulatory wave (mm/day)	0.9 ± 0.1
Mean max diameter of CL (mm)	12.1 ± 0.2
Lifespan of the CL observed by ultrasound (days)	17.8 ± 0.3
Mean max concentration of P4 (ng/mL)	13.3 ± 1.7
Day of max concentration of P4	15 ± 0.3
Day of lowest concentration of P4	1.0
Mean luteal phase length (days)[a]	16 ± 0.4
Mean follicular phase length (days)[b]	5 ± 0.3

[a] When concentrations of progesterone in plasma were ≥1 ng/mL.

[b] When concentrations of progesterone in plasma were <1 ng/mL.

The ovulatory follicle was derived from the fourth follicular wave in 71.4% (10/14) of goats. Boer goats had a naturally high incidence of multiple ovulation, with 92.8% (13/14) of goats having double ovulations and one goat (7.1%; 1/14) having a triple ovulation. In 61.5% (8/13) of does with multiple ovulations, ovulatory follicles were originated from the same follicular wave and the same ovary, but 38.5% (5/13) of multiple ovulations originated from the same follicular wave but from different ovaries. Two ovulations from different follicular waves were observed in 7.1% (1/14) of oestrous cycles. In the one goat in which this was observed, a second ovulatory wave emerged four days after the first ovulatory wave.

In 35.7% (5/14) of does that had ovulated at the start of the period of monitoring during the breeding season, a follicle within the same cohort as the ovulatory follicles did not ovulate but, instead, persisted and became luteinized. The average maximum

diameter of these large anovulatory follicles was 11.2 ± 0.4 mm which was greater than the mean diameter of ovulatory follicles (7.4 ± 0.3 mm, Table 5.3; P = 0.001). The size of these follicles, therefore, resembled follicular cysts. These goats ovulated after the next natural oestrus and had an interovulatory interval of 19.7 ± 0.2 days. The ovulation rate of goats having a follicular cyst compared to those that did not have a follicular cyst was 1.4 ± 0.3 versus 2.0 ± 0.2, respectively (P = 0.128).

5.4 Discussion

This study compared the follicular dynamics and progesterone profiles of Boer goats during the breeding and non-breeding season in a tropical region in northern Queensland. To the authors' knowledge this is the first report to describe follicular dynamics of the same Boer goats examined during both the non-breeding and breeding seasons. As previously described by Nogueira et al. (2015b) on Chapter 4, this study confirmed the occurrence of a natural non-breeding season in Boer goats during the summer period (September to October) at latitude of 19°19'30" South.

Previous studies that have examined follicular dynamics during the oestrous cycle of goats suggest that there are between two and six waves of follicular development during an oestrous cycle with an average of four waves per cycle (Ginther and Kot 1994; de Castro *et al.* 1999; Menchaca and Rubianes 2002; Medan *et al.* 2005; Simões *et al.* 2006). Our findings are in agreement with these studies with the recording of a mean of 4.5 follicular waves during the oestrous cycle. The number of follicular waves recorded during a 3-week recording period was greater in the non-breeding season compared to the breeding season. However, the number of codominant follicles, the maximum diameter of the largest follicle within a follicular wave and main growth rate were greater in the breeding season compared to the non-breeding season.

The presence of follicular waves with codominant follicles has been observed in does both in this study and in other studies (Rubianes and Menchaca 2003; Gonzalez-Bulnes *et al.* 2005), but in this study we observed that, in the same animals, more codominant follicles were detected in the breeding compared to the non-breeding season. The greater number of codominant follicles during the breeding season can be explained by greater number of follicles which are recruited and selected, which was evidenced on Day 1 of ultrasound evaluations (Fig. 5.4a). Follicular recruitment and selection is coordinated by endocrine and paracrine regulation involving changes in the

secretion of gonadotrophins and numerous growth factors (Hunter *et al.* 2004). The number of codominant follicles and the number of ovulatory follicles can be increased by decreasing the sensitivity of the hypothalamo-pituitary-ovarian axis to the negative effect of oestradiol to maintain the concentration of FSH above the threshold level for longer, thus allowing more time for follicles to pass through the so called, "widened gate" (Baird and Campbell 1998; Hunter *et al.* 2004; Scaramuzzi *et al.* 2011).

In the breeding season, the diameter of the largest follicle within waves and the duration of a wave differed between follicular waves. It has previously been reported in goats that the largest follicle of the first and the fourth waves usually attain greater diameters than the largest follicles of second and third waves which is in agreement with our findings (Ginther and Kot 1994; Simões *et al.* 2006). In the present study, the shorter duration of the fourth follicular wave compared to the first, second and third follicular waves was probably due to the fourth wave being the ovulatory wave in 71% of goats. Increasing concentrations of progesterone during the first follicular wave and persistence of elevated concentrations of progesterone during the second and third follicular waves prevents a preovulatory LH surge (de Castro *et al.* 1999; Menchaca and Rubianes 2002), resulting in a period of persistence of dominant follicles before atresia ensues. The onset of luteolysis and an LH surge coincident with the development of the fourth follicular wave in the majority of goats would contribute to a shorter duration of the fourth follicular wave compared to earlier waves (Ginther and Kot 1994; de Castro *et al.* 1999). In contrast, during the non-breeding season, circulating concentrations of progesterone were less than 0.65 ng/mL and were similar throughout the growth of each follicular wave (Fig. 5.2). This would mean that the gonadotrophic stimulation of follicular development would have been similar throughout the period of monitoring contributing to similar wave dynamics between follicular waves. Furthermore, longer day length in the non-breeding season is known to reduce the secretion of melatonin and to increase the negative feedback of oestradiol, which in turn inhibits the secretion of GnRH and results in a reduction in pulsatile LH secretion (Fatet *et al.* 2011). A reduction in the frequency of release of LH has been demonstrated in anoestrous sheep (Bartlewski *et al.* 2000) and this would contribute to the lower follicular growth rates and the smaller mean maximum diameters of follicles within follicular waves that were observed in the non-breeding compared to the breeding season in this study. Thus, differences in gonadotrophin secretion (Bartlewski *et al.* 1999; Bartlewski *et al.* 2000) would explain why differences were observed in this study in follicle dynamics between

waves within the breeding season and differences in follicle dynamics between the breeding and non-breeding seasons.

The mean diameters of the largest follicle that were obtained in the breeding and non-breeding seasons in this study were similar to those reported previously. Cruz *et al* (2005) reported that the mean maximum diameter of the largest follicle during the non-breeding season was 6.5 mm in Anglo-Nubian goats and 6.8 mm in Saanen goats. Medan *et al*. (2005) reported that during the breeding season that the diameter of the largest follicles in Shiba goats was 6.7 mm in anovulatory waves and 8.0 mm in ovulatory waves, which was similar to what we observed in Boer goats in the current study.

In the present study, we found that mean growth rates were significantly less in the non-breeding (0.6 mm/day) compared to the breeding season (0.8 mm/day) and somewhat less than those previously reported. In the breeding season, follicular growth rates between the day of emergence and the day of maximum diameter have been reported to be approximately 1.0 mm/day (Ginther and Kot 1994; Medan *et al.* 2003; Simões *et al.* 2006). The lesser growth rates reported in this study in both seasons compared to the results of others could be attributed to differences in breeds and age (Ginther and Kot 1994; de Castro *et al.* 1999; Driancourt 2001) and greater exposure to sexually active bucks in some studies (Delgadillo *et al.* 2011). In anoestrus goats raised in subtropical latitude, follicles increased their growth rate after the introduction of bucks from 1.1 mm/day to 1.5 mm/day (Delgadillo *et al.* 2011). Furthermore, in the breeding seasons increasing secretion of LH would have likely maintained faster follicular growth rates compared to during the non-breeding season (Ginther and Kot 1994; Evans 2003). Increases in LH pulses following luteolysis would also have contributed to the shorter mean duration of the last follicular wave during the observation period and increased follicular growth rates during the breeding season compared to the non-breeding season.

The reasons why there was a significantly greater number of small and total number of follicles in the non-breeding season when compared to the breeding season is unclear from the results of this study (Fig. 5.4). In Western White-faced ewes, Bartlewski *et al.* (1998) also reported a greater number of small and medium antral follicles as anoestrus advances, but the causes remained unknown. In our study, the presence of larger follicles in the first and fourth waves during the breeding season could have obscured the presence of smaller follicles, thereby reducing the total number

of follicles that were visible in the breeding season. Another possible explanation for these results is that during the breeding season the presence of a greater number of codominant follicles resulted in a decrease in the number of small follicles being counted, as more gonadotrophin-responsive follicles within the cohort tended to progress to larger diameters. On the other hand, in the non-breeding season more follicles are arrested at the gonadotrophin independent phase of development and a lower number of follicles are able to progress further in their development because of the lower concentrations of FSH and LH (Driancourt 2001), which could be one cause of the greater number of smaller follicles being observed during the non-breeding season.

The duration of the oestrous cycle observed in Boer goats (20.7 ± 0.2 days) and the number of ovulations (2.1 ± 0.1) after natural oestrus were similar to those reported in Boer goats and other breeds (Ginther and Kot 1994; Greyling 2000; Medan *et al.* 2005; Simões *et al.* 2006). In 7.1% (1/14) of goats that double ovulated, the ovulatory follicles emerged as part of two different follicular waves that emerged at different times. Similar results have been previously reported by Ginther and Kot (1994), in 10% (2/20) of the interovulatory intervals in Saanen goats, and by Gonzalez-Bulnes *et al.* (2005) in 20% (3/15) Murciano-Granadina goats. These results confirm that the phenomenon observed is uncommon being evident in 12.2% (6/49) of goats when the results of these three studies are combined. Ovulation of dominant follicles from earlier follicular waves can be explained by older dominant follicles losing functional dominance and thus enabling a new ovulatory follicle to emerge, but still appear to retain the ability to ovulate in the presence of a preovulatory LH surge (Gonzalez-Bulnes *et al.* 2005).

The present study showed that the mean maximum concentration of progesterone (13 ng/mL) was attained around Day 15 of the oestrous cycle (Fig. 5.2), which agrees with de Castro *et al.* (1999) who reported that progesterone profiles in all Saanen goats started to decline on Day 15 and attained basal level on Day 19 of the interovulatory interval. The lifespan of corpora lutea observed by ultrasound (18 days) was longer than the duration of the luteal phase (16 days). These results are in agreement with Castro *et al.* (1999) who reported the corpora lutea remained detectable by ultrasound after a significant decrease in progesterone concentration.

This study has highlighted the occurrence of factors that could reduce reproductive performance in Boer does in a tropical environment. These include the

occurrence of short oestrous cycles, cystic follicles and differences in the number of codominant follicles between the breeding and non-breeding seasons. During the breeding season, 14.3% of does experienced short cycles and 35.7% of does developed ovarian follicles that resemble follicular cyst. These results might be compounded by the administration of cloprostenol during the breeding season, as cloprostenol was not administered in the non-breeding season. Thus, in this study, it is not possible determine if these short cycles and follicular cysts were associated in goats during transition from the non-breeding to the breeding season (de Castro *et al.* 1999) or induced with the administration of cloprostenol. In other species, such as cows, short oestrous cycles and premature ovulations can be induced with cloprostenol and gonadotropin-releasing hormone (Taponen *et al.* 2002). Perhaps, following administration of cloprostenol in some does, the rapid onset of pro-oestrus led to the induction of a preovulatory LH surge, but the emerging dominant follicles differed slightly in their degree of maturity with one being mature enough to ovulate and the other not having a sufficient number of LH receptors to ovulate (Garverick *et al.* 1992). The development of follicular cysts could potentially reduce ovulation rate, although further work with a greater number of animals is needed to determine if ovulation rates are significantly reduced in does with cystic follicles.

5.5 Conclusions

These results have identified a period of anoestrus in Boer goats maintained at latitude 19º19’S, that extended in over 90% of goats from September to December, and have described differences in follicular dynamics in the same Boer goats examined during the breeding and non-breeding seasons. The pattern of follicular dynamics over 21-day period was most frequently characterized by four follicular waves in the breeding season and five waves in the non-breeding season, but the number of codominant follicles within waves was greater in the breeding season. In the non-breeding season, the ovaries remained active and follicles continued to grow to reach the equivalent size of preovulatory follicles. Follicular dynamics in the breeding season compared to the non-breeding season was characterised by the development of larger follicles and greater follicular growth rates. Short oestrous cycles and follicular cysts may also potentially reduce ovulation rate in Boer goats in the breeding season.

CHAPTER 6: Effect of hormonal synchronisation and/or short-term supplementation with maize on follicular dynamics and hormone profiles in goats during the non-breeding season

Study 5:

Abstract. This study aimed to evaluate the reproductive response of anoestrus goats that were either hormonally treated and/or 9-day supplemented with maize to determine which treatment combination was the most effective in enhancing follicular development and ovulation rate, and whether these responses were associated with increases in circulating concentrations of metabolic hormones. The experiment was carried out using 28 does, using a 2x2 factorial design with seven replicates in each group to test the effect of synchronization of oestrus, supplementation with maize and their interactions. The number of codominant follicles on Day 9, diameter of the largest follicles and growth rate of follicles were greater ($P < 0.001$) in the does with synchronised oestrous cycles compared to the non-synchronised groups. However, for the same variables, there was no effect ($P > 0.05$) of supplementation with maize or interaction between the two treatments. Compared to non-supplemented animals, supplementation with maize increased ($P = 0.039$) the total number of follicles between Days 7 and 9 of the treatment. In addition, nutritional supplementation with maize in combination with synchronisation of oestrus increased the ovulation rate by 43% ($P = 0.074$). Concentrations of progesterone, insulin, leptin and IGF-1 were affected by day of blood collection ($P < 0.001$). Interactions between time and supplementation with maize ($P < 0.001$) showed that concentrations of insulin, leptin and IGF-1 were greater in does supplemented with maize compared to non-supplemented does. Concentrations of LH and frequency of LH pulses were not significantly affected ($P = 0.225$) by supplementation with maize, by synchronisation of oestrus or by interaction between these treatments. The findings show that hormonal synchronisation had the most influence on modifying follicular development and ovulation in anoestrous goats, although supplementation with maize appeared to have some influence. Supplementation with maize increased the concentrations of metabolic hormones, which could be modifying the sensitivity of follicles to gonadotrophins and reducing rate of atresia, but these changes were not mediated by changes in LH secretion.

Keywords: Anoestrus, breed, LH pulses, progesterone, reproduction, seasonality.

6.1 Introduction

Photoperiod and the availability of nutrition limit times during the year when does ovulate and conceive, and these factors can, therefore, limit productivity. Management strategies that have been used to increase the duration of the breeding season or to induce ovulation during the non-breeding season and hence improve productivity in goats and sheep include synchronisation of oestrus using exogenous administration of progestins (Scaramuzzi and Martin 1984), manipulating the duration of photoperiod that does are exposed to, administration of melatonin (Chemineau *et al.* 1992b; Delgadillo *et al.* 2001), exposure to bucks (López-Sebastian *et al.* 2007; Delgadillo *et al.* 2011) and nutritional supplementation (Zarazaga *et al.* 2005; Duarte *et al.* 2008). These strategies are aimed at altering the hypothalamus-pituitary-ovarian axis to increase the likelihood that ovulation will occur during the non-breeding season.

Data supporting an increase productivity in goats and sheep following nutritional supplementation in the non-breeding season are equivocal. In Payoya goats kept under a natural photoperiod (37°15' N), the duration of non-breeding season was 32 days shorter when does were fed 1.5 times maintenance compared with those that were fed a maintenance diet (Zarazaga *et al.* 2005). In contrast, reproductive seasonality in goats in a subtropical environment (26°23' N) persisted independently of food availability and it was concluded that photoperiod was the key factor regulating seasonality in subtropical latitudes (Duarte *et al.* 2008).

Supplementation with high-energy and/or high-protein diets exert a significant influence on reproductive function in ruminants by affecting follicular development and ovulation rate (Scaramuzzi *et al.* 2006; Scaramuzzi and Martin 2008). The action of nutrition on folliculogenesis is thought to be mediated by different physiological pathways. Studies have reported that the stimulatory effects of short-term supplementation on folliculogenesis are mediated by metabolites such as glucose and fatty acids and several metabolic hormones acting directly at the ovarian level (Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011). In ewes, the effect of five to nine days supplementation with 70% of clover hay and 30% concentrate (80% corn and 20% soybean) was associated with an increase in concentrations of glucose, insulin, IGF-1 and leptin (Viñoles *et al.* 2005). Changes in these metabolites and hormones was thought to promote increased follicular steroidogenesis and an increase in ovulation rate, without peripheral changes in serum concentrations of FSH (Viñoles *et al.* 2005).

Insulin and leptin are two key metabolic hormones that appear to mediate an effect of nutrition on the reproductive axis. Insulin stimulates the uptake of glucose by cells (Scaramuzzi *et al.* 2010), may increase the synthesis of IGF-1 in the liver and enhances follicular development (Lucy 2000; Webb *et al.* 2004). Exogenous administration of insulin has also been shown to promote an increase in the number of small and large follicles in goats during the non-breeding season (Sarath *et al.* 2008). Leptin is a member of a cohort of factors, humoral and perhaps neural that influence the homeostasis of glucose in the body and GnRH-LH pulse secretion (Blache *et al.* 2000a; Zhang *et al.* 2004), thereby potentially influencing ovarian follicular development.

To the authors' knowledge, there are limited publish data on the effect of a short-term supplementation with maize on follicular development, ovulation rate and metabolic hormones in anoestrous goats. Supplementation with maize is expected to increase the delivery of glucose to the small intestine (Landau *et al.* 1992) and as such increase concentrations of glucose, IGF-1, which could in turn modify the sensitivity of the ovary to gonadotrophins and increase ovulation rates. A few studies have evaluated the effect of supplementation with maize on reproductive response (Fasanya *et al.* 1992; De Santiago-Miramontes *et al.* 2008). De Santiago-Miramontes *et al.* (2008) observed a greater ovulation rate in anoestrous dairy goats supplemented with, maize, lucerne hay and soybean for seven days before exposure to sexually active bucks, compared to non-supplemented females goats. Fasanya *et al.* (1992), however, reported that Savana Brown goats supplemented with cottonseed cake attained puberty at an earlier age and heavier weight than those goats supplemented with maize.

The aim of this study was to evaluate the reproductive response of seasonally anoestrus goats that were either hormonally treated and/or supplemented with maize to determine which treatment combination was the most effective in enhancing follicular development and ovulation rate and whether these responses were associated with increases in circulating concentrations of glucose, insulin, leptin and LH in anoestrous goats.

6.2 Material and Methods

Location, animals and evaluation period

The experiment was carried out at James Cook University, Townsville (19˚19'30" S; 146˚45'44" E), which is located in a tropical region of Queensland, Australia. The experiment was conducted between October and November 2011, during the non-breeding season. A total of 28 nulliparous, anoestrous, and non-pregnant female goats (20 rangeland and 8 Boer goats) were selected for this study. At the start of the study every goat was classified as being in anoestrous after i) no corpora lutea were observed in the ovaries during two examinations that were conducted 14 days apart using transrectal ultrasonography, and ii) oestrous behaviour was not observed in any goat following twice daily observations in the presence of two mature bucks over the same period. At the start of the experiment, the does were 1.5 ± 0.3 years old and had a live weight of 36.7 ± 0.7 kg (mean ± SEM). All experimental procedures for this study were approved by the Animal Ethics Committee of James Cook University (approval number: A1725).

Animal management and experimental design

Prior to commencement of the study, goats were adapted to housing for seven days (Days -7 to 0) by maintaining goats within single pens and supplementing them daily with a base ration consisting of lucerne pellets and lucerne hay, in order to provide nutritional requirements for 1.1 times maintenance (7.6 MJ ME/day) for a goat weighing 40 kg (NRC 2007). Goats were then transferred to individual metabolic crates, allocated homogeneously to four groups of seven animals (**Table 6.1**). They were supplemented over 9 days with the following diets: Control diet, goats were fed with a base ration of lucerne pellets and lucerne hay; Maize diet, fed with the same base ration plus supplementation with 220 g of cracked maize per day; Synch diet, fed the base ration plus treated with an intravaginal progesterone releasing device (CIDR, Eazi-Breed® CIDR®, Pfizer Australia, NSW) from Days 0 to 9 and eCG (250 IU IM; Folligon®, Intervet Australia, Victoria) administered on Day 7 (**Fig. 6.1**), and Synch x Maize diet, the same treatment as described for Synch group plus supplementation with 220 g of cracked maize per day.

From Days 0 to 9, maize and lucerne pellets were offered at 8 am and lucerne hay was offered at 5 pm. Each day cracked maize was given about 15 minutes before

the lucerne pellets to help ensure that all of the maize was consumed. The feed intake of animals was monitored individually to confirm that the animals ate all the feed allocated each day. On Days 10 and 11, does were fed the same base ration of lucerne pellets and hay that was fed from Days -7 to 0.

On Days 10 and 11, does were tested twice daily (9 am and 5 pm) for behavioural signs of oestrus with two mature bucks for 30 min, starting from 16 h after removal of CIDR inserts and continued until 48 h after removal of inserts. Does which allowed any buck to mount were classified as being in oestrus. Intromission by the buck during mounting was prevented by manual withdrawal of the buck from the doe before mating occurred.

Table 6.1 Experimental groups and components of the ration and total energy (ME/day) administered from Days 0 to 9 for each group

Variables	Experimental groups			
	Control	Maize	Synch	Synch+Maize
Animals (n)	7	7	7	7
Lucerne pellets (g/day)	820	820	820	820
Lucerne hay (g/day)	150	150	150	150
Cracked maize (g/day)	0	220	0	220
Total energy (MJ ME/day)	7.6	10.6	7.6	10.6

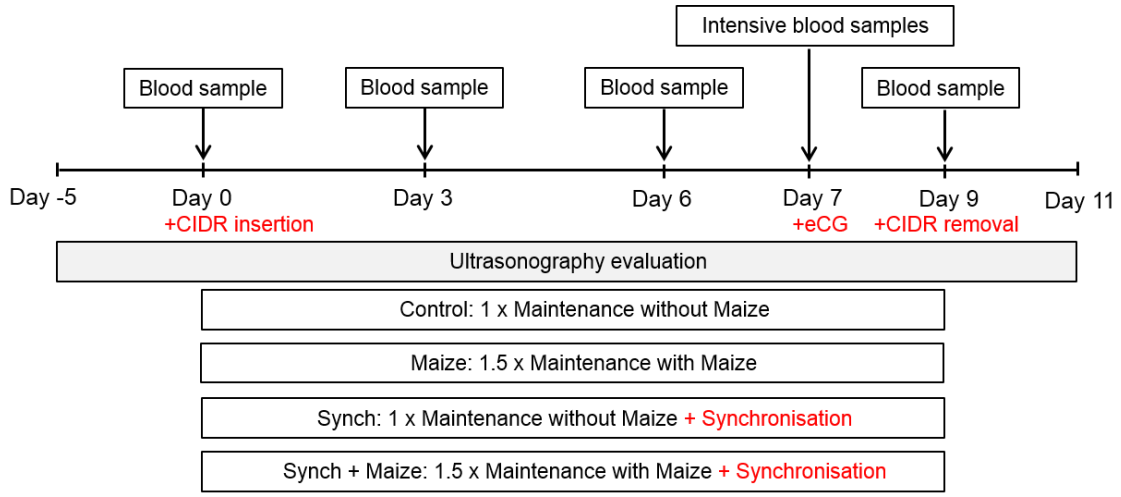


Fig. 6.1 Schematic representation of the experimental treatments, blood sampling, ultrasonography and synchronisation of oestrus. The synchronized groups received a progesterone releasing device (CIDR) and equine chorionic gonadotropin (eCG).

Blood samples and hormonal assays

Blood samples were collected from the jugular vein into 10 mL evacuated tubes containing heparin (BD Vacutainer®, Plymouth, UK) on Days 0, 3, 6 and 9. On Days 3, 6 and 9, samples were collected two hours after goats were fed the morning allocation of ration. On Day 0, samples were collected before insertion of CIDRs and, on Day 9, blood was collected nine hours after removal of inserts. On Day 7, indwelling intravenous catheters (14G x 5.25 in, BD Angiocath®, Oxford, UK) were inserted into the jugular vein of four goats from each treatment for intensive blood collection. Blood samples were collected every 15 minutes for five hours, starting at 0700 h and concluded before eCG was administered. In addition, blood samples were collected every four hours, from 12 to 56 hours after the end of supplementation on Day 9.

Blood samples were stored on ice then centrifuged (2500 g for 15 minutes) within two hours of collection. Plasma was then isolated and frozen (-20^{o}C) until the time of assay. Plasma samples were analysed for concentrations of glucose, progesterone, LH, insulin, leptin and IGF-1. Plasma concentrations of glucose were measured using a commercial analyser (AU480 Beckman Coulter Australia Pty Ltd, Brisbane, Qld). The sensitivity of the assay was 0.04 mmol/L.

Plasma concentrations of progesterone in plasma were determined by Radioimmunoassay (RIA) using anti-progesterone antibody-coated tubes (RIA Progesterone IM1188, Beckman Coulter Australia Pty Ltd, Yeerongpilly, QLD). The sensitivity of the assay was 0.05 ng/mL. The inter-assay coefficients of variation for low (0.80 ng/mL) and high (4.55 ng/mL) quality controls were 14.7% and 7.1%, respectively. The corresponding intra-assay coefficients of variation were 4.5% and 3.2%, respectively.

Plasma concentrations of insulin were measured by a double-antibody RIA that had been validated for ruminant blood samples (Miller *et al.* 1995). 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 using a double-antibody RIA method previously described by Blache *et al.* (2000b). 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 (Breier *et al.* 1991). 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, which were 8.3% and 6.4%, respectively.

Plasma concentrations of LH were determined in samples collected during the intensive blood collection on Day 7 using a double-antibody RIA as described by Hötzel *et al*. (2003) which used ovine LH (NIDDK-oLH-I-4) for radio-iodination and AFP-8614B as a reference standard. 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 7.2%, 5.8% and 5.0%, respectively.

Between Days 9 and 12, concentrations of LH were determined using a quantitative ELISA sandwich test (LH DETECT®, ReproPharm, Nouzilly, France). During this period, the LH surge was determined to occur when concentrations of LH first reached a concentration corresponding to three times the standard deviation above basal concentrations. The sensitivity of this assay was 0.1 ng/mL. The intra-assay coefficients of variation for low (0.5 ng/mL) and high (4 ng/mL) quality controls were 12.5% and 7.0%, respectively. The corresponding inter-assay coefficients of variation were 15.9% and 13.9%, respectively.

LH pulses and amplitude in individual profiles on Day 7 were defined according to criteria described by Merriam and Wachter (1982). A pulse was defined when the concentration of LH exceeded the mean concentration (sum of LH/ number of blood samples) in a single point five times the standard deviation (SD), or in 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.

Follicular dynamics

Trans-rectal ultrasound examinations of the ovaries were performed once daily from Days -5 to 11. Goats were monitored using a 6.6 MHz transrectal transducer (MyLab^{TM} FiveVET, Medical Plus Australia Pty Ltd, Tullamarine, Victoria). Video

recordings of each ultrasound examination were made. All follicles ≥2 mm in diameter and corpora lutea were measured using electronic callipers and ovarian maps were drawn. A follicular wave was defined as one or more antral follicles growing from 3 to ≥5 mm in diameter before subsequently regressing and being no longer detectable. Follicles were classified according to their diameter into three categories: small (2 to 3 mm), medium (>3 and <5 mm) and large follicles (≥5 mm). Follicular growth rate (mm/day) was the time taken for a follicle to grow from the first time it was observed to its maximum diameter on Day 9. The day of emergence of follicles was identified as the day on which the dominant follicle within a given follicular wave was retrospectively first observed to be ≥3 mm in diameter (Nogueira *et al.* 2015a). The day of maximum follicular diameter was the first day when a dominant follicles reached a maximum diameter ≥5 mm. Follicles were classified as codominant when two or more follicles ≥5 mm were present within the same follicular wave. When codominant follicles were observed only data related to the largest follicle was used for the purpose of analyses related to the assessment of follicular waves. The day of ovulation was defined by the sudden loss of a follicle ≥5 mm in diameter followed by the development of a corpus luteum within same ovary. The total number of corpora lutea observed in the ovaries of each doe was recorded as the ovulation rate for each doe. During the present study, all ultrasound examinations were performed by the same operator.

Statistical analyses

Statistical analyses were conducted using the statistical software package IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp. Released 2013, Armonk, NY) using a 2x2 factorial design with seven replicates in each group. Analysis of variance (ANOVA) was used to compare the effects of treatments and breed (rangeland or Boer goats) for the variables: interval from device removal to onset of oestrus, maximum diameter of the largest follicle, growth rate of follicles, and number of small, medium and large follicles. Where mean differences between experimental groups were significant, Fisher's protected least significant difference (LSD) was used as a Post-hoc multiple comparison test. Before ANOVA, data were tested for normal distribution using Q-Q plots and Levine's test was used to assess homogeneity of variance. Data which were not normally distributed (ovulation rate and the number of codominant follicles) were analysed using the Poisson regression (log-linear model). Repeated measures ANOVA was used to compare the effects of treatments (Maize, Synch or

interaction between Maize x Synch), time and their interactions (Maize x Time, Synch x Time, Maize x Synch x Time) for the variables: the mean total number of small, medium and large follicles, plasma concentrations of progesterone, LH, insulin, leptin and IGF-1 between Days 0 and 9. If 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 $P < 0.05$.

6.3 Results

For all analyses, effects of breed and the interaction of breed with treatment were not significant, so effects due to breed were removed from subsequent analyses and not reported. Behavioural signs of oestrus were detected in every doe that was subjected to the synchronisation treatments, but were not detected in any of the does in the non-synchronised treatments ($P < 0.001$; **Table 6.2**). Supplementation with maize also did not significantly affect the interval from removal of inserts to onset of oestrus in goats with synchronised oestrous cycles. The interval to onset of oestrus was 22.9 ± 3.2 h for both synchronised treatments.

There was a significant effect of synchronisation of oestrus on the ovulation rate, number of codominant follicles on Day 9, diameter of the largest follicles on Day 9 and growth rate of follicles, but there were no effect of the addition of maize in the diet or the interaction between synchronisation treatments and supplementation with maize on these variables (**Table 6.2**). Ovulation was observed in all of the does treated with a synchronisation treatment, but only one of the does subjected to a non-synchronised treatment ovulated. While the ovulation rate was increased by 43% in the Synch x Maize group compared to the Synch group, differences in the mean ovulation rate between these groups was not significant ($P = 0.074$; **Table 6.2**). The number of codominant follicles on Day 9, diameter of the largest follicles and growth rate between the follicular emergence and Day 9 were greater ($P < 0.001$) in the does with synchronised oestrous cycles compared to the non-synchronised groups (**Table 6.2**). However, for the same variables, there was no effect of supplementation with maize ($P > 0.05$) or interaction between synchronisation and supplementation with maize ($P > 0.05$).

Table 6.2 Characteristics of oestrus, ovulation rate and follicular development in goats treated with a combination of either synchronisation of oestrus and/or maize supplementation

Variables	Control	Maize	Synch	Synch x Maize	Probability Maize	Synch	MxS[1]
Animals (n)	7	7	7	7	-	-	-
Oestrous detection (%)	0.0[b]	0.0[b]	100.0 [a]	100.0[a]	1.000	<0.001	1.000
Ovulation rate/doe	0.0[b]	0.1±0.1[b]	2.3±0.3[a]	3.3±0.5[a]	0.074	<0.001	0.074
Codominant follicles on Day9 (n)	1.1±0.3[b]	1.3±0.3[b]	2.3±0.3[a]	3.3±0.3[a]	0.086	<0.001	0.192
Largest follicles on Day9 (mm)	5.8±0.3[b]	5.9±0.3[b]	6.9±0.3[a]	7.4±0.3[a]	0.428	<0.001	0.561
Emergence of largest follicles Day9 (day)[2]	4.3±0.6	5.2±0.6	5.0±0.6	4.8±0.6	0.472	0.810	0.339
Growth rate (mm/day)	0.6±0.1[b]	0.7±0.1[b]	0.9±0.1[a]	1.1±0.1[a]	0.309	0.004	0.761

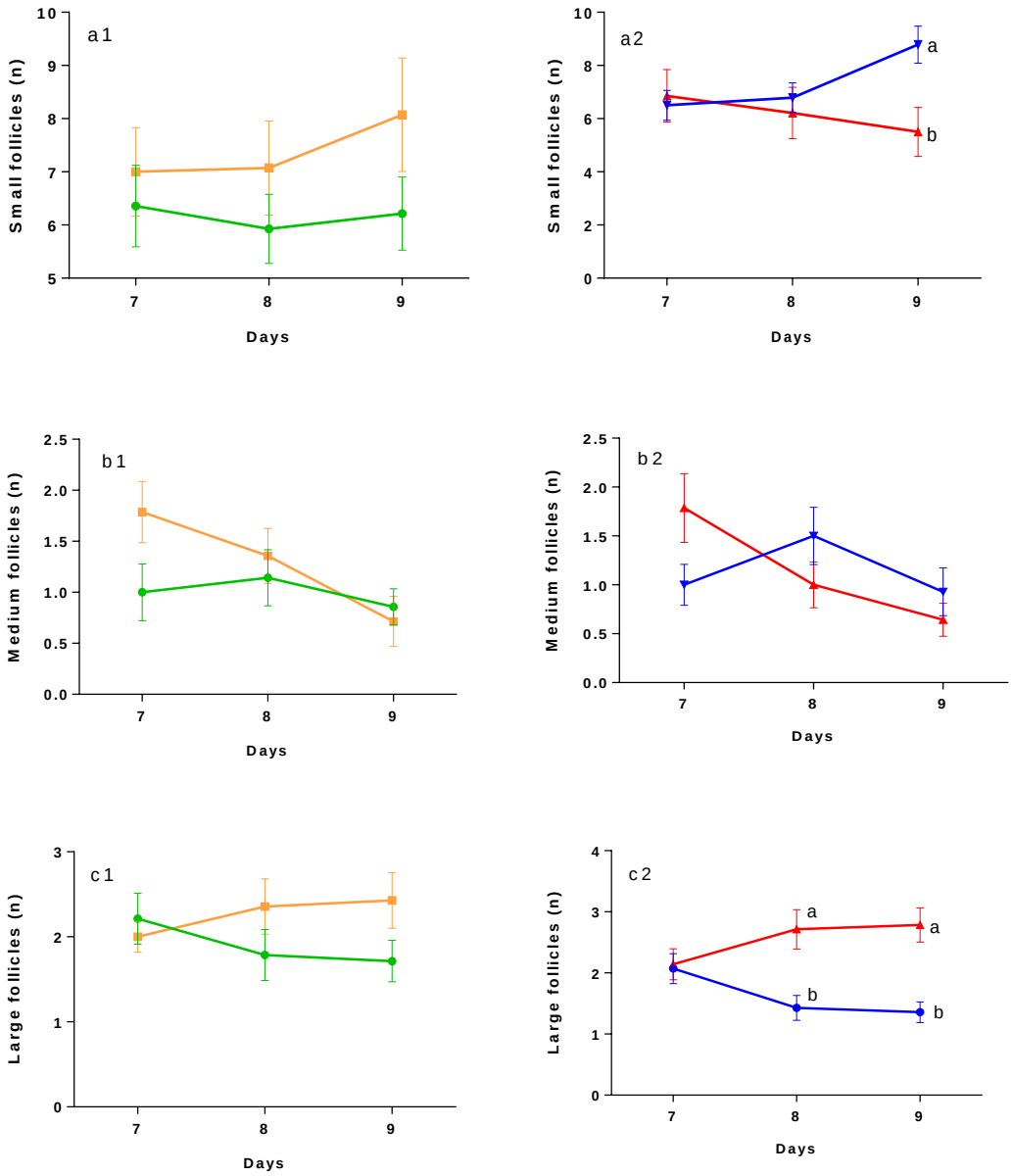
[1]Interaction between maize and synch groups. [2] Day of emergence of the largest follicles on Day 9 in relation to the beginning to the nutrient supplementation. Values with different letters in the same row are significantly different ($P < 0.05$).

For the each variable evaluated, no significant interactions were detected between Maize x Synch ($P > 0.221$) and Time x Maize x Synch ($P > 0.069$), so the results for each treatment over time were graphed and reported separately (**Figs. 6.2, 6.3, 6.4** and **6.5**).

The number of small and medium follicles from Days 7 to 9 of ultrasound evaluations were not significantly affected by the synchronisation of oestrus ($P > 0.237$) or by supplementation with maize ($P > 0.219$). Significant interactions between time and synchronisation of oestrus ($P = 0.008$) were observed for the number of small follicles (**Fig. 6.2a**). Before Day 9, the number of small follicles were similar between treatments, but on Day 9, the number of small follicles was greater in the non-synchronised does than synchronised does.

The number of large follicles was significantly affected by the synchronisation of oestrus ($P = 0.003$) and by interaction between time and synchronisation ($P = 0.006$), but were not affected by supplementation with maize ($P = 0.219$). On Days 8 and 9, the number of large follicles were greater ($P < 0.001$) in the synchronised groups compared to the non-synchronised groups (**Fig. 6.2c**). In addition, on Day 9 the number of large follicles tended to be greater ($P = 0.078$) in the does supplemented with maize than in the does not supplemented with maize (**Fig. 6.2c**).

The total number of follicles were affected by supplementation with maize (P = 0.039) and by interaction between time and synchronisation (P = 0.021), but were not affected by synchronisation treatment (P = 0.782). The total number of follicles were greater in does supplemented with maize compared to those that were not supplemented with maize (**Fig. 6.2d**). Moreover, on Day 9 the total number of follicles was greater in the non-synchronised does than synchronised does.



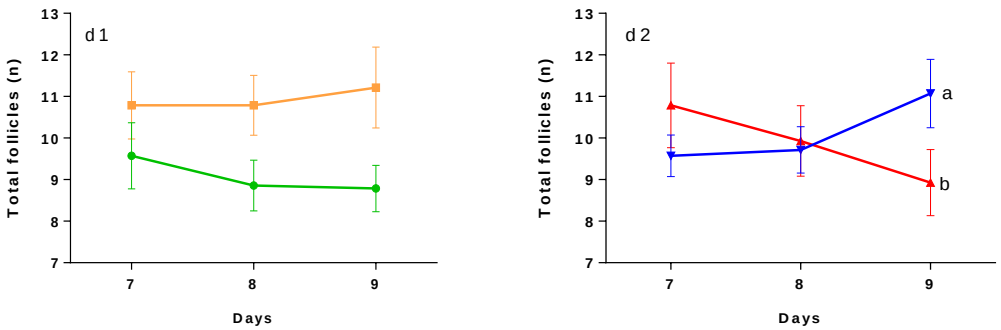


Fig 6.2 Mean (±SEM) number of (**a1** and **a2**) small (2 to 3 mm), (**b1** and **b2**) medium (>3 and <5 mm), (**c1** and **c2**) large (≥5 mm), and (**d1** and **d2**) total number of follicles ≥ 3 mm during Days 7 to 9 of ultrasound evaluations in goats supplemented with maize (■) or not supplemented with maize (●), and goats subjected to synchronization of oestrus (▲) or non-synchronised goats (▼) in the non-breeding season (different letters, within days indicate differences between groups; $P < 0.05$).

Overall, concentrations of glucose, insulin, leptin, IGF-1 group and LH were not affected by synchronization of oestrus ($P > 0.142$), so these results were not reported anymore. On Day 7, during intensive blood collection, concentrations of glucose were not affected by supplementation with maize ($P = 0.423$) and there were no interactions with time ($P > 0.377$), but there was an effect over time ($P < 0.001$). Mean concentrations of glucose increased from 0700 h until the fifth hour after feeding in all experimental groups (**Fig. 6.3**).

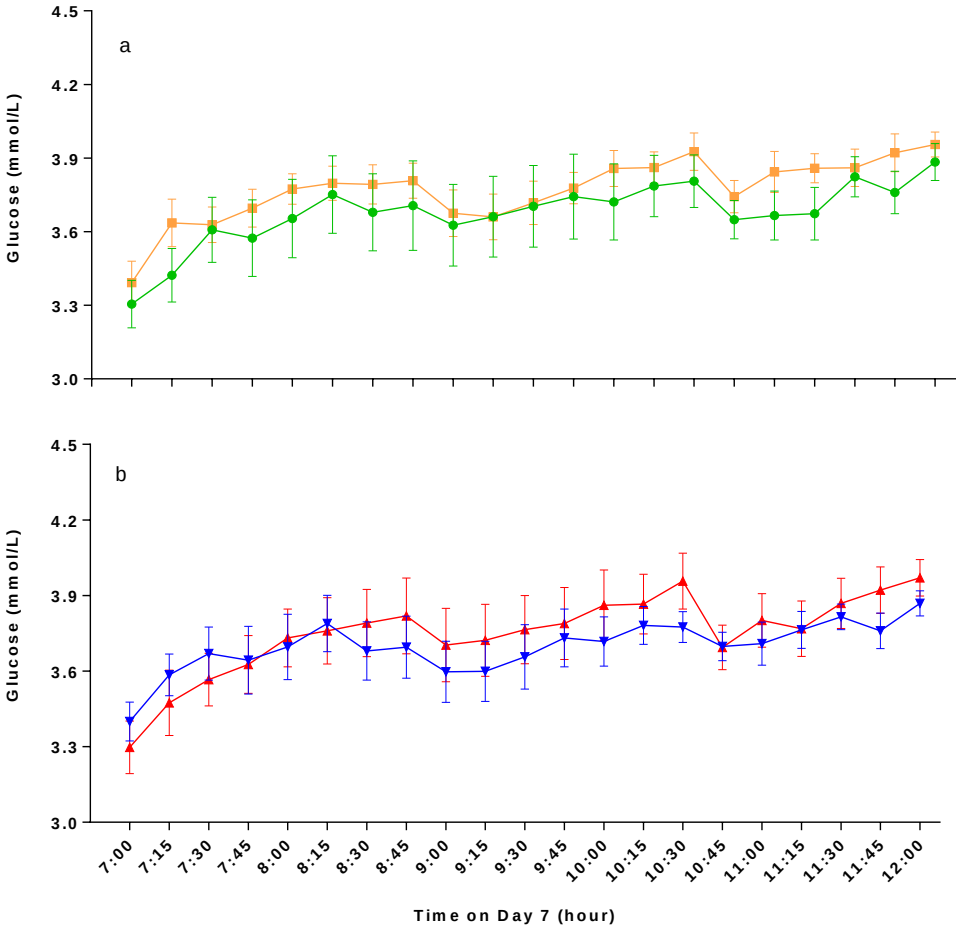


Fig. 6.3 Plasma Plasma concentrations of glucose on Day 7 of the study from anoestrus goats (**a**) supplemented with maize (■) or not supplemented with maize (●), (**b**) and goats subjected to synchronization of oestrus (▲) or non-synchronised goats (▼) in the non-breeding season.

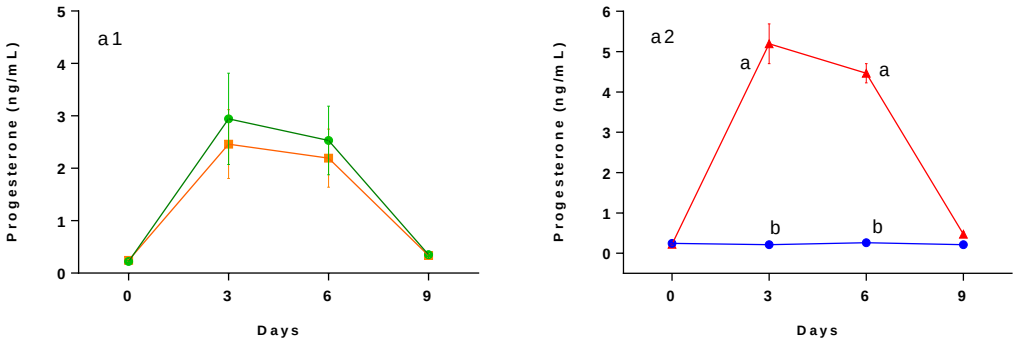
Plasma concentrations of progesterone were affected by the synchronisation treatment ($P < 0.001$), by time ($P < 0.001$) and an interaction between time and the synchronisation treatment was detected ($P < 0.001$). Concentrations of progesterone were not significantly affected by supplementation with maize ($P = 0.247$), and a significant interaction between time with maize ($P = 0.373$) were not detected. On Days 3 and 6, concentrations of progesterone were greater ($P < 0.05$) in the does with synchronised oestrous cycles compared to does in the non-synchronised groups (**Fig. 6.4a**).

Plasma concentrations of insulin were affected by supplementation with maize ($P = 0.038$), time ($P = 0.001$) and an interaction between time and supplementation with

maize was detected (P = 0.042). Mean concentrations of insulin increased from Days 0 to 9 of the treatment. On Days 6 and 9, concentrations of insulin were greater (P < 0.05) in does supplemented with maize compared to does non-supplemented with maize (**Fig. 6.4b**). Concentrations of insulin were not affected by any interactions between time and the synchronisation treatment (P > 0.290).

Plasma concentrations of leptin tended to be affected by the supplementation with maize (P = 0.075). Concentrations of leptin were affected by time (P = 0.001) and an interaction between time and supplementation with maize was found (P < 0.001), but no other significant interactions were detected. Mean concentrations of leptin increased from Days 0 to 3 and then remained stable from Days 3 to 9 of the study. On Days 3, 6 and 9, concentrations of leptin were greater (P <0.05) in does supplemented with maize, compared to does not supplemented with maize (**Fig. 6.4c**).

Plasma concentrations of IGF-1 tended to be affected by supplementation with maize (P = 0.077) and concentrations of IGF-1 did not change significantly over time (P = 0.124). However, concentrations of IGF-1 were affected by the interactions between time and supplementation with maize (P < 0.001) and time and synchronization of oestrus (P = 0.002). On Day 6, concentrations of IGF-1 were greater (P = 0.002) in does with synchronised oestrous cycles compared to does in the non-synchronised groups. In addition, on Days 6 and 9, animals supplemented with maize had greater (P < 0.05) mean concentrations of IGF-1 than animals not supplemented with maize (**Fig. 6.4d**).



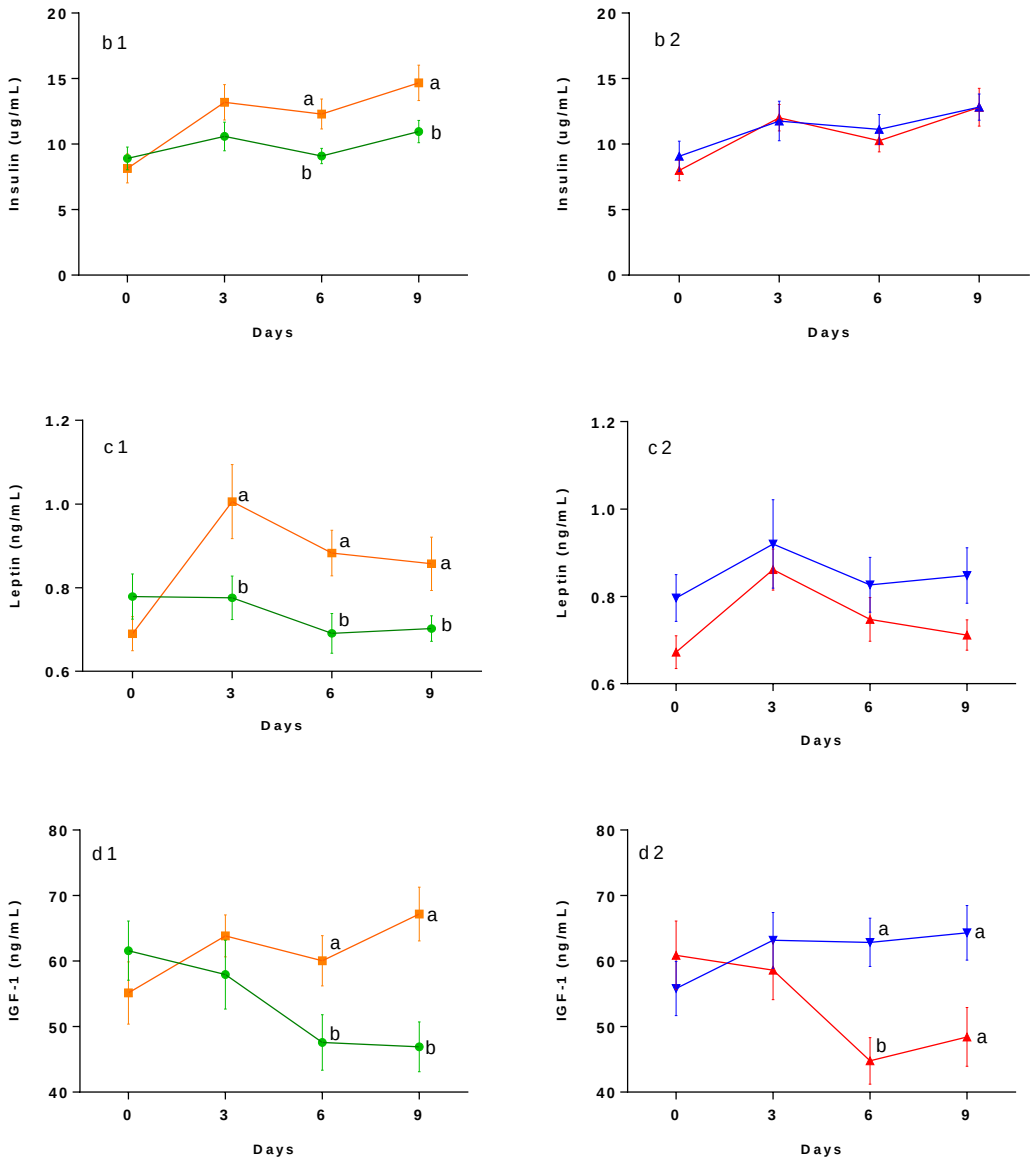


Fig. 6.4 Concentrations of progesterone (**a1** and **a2**), insulin (**b1** and **b2**), leptin (**c1** and **c2**) and IGF-1 (**d1** and **d2**) in goats supplemented with maize (■) or not supplemented with maize (●), and goats subjected to synchronization of oestrus (▲) or non-synchronised goats (▼) the non-breeding season (different letters, within days indicate differences between groups; $P < 0.05$).

On Day 7, plasma concentrations of LH were not affected by supplementation with maize ($P = 0.225$), by time ($P = 0.255$) or any interactions with time ($P = 0.166$) (**Fig. 6.5**).

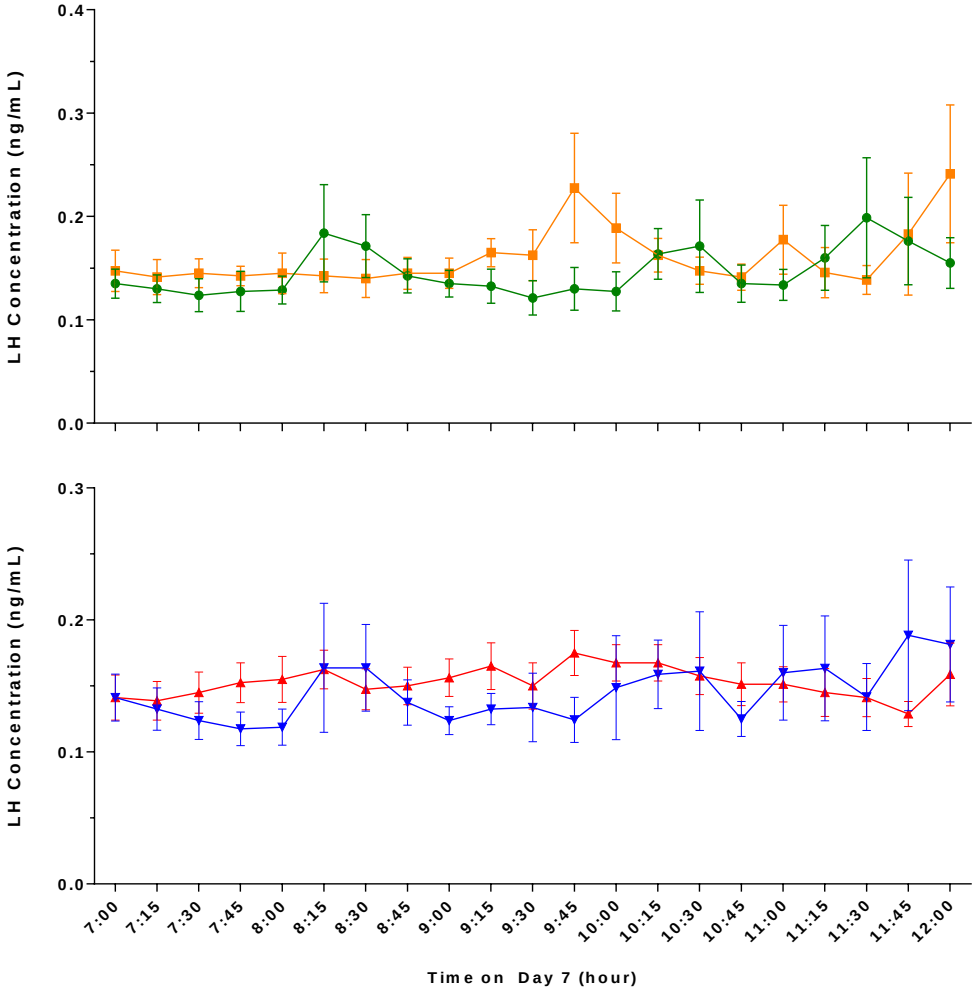


Fig. 6.5 Mean (± SEM) concentrations of LH on Day 7 of the study from anoestrus goats (**a**) supplemented with maize (■) or not supplemented with maize (●), and (**b**) goats subjected to synchronization of oestrus (▲) or non-synchronised goats (▼).

The frequency of LH pulses was not affected by the synchronisation of oestrus (P = 0.295) and by supplementation with maize (P = 0.295) (**Table 6.3**). The amplitude of LH pulses was affected by synchronisation of oestrus (P = 0.004), but not affected by supplementation with maize (P = 0.473). The amplitude of LH pulses was greater in the non-synchronised does compared to the does that were subjected to synchronisation of oestrus (**Table 6.3**).

Table 6.3 Frequency and amplitude of LH pulses on Day 7 (pulses/5h) in anoestrous goats treated with a combination of either synchronisation of oestrus and/or maize supplementation

Variables	Control	Maize	Synch	Synch x Maize	Probability Maize	Synch	MxS[1]
Animals (n)	4	4	4	4	-	-	-
Pulses/5h (mean±SEM)	0.7±0.2	1.0±0.1	0.5±0.2	0.7±0.1	0.295	0.295	1.000
LH amplitude (ng/mL)	0.4±0.1[a]	0.5±0.3[a]	0.05±0.1[b]	0.09±0.1[b]	0.473	0.004	0.738

[1]Interaction between maize and synch groups. Values with different letters in the same row are significantly different ($P < 0.05$).

The percentage of animals in which an LH surge was detected and the mean maximum concentrations of LH between 12 and 56 h after removal of inserts were affected by synchronisation of oestrus ($P < 0.001$), but there was no effect of the addition of maize ($P = 0.378$) (**Table 6.4**). Compared to non-synchronised does, the percentage of animals in which an LH surge was detected and the mean maximum concentration of LH were greater in the synchronised groups. However, the mean interval between removal of inserts and the LH surge was not affected by supplementing synchronised goats with maize ($P = 0.320$; **Table 6.4**).

Table 6.4 Characteristics of LH secretion in does treated with a combination of either synchronisation of oestrus and/or maize supplementation 12 to 56 h after ending treatments

Variables	Control	Maize[1]	Synch	Synch x Maize	Probability Maize	Synch	MxS[2]
Goat (n)	4	4	4	4	-	-	-
Goats with LH surge %(n)	0[b]	25(1)[b]	100(4)[a]	100(4)[a]	1.000	<0.001	1.000
Max concentration of LH (ng/mL)	0.5±0.7[b]	0.7±0.7[b]	3.6±0.7[a]	4.9±0.7[a]	0.378	<0.001	0.447
Interval to LH surge (h)	.	56	26±1.9[a]	23±1.9[a]	0.320	<0.001	0.320

[1]One doe in the maize group had an LH surge and a single ovulation. [2]Interaction between maize and synch groups. Values with different letters in the same row are significantly different ($P < 0.05$).

6.4 Discussion

The findings of this study demonstrate that hormonal synchronisation was a highly effective method of inducing oestrus and ovulation in anoestrous goats during the non-breeding season. Nutritional supplementation with maize for nine days without administration of progesterone and eCG promoted changes in systemic concentrations of glucose, insulin and leptin over time, but did not induce oestrus behaviour or a greater ovulation rate compared to does that were treated with exogenous hormones. In does that were treated with progesterone and eCG, and supplementation with 220 g of maize during the 9-day treatment period there was a tendency for ovulation rate to increase compared to does that had only their oestrous cycles synchronised, with ovulation rate increasing by 43% (**Table 6.2**). This demonstrated that supplementation with a relatively small quantity of maize has the potential to increase ovulation rate in anoestrous does when treated with exogenous hormones, but was ineffective in inducing ovulation in non-synchronised does.

In this study, the failure of supplementation with maize to significantly increase ovulation rate in does with synchronised oestrous cycles can be explained by the use of only seven goats in each experimental group and possibly the small difference in the levels of energy between our experimental groups (1.0 times maintenance vs 1.5 times maintenance). De Santiago-Miramontes *et al.* (2008) used two groups of 25 goats in postpartum anoestrous and reported that the number of females showing oestrous behaviour and the ovulation rate detected within 5 days of exposure of bucks was significantly greater in does supplemented with 950 g of lucerne hay, 290 g of maize and 140 g of soy bean compared to non-supplemented females. These authors fed the goats using an average total energy of 13.9 MJ ME/day, which is equivalent to nutritional requirements of 2.0 times maintenance for a goat weighing 40 kg.

Other studies that have reported greater concentrations of metabolites in the higher-energy group, where authors have used a greater difference in the levels of energy between animals fed high and low plane of diets. For instance, 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 with higher-energy diet (Haruna *et al.* 2009). In addition, greater concentrations of glucose, insulin and leptin were recorded in ewes supplemented with twice their maintenance requirements compared to ewes fed at maintenance (Viñoles *et al.* 2005; Viñoles *et al.* 2010). These

studies also used a larger number of animals per group when compared to the present study.

The effects of short-term nutrient supplementation on follicular development and ovulation rates have been equivocal. This inconsistent effect could suggest that any influence of nutritional supplementation on ovulation rates may depend on whether short-term nutritional supplementation coincides with new wave emergence. To be more effective, if nutrient supplementation is to influence ovulation rate it needs to begin at the time of the emergence of the ovulatory wave (Viñoles *et al.* 2005; Viñoles *et al.* 2010). In our study, the nutritional supplementation started between 4-5 days before the emergence of the largest follicles on Day 9, but the day of follicular emergence was not spread widely between experimental groups (**Table 6.2**). In addition, nutritional supplementation started from 4 to 8 days before ovulation in the ovulatory groups, as suggested by Viñoles *et al*. (2010). Therefore, the argument that nutritional supplementation started at the wrong time is not supported.

While significant effects of synchronisation of oestrus and time interactions were detected for the numbers of different classes of follicles between Days 7 and 9, there was no clear independent effects of supplementation with maize on enhancing the numbers of small, medium and large follicles. Greater follicular growth rates and diameters of the largest follicles on Day 9 were detected in does with synchronised oestrus cycles, but these variables were not significantly affected by supplementation with maize alone. This suggests that the synchronisation treatment was the main factor affecting these follicular characteristics by Day 9. On Day 9, the number of small follicles were greater in the non-synchronized groups compared to the synchronised groups of does (**Fig. 6.2**). In the synchronised does, more of the smaller follicles were likely to have progressed into larger follicles which could have contributed to fewer smaller follicles being visualised in these does. However, the tendency for more larger follicles to be present in the ovary of does supplemented with maize on Day 9 and a greater total number of follicles throughout the study in does supplemented with maize could suggest that supplementation with maize was exerting some influence on follicular development independent of the synchronisation treatment. Studies in sheep have indicated that nutrition supplementation above maintenance reduces atresia among large gonadotrophin-dependent follicles, increasing the number of ovulatory follicles (Viñoles *et al.* 2002).

This along with numerical differences in ovulation rates (+43%) in the group of does treated with exogenous hormones plus supplementation with maize suggest that some growing follicles were prevented from atresia and that the development of a greater number of codominant follicles within a follicular wave were facilitated to a greater extent than in does treated with exogenous hormones alone. 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 (Baird and Campbell 1998; Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011). According to the same authors, the number of large ovulatory follicles can be increased by decreasing the sensitivity of the hypothalamic-pituitary-ovarian axis to the negative effect of oestradiol to maintain the concentration of FSH above the threshold level for longer, thus allowing more time for follicles to pass through the so called, "widened gate". Perhaps supplementation with maize during the time of new wave emergence in does with synchronised oestrous cycles further reduces the sensitivity of the hypothalamus to oestradiol negative feedback and further stimulates gonadotrophin-dependent follicles to become more sensitive to FSH and hence develop precociously (Scaramuzzi *et al.* 2011) compared to does that are synchronised without supplementation.

In this study, the hypothalamus of anoestrous does subjected to synchronization of oestrus might be able to respond to maize supplementation resulting in concentrations of FSH to remain higher for longer, but this has not occurred in does that were not synchronised. In the non-synchronised does, the sensitivity of the hypothalamus to oestradiol might have remained high, thus preventing a prolongation of the surge release of FSH that occurs at the time of wave emergence. Therefore, if supplementation with maize is to increase the number of co-dominant follicles and potentially increase ovulation rate in anoestrous does, concurrent treatment with progesterone and eCG appears to be necessary. Further studies are needed to explain physiological reasons for the apparent synergistic relationship between treatment with progesterone and supplementation with maize on the number of codominant follicles and ovulation rate.

On Days 6 and 9 of this study, the interactions between time and supplementation with maize showed that concentrations of insulin, leptin and IGF-1 were greater in does supplemented with maize compared to the does that were not supplemented with maize (**Fig. 6.4**). These results are in accordance that nutritional

supplementation increases the plasma concentrations of glucose and insulin (Viñoles *et al.* 2005; Haruna *et al.* 2009; Zabuli *et al.* 2010), leptin (Muñoz-Gutiérrez *et al.* 2002; Viñoles *et al.* 2005; Maidin *et al.* 2014) and possible production of IGF-1 (Lucy 2000; Webb *et al.* 2004). Supplementation with maize appeared to have selective effects on follicular development from Day 6 to Day 9 of this study. Maize has been reported to be partially undegradable in the rumen of sheep (Nocek and Tamminga 1991; Landau *et al.* 1995) and this provides good amounts of 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 (Landau *et al.* 1997; Banchero *et al.* 2007). This may promote uptake of glucose by the ovaries that stimulates folliculogenesis by direct intrafollicular effect of insulin or insulin-mediated glucose uptake (Scaramuzzi *et al.* 2010). The effect of insulin may also be mediated via leptin, and both insulin and leptin may inhibit production of oestradiol and stimulate folliculogenesis (Marie *et al.* 2001). In sheep, insulin and leptin showed a strong association, due to actions of insulin on adipose tissue, the site of production of leptin (Marie *et al.* 2001). In addition, insulin and IGF-1 play a critical role in the selection of dominant follicles and by modifying the sensitivity of dominant follicles to respond to low levels of FSH (Monget and Martin 1997; Muñoz-Gutiérrez *et al.* 2004).

As expected, concentrations of progesterone were greater in does that were treated with exogenous progesterone, but concentrations of progesterone were not affected by supplementation with maize. Similarly, when Australian Cashmere goats were treated with exogenous progesterone and fed twice their maintenance requirement with 510 g of lupin grain per day, concentrations of progesterone were similar to goats fed at maintenance with only a base ration of 495 g of oaten chaff (Maidin *et al.* 2014). Parr *et al*. (1993), however, demonstrated that acute nutritional supplementation in sheep increases the metabolic clearance rate by the liver and a decrease in plasma concentrations of progesterone. The reason for this difference is unclear, although it might be related to differences between species or perhaps differences in the level or type of supplementation provided in different studies. Further study will be needed to determine if there is an effect of the supplementation rate of maize on peripheral concentrations of progesterone in goats and whether responses differ to those recorded in ewes.

On Day 7, mean concentrations of LH and frequency of LH pulses were not significantly affected by supplementation with maize, by synchronisation of oestrus or

the combination of both treatments, although LH amplitude was reduced when does were synchronised. The effects of nutritional supplementation on gonadotrophin secretion are contradictory. Some studies report the follicular development and ovulation rate are mediated by increase in gonadotrophin secretion (Hötzel *et al.* 2003; Zhang *et al.* 2004; Haruna *et al.* 2009; Seekallu *et al.* 2009). On the other hand, other studies suggest that the effect of nutrition on follicular development and ovulation rate does not involve enhanced secretion of GnRH, LH or FSH (Downing *et al.* 1995a; Viñoles *et al.* 2005; Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011). For instance, Haruna *et al.* (2009) reported that when Shiba goats were fed at 2.5 times above maintenance requirements during seven days, does showed a higher frequency of pulsatile LH secretion on Day 11 of the luteal phase compared to a control group that was fed at maintenance. In contrast, Downing *et al.* (1995a) observed a tendency to increase ovulation rate without any changes in LH pulse frequency nor FSH secretion in crossbred Merino sheep supplemented with 750 g of lupin grain for 11 days when compared to ewes fed at below maintenance. The same authors suggested that LH pulse frequency during the luteal phase of the oestrous cycle had no role in determining ovulation rate. This previous result is confirmed by the present study, although our results of LH pulse frequency were collected in anoestrus goats, not in the breeding season.

The lower amplitude of LH pulses in the synchronised does compared to the non-synchronised does can be explained by the concentrations of progesterone released from the intravaginal devices and any potential dietary modulation of the LH pulse amplitude was masked by the suppressive effect of exogenous treatment with progesterone. Although this study did not find significant differences in LH pulse frequency, greater concentrations of progesterone in the luteal phase in ewes are associated with lower LH pulse frequency when compared to the follicular phase (Seekallu *et al.* 2009).

The duration of the intensive blood collection (5 hours) might have been too short to detect changes in the frequency of release of LH. Other studies reported significant differences in LH pulse frequency when sheep blood samples were collected for at least 24 hours (Blache *et al.* 2003; Hötzel *et al.* 2003; Zhang *et al.* 2004) while other studies reported significant differences when blood samples were collected over only 6 hours (Haruna *et al.* 2009; Seekallu *et al.* 2009; Seekallu *et al.* 2010). The greater percentage of goats with LH surge and the greater mean maximum concentration of LH

between 12 h and 56 h after removal of inserts in the synchronised groups compared to the non-synchronised does can be explained by the occurrence of ovulation in all does treated with a synchronization treatment, but in only one doe supplemented with maize that was not treated with exogenous hormones.

Overall, supplementation with maize affected the concentrations of metabolic hormones which could be modifying the sensitivity and responsiveness of follicles to gonadotrophins. In addition, the results of this study corroborate that the effect of nutritional supplementation with maize on the total number of follicles and the tendency to increase ovulation rate was not mediated by changes in LH secretion, but by increased concentrations of insulin, leptin and IGF-1. Supplementation with a relatively small quantity of maize has the potential to increase ovulation rate in anoestrous does when treated with exogenous hormones. Numerical differences in ovulation rates (+43%) in the group of does synchronised plus maize, suggest that supplementation with maize in combination with the synchronisation of oestrus requires further investigation as a mechanism of potentially increasing ovulation rate in seasonally anoestrus goats, with larger groups of animals.

6.5 Conclusion

Hormonal synchronisation had the most influence on modifying follicular development, inducing oestrus behaviour and ovulation in anoestrous goats. A short-term nutritional supplementation with maize increased the concentrations of insulin, leptin and IGF-1 and appeared to have some influence on follicular development, but these changes were not mediated by an increase of the mean concentrations of LH and frequency of LH pulses. The responsiveness of growing follicles to gonadotrophins and, consequently, the reduced rate of atresia may be the mechanism by which synchronised does plus supplementation with maize has increased the ovulation rate in 43%.

CHAPTER 7: Short-term supplementation with maize increases ovulation rate in goats when total dietary energy provides requirements for both maintenance and 1.5 times maintenance

Study 6:

Abstract. This study aimed to evaluate the ovarian follicular dynamics in goats which were undergoing oestrus cycles supplemented with diets that differed in the metabolisable energy content. The experiment was carried out using 42 does allocated into three treatments of 14 animals each; 1M: fed with 1.0 times maintenance without maize; 1MM: fed with 1.0 times maintenance with maize; and 1.5MM: fed with 1.5 times maintenance with maize. The nutritional supplementation was given for nine days. Oestrus was synchronised with two injections of cloprostenol given seven days apart. Does were also treated with intravaginal progesterone inserts and eCG. The interval to oestrus and duration of oestrus did not differ ($P = 0.382$) between treatments. Does fed with 1MM and 1.5MM had a similar number of ovulations, but a greater ($P = 0.028$) number of ovulations than goats fed with 1M. 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, goats fed with maize at maintenance or 1.5 times maintenance significantly increased ovulation rates, but did not alter the concentrations of hormones and metabolites. Similar results between groups fed diets that included maize and provided metabolisable energy at 1.0 and 1.5 maintenance demonstrate that in order to increase ovulation rate when synchronising oestrous cycles in does, dietary supplementation with maize can be restricted to provide a maintenance level of metabolisable energy only thus saving on the cost of the diet.

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

7.1 Introduction

Reproductive efficiency can be measured and expressed as fertility, prolificacy, weaning rate and kidding interval. Prolificacy, which is determined by ovulation rate, is a key factor in reproductive efficiency that can be improved by nutritional supplementation (Scaramuzzi *et al.* 2006). Nutrition exerts a significant influence on reproductive function through changes in body weight and body condition, affecting processes of follicular development and ovulation rate (Lindsay *et al.* 1993; Scaramuzzi *et al.* 2006; Scaramuzzi and Martin 2008). Nutritional supplementation influences the selection of dominant follicles, increases the follicular growth and improves the quality of oocytes (Lucy 2000; Webb *et al.* 2004; Scaramuzzi *et al.* 2011). These changes in the 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 (Blache *et al.* 2008).

The supplementation of high-energy diets with carbohydrate content, such as starch from maize, may provide a rapidly available source of energy to the rumen microbes (Landau *et al.* 1995). The average rumen degradability of starch from cracked maize is 65% with the principal ruminal metabolic end product being propionate (Nocek and Tamminga 1991), which is subsequently absorbed into the bloodstream and used as a precursor for glucose synthesis. Starch that is not degraded in the rumen passes into the small intestine a (Nocek and Tamminga 1991), where it is broken down into glucose thus increasing the entry rate of glucose into the bloodstream (Landau *et al.* 1997; Banchero *et al.* 2007). This can provide more glucose for uptake by the ovary which can enhance follicular development (Scaramuzzi *et al.* 2010).

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. Some studies have shown that short-term nutritional supplementation for four to 11 days can promote an increase in ovulation rate in sheep (Stewart and Oldham 1986; Nottle *et al.* 1990; Downing *et al.* 1995a). In contrast, most studies have failed to demonstrate that short-term nutritional supplementation can increase ovulation rate, but did demonstrate an increase in the number of large follicles or in the total number of follicles in sheep (Viñoles *et al.* 2005; Letelier *et al.* 2008; Viñoles *et al.* 2010; Ying *et al.* 2011) and an increase in concentrations of glucose and insulin in goats (Haruna *et al.* 2009). Furthermore, a few publications have evaluated

the effect of supplementation with maize on ovarian function in sheep (Letelier *et al.* 2008) and in goats (Fasanya *et al.* 1992; De Santiago-Miramontes *et al.* 2008). De Santiago-Miramontes *et al.* (2008) observed a greater ovulation rate in anoestrous dairy goats supplemented with maize, lucerne hay and soybean for seven days before exposure to sexually active bucks, compared to non-supplemented females goats. Fasanya *et al.* (1992), however, reported that Savana Brown goats supplemented with cottonseed cake attained puberty at an earlier age and heavier weight than those goats supplemented with maize.

Multiple hormones and metabolites appear to influence follicular development, for example FSH, LH, GH, glucose, insulin, leptin and IGF-1 (Viñoles *et al.* 2005; Scaramuzzi *et al.* 2011). Viñoles *et al.* (2005) 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, and glucose, fatty acids and several metabolic hormones have all been shown to have direct action on the follicle (Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011). 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.

In order to try to gain a better understanding of the effect of different levels of energy in the ovarian follicular development, it is important to monitor the concentration of these hormones and metabolites in association with dietary changes. While overall differences in concentrations of these hormones and metabolites have not been demonstrated in every study, supplementation with maize is expected to increase the delivery of glucose to the small intestine and as such increase concentrations of glucose and IGF-1, which could in turn modify the sensitivity of the ovary to gonadotrophins and increase ovulation rates.

Previous studies have tried to address changes in ovarian function by changing the level of energy provided in diets to experimental animals (Viñoles *et al.* 2005; Haruna *et al.* 2009). It has been shown that the efficiency of utilization of energy for maintenance increases when sheep and cattle are supplemented with maize (Blaxter and

Wainman 1964). There are no reports of whether changing the dietary ingredients while still maintaining the dietary provision of metabolic energy at maintenance requirements could be used as an alternative to increase follicular development without increasing supplemental energy above levels required for maintenance only. This method of changing the nutrient composition of the diet without changing the overall level of energy could provide a novel method of influencing ovarian function in goats at more modest cost compared to supplementing does above their maintenance requirements.

We hypothesized that goats supplemented with maize for a short term, with diets designed to provide metabolisable energy at either maintenance or 1.5 times above 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 to goats fed a diet that provides a maintenance level of metabolisable energy without the inclusion of maize. To confirm this hypothesis, this study aimed to evaluate the follicular dynamics and changes in hormones and metabolites in goats that were undergoing oestrous cycles and supplemented with diets that differed in the content of maize and the level of metabolisable energy that diets provided.

7.2 Material and Methods

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 does (21 Boer and 21 rangeland goats) nulliparous and non-pregnant goats were used in this study. At the start of the experiment, the 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 numbers: A1695 and A1725).

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 group in each block. Goats were randomly assigned to each treatment but treatments were balanced for live weight and breed. Different animals were used in both 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 the housing for five days by maintenance in single pens and 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 of 40 kg (NRC 2007). Beginning 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 7.1**). The maize and lucerne pellets were offered at 8 am and Rhodes grass was offered at 5 pm. 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, every doe was fed the maintenance diet that consisted of lucerne pellets and Rhodes grass 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. 7.1**). 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. 7.1**).

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

Table 7.1 Quantities fed of the different dietary ingredients to does within each treatment, and chemical composition of diets to provide energy requirements 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
Chemical composition (%)			
Dry matter	85.7	83.8	84.8
Organic matter	79.3	78.9	79.3
Ash,	6.4	4.9	5.5
Acid detergent fibre	28.4	22.8	23.7
Neutral detergent fibre	41.1	34.4	34.8
Crude protein	13.5	11.4	12.7
Metabolic Energy (MJ/day)	**6.7**	**6.7**	**10.0**

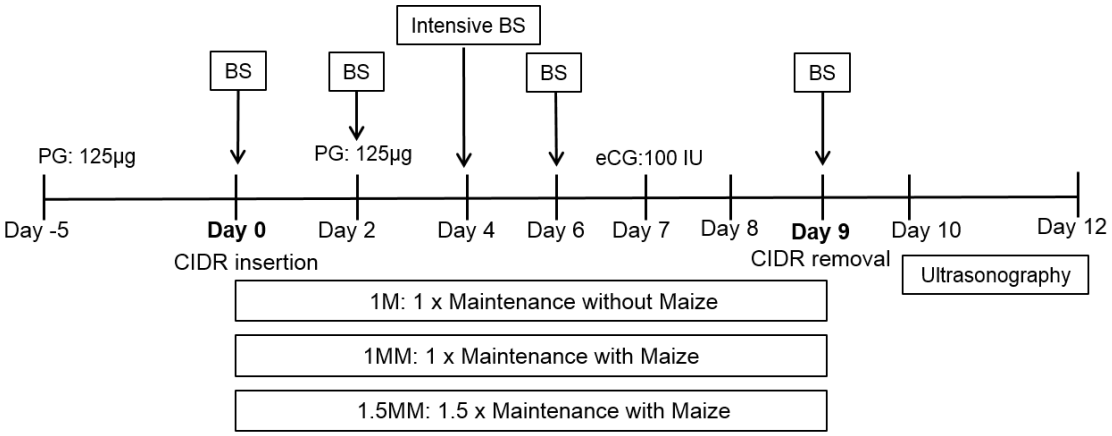


Fig. 7.1 Schematic representation of the experimental treatments outlining the timing of administration of the experimental diets, protocol used to synchronise oestrus (PG: prostaglandin, eCG: equine chorionic gonadotropin and CIDR: progesterone releasing device), and the timing of blood sampling (BS) and ultrasonographic evaluations.

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, for intensive blood collection (every 15 minutes for 5 hours). Blood samples were stored on ice then centrifuged (2500 g for 15 minutes) 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 the 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 (Miller *et al.* 1995). 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.* (2000b). 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.* 1991). 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 Hötzel *et al*. (2003) 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 (1982). A pulse was defined when the concentration of LH exceed the mean concentration in a single point 5 times the standard deviation (SD), or in 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.

Follicular dynamics

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). Follicles were classified as codominant when two or more follicles $\geq$5 mm were present within the same follicular wave. The day of ovulation was defined by the sudden loss of a follicle $\geq$5 mm in diameter

followed by the development of a corpus luteum within the same ovary. The total number of corpora lutea observed in the ovaries of each doe was recorded as the ovulation rate for each doe. During the present study, all ultrasound examinations were performed by the same operator.

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 oestrus, maximum diameter of the largest follicle, number of ovulations, number of codominant follicles 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 $P < 0.05$.

7.3 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 the model. There was a significant interaction ($P = 0.016$) between block and treatment for the concentrations of insulin and, therefore, block was included in the statistical model to analyse insulin.

There was no significant difference among treatments for the percentage of does in oestrus, interval to onset of oestrus and duration of oestrus (**Table 7.2**). The number of ovulations observed was similar between goats treated with 1M and 1.5MM, but was

greater (P< 0.05) in does fed these diets compared to those fed a diet that provided dietary energy at 1M (**Table 7.2**).

The number of codominant follicles on Day 10 was greater (P < 0.05) in the group fed at 1.5MM compared to the group fed at 1M. The diameters of the largest follicles on Day 10 tended to differ between treatments (**Table 7.2**).

Table 7.2 Percentage of does in oestrus, mean (±SEM) interval to onset of oestrus, duration of oestrus, ovulation rate, number of codominant follicles and diameter of the largest follicles of goats

	Treatments			
Variables	1M	1MM	1.5MM	P
Animals (n)	14	14	14	
Females in oestrus (%)	100.0	100.0	92.9	0.359
Interval to oestrus (h)*	18.3 ± 2.3	15.7 ± 0.8	16.6 ± 0.9	0.582
Duration of oestrus (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
Codominant follicles Day 10 (n)	1.8 ± 0.1^{b}	2.1 ± 0.1^{ab}	2.5 ± 0.1^{a}	0.019
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.

The mean number of small, medium and large follicles and total number of follicles on Days 10 to 12 of ultrasound evaluations did not differ (P = 0.204) among treatments and there were no significant interactions between time and treatments (P = 0.110) for these variables (**Fig. 7.2**). 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).

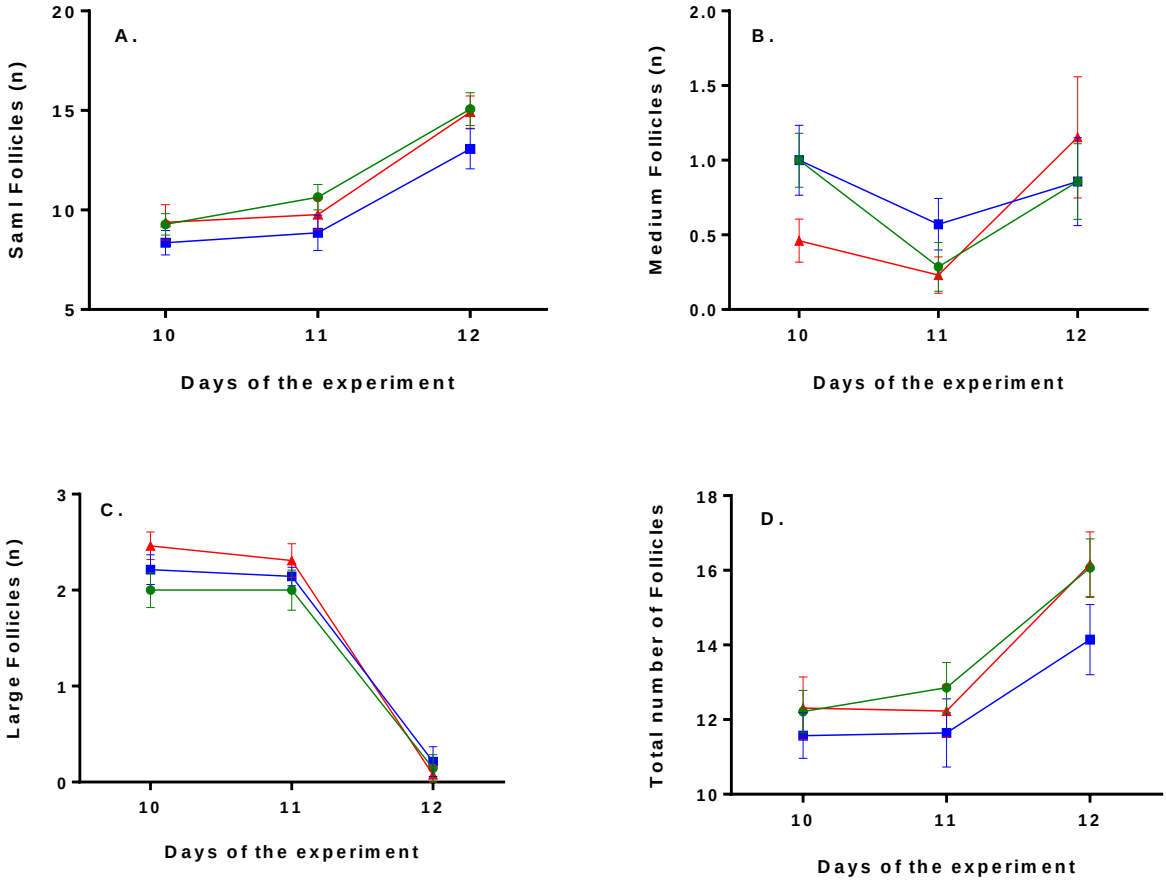


Fig 7.2 Number of (A) small (2 to 3 mm), (B) medium (>3 and <5 mm), (C) large (≥5 mm), and (D) total number of follicles ≥ 3 mm on Days 10 to 12 of the study for goats supplemented with diets that provided energy at 1M without the inclusion of Maize (●), 1MM (■) or 1.5MM (▲) in the diets.

Concentrations of glucose and insulin on Day 4 of the study are shown in **Figure 7.3**. Between 2h and 5:30h 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. 7.3a**). 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. 7.3b**). 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).

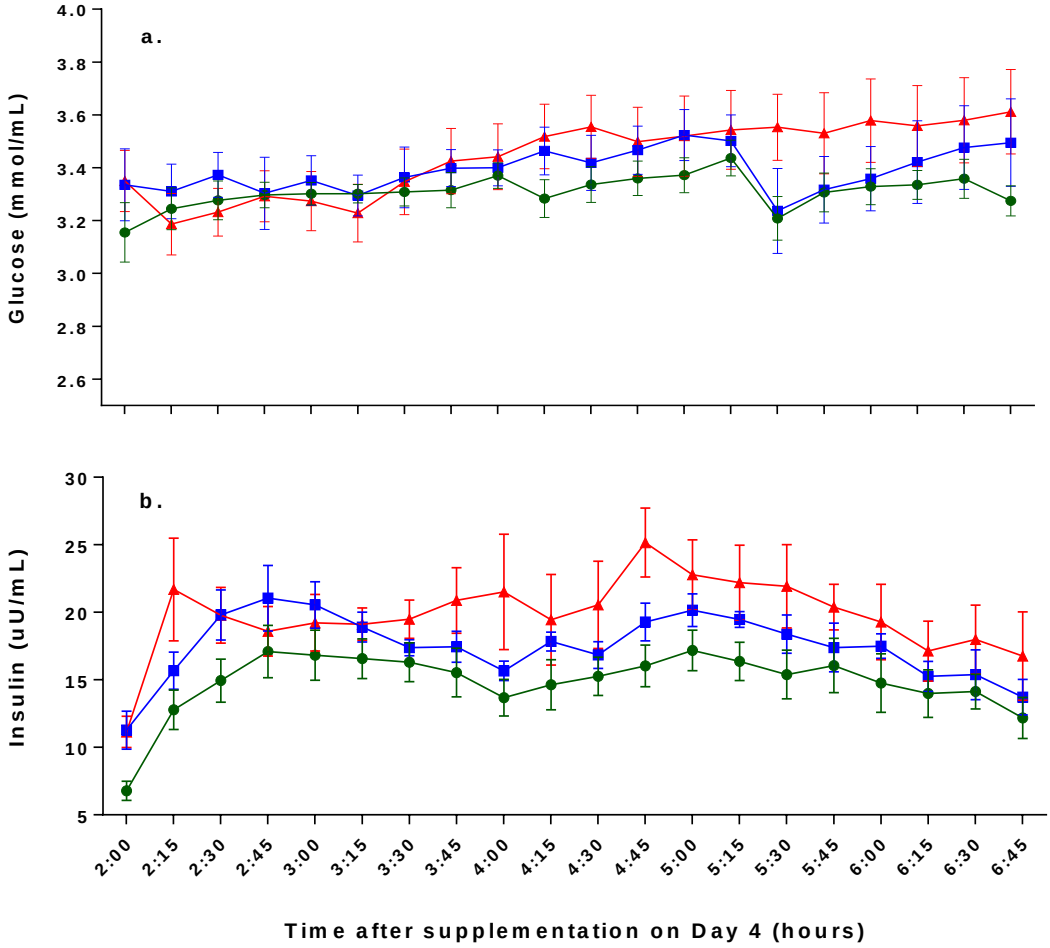


Fig. 7.3 Plasma concentrations of glucose (a) and insulin (b) on Day 4 of the study in goats supplemented with diets that provided energy at 1M without the inclusion of Maize (●), 1MM (■) or 1.5MM (▲).

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 an effect of time ($P < 0.001$) and interaction between time and treatment ($P < 0.037$) (**Fig. 7.4**). 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 to both groups fed at 1M and 1MM (**Fig. 7.4c**). 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. 7.4b**), then concentrations of leptin remained relatively constant between Days 2 and 9 (**Fig. 7.4b**).

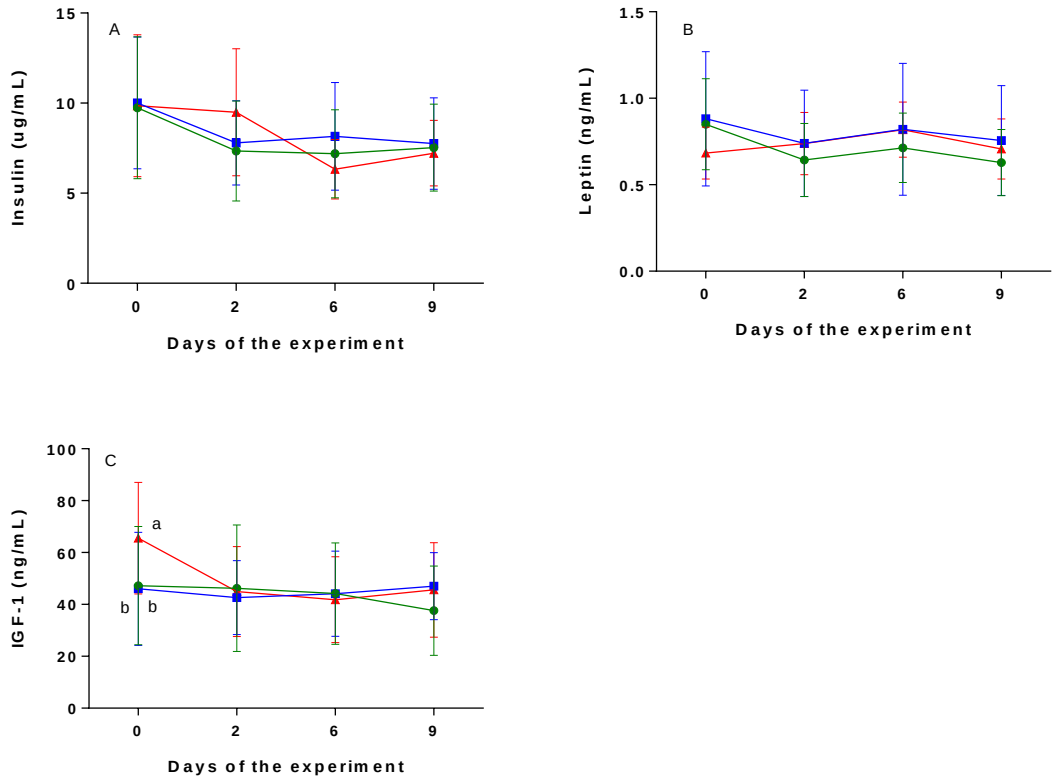


Fig. 7.4 Concentrations of insulin (A), leptin (B) and IGF-1 (C) of goats supplemented with diets of 1M without Maize (●), 1MM (■) or 1.5MM (▲) during the breeding season (different letters, within days indicate differences between groups; $P < 0.05$).

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 7.3**). 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 2h and 3h after sampling, but there was no interaction of time with treatment ($P = 0.240$). The LH pulse frequency and amplitude were not significantly affected by treatment (**Table 7.3**).

Table 7.3 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.

7.4 Discussion

To authors' knowledge, this is first study to demonstrate that short-term nutritional supplementation with maize can increase ovulation rate in goats with synchronised oestrous cycles during the breeding season. An additional novel finding of this study was that ovulation rate could be increased when maize was included in diets that provided both requirements for maintenance and 1.5 times above maintenance levels of metabolic energy. The present study shows that 9-days supplementation with relatively low levels of maize to the diets of goats with synchronised oestrus cycles can enhance ovulation rate and may improve prolificacy with little additional cost. These results, therefore, support the previous report that the principal nutritional factors that stimulate increases in the ovulation rate in sheep (Teleni *et al.* 1989) and goats are the energy-yielding nutrients.

The lack of statistical differences of treatments on the number of small, medium, large and total number of follicles from Days 10 to 12 suggest that number of follicles recruited and selected were not influenced by the level or dietary precursors of energy supplied. The effects of nutritional supplementation on the number of follicles are not consistent. For instance, no significant effect on the number of small and large follicles was observed by Somchit *et al.* (2007) after dietary supplementation of ewes with lupins associated with synchronization of oestrous during the breeding season. On the other hand, studies showed that in ewes fed with a twice-maintenance diet during the course of one oestrus cycle increased the number of small follicles (Haresign 1981). Furthermore, supplementation with steam-flaked corn for five days in ewes with synchronized oestrous cycle increased the number of follicles greater than 4 mm in diameter, without any effect on the number of small follicles (Letelier *et al.* 2008).

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 undegradable in the rumen of sheep (Nocek and Tamminga 1991; Landau *et al.* 1995) 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 (Landau *et al.* 1997; Banchero *et al.* 2007). This may promote greater uptake of glucose by the ovaries which may enhance follicular development (Scaramuzzi *et al.* 2010).

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 number of codominant follicles and ovulation rate. A sudden reduction in the number of large follicles (**Fig. 7.2c**) and increase in the number of small follicles (**Fig. 7.2a**) was observed on Day 12, which was most likely a result of most goats ovulating after Day 11 and an increase in concentrations of FSH occurring around the time of ovulation, which is associated with new wave emergence and recruitment of additional number of growing follicles (Medan *et al.* 2003). The greater number of codominant follicles and ovulation rate in the groups supplemented with maize could be attributed to a lower atresia rate of large follicles (Nottle *et al.* 1997; Viñoles *et al.* 2005). 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 (Baird and Campbell 1998; Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011). In addition, higher concentration of insulin after supplementation enhances the synthesis of IGF-1 in the liver, which in turn increases the number of receptors and sensitivity to LH, resulting in an increase in synthesis of oestradiol from dominant follicles and a reduction in the rate of atresia (Lucy 2000; Webb *et al.* 2004; Scaramuzzi *et al.* 2010). In the present study, it is possible that the lower rate of atresia and the greater survival of large follicles led to a greater number of codominant follicles on Day 10 and greater ovulation rates in does supplemented with maize.

The results of this study did not demonstrate any effect of supplementation of maize on the 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 anoestrous does were supplemented with maize (Nogueira et al., 2015_**Study 5**). Circulating concentrations of glucose are not always increased when maize is fed to ruminants, but appears to be affected by the degradability of maize or other energy substrates in the rumen and hence rumen glucogenic activity (Landau *et al.* 1992). In addition, if cracked maize is slowly degraded in the rumen, perhaps no increases in these metabolic parameters should be expected and, in fact, maize may cause extra amino acids or volatile fatty acids to be available to the ovary as an energy source. Nocek and Tamminga (1991) have speculated that the addition of maize in the diet can cause an increase of the availability of amino acids by the liver for gluconeogenesis. Our results suggest that the increasing in ovulation rate in association with supplementation with 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 the higher-energy group, where authors have used a greater difference in the levels of energy that were fed to treatments that represented high and low planes of energy supplementation. For instance, 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 higher-energy diet (Haruna *et al.* 2009). In addition, greater concentrations of glucose, insulin and leptin were recorded in ewes supplemented twice the maintenance diet compared to ewes fed at maintenance diet (Viñoles *et al.* 2005; Viñoles *et al.* 2010). Second, the timing of blood samples in relation to when animals were fed in this study may also have influenced the concentrations of metabolic hormones that were measured. In this study, blood samples were collected two hours after goats were fed. 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 (Zhang *et al.* 2004), 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 7.3**). There are two possible explanations for these results. First, it should be noted that on Day 4, all animals were treated with progesterone releasing inserts and any potential dietary modulation of LH secretion could have been masked by the suppressive effect of exogenous treatment with progesterone. This is in agreement with Seekallu *et al.* (2009) who reported that LH pulse frequency is enhanced in the normal follicular phase in ewes compared to ewes in the luteal phase, and is consistent with the suppression of LH pulse frequency that has been observed in cattle in association with increasing circulating concentrations of progesterone (Bergfeld *et al.* 1996). Second, the duration of the period of intensive blood collection (5 hours) might have been too short to detect changes in the frequency of release of LH. Other studies, in sheep fed with lupin grain, reported significant differences in LH pulse frequency when sheep blood samples were collected for at least 24 hours (Blache *et al.* 2003; Hötzel *et al.* 2003; Zhang *et al.* 2004), while other studies reported significant differences when blood samples were collected over only 6 hours (Haruna *et al.* 2009; Seekallu *et al.* 2009; Seekallu *et al.* 2010).

Up to date, the effects of nutritional supplementation on gonadotrophin secretion are still equivocal. Some studies report that the follicular development and/or ovulation rate are mediated by increase in gonadotrophin secretion (Hötzel *et al.* 2003; Zhang *et al.* 2004; Seekallu *et al.* 2010). This gonadotrophin secretion can affected by nutritional supplementation (Zhang *et al.* 2004), by photoperiod and seasonality (Hötzel *et al.* 2003) or the luteal phase of the oestrus cycle (Seekallu *et al.* 2009). In contrast, other studies suggest that the effect of nutrition on ovulation rate does not involve extra secretion of GnRH, LH or FSH (Viñoles *et al.* 2005; Meza-Herrera *et al.* 2008).

Overall, our results suggest that the effect of nutritional supplementation on follicular development and ovulation rate is not mediated by changes in mean concentrations of LH or by the pattern of LH secretion. However, concentrations of LH may be need to be monitored over a longer duration of intensive blood sampling to

determine if changes in the pattern of secretion of gonadotrophins are occurring in relation to the diets that were fed in this study.

Other studies have focused on increasing ovulation rates by increasing dietary sources of energy (Nottle *et al.* 1990; Downing *et al.* 1995a). 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 (Haruna *et al.* 2009) can also be used to increase ovulation rate in does. These results suggest that short-term changes in dietary composition can be used to influence ovarian function in does. 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.

7.5 Conclusion

Goats supplemented with maize in diets designed to provide metabolisable energy at a level of 1.0 or 1.5 times maintenance significantly increased ovulation rates compared to goats fed a diet that did not contain maize but provided metabolisable energy at the level of 1.0 times maintenance. When attempting to increase ovulation rates in Boer and rangeland goats with synchronised oestrous 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 metabolisable energy at a level of 1.0 times maintenance with maize is fed compared to a diet that provides metabolisable 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. The reduced rate of atresia may be the mechanism by which synchronized does plus supplementation with maize has increased the ovulation rate.

CHAPTER 8: General discussion, outcomes and limitations

8.1 The meat goat Survey

The survey (**Studies 1** and **2**) provides the first comprehensive overview of the meat goat producing enterprises in New South Wales and Queensland. The total goat herd reported in this survey was 160,010 animals. The reported goat herd in New South Wales represented 71.5% and Queensland represented 28.5% of the total goat herd covered in this survey (**Study 1**). Similar proportions were found by Pople and Froese (2012) who reported that New South Wales represents 73.8% of the goat herd and Queensland represents 12.3% (**Table 8.1**). With the large number of goats present in Australia and extensive areas of land suitable to the farming of goats, Australia has the potential of becoming one of the largest goat producers in the world (Malan 2000).

Table 8.1 The distribution of goat population in Australia

State	Heads	Percentage
NSW	2,950,000	73.8
QLD	491,000	12.3
SA	322,000	8.1
WA	150,000	3.8
NT + Vic	87,000	2.2
Total	**4,000,000**	**100.0**

Source: Pople and Froese (2012)

The results showed that the Australian meat goat industry is based on the harvest of rangeland goats (55%) and the export carcass market was the most important sector (100%) of the properties in pastoral regions (**Study 1**). To the authors' knowledge, Australia is the only country in the world where 'feral goats or rangeland goats' are harvested to be exported overseas. In addition, it is difficult to understand that an important source of protein for human nutrition can be considered as a pest in every state and territory in Australia, with exception of the state of New South Wales (Restall *et al.* 1982; Parkes *et al.* 1996). Thus, rangeland goats are considered as detrimental to

the environment and some authors recommend that rangeland goats should be eradicated rather than used as a potential source of income (Khairo *et al.* 2013).

Probably, in Australia, there is an apparent lack of knowledge about the health benefits of the goat meat (Pratiwi *et al.* 2007) or cultural preferences and heritage have a strong influence on goat meat consumption (Murray-Prior *et al.* 2013). Furthermore, this survey showed that rangeland goats in Australia are adapted to eat a variety of plants including wattle, gum trees, mulga and prickly acacias, and that some of the woody weeds that are not readily utilised by cattle and sheep can be utilized for goat production (**Study 1**). An important benefit of having goats on the pastoral regions was the control of weeds and undesirable browse species (**Study 1**). Goats are well adapted to rangeland environments and should be a good economical alternative, as almost 80% of Australia is broadly defined as rangelands. In some rangelands it might be more appropriate to run goats as single grazing species (Thompson *et al.* 2002).

The results from this study showed that most of producers in the pastoral regions do not keep many records on animal health and animal performance (**Study 2**). These results can be explained by the size of some properties that can be larger than 90,000 ha, with an estimation of 20.000 head of goats associated with sheep and cattle. The area of a few properties in Australia can be equivalent to size of a small country in Europe. The large size of the properties can be associated with high percentage (97%) of producers carrying out some fencing activity over the last 5 years. Use of fencing was a constraint for producers in all regions (**Study 1**). In all properties from pastoral and high rainfall regions, the lack of fences or no fencing plans to create holding paddocks (**Study 2**) can be the cause of low adoption of weaning (29%), low use of controlled mating season (45%) or lack of castration of male kids (52%). Due to lack of fences, the age at which maiden does were mated was reported to be less for the pastoral region (8.5 months) compared to the high rainfall region (15.2 months) (**Study 2**), as in the pastoral regions producers do not segregate males and females.

The animal production system in Australia in large properties is very different from other parts of the world. For instance, with industrialisation of agriculture and intensification that developed during the 20th century, animal production sectors (dairy cows, beef meat, poultry and pigs) became more intensified in small properties (Dubeuf *et al.* 2004) and this was not observed in Queensland and New South Wales for most goat production. In summary, goats on properties in the pastoral regions showed low pregnancy and kidding rates, early age at first mating, high mortality rates, poor

performance of Boer bucks and lower weight gain than properties in the high rainfall regions (**Study 2**). Producers who engage in opportunistic goat harvesting maintain few records related to herd management and animal health. On the other hand, commercial and seedstock producers generally keep more detailed records and are trying to improve the productivity of their goat herds. The results from this survey have highlighted areas that require further study to validate the observations of producers, for instance, factors that may be limiting the fertility of Boer goats in rangeland environments, the incidence of gastrointestinal parasites and infectious diseases, the use of Kidplan® and management strategies to improve goat productivity.

8.2 Seasonality of reproduction

In goats and sheep, the reproductive cycle is regulated by seasonal changes in photoperiod, and the breeding season of goats commences as day length decreases (Fatet *et al.* 2011). The breeding season can be also influenced by temperature (heat stress) and low rainfall that promotes a lack of feed supply (Mellado *et al.* 1991; Martin *et al.* 2004; Scaramuzzi and Martin 2008). In the tropical region of north Queensland (19˚19' S), we have identified a period of anoestrus in Boer goats that extended in over 90% of goats from September and December (**Study 4**). Moreover, Boer goats were more precocious than rangeland goats, because Boer goats started the breeding season two months earlier than rangeland goats (**Study 3)**.

The seasonality of reproduction in goats raised in Townsville is the most probably caused by the effect of photoperiod and not caused by heat stress, low rainfall or lack of feed supply. There are three reasons to support this argument. First, there is a numerical difference of 2.3 hours in day length between the longest and shortest days in Townsville (**Fig. 1.2**). Second, all female goats had *ad libitum* access to a pasture of annual ryegrass in order to provide nutritional requirements above maintenance (7.6 MJ ME/day) for a goat weighing 40 kg (NRC 2007). Third, in Townsville, the mean maximum (28.9ºC) and mean minimum (19.8ºC) temperatures and the average annual rainfall is 1,150 mm (Timeanddate 2014), and these may not be a cause of heat stress to the animals. The experimental studies (**Studies 3** and **4**) were not designed to test the cause of seasonality of reproduction in goats, but to evaluate the ovarian responses to the effect of seasonality. Some of the limitations of **Study 3** were that only the timing in onset of the breeding season was assessed rather than the duration of the breeding

season. Further studies could determine if the duration of the breeding season or responsiveness to the presence of males or hormonal treatments that can be used to induce cyclicity in goats and whether there are differences between Boer and rangeland goats. In addition, patterns of cyclicity when does exposed to moderate or severe nutritional stress could also vary between these breeds and warrants further examination as breeds or genetic crosses that have longer breeding seasons may be more attractive to commercial farmers.

The reason why Boer goats started the breeding season two months earlier than rangeland goats can be explained by different genetic sensitivity to melatonin and/or oestradiol (**Study 3**). Melatonin is secreted by the pineal gland during darkness and influences the secretion of GnRH by the hypothalamus (Chemineau *et al.* 1992b; Fatet *et al.* 2011). As Boer and rangeland goats have different genetic backgrounds it could be that, they have different abilities to translate the signal of melatonin in the pituitary gland and hypothalamus. In addition, the seasonality of reproduction in sheep is primarily due to changes in the responsiveness of the hypothalamus to the negative feedback of oestradiol, which in turn is dictated by variations in the length of the daily photoperiod (Rosa and Bryant 2003). Oestradiol is reported to have opposing actions on the hypothalamus in the non-breeding compared to the breeding season. In the breeding season each preovulatory rise of oestradiol is reported to be accompanied by a parallel increase in LH while in the non-breeding season an induced oestradiol rise is accompanied by a pronounced drop in LH levels (Legan and Karsch 1980).

Boer goats may have a greater sensitivity to melatonin and lower sensitivity to oestradiol than rangeland goats and, consequently, concentrations of LH should be greater in Boer goats than rangeland goats during transition from anoestrous to the breeding season (**Fig. 8.1**). Finally, the author also speculate that the difference in temperament between Boer and rangeland goats may contribute to the longer timing for the onset of the breeding season. In this study, it was observed a greater flight zone for the rangeland goats compared to the Boer goats. The greater flight zone and other stressors are associated with activation of the hypothalamus-pituitary-adrenal axis to increase concentrations of cortisol in goats (Kannan *et al.* 2000). Furthermore, the circadian rhythm also influences cortisol production and is associated with changes in photoperiod (Alila-Johansson *et al.* 2003). Although unmeasured in this study, it is possible that concentrations of cortisol may have contributed to the delay in the onset of the breeding season in rangeland goats (**Study 3**).

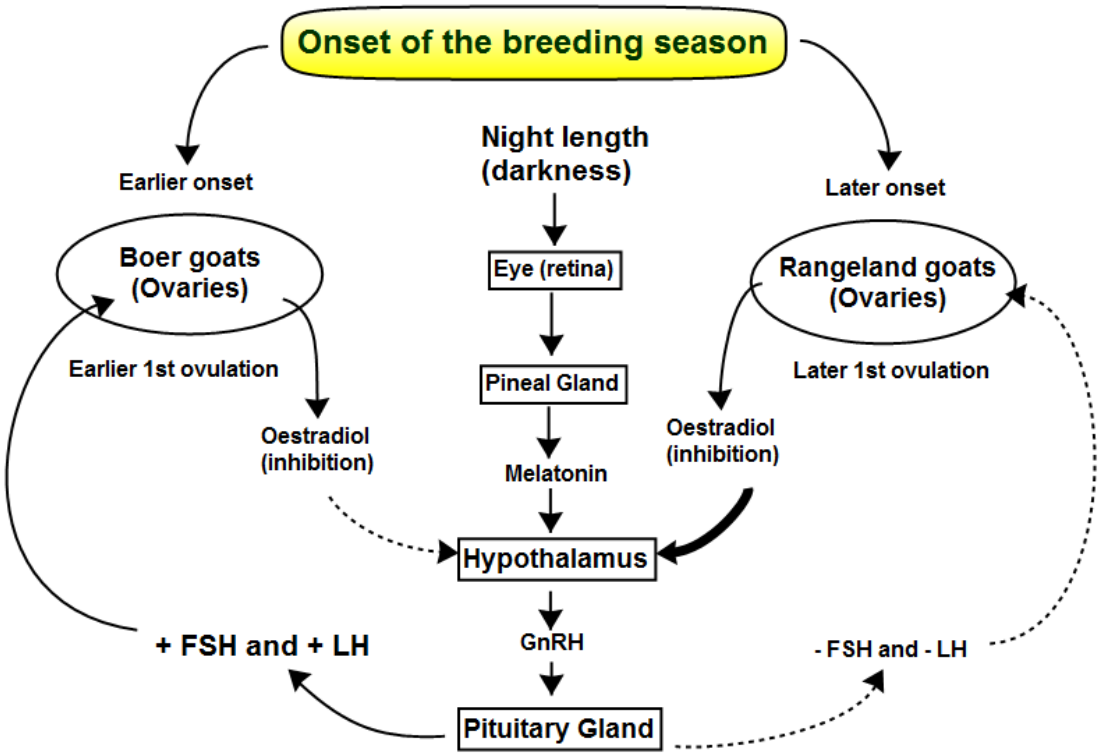


Fig. 8.1 Diagrammatic representation for the onset of the breeding season in Boer and rangeland goats evaluated in the same tropical environment (19º19' South). Solid lines show strong effects and the dashed lines represent weak effects.

To the author knowledge, **Study 4** is the first report to describe follicular dynamics of the same Boer goats examined during both the non-breeding and breeding seasons. The number of follicular waves recorded during a 21-day recording period was greater in the non-breeding season compared to the breeding season. However, the number of codominant follicles were greater in the breeding season compared to the non-breeding season (**Fig. 8.2**). These findings are in agreement with Cruz *et al.* (2005) who reported that ovaries of anoestrus Anglo-Nubian and Saanen goats remained active and follicles continued to grow to reach the equivalent size of preovulatory follicles. The greater number of codominant follicles in the breeding season can be explained by greater number of follicles which are recruited and selected, producing a greater number of codominant follicular waves with follicles greater than 5 mm in diameter (Rubianes and Menchaca 2003; Medan *et al.* 2005).

Study 4 have highlighted the occurrence of factors that could reduce reproductive performance in Boer does in a tropical environment. These factors include the occurrence of short oestrous cycles and cystic follicles. Development of cystic follicles occurs when a dominant follicle fails to ovulate after a surge release of LH (de Castro *et al.* 1999; Medan *et al.* 2004). Cystic follicles were observed in goats during transition from the non-breeding to the breeding season and can be associated with the occurrence of short oestrous cycles and potentially reduce fertility in goats (de Castro *et al.* 1999). Physiological causes of follicular cysts in both goats (Medan *et al.* 2004) and other ruminants (Lopez-Diaz and Bosu 1992) have been attributed to an inadequate release of hypothalamic GnRH or reduced sensitivity of the hypothalamus to oestrogen positive feedback and/or an inadequate surge of LH (Medan *et al.* 2004). In addition, an increase in LH receptors and its mRNA in the dominant follicle are also necessary for ovulation to occur and these could be reduced in cystic follicles (de Castro *et al.* 1999; Kawate 2004; Medan *et al.* 2004). The results from **Study 4** support the concept that differences in gonadotrophin secretion and/or sensitivity of ovarian follicles to gonadotrophins and/or differences in hypothalamic sensitivity to ovarian steroids may differ in goats between the non-breeding and breeding season, which may contribute to differences in follicular dynamics that were observed in this study.

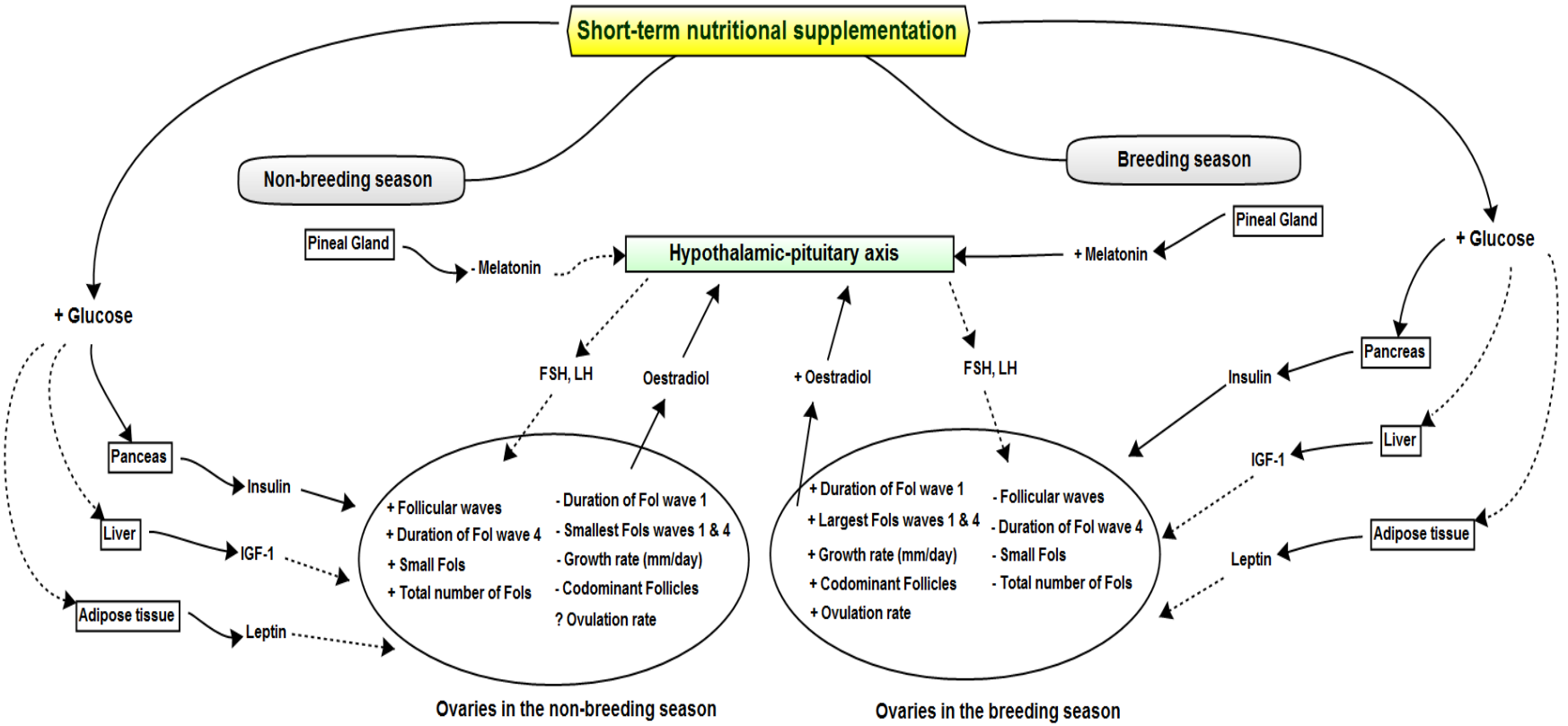


Fig. 8.2. Diagrammatic representation of follicular dynamics in goats during the non-breeding season (right) and breeding season (left), and the possible mechanisms of the effect of short-term supplementation during the non-breeding and breeding seasons. The dashed lines indicate interactions that have not been confirmed in this present study.

8.3 Influence of nutrition on ovarian function

There is a large amount of information on the effect of nutritional supplementation on ovulation rate. However, most of the research on nutrition supplementation was done in sheep and there is a temptation to transfer the findings from sheep to goats. It is important to understand that there are differences between species in their reproductive responses to nutrition and these differences can affect their productive and reproductive performance. Therefore, we cannot just adopt and adapt the same nutritional supplementation used in sheep and expect similar reproductive responses in goats.

Overall, these results support the hypothesis that the principal nutritional factors that stimulate increases in the ovulation rate in sheep (Teleni *et al.* 1989) and goats are the energy-yielding nutrients. Supplementation with maize appeared to have selective effects on ovarian follicular development before the time of ovulation in this study. This is reason why the author choose the supplementation with maize. These results support the previous reports that supplementation with maize provides good amounts of non-degradable starch to pass into the small intestine, increasing the entry rate of glucose and other energy-yielding substrates into the blood stream for a greater period of time (Landau *et al.* 1997; Banchero *et al.* 2007). The uptake of glucose by the ovaries may influence the selection of dominant follicles, increases the follicular growth and improves the quality of oocytes (Lucy 2000; Webb *et al.* 2004; Scaramuzzi *et al.* 2010).

The findings of **Study 5** showed that hormonal synchronisation was a highly effective method of inducing oestrus and ovulation in anoestrous goats during the non-breeding season and that nutritional supplementation with maize in combination with hormonal treatment increased by 43% the ovulation rate. Nutritional supplementation with maize for nine days in non-synchronised does promoted changes in systemic concentrations of glucose, insulin and leptin over time, but did not induce oestrus behaviour or a greater ovulation rate compared to does that were treated with exogenous hormones. The failure of supplementation with maize to significantly increase ovulation rate in does with synchronised oestrous cycles can be explained by the small difference in the levels of energy between our experimental groups (1.0 times maintenance vs 1.5 times maintenance). Other studies that have reported greater concentrations of metabolites in the higher-energy group, where authors have used 2.0 or 2.5 times above the maintecance requirements in the high-energy plane compared to 1.0 times

maintenance in the low plane of diets (Viñoles *et al.* 2005; Haruna *et al.* 2009). These studies also used a larger number of animals per group when compared to the present study.

In **Study 6**, it was used double the number of animals per group compared to the last experiment to increase the statistical power. To our knowledge, **Study 6** is the first study to demonstrate that short-term nutritional supplementation with maize can increase the ovulation rate in goats. One of the most important results from this study was that ovulation rates could be increased when maize was included in diets that provided both 1.0 and 1.5 times nutritional requirements for maintenance. The implications of this management strategy are that that there is no necessity to increase the level of energy of a diet at 1.0 times maintenance with maize compared to a diet at 1.5 times maintenance with maize because this might increase the cost of the diet (**Study 6**).

The effects due to breed (Boer and rangeland goats) and interactions of breed with treatment or breed with block were not significant and were removed from the model. The small number of animals in each breed (around 7 animals) might not have been large enough to promote a statistical significance between breeds.

Ovulations were detected in 100% (14/14) of goats that were subjected to the synchronisation treatments in **Study 5** and in 97% (41/42) of goats in **Study 6**. The association of synchronisation of oestrus plus supplementation with maize increased the ovulation rate by 43% in **Study 5** and 29% in **Study 6**. An increase in ovulation rate may be the consequence of an increase in the number of small and medium-sized gonadotrophin-responsive follicles, and/or a longer period under high levels of FSH that prolongs the recruitment window (Scaramuzzi *et al.* 1993). However, these results suggest that the increase in the number of recruited follicles is the less likely mechanism, since the total number of small follicles were similar among treated groups in both **Studies 5** and **6**. In these studies, it is possible that the lower rate of atresia and the greater survival of large follicles (gonadotrophin-dependent follicles) led to a greater number of codominant follicles and greater ovulation rates in does supplemented with maize (Nottle *et al.* 1997; Viñoles *et al.* 2005). Therefore, the ovulation rate can be increased by decreasing the sensitivity of the hypothalamic-pituitary-ovarian axis to the negative effect of oestradiol to maintain the concentration of FSH above the threshold level for longer, thus allowing more time for follicles to pass through the so called,

"widened gate" (Baird and Campbell 1998; Meza-Herrera *et al.* 2008; Scaramuzzi *et al.* 2011).

Short-term nutritional supplementation with maize did not affect the concentrations of insulin, leptin and IGF-1 in **Studies 5** and **6** (**Fig. 8.2**). However, in **Study 5**, the interactions between time and supplementation with maize showed that concentrations of insulin, leptin and IGF-1 were greater in does supplemented with maize compared to the does that were not supplemented with maize. We speculate that supplementation with maize affected the concentrations of these metabolic hormones, which could be modifying the sensitivity and responsiveness of follicles to gonadotrophins (**Fig. 8.2**).

In addition, in both **Studies 5** and **6**, concentrations and LH pulse frequency were not affected by nutritional supplementation. The effect of nutritional supplementation on the secretion of gonadotrophins remains confusing and difficult to demonstrate (Viñoles *et al.* 2010). For instance, experimental designs suitable to measure the concentration of LH requires a small number of animals to perform frequent blood sampling, as every 15 minutes. At the same time, a large number of animals are needed to increase the statistical power of the experiment.

The mechanism to explain the effect of nutrition supplementation on ovulation rate is not fully understood, as there is no direct relationship between nutrients and production of a specific hormone or metabolite (Blache *et al.* 2008). The results from both **Studies 5** and **6** suggest that the effect of short-term nutritional supplementation with maize on follicular development and ovulation rate was not mediated by changes in LH secretion, but by increased concentrations of insulin, leptin and IGF-1 **(Study 5**). Finally, the responsiveness of growing follicles to gonadotrophins and, consequently, the reduced rate of atresia may be the mechanism by which synchronised does plus supplementation with maize has increased the ovulation rate.

8.4 Outcomes from this research:

1. This research provided the first comprehensive overview of farming practices related to the management of meat goat producing enterprises within Queensland and New South Wales;
2. This research has gained further knowledge in the seasonality of reproduction of Boer and rangeland female goats raised within the tropical regions of Australia;
3. For an earlier start of the breeding programs, Boer goats may be a better option than rangeland goats, because Boer goats started their breeding season two months earlier;
4. This research is the first to describe the patterns of the ovarian follicular dynamics in the same Boer goats during the non-breeding and breeding seasons;
5. During the non-breeding season, the ovulation rate can be induced and modified by hormonal synchronization of oestrus and nutritional supplementation;
6. This research is the first to demonstrate that 9-days supplementation with relatively low levels of maize to the diets of goats can increase ovulation rates;
7. This research has established that nutritional supplementation with maize at maintenance can be used as a management strategy to increase ovulation rate and potentially improve the prolificacy in female goats raised in the tropics.

8.5 Limitations and recommendations for further research

1. This research did not determine the duration of the breeding season in goats raised in the tropics of Australia;
2. This research did not explain the causes of reproductive seasonality in goats raised in the tropics of Queensland; if is either influenced by photoperiod, heat stress or rainfall;
3. This research did not study the causes that Boer goats were more precocious than rangeland goats to the onset of breeding season;
4. Further research is needed to better understand the effect of nutritional supplementation on female goats metabolic hormones;
5. Further research is needed to study the factors that may be limiting the fertility of Boer goats in rangeland environments;
6. Further work is required to determine the prevalence of gastrointestinal parasites.

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Appendices

Appendix 1: Hormonal Validation

Hormonal and metabolic assays

The concentrations of progesterone, LH surge and insulin (Millipore's porcine insulin) in the plasma samples were determined by RIA or ELISA at James Cook University. Analysis of insulin (double-antibody RIA), leptin, IGF-1 and LH were determined in the RIA laboratory in University of Western Australia.

The precision of each assay was expressed as coefficients of variation (CV) and was estimated from the quality control plasma sample included in each assay. Inter-assay CV: the between-assay coefficient of variation was calculated from the standard deviation of the mean concentrations of different assays (Inter-assay CV = SD/mean). Intra-assay CV: The within-assay coefficient of variation was calculated from the standard deviation among the replicates for samples of plasma (mean ± SEM).

Progesterone

Concentrations of progesterone were determined using either ELISA (**Study 3**) or Radioimmunoassay (**Studies 4, 5** and **6**). The sensitivity of ELISA assays (Access Progesterone 33550, Beckman Coulter Australia Pty Ltd, Lane Cove, NSW) was 0.10 ng/mL (0.32 nmol/L). The intra-assay coefficients of variation for low (0.62 ng/mL) and high (5.81 ng/mL) controls were 9.5% and 6.8%, respectively. The corresponding inter-assay coefficients of variation were 17.3% and 14.5%.

Concentrations of progesterone in plasma were also determined by Radioimmunoassay (RIA) using anti-progesterone antibody-coated tubes (RIA Progesterone IM1188, Beckman Coulter Australia Pty Ltd, Yeerongpilly, QLD). The sensitivity of the assay was 0.05 ng/mL. The intra-assay coefficients of variation for low (0.80 ng/mL) and high (4.55 ng/mL) quality controls were 4.1% and 3.5%, respectively. The corresponding inter-assay coefficients of variation were 13.8% and 9.7%, respectively.

Standards concentrations used in the ELISA assay

The following concentrations were use for the standard curve of progesterone (ng/mL) with ELISA: zero, 0.99, 3.80, 10.10, 19.80 and 40.0 ng/mL. Extra quality controls (low and high) were created.

Parallelism with ELISA assay

Parallelism is a way of determining if the assay is actually measuring what it should be measuring. Parallelism with ELISA was assessed by nine serial dilutions of plasma samples collected from goats in which a CL was observed between days 12 and 15 of oestrous cycle (**Tables 9.1** to **9.3**).

Table 9.1 Parallelism for progesterone validation with ELISA, goat sample 1

Dilution (Sample 1)	**Observed (O) (ng/mL)**	**Calculated Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**16.26**	-	-
90%	13.21	14.63	90.3
80%	13.02	13.01	100.1
70%	11.45	11.38	100.6
60%	10.22	9.76	104.8
50%	9.67	8.13	118.9
40%	7.09	6.50	109.0
30%	5.72	4.88	117.3
20%	3.90	3.25	119.9
10%	2.30	1.63	141.5
			Mean = 111.4%

Table 9.2 Parallelism for progesterone validation with ELISA, goat sample 2

Dilution (sample 2)	**Observed (O) (ng/mL)**	**Calculated Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**18.32**	-	-
90%	16.62	16.49	100.8
80%	15.41	14.66	105.1
70%	13.56	12.82	105.7
60%	11.71	10.99	106.5
50%	8.62	9.16	94.10
40%	7.46	7.33	101.8
30%	5.97	5.50	108.6
20%	5.08	3.66	138.6
10%	2.34	1.83	127.7
			Mean = 109.9%

Table 9.3 Parallelism for progesterone validation with ELISA, goat sample 3

Dilution (sample 3)	Observed (O) (ng/mL)	Calculated Expected value (E) (ng/mL)	Efficacy (%) (O/E)*100
100% (Pure)	**11.95**	-	-
90%	10.66	10.76	99.1
80%	9.58	9.56	100.2
70%	8.93	8.37	106.8
60%	6.81	7.17	95.0
50%	6.09	5.98	101.9
40%	4.89	4.78	102.3
30%	4.09	3.59	114.1
20%	3.09	2.39	129.3
10%	1.56	1.20	130.5
			Mean = 108.8%

Standards concentrations used in the RIA

Extra standards were created by diluting the original standards with zero standards provided in the Kit. The following concentrations were use for the standard curve of progesterone (ng/mL): zero, 0.055, 0.235, 0.47, 1.7, 3.85, 7.7, 11.25 and 22.5 ng/mL. Plasma pools for quality control samples were prepared from high and low concentration of progesterone.

Assay procedure with RIA

Step 1: All tubes were labelled from 1 to 100. Plasma samples, quality controls (QC), Non-specific binding (NSB) and standards (50 µl) were pipetted in duplicate into coated tubes.

Step 2: Tracer of I-125 reagent (500 µL) was added to all tubes before incubation with shaking (350 rpm) at 25^{o}C for 1 hour.

Step 3: The contents of all tubes except the tracers (total counts) were careful aspirated.

Step 4: The tubes were then counted in the gamma counter.

Parallelism with RIA

Parallelism was assessed by four serial dilutions of samples collected from goats in which a CL was observed between days 12 and 15 of oestrous cycle (**Tables 9.4** to **9.6**).

Table 9.4 Parallelism for progesterone validation with RIA, goat sample 1

Dilution (goat 1)	**Observed (O)* (ng/mL)**	**Calculated Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**3.69**	-	-
80%	2.70	2.95	91.4
60%	2.05	2.21	92.7
40%	1.48	1.48	100.2
20%	0.88	0.74	118.8
0%	0.0	0.0	100.0
* Average values from duplicates			**Mean = 100.6%**

Table 9.5 Parallelism for progesterone validation with RIA, goat sample 2

Dilution (goat 2)	**Observed (O)* (ng/mL)**	**Calculated Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**2.65**	-	-
80%	2.13	2.12	100.5
60%	1.65	1.59	103.7
40%	1.11	1.06	104.8
20%	0.59	0.53	111.3
0%	0.0	0.0	100.0
* Average values from duplicates			**Mean = 104.0%**

Table 9.6 Parallelism for progesterone validation with RIA, goat sample 3

Dilution (goat 3)	**Observed (O)* (ng/mL)**	**Calculated Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**4.10**	-	-
80%	3.31	3.28	100.9
60%	2.61	2.46	106.1
40%	1.85	1.64	112.8
20%	1.10	0.82	134.1
0%	0.0	0.0	100.0
* Average values from duplicates			**Mean = 110.8%**

Spiking Recovery with RIA

Spiking Recovery was performed by adding a known amount of progesterone (spiked) into the natural goat plasma sample and its response was measured (recovered) in the assay by comparison between observed and expected results. A spiking working solution of 100 ng/mL progesterone was prepared and then aliquots of 10 µl, 50 µl, 100 µl and 250 µl were added into goat plasma samples.

To prepare the working solution, initially, I dissolved 10 mg of progesterone in 100mL ethanol in a volumetric flask. The concentration of this stock solution was 10^5 ng/mL or 100,000 ng/ mL. To prepare the working solution, I took 0.1 mL (100 µl) of the stock solution and completed to 100 mL. The final concentration for the working solution was 100ng/mL. For the spiking recovery validation, aliquots (10 µl, 50 µl, 100 µl and 250 µl) from 100 ng/mL were added into the three samples of goat plasma measured in duplicates **(Tables 9.7** to **9.9**).

Table 9.7 Spiking recovery for progesterone validation with RIA, goat sample 1

Sample	**Observed (O)[a] (ng/mL)**	**Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
Sample A	**2.66**	-	-
A + 10 µl (1 ng)	3.61	3.66	98.5
A + 50 µl (5 ng)	7.08	7.66	92.4
A + 100 µl (10 ng)	11.80	12.66	93.2
A + 250 µl (25 ng)	15.18	27.66	54.9 [b]

[a] Average values from duplicates. [b] For high values of progesterone, RIA was not accurate.

Table 9.8 Spiking recovery for progesterone validation with RIA, goat sample 2

Sample	**Observed (O)[a] (ng/mL)**	**Expected value (E) (ng/mL)**	**Efficacy (%) (O/E)*100**
Sample B	**0.66**	-	-
B + 10 µl (1 ng)	2.11	1.66	127.1
B + 50 µl (5 ng)	6.53	5.66	115.1
B + 100 µl (10 ng)	12.40	10.66	116.3
B + 250 µl (25 ng)	16.40	25.66	63.9 [b]

[a] Average values from duplicates. [b] For high values of progesterone, RIA was not accurate.

Table 9.9 Spiking recovery for progesterone validation with RIA, goat sample 3

Sample	Observed (O)[a] (ng/mL)	Expected value (E) (ng/mL)	Efficacy (%) (O/E)*100
Sample C	**3.41**	-	-
C + 10 µl (1 ng)	4.22	4.41	95.6
C + 50 µl (5 ng)	7.07	8.41	84.0
C + 100 µl (10 ng)	12.38	13.41	92.3
C + 250 µl (25 ng)	10.37	28.41	36.5 [b]

[a] Average values from duplicates. [b] For high values of progesterone, RIA was not accurate.

Insulin

Insulin concentrations in plasma were quantified by Millipore's porcine insulin RIA kit (MPPI12K; Abacus ALS, Brisbane, QLD). 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. This assay sensibility was 1.611 µU/mL when using a 100 µl sample.

The ratios for observed to expected values for dilution parallelism with the standard curve for the assay was assessed using four 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.

Porcine insulin antibody

Insulin antiserum from Guinea pigs was provided in the kit.

Preparation of standards concentrations

The following concentrations were used for the standard curve of insulin (µU/mL): zero, 0.78, 1.56, 3.125, 6.25, 12.5, 25, 50, 100 and 200). The standard curve was prepared by serial dilutions of the 200 µU/mL standard provided in the kit. To prepare

the serial dilutions, I labeled eight glass tubes and added 1.0 mL assay Buffer to each of the eight tubes. The first dilution was done by adding 1.0 mL of the 200 µU/mL to tube 1, mixed well and transferred 1.0 mL of tube 1 to tube 2, mixed well and transferred 1.0 mL of tube 2 to tube 3, and so one until the transfer 1.0 mL of tube 8 to tube 9.

Quality controls

The Insulin RIA kit provided two quality controls: low (12.2 µU/mL) and high (51.2 µU/mL). Additional quality controls were created by intravenous injection of 50 mL 50% glucose (500 g/L)/animal in two goats, followed by blood collections every 15 minutes until 60 minutes after the glucose infusion (**Fig. 9.1**).

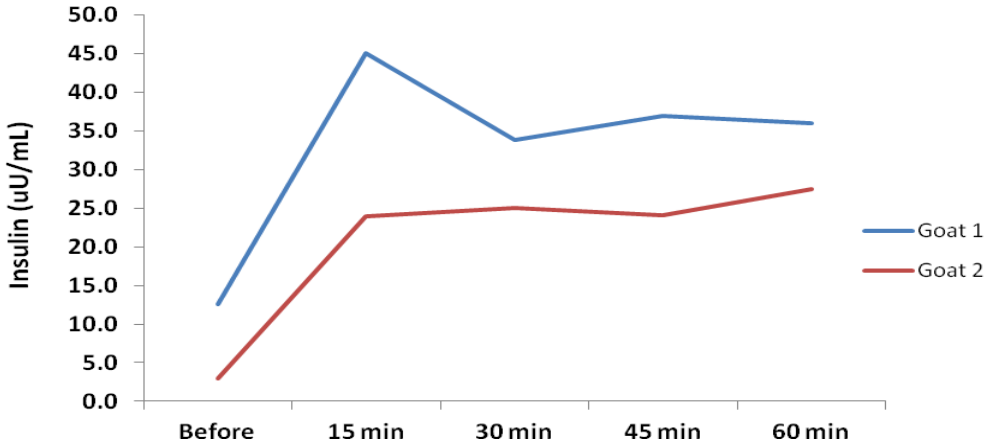

Fig. 9.1 Concentrations of insulin (µU/mL) in two goats after intravenous injection of 50 mL of 50% glucose per animal.

Assay procedure for insulin

Day One

1) Pipette 300 µl of Assay Buffer to the Non-Specific Binding (NSB) tubes (3-4), 200µl to Reference tubes (5-6), and 100 µl to tubes 7 though the end of the assay.
2) Pipette 100 µl of Standards and Quality Controls in duplicate.
3) Pipette 100 µl of each plasma samples in duplicate.
4) Pipette 100 µl of tracer I-125 insulin to all tubes.
5) Pipette 100 µl Porcine insulin antibody to all tubes, except Total Count tubes (1-2) and NSB tubes (3-4).
6) Vortex, cover and incubate overnight (20-24 hours) at 4^{o}C.

Day Two

1) Add 1.0 mL of cold (4°C) Precipitating Reagent to all tubes, except Total Count tubes (1-2).
2) Vortex and incubated for 20 minutes at 4°C.
3) All tubes were centrifuged at 4°C for 20 minutes at 3,000 xG, except Total Count tubes (1-2).
4) The supernatant was decanted in all tubes, except Total Count tubes (1-2). The tubes were drained for at least 60 seconds and the excess liquid from the lip of tubes was removed. The tubes were inverted only once to avoid slipping of pellets.
5) The activity of precipitate (pellets) was determined in the gamma counter.

Parallelism for insulin RIA

Parallelism was assessed by four serial dilutions of three goat plasma samples measured in duplicates (**Tables 9.10** to **9.12**). The slopes of the lines between observed and expected values is shown in Figure 9.2.

Table 9.10 Parallelism for insulin assay validation with RIA, goat sample 2

Dilution (goat 2)	**Observed (O)* (µU/mL)**	**Expected value (E) (µU/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**36.94**	-	-
80%	33.17	29.55	112.2
60%	26.57	22.17	119.9
40%	21.27	14.78	144.0
20%	12.38	7.39	167.6
0%	0.0	0.0	100.0

* Average values from duplicates **Mean = 128.7%**

Table 9.11 Parallelism for insulin assay validation with RIA, goat sample 1

Dilution (goat 1)	**Observed (O)* (µU/mL)**	**Calculated Expected value (E) (µU/mL)**	**Efficacy (%) (O/E)*100**
100% (Pure)	**25.9**	-	-
80%	21.65	20.07	107.9
60%	18.24	15.05	121.2
40%	15.53	10.03	154.8
20%	7.41	5.02	147.7
0%	0.00	0.00	100.0

* Average values from duplicates **Mean = 126.3%**

Table 9.12 Parallelism for insulin assay validation with RIA, goat sample 3

Dilution (goat 3)	Observed (O)* (µU/mL)	Calculated Expected value (E) (µU/mL)	Efficacy (%) (O/E)*100
100% (Pure)	**24.01**	-	-
80%	20.00	19.21	104.1
60%	16.46	14.41	114.2
40%	13.17	9.60	137.1
20%	7.33	4.80	152.6
0%	0.0	0.0	100.0
* Average values from duplicates			**Mean = 121.6%**

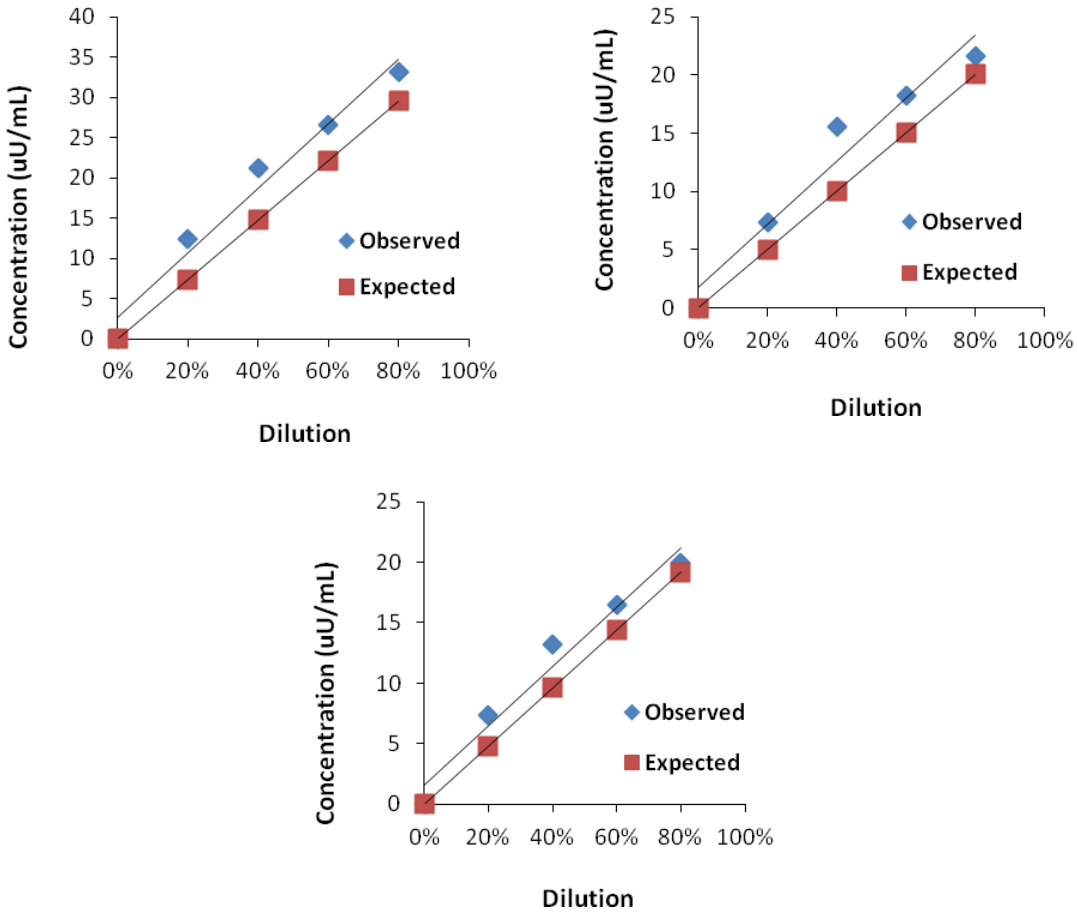

Fig. 9.2 Slopes of the lines between observed and expected values in Parallelism for samples 1, 2 and 3.

Spiking Recovery for insulin RIA

Four concentrations of standard solutions of insulin (6.25, 12.5, 25 and 50 µU/mL) were added to three unknown caprine plasma samples which were determined to have concentrations of 3.03, 12.57 and 40.70 µU/mL. A 50 µl aliquot of each standard solution (6.25, 12.5, 25 and 50 µU/mL) was spiked into 150 µl of each of the three samples of caprine plasma.

Expected values were calculated using the **following steps.**

Step 1. Concentration of insulin in each 50 µl of standard solution

Standard solutions	Concentration (µU/ 1.0 mL)	Concentration (µU/50 µl)
1	6.25	0.31
2	12.5	0.63
3	25	1.25
4	50	2.50

Step 2. Concentration of insulin in each 150 µl of plasma sample

Sample	Concentration (µU/ 1.0 mL)	Concentration (µU/150 µl)
A	3.03	0.45
B	12.57	1.89
C	40.7	6.11

Step 3. Sum of the total concentration of insulin in 200 µl (Step 1 + Step 2)

Sample A (µU/200 µl)	Sample B (µU/200 µl)	Sample C (µU/200 µl)
0.31 + 0.45 = 0.76	0.31 + 1.89 = 2.20	0.31 + 6.11 = 6.42
0.63 + 0.45 = 1.08	0.63 + 1.89 = 2.51	0.63 + 6.11 = 6.73
1.25 + 0.45 = 1.70	1.25 + 1.89 = 3.14	1.25 + 6.11 = 7.36
2.5 + 0.45 = 2.95	2.50 + 1.89 = 4.39	2.50 + 6.11 = 8.61

Step 4. The expected value was the concentration of insulin in 1.0 mL (Step 3 x 5)

Sample A (µU/mL)	Sample B (µU/mL)	Sample C (µU/mL)
0.76 x 5 = 3.80	2.20 x 5 = 10.99	6.42 x 5 = 32.09
1.08 x 5 = 5.39	2.51 x 5 = 12.55	6.73 x 5 = 33.65
1.70 x 5 = 8.52	3.14 x 5 = 15.68	7.36 x 5 = 36.78
2.95 x 5 = 14.77	4.39 x 5 = 21.93	8.61 x 5 = 43.03

Observed and expected values are shown in **Table 9.13**.

Table 9.13 Spiking recovery for insulin validation with RIA

Spiking solution (µU/mL)	Observed (O)[a] (µU/mL)	Expected value (E) (µU/mL)	Efficacy (%) (O/E)*100
Sample A	**3.03**	-	-
A + 6.25	2.71	3.80	71.3
A + 12.5	5.80	5.39	107.6
A + 25	10.29	8.52	120.8
A + 50	18.33	14.77	124.1
Sample B	**12.57**	-	-
B + 6.25	9.88	10.99	89.9
B + 12.5	13.63	12.55	108.6
B + 25	16.07	15.68	102.5
B + 50	24.70	21.93	112.6
Sample C	**40.70**	-	-
C + 6.25	33.42	32.09	104.1
C + 12.5	34.02	33.65	101.1
C + 25	37.16	36.78	101.0
C + 50	45.54	43.03	105.8

[a] Average values from duplicates.

Luteinizing hormone (LH) with ELISA

Concentrations of the LH surge were determined using a quantitative ELISA sandwich test (LH DETECT®, ReproPharm, Nouzilly, France). LH surge was determined to occur when concentrations of LH first reached a concentration corresponding to three times the standard deviation above basal concentrations. The sensitivity of this assay was 0.1 ng/mL. The inter-assay coefficients of variation for low (0.5 ng/mL) and high (4 ng/mL) quality controls were 15.9% and 13.9%, respectively. The corresponding intra-assay coefficients of variation were 12.5% and 7.0%, respectively.

Standards concentrations used in the LH ELISA Kit

The following concentrations of LH were used for the standard curve: zero, 0.06 ng/mL, 0.12ng/mL, 0.25 ng/mL, 0.50 ng/mL, 1.0 ng/mL, 2.0 ng/mL and 4.0 ng/mL

Preparation of reagents and samples:

Before starting the operation, the reagents AC2, AC3, Substrate TMB and STOP were thawed and I allowed the microplate to reach room temperature (+18^{o}C to +22^{o}C). Plasma samples were not diluted; I used pure plasma samples.

Assay procedure for LH assays

Step 1: 100 µl of Standards and 100 µl of plasma samples were placed in a dummy plate (Multiple Well Plate, flat bottom with lid ref: 82.1581.001) to facilitate the transfer to the microplate.

Step 2: Standards and plasma samples were transferred to the microplate using a multichannel pipette then covered using adhesive strip.

Step 3: Microplate was incubated for 45 minutes at 37^{o}C.

Step 4: Microplate was emptied and washed five times by filling up the wells with wash solution of PBS-Tween 20%. Between washes, the microplate was turned over and it was tapped on absorbent paper.

Step 5: Distribution of 100 µl antibody AC2 per well, then cover with adhesive strip.

Step 6: Microplate was incubated for 45 minutes at 37^{o}C.

Step 7: Microplate was emptied and washed five times, as described in Step 4.

Step 8: Distribution of 100 µl antibody AC3 per well, then cover with adhesive strip

Step 9: Microplate was incubated for 45 minutes at 37^{o}C.

Step 10: Microplate was emptied and washed five times, as described in Step 4.

Step 11: Distribution of 100 µl substrate TMB per well, then the plate was covered with foil to avoid the light, and left at room temperature for 15 minutes. The substrate developed a blue colour.

Step 12: Distribution of 50 µl of STOP solution and the plate was taken to spectrophotometer at 650 nm. The colour turned from blue to yellow.

Preparation of 10X Phosphate Buffered Saline (PBS):

NaCl (Sodium Chloride) = 80.0 g

KCl (Potassium Chloride) = 2.0 g

Na_2HPO_4 (di-sodium Hydrogen Orthophosphate) = 14.4g

KH_2PO_4 (Potassium dihydrogen) = 2.4 g

Distilled H_2O was added to make a final solution of 1 Litre.

The final solution should have the pH between 7.2 and 7.4. You can adjust if necessary.

Preparation of the wash solution (PBS Tween 20%):

Step 1: 100 mL of PBS Buffer was diluted in 900 mL of distilled H_2O = 1 L

Step 2: 1 mL of Tween 20% was added in the 1L of solution.

Appendix 2: Questionnaire for the goat survey

Australian Meat Goat Industry Survey

Interviewer: _____

Section 1: General Property Information

Owner/ Manager name: _____

Property/ Station name: _____

Info: 30,000 Acres / **2.47** = 12,145 **ha**

1) Where is your property located? Pastoral district?

   _____

   Latitude: (S) _____ Longitude: (E) _____

2) Local Government authority: _____
3) What is the area of your property (ha)? _____
   a. What % of the property is currently utilised? _____
   b. What % of the property can be potentially utilised? _____
   c. What % is utilised for goat production? ____
4) What is your main livestock enterprise (cattle, sheep, goat, horses, etc)? _____
5) What is the main purpose of running goats?
   a. Weed control
   b. National market
   c. International market
6) How many livestock are carried on the property?
   a. Goats:_____
   b. Cattle:_____
   c. Sheep:_____
   d. Horses:_____
7) How many breeding Does and Bucks does your property run today?
   a. Does: _____
   b. Bucks: ____

Extra How many fulltime workers + Family members? _____

Info: 17 inches **X 25.4** = 431.8 **mm**

8) Do you keep daily **rainfall records**? (yes/no)_____

9) What is the average annual rainfall record for your property (mm)? _____

10) How many paddocks do you have? _____

11) What goat enterprises are carried out on this property?

a. Opportunistic harvesting
b. Breeding stores/ replacements
c. Seedstock producer
d. Breeding-finishing on crop
e. Breeding-finishing on pasture
f. Buying-finishing on crop
g. Buying-finishing on pasture
h. Buying-finishing within feedlot
i. Goatmeat exporter
j. Live goat exporter

12) Does your property run in conjunction with another property? (yes/no)_____

a. If yes, where is the other property? _____

13) Do you buy goats to finish on your property? (yes/no)_____

a. If yes, what age of goat do you buy?
   i. Kids (up to 6 months old)
   ii. 6 months to 1 year old
   iii. 1 to 2 years old
   iv. > 2 years old

14) What nutrient deficiencies affect goat production on your property?

a. Calcium
b. Cobalt
c. Copper
d. Salt
e. Sulphur
f. Phosphorus
g. Protein/Nitrogen
h. Energy
i. Fibre
j. Iodine/ Selenium
f. l) None that I know Other: _____

15) What are the major soil types on your property?

a. Clay soils
b. Brigalow soils
c. Scrub soils
d. Ashy Downs
e. Yellow/ Red Soils
f. Sandy Soils
g. Other type: _____

16) *What is the main source of water your for goats?

a. Bore well
b. Dam
c. Creek or river
d. Municipal water
e. Others:_____

17) *Do you have problem with Rats, mice or other rodents in your property? (yes/no)_____

a) If yes, do they get into feed storage areas? (yes/no)____

Section 2: Pasture Management and Development

18) What is the major browse species on these soils types?

Soil type	Major BROWSE species		% of property	Stocking rate
	Rosewood /Hop bush Gidgee/ Mulga	Bluebush/ Brigalow Leopard/ Mesquite		
	Prickly acacia	Wattle spp.		
	Turkey/ Brown bush Salt bush	Belah/ Black Oak Box/ Cabbage bush		

19) On these soils type what is the major pasture species?

Soil type	Major PASTURE species		% of property	Stocking rate
	Buffel grass	Spear/Summer grass		
	Wire grass	Bindi Grass/ Rhodes		
	Mitchell grass Flinders grass	Panicum Humidicola (*Urochloa* sp.)	Kikuyu: *Pennisetun* Couch grass (*Cynodon* sp.)	

20) How do you rate the condition of your pastures (2011/2012)?

Pasture type	Poor	Average	Good	Very Good

21) How do you rate your Land conditions (2012/2013)? (Poor, Average, Good, Very Good)

22) What is the stocking rate (**carrying capacity**) for the available grazed area? _____

23) How do you determine stocking rate? (**eg. 1 goat / ha** or **1 goat to 2.47 Acres**)

a. Set stock
b. Eye and experience
c. Calculate sufficient stocking rate at the end of growing season using a particular utilization rate
d. Carry sufficient stock to meet income requirements
e. Other way: _____

24) Have you carried out any fencing over the last 5 years?

a. No fencing
b. Yes. Not associated with new waters. If so, see below.
c. Yes. Associated with new waters. If so, see below.

(…) 24) This additional fencing has been used to:

i. Create new paddock
ii. Goat management paddock
iii. Build a new lane
iv. Fence out a problem area
v. Fence. Dog control

25) Have you planned any fencing for the future (yes/no)?

a. No fencing for the future
b. Yes. If yes, what have you planned to do?
   i. Create a new holding paddock
   ii. Create a new main paddock
   iii. Fence out certain country types
   iv. Fence out problem areas
   v. Replace old fence
   vi. Build lane ways
   vii. Fence to land type
   viii. Other fence reason: _____

26) What kind a fence do you use?

a. Plain wire b. Barbed wire c. Electric fence d. Hinge joint

27) Do you have any areas on your property which are salted, eroded, infested or dominated by undesirable weeds?(yes/no)

If yes, on which soil types are these areas?

a. All soils types
b. Brigalow soils
c. Clay soils
d. Scrub soils
e. Ashy Downs
f. Other type of soils_____

28) Do you preferentially graze or spell different paddocks? (yes/no)

29) Do you currently manage areas to encourage pasture regeneration? (yes/no)

30) Do land management issues affect your basic management planning? (yes/no)

a. If yes, please describe in what way? _____

31) What is your policy on the use of fire (yes/no)?

a. Do not burn
b. Control wood weeds
c. Control undesirable pasture species
d. Encourage improved pasture species
e. Reduce rank pasture material
f. Reduce fire risk
g. For grazing management
h. Other fire policy:_____

32) What pasture development strategies do you use (If no, go to next)?

a. Pull trees/vegetation and use native pasture
b. Pull trees/vegetation and sow improved grasses
c. Pull trees/vegetation and sow improved grasses/legumes
d. Poison trees/vegetation and use native pasture
e. Poison trees/vegetation and sow improved grasses
f. Poison trees/vegetation and sow improved grasses/legumes
g. Sow improved grasses under timber
h. Sow improved legumes under timber
i. Blade plough only
j. Blade plough and sow improved grasses
k. Blade plough and sow improved grasses and legumes
l. 'Crash graze' with goats and sow improved grasses/legumes
m. 'Crash graze' with goats and sow use native pasture
n. Broadcast seed into nature grassland
o. Use Fertiliser
p. No pasture development
q. Other strategies: _____

33) How long ago was the most recent pasture development carried out?

a) Never, b)This year/Last year, c) >2 year ago)

34) If pasture improvement has been carried out, what species have been used?

a. Legumes:

i. Stylosanthes sp. ii. Desmanthus sp. iii. Leucaena sp

Other legumes: _____

b. Grasses

i. Buffel grass ii. Urochloa or brachiaria iii. Rhodes grass

iv. Sabi grass v. Mitchell vi. Setaria

vii. Flinders iii. Other grasses:_____

35) Are any introduced **weed species** spreading naturally on your property? (yes/no) _____

If yes, which ones?

a. Native Acacia (gidgee/bone)
b. Prickly Acacia
c. Brigalow regrowth
d. Eucalypt regrowth
e. Rubber vine
f. Mesquite (Prosopis sp.)
g. Chinee apple
h. Thistles
i. Brian
j. Pimelea
l. Billy goat
m. Praxales
n. Lantana
o. Other weeds: _____

36) Do you control any following pests?

a. Feral cats e. Kangaroos

b. Feral pigs f. Foxes, Rabbits & Donkeys

c. Feral horses g. Dogs (dingos)

d. Buffalo/Camel h. Eagles i) Other: _____

37) Are toxic plants reducing the performance of your herd? (yes/no)

If yes, list the toxic plants that you consider to be causing problems: _____

38) Do you implement any management or any strategies to control toxic plants? (yes/no)

If yes, list your strategies to control toxic plants: _____

Section 3: Herd Management and Performance

39) How many goats would you carry during the following types of season?

Class	Poor Season	Average Season	Good Season
Bucks + Kids			
Does			
Total :			

40) Is there a **natural** breeding season for goats? (yes/no). _____

If yes, which months:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec

41) During which months do a majority of kids seem to drop?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec

42) *What is the average liveweight at birth? (kg) _____ ± _____

43) Do you separate kids from their mothers (wean)? (yes/no)

If yes, during what months do you wean?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec

a. If yes, what age do you wean the kids? (months) _____

b. Do you wean your kids according to weight or age? (weight/Age)

c. What is the average liveweight at wean? (kg) _____ ± _____

d. What is your target weaning weight? (kg) _____ ± _____

** Extra** In what age do you Castrate the males (Wethers)? _____

44) In poor seasons, do you wean earlier than normal? (yes/no)____

a. If yes, how old do you wean? (months)_____

45) Do you pregnancy test your females? (yes/no)____

a. What is the % of twins in your herd? _____

b. What is the % of triples in your herd? _____

c. Do you have special management for multiple pregnancies comparing with single pregnancies?(yes/no)____

46) Do you plan to change your age of turn-off in the next 5 years? (No/ Yes older/ Yes younger)

47) Are any classes of animals in the herd segregated from the rest of the herd any time? (yes/no)

a. If yes, which ones? (bucks/ does/ kids)

b. If yes, why? _____

48) Do you generally use rumen modifiers on your goats? (yes/no)____

a. If yes, in what classes of stock? (bucks/ does / both)

b. Which rumen modifiers (bugs for rumen digestion) do you use? _____

49) Do you keep stock records? (yes/no)_____

If yes, what kind?

i. Stock numbers

ii. Sales or Kill sheets

iii. Paddocks records

iv. Births

v. Deaths

vi. Pregnancy status

vii. Supplement records

viii. Other records: _____

50) Do you use any of the following supplements (Yes/No)?

a. Phosphorus (P) only

b. Molasses-urea

c. Molasses-urea-P

d. Molasses-urea-protein meal

e. Molasses-urea-protein-P meal

f. Salt-protein-Sulphur (S) meal

g. Salt-urea

h. Salt-urea-P

i. Mixes (name): _____

j. Protein meal (soy bean)

l. Protein meal (copra)

m. Whole cottonseed

n. Crops

o. Feed blocks

p. Grain

q. Salt-urea-sulphate of ammonia

r. Salt-urea-sulphate of ammonia-P

51) What months do you feed with supplements?

Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Out**	**Nov**	**Dec**

52) What class of animals do you feed?

a. Bucks
b. Does
c. Kids
d. Sheep
e. Cattle
f. Horses

53) What are the main preferred criteria that you select your bucks in your herd?

a. Colour
b. Conformation
c. Temperament
d. Kid Plan
e. Milk production
f. Weight for age Other criteria: _____

54) What are your reasons for culling?

a. Do not cull

Mature bucks

b. Temperament
c. Disease
d. Physical defects/ Conformation
e. Reproductive problems
f. Age
g. Fat
h. Other: _____

Mature does

i. Failure to get pregnant
j. Out of season pregnancy
k. Mastitis
l. Failure to rear a kid
m. Poor quality/performing kids
n. Age
o. Fat
p. Multiple teats; q. Other_____

55) If a doe fails to deliver a kid, what management do you apply?

a. Maiden? (Cull/ Rebreed)
b. 2 years old (Cull/ Rebreed)
c. > 2 years old (Cull/ Rebreed)

56) At what age are Does normally **culled/sold**? (months) _____± _____

57) At what age are Bucks normally **culled/sold**? (months) _____ ± _____

58) At what age do young does (maiden) enter the breeding season herd? (months) _____ ± _____

a. They are always kept in the herd (Not removed)

59) At what age do your does first kid (give birth)? Months _____ ± _____

60) What is the liveweight of your does at first kidding?(kg) _____ ± _____

61) Do you body condition Score (BCS) your does? (yes/no)_____

a. If yes, what is the BCS (range 1 to 5) for does at kidding? _____

62) At what age are young females and males **sold**? _____ ± _____

63) What % of young does is retained for the breeding herd? _____

64) Over the next 5 years what are you going to change to increase or boost profitability? Why?

a. Make no changes
b. Reduce turn-off age
c. Increase turn-off age
d. Increase turn-off weight
e. Reduce death rate
f. Increase herd size
g. Reduce herd size
h. Target markets
i. Improve pasture management
j. Increase marking rate
k. Introduce better quality bucks
l. Introduce new breed
m. Other change: _____

Explain why: _____

65) What are the numbers of your current breed(s) in your herd?

a. Feral (Rangeland goats) Nº:____
b. Boer Nº:____
c. Anglo-Nubian Nº:____
d. Savannah Nº:____
e. Angora Nº:____
f. Toggenburg Nº:____
g. British Alpine Nº:____
h. Saanen Nº:____
i. Cashmere Nº:____
j. Australian Rangeland Nº:____
k. Kalahari/Red Nº:____
l. **Crossbred Boer**: _____

66) What is your desired genotype for doe herd? _____

a. Why?_____

67) What breeds of bucks have you used in the past and numbers?

a. Feral goats Nº:____
b. Boer Nº:____
c. Anglo-Nubian Nº:____
d. Savannah Nº:____
e. Angora Nº:____
f. Toggenburg Nº:____
g. British Alpine Nº:____
h. Saanen Nº:____
i. Cashmere Nº:____
j. Australian Rangeland Nº:____
k. Kalahari/ Red Nº:____
l. Other breed: _____

When did you change to this breed? _____

68) What do you see as the breed(s) of the future for your herd and property? _____

a. Why do you think this breed is important in the future? _____

69) **Do you have records of **pregnancy rate** (Fertility), **kidding rates** (% of kids) and **prolificac**y (kids born to each doe)? (Yes/ No)____

a. What is the Pregnancy (fertility) rate (%)? _____ ± _____

b. If you know, what is the kidding interval (period between two parturitions in months)? ____ to ____

c. If you know, what is the average prolificacy for your does? _____ to _____ (kids/doe)

70) What is the average **kidding rate** (%) for the following seasons?

Class of Livestock	**Poor Season**	Average Season	**Good Season**
Young does (≤ 2 years)			
Old does (> 2 years)			

71) Indicate the type of season (Poor, Average, Good or Excellent), kidding rate and annual rainfall for last three years

Year	**Type of season**	**Kidding rate (%)**	**Rainfall (mm)**
2013			
2012			
2011			

72) How many joined breeding does have you carried over the last 3 years and how many kids were marked (weaned)?

Year	**Number of joined females**	**Number of kids marked (weaned)**
2013		
2012		
2011		

73) *Do you have records of live weight and gains? (yes/no) *(refer to q.42)*

a. What in the average adult live weight (kg) for MALE: _____ ± _____

b. How long does it take to reach an adult weight for males? _____

c. What is the average adult liveweight (kg) for FEMALE: _____ ± _____

d. How long does it take to reach an adult weight for females? _____

Section 3.1) Questions about Animal Health

74) What is your **annual mortality rate** for kids and adults?

Class of Livestock	Good season	Average season	Poor Season
Kids (0 to 3 months)			
Young (4 to 12 months)			
Adults (> 12 months)			

75) What are the possible causes of mortality in your herd? _____

76) **How many kids died last year? _____ *(Refer to q.69)*

77) What was the mortality rate (%) from birth to weaning last year? _____

78) Is it common to find abortions? (Yes/No)

   a. What was the number of abortions last year? _____

79) What is the frequency (%) of abortion in your herd? _____

80) Do you cure the umbilical cord? (Yes/No)

81) What are the main diseases in your herd?

   a. Infections of worms (hydatids, lung worms, nodule worms, etc)
   b. Caseous lymphadenitis (Cheesy gland)
   c. Contagious ecthyma (Scabby mouth)
   d. Caprine Arthritis Encephalitis (CAE)
   e. Infection of lice
   f. Clostridiosis
   g. Coccidiosis
   h. Leptospirosis or Kidney disease
   i. Other disease: _____

82) Do you vaccinate your herd to control any of the following diseases?

   a. Botulism
   b. Enterotoxaemia
   c. Clostridium diseases (5 in 1) or (6 in 1)
   d. Contagious ecthyma (Scabby mouth)
   e. Caseous lymphadenitis (Cheesy gland)
   f. Leptospirosis
   g. Other vaccinations:_____

83) Do you treat your herd for lice control? (yes/no) ____

If yes, when? As required: (yes/no) _____

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec

84) Do you treat your herd against worms (Drench)? (yes/no)____

If yes, when?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Out	Nov	Dec

a. How often do you Drench (1x, 2x, 3x or 4x/year)?_____

b. As required.

85) If you treat for worms, what deworming products did you use in the last three years?

a. Albendazol
b. Oxifendazol
c. Levamisol
d. Fenbendazol
e. Closantel
f. Ivermectin
g. Abamectin + Closantel
h. Doramectin
i. Moxidectin
j. Abamectin
k. Capramec
l. Monepantel (Zolvix)
m. Rametin (organophosphate)

86) Do you use any diagnostic test? (Yes/No) ____

a. F.E.C. (Faecal Eggs Count)
b. Dipstick
c. CMT (Mastitis)
d. Blood collection for _____
e. Famacha: _____

87) Do you isolate sick animals? (Yes/No) _____

88) Do you have a quarantine period for the new animals? (Yes/No) _____

Section 3.2) Questions about Market

89) For what market are you aiming to produce goats?

a. No market
b. Domestic
c. Live Export
d. Prime (restaurant)
e. Stores
f. Carcass Export

What average weight (kg) are the goats? _____±_____ **Carcass weight (kg)?** _____±_____

a. What age? (months)_____

b. What sex do they prefer? (Male/Female) _____

90) Do you follow your goats through the abattoir? (Yes/No)_____

If yes, why?

a. Assess/Plan breeding objectives
b. Animal selection for sale/markets
c. Monitor herd progress/performance
d. Other reason: _____

91) What is the distance of abattoir from your property (km)? _____

92) Do you value the information from the kill sheets (abattoir)? (Yes/No)____

If yes, how?

a. Assess/Plan breeding objectives
b. Animal selection for sale/markets
c. Monitor herd progress/performance
d. Other reason: _____

93) Why do you choose to target a particular market?

a. Price/Financial return
b. Neighbours do it
c. Marketing
d. Suits country –breed mix
e. Prestige
f. Other reason: _____

94) At what age and liveweight do you normally turn-off your goats and for which markets?

Market	Age of turn-off	Liveweight (kg)	Class of livestock
Asia (?)			
Middle East (?)			
USA (?)			

95) Over the last three years what percentages (%) of your sales have gone to the following markets?

Market	2013	2012	2011
Asia (?)			
Middle East (?)			
USA (?)			

96) Indicate the number of goats sold (or transferred) from your property in the last three years.

Year	Males	Females	Total
2013			
2012			
2011			

97) Indicate the average age the classes of livestock are sold. (months)

a. Does: _____ b. Bucks: _____ c. Young animals:_____

Section 4: Source of information and Feedback

98) Do you use a personal computer **to assist you in property management**? (yes/no)

If yes, what do you do with your computer?

a. Internet/e-mail
b. Herd recording
c. Accounting/ Financial record
d. Education
e. Resource mapping
f. Spreadsheets
g. Planning property improvements
h. Word processing

99) What are **your present sources** of property management information?

a. Software/ Internet
b. Field days/ Meetings
c. Advisor/ Consultant
d. Printed material (Newsletters, books, etc). **Which ones?** _____
e. Radio/ TV/ Videos
f. Goats on the move
g. Going into goats guide
h. Other source: _____

100) What is **your preferred method** for the communication of information from research projects?

a. Software/ Internet
b. Field days/ Meetings
c. Advisor/ Consultant
d. Printed material (Newsletters, books, etc)
e. Radio/ TV/ Videos Other source: _____

101) Of the printed material, which do **you find the most useful** to learn about new research findings in property management?

a. Newsletters
b. Newspapers
c. Pamphlets
d. Magazines
e. Other material: _____

102) Of the printed material, which do **you find is the most interesting** information about research findings?

a. Tables
b. Graphs
c. Diagrams
d. Photos Other idea: _____

103) From which do **you find the most useful** as a source of information about research findings and property management?

a. Print media
b. Television
c. Radio
d. Videos
e. Other media: _____

104) From which of the group activities do you feel **you learn the most**?

a. Field days
b. Focus groups
c. Group meetings
d. Face to face with consultants
e. Other activity: _____

105) How are the records that you collect used in the management of your property?

a. I don't make records
b. No use made from my records
c. Assessing herd performance
d. Marketing
e. Brenchmarking
f. Business analysis and planning
g. Monitoring herd size
h. Monitoring resources
i. Plan herd improvement
j. Plan property improvement
k. Seasonal trends
l. Stock number adjustment
m. Taxation
n. Other: _____

106) Do you have any other comments about the factors that affect goat production? What kind of help would you like to receive from Research &Development & Extension Agencies?

_____

_____

_____

_____

Appendix 3: Poster published in conference

Australian Society of Animal Production

JAMES COOK UNIVERSITY AUSTRALIA

Embrapa BRAZILIAN GOVERNMENT BRASIL

The Effect of Hormonal Treatment and Energy Supplementation on Reproductive Performance in Rangeland Goats During the Non-breeding Season: Preliminary Results

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INTRODUCTION

The non-breeding season in goats is related to the day length and latitude (Figure 1). Recent evidence suggests that the stimulatory effects of short-term supplementation are mediated directly at an ovarian level (Scaramuzzi et al 2011). In addition, glucose, fatty acids and several metabolic hormones have all been shown to affect the growth and function of ovarian follicles.

Research question

Can nutritional supplementation modify reproductive response of Rangeland goats during the non-breeding season?

Objective

Evaluate the reproductive response of seasonally anoestrus Rangeland goats that were either hormonally treated and/or supplemented with maize to determine which treatment was the most effective for inducing oestrus and enhancing ovulation rate.

Figure 1. Seasonality of reproduction can limit productivity in goats

MATERIAL AND METHODS

Location: School of Veterinary & Biomedical Science, Townsville (19°19'48" S), Australia.
Animals: 28 female Rangeland goats.
Management: Does were allocated into four groups of seven animals each .
Group 1: Control
Group 2: Maize diet (9 days)
Group 3: Synchronization
Group 4: Synchronization + Maize dict
Ovulation was detected using transrectal ultrasonography (Figure 2)

Experimental Protocol

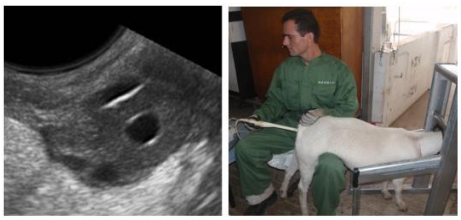

Figure 2. Transrectal ultrasonography in goats

RESULTS

The findings of this study show that hormonal treatment was a highly effective method of inducing oestrus and ovulation in seasonally anoestrus goats. Nutritional supplementation in combination with hormonal treatment did not significantly increase the ovarian responses to treatment (Table 1).

Table 1. Percentage of does in oestrus, interval to onset of oestrus and ovulation rate of goats treated with a combination of either synchronization of oestrus and/or maize supplementation.

Variable	Treatments			
	Control	Maize	Synch	Synch + Maize
Oestrous detection rate (%)	0.0^b	0.0^b	100.0^a	100.0^a
Interval to oestrus (h)	-	-	22.9 ± 3.2^a	22.9 ± 3.2^a
Total number of ovulations (n)	0^b	1^b	16 ± 0.5^a	24 ± 1.6^a
Ovulation rate/doe	0^b	0.1^b	2.3 ± 0.3^a	3.4 ± 0.6^a

Values with different letters in the same row are significantly different ($P<0.05$).

CONCLUSION

Numerical differences in ovulation rates suggest that energy supplementation in combination with the synchronization of oestrus requires further investigation as a mechanism of potentially increasing ovulation rate in seasonally anoestrus rangeland goats, with larger groups of animals.