Use and limitations of alternative feed resources to sustain and improve reproductive performance in sheep and goats

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Abstract

In tropical, semi-arid, and arid areas, animal production is increasingly reliant on supplemental feeding, especially during energetically expensive reproductive seasons. The cost of many traditional feeds restricts their use in many countries, and producers are turning to alternative feed sources. These feed sources may supply the energy and protein requirements for reproduction, but can contain plant secondary compounds that affect various components of the reproductive cycle. In this article, we outline the intake requirements for reproduction in both sexes of sheep and goat, highlighting the importance of timing, as well as quantity, of supplementation on reproductive performance. We investigate examples of various alternative feedstuffs that have been studied throughout

Abbreviations: AFR, alternative feed resources; DM, dry matter; FSH, follicle stimulating hormone; g/h/d, gram per head per day; GnRH, gonadotrophin releasing hormone; LH, luteinising hormone.

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the world, such as willow cuttings, lupin seed, feed blocks, and alternative pasture species. We then review what is known about the effects of these feeds on reproduction in sheep and goats, from the well known estrogenic effects to some positive effects from feeds containing condensed tannins.

Keywords: Energy balance; Timing; Reproduction; Secondary compounds; Sheep; Goat

1. Introduction

Reproductive activity is affected by a range of external factors, including socio-sexual cues, photoperiod and energy balance (Fig. 1). In breeds selected for production in temperate latitudes, photoperiod is a very potent input controlling reproductive activity. Because reproduction is very energetically demanding, energy balance is arguably the next most powerful regulator of reproductive function. Variation in the level of nutrition (and changes in energy balance) can affect the reproductive cycle at almost any stage (Fig. 2). In addition to these short-term effects on the reproductive activity of the parents, nutrition also has long-term effects with consequences for the reproductive capacity of the next generation (Fowden et al., 2006). Therefore, any animal production system will be successful only if flock nutrition is adequate over the whole reproductive cycle, and the requirements of

![Fig. 1. Schematic representation of the relationships between photoperiodic, climactic, nutritional and social cues and the way that they interact with genotype and steroid feedback in the control of the hypothalamo–pituitary–gonadal axis and sexual behaviour in sheep. This model is adapted from the working model used for the study of the relationship between nutrition and reproduction in male sheep (Blache et al., 2003).](image-url)
both males and females are met. In tropical, semi-arid or arid climates it is often difficult to meet these requirements because quantity and quality of forage varies with season, and can be scarce during dry-seasons. Producers in such regions often resort to alternative feed resources (AFR). This paper first introduces the bioenergetics of reproduction, then discusses the effect of nutrition on the reproductive cycle, with a particular focus on the quality of feed but more importantly on the timing of dietary supplementation. Later, we review the successful uses of AFR to improve reproduction, illustrating some limitations in their use with some known effects of secondary compounds on the reproductive system.

2. Reproductive cycle and bioenergetics

A full reproductive cycle starts with the emergence of sexual activity in both sexes of a species and finishes with emergence of sexual activity in the subsequent generation. Different phases of the reproductive cycle differ in their duration between the sexes. Production of sperm takes 49 days in rams, but the interval between ovulations is 17 days in ewes, lactation can last over 14 weeks in dams, and gestation lasts around 150 days in both goats and sheep (Fig. 2). There are energy costs attached to all components of the reproductive cycle, from the expression of specific behaviours, such as sexual behaviour or maternal behaviour, to the production of morphological elements, such as gametes, fetus and milk. In mammals, reproduction is energetically more demanding for the females than for the males, because of gestational development of the young and the production of milk over many months. The energy cost of reproduction also differs in its timing between the sexes, with the male investing most energy before fertilization, while females invest most of their energy following fertilization (Horton and Rowsemitt, 1992). Animals are able to meet the energy cost of reproduction, and produce offspring, only if their energy balance is either positive or slightly negative during the reproductive cycle.

![Fig. 2. Periods during the reproductive cycle of small ruminants when feeding may affect the reproductive success of the flock. Generally, nutritional supplements are beneficial, but early embryo development may be an exception because there is some evidence that overfeeding at that time can provoke embryo mortality. Modified after Martin et al. (2004b).](image-url)
2.1. Energy balance and the reproductive axis

Changes in energy balance, defined as the difference between the pool of disposable energy and the pool of expended energy, can influence any of the three levels of the reproductive axis (hypothalamus, pituitary gland, gonads) as well as impacting on regulatory feedback mechanisms (Fig. 3). Energy deficits, caused by low intake or by excessive expenditure (e.g., exercise, extensive walking to find food), decrease gonadotrophin secretion in both sexes of many species and restoration of normal feeding patterns reverses the gonadotrophin deficit (Vigersky, 1984; Thompson, 1992; Cameron, 1996). Several steps in the reproductive cycle are very sensitive to metabolic inputs. In the female, ovulation is the key step in the control of reproductive activity and ovulation is affected by changes in energy balance (Villa-Godoy et al., 1988; Villa-Godoy et al., 1990). Increasing the plane of nutrition, towards a more positive energy balance, increases the reproductive capacity of both ewes and goats (Sachdeva et al., 1973). In mature rams, similar effects of energy balance on the reproductive axis have been observed. Reduction in feed intake leads to reductions in LH pulse frequency (Martin and Walkden-Brown, 1995), while an increase in energy and protein intake induces an increase in GnRH and LH pulse frequencies, and FSH secretion, within a few days. In the long-term, a sustained increase in nutrition leads to an increase in both sperm production and testis size in both the ram and buck (Martin et al., 1994).
2.2. **Quantity and timing**

In farmed animals, targeted feeding is a very potent tool to manipulate reproduction. Because energy requirements vary throughout the reproductive cycle (Fig. 2), the effect of nutrition on reproduction is dependent on both the timing and the amplitude of the changes in nutritional inputs. Experimental manipulations of nutritional status have begun to reveal when supplementation is favorable and by how much it can affect reproduction in the long-term or the short-term. Recently, a number of reviews have discussed the interactions between nutrition and reproduction in both male and female small ruminants. They all conclude that the timing of supplementation is just as important as the amount of energy provided by the supplement in terms of its effect on the reproductive axis (Blache et al., 2000; Robinson et al., 2002; Blache et al., 2003; Rhind et al., 2003; Rhind, 2004; Blache et al., 2006; Robinson et al., 2006).

3. **How alternative feed sources can be used to meet requirements during the reproductive cycle**

Alternative feed sources are used mainly by producers who do not have access to conventional feed resources or who cannot afford the cost of conventional feed resources. A common problem is a ‘feed gap’ that coincides with dry periods where forage or pasture growth is non-existent or very low. In this context, the use of alternative feed sources to compensate the lack or absence of energy and protein rich pasture is particularly important. In developing countries it forms a vital management tool to sustainable animal production. In the following section, we will describe the effect of nutrition on each step of the reproductive cycle and illustrate how the use of alternative feed stuffs has been successful in sustaining, or sometimes improving, reproduction.

3.1. **Puberty**

In both the male and the female, the timing of sexual maturity, or puberty, is very much dependent on body reserves (Adam and Robinson, 1994). In seasonal breeders, the timing of puberty is especially important because failure to reach puberty in one season results in a year’s delay to reproduction, reducing lifetime production. In many farming systems, it is important that lambs are born as early as possible in the season of abundant, high-quality feed. This allows the progeny to develop fast enough to be pubertal before the end of the next breeding season. An adequate level of nutrition during both pregnancy and post partum is a crucial factor that controls the timing of puberty (Adam and Robinson, 1994; Rhind et al., 2003). Alternative feed resources can be used to improve other aspects of the reproduction cycle. For example, feeding Sudan desert ewes, which are non-seasonal breeders, with groundnut (*Arachis hypogea* L.) seed cake for six weeks before breeding improved their conception rate by almost 30% (El-Hag et al., 1998). Moreover, AFR may be able to provide adequate nutrients to growing animals to reduce their age at puberty, however, to our knowledge, there has been no scientific report supporting this potential application of AFR.
3.2. Male reproduction

In males, under-nutrition reduces sperm production and sperm quality. In addition under-nutrition also affects the libido of rams and bucks as part of a general decrease in vigour (Tilbrook and Cameron, 1990). In extensive systems, the search, and inter-male fighting, for females increases the cost of reproduction for males (Lynch et al., 1992). Even if the cost of reproduction at the gonad level is not extreme, a high plane of nutrition can activate sperm production and increase sperm count in both bucks and rams (Oldham et al., 1978; Cameron et al., 1988).

3.3. Ovulation rate

In grazing animals, ovulation rate can be increased by supplementation with lupin grain (Stewart and Oldham, 1986), soybean meal, or corn grain (Molle et al., 1995; Molle et al., 1997). The timing of the supplementation has been shown to be very important and only a few days (days 5–8 of the oestrous cycle) of adequate supplementation are required to increase the ovulation rate (Oldham and Lindsay, 1984; Stewart and Oldham, 1986). There are some very impressive results from the use of alternative pasture species. Feeding *Lotus corniculatus* has a positive effect on ovulation rate under commercial dry-land farming conditions (for review see Ramirez-Restrepo and Barry, 2005). The high digestibility of *Lotus* compared to white clover pasture and ryegrass could explain this positive effect of grazing sward of *Lotus* on reproduction (Ramirez-Restrepo et al., 2005). Supplementation with tagasaste forage, of moderate to high condensed tannin concentration, also increased ovulation rate but did not improve the survival of twin ova in merino ewes (Wilkins, 1997). In summary, the ovary can be stimulated by a variety of diets as long as the diet can increase the amount of energy and/or protein for a few days at the right time (immediately prior to ovulation).

3.4. Embryo loss

The role of nutrition in fertility and embryo loss is not fully established. The effect of nutrition on the general metabolic activity of the liver, and consequently on the metabolism of ovarian steroids, has been suggested as a possible explanation of the effect of nutrition on early pregnancy. For example, overfeeding during early pregnancy reduces the pregnancy rate in sheep (Parr et al., 1987) mainly because increased liver blood flow leads to more rapid clearance of progesterone (Parr et al., 1993). However, the effects of nutrition on other endocrine factors responsible for the control of implantation, or indeed a direct effect of nutrient intake on the reproductive tract, cannot be ruled out. Alternative feed resources are used mainly in situations when the basal intake is not adequate. Therefore, embryo loss due to overfeeding is not likely to be a major problem, but producers should keep in mind that there is a danger in overfeeding ewes just after mating. On the other hand, under-nutrition can affect embryonic development during the first month of gestation (days 11–21 post mating) if food restriction is severe, such as down to 25% of maintenance requirement (Parr and Williams, 1982). The provision of extra feed before mating can prevent loss of body condition and reduce abortion rate, where AFR can be just as effective as conventional
feedstuffs (e.g., abortion rate reduced by 20% with feeding groundnut seedcake; El-Hag et al., 1998).

3.5. Gestation

Fetal growth follows an exponential curve, with 90% of the birth weight gained during the last 40% of gestation (days 90–150 of gestation in sheep). Gestation costs about 3% of the daily energy expenditure in grazing ewes during the first 3 months and 20% during the last 2 months (Fierro and Bryant, 1990). It is not surprising, then, that under-nutrition in the late gestation period leads to a decrease in the birth weight and the chances of lamb or kid survival. A decrease in maternal body weight of 12% during the first 90 days of pregnancy decreased the fetal weight by 10%, a response mediated through effects on the placenta, as evidenced by the 30% reduction in cotyledon weight (Everitt, 1967). A loss of 7% of body weight, in contrast, was without consequence to the fetus (Wallace, 1948), indicating that fetal growth is buffered to some extent from maternal under-nutrition. This buffering by using maternal reserves for fetal growth and development may have long-term consequences for the mother’s subsequent reproductive performance. Whilst under-nutrition during pregnancy is the most common cause of reproductive failure, over feeding during late gestation should be avoided as it can increase the occurrence of dystocia.

It seems that ewes are more sensitive to under-nutrition during gestation than goats (Squires, 1981). Low protein intake in ewes exacerbates the detrimental effect of restricted energy intake on birth weight. In the longer term, unbalanced nutrition during gestation has consequences on the fertility of the offspring. The level of maternal nutrition affects the timing of puberty in male lambs (Da Silva et al., 2001), cellular structure of the testis (Bielli et al., 2002), and ovulation rate in female lambs (Rae et al., 2001). These effects are due to a fetal programming of the gonads rather than an effect on the hormones controlling their activity (for review see Robinson et al., 2006). Similarly, restricted nutrition during the first weeks of life, pre-weaning, have long-term consequences on the reproductive performance at adult age. In female sheep, under-nutrition or growth restriction during the pre-weaning period reduces the ovulation rate and number of offspring produced (Rhind et al., 1998).

Because lactation accounts for 50% of the daily energy expenditure in grazing sheep (Graham, 1964; Fierro and Bryant, 1990) adequate feeding of the mother during lactation is extremely important. To meet these high requirements, supplementation of extra protein, like soybean meal, can improve milk production in both sheep (Pulina, 2004) and goats (Hadjipanayioutou and Photiou, 1995) when the pasture, stubble, or fodder intake is limited or if the feedstuff is of low digestibility.

3.6. Some successful uses of alternative feed sources to improve reproduction rate

When nutritional requirements are not met, production losses can be severe. In Morocco, early surveys showed that low levels of nutrition (grazing pasture or cereal stubble in summer–autumn) decreased ewe bodyweight at lambing, the lambing rate, the birth weight of lambs, and was associated with an increase of up to 100% in lamb mortality (Chaarani et al., 1991; Chaarani and Robinson, 1992). To overcome these problems, producers in tropical, arid and semi-arid regions have used stubble, fodder, non-conventional pasture,
and feed blocks to sustain, or even improve, reproduction. The more successful use of AFR illustrates the fact that meeting requirements at the right time is the key to improving reproductive performance under challenging conditions.

Supplementation with willow cuttings has improved lamb survival, with the magnitude of response being proportional to the length of time that ewes were offered the willow supplement (McWilliam et al., 2005a). The supplementation with willow cuttings had no effect on conception rate or twining rate, suggesting that the nutritional input was not sudden enough, or high enough, to “flush” the ewes, but adequate to sustain gestation and lactation. Willow cuttings, because it contains condensed tannins, also enhance the essential amino acid supply during critical periods of embryonic development (see Section 4.3). The lack of effect on ovulation rate in the study was attributed to the presence of zearalenone, a toxin produced by a fungi (Fusarium) growing in the pasture (McWilliam et al., 2005a, see below for details). Other experiments have shown that willow cuttings can boost fecundity (conception rates), which in some cases is accompanied by an increase in twinning rate (McWilliams et al., 2005b; Pitta et al., 2005) and in other cases not (Pitta et al. (2007). The variability in the effect of willow blocks on ovulation rate and lamb survival illustrates the fact that these blocks are a particularly effective supplement when environmental conditions such as bad weather (Pitta et al., 2007) or fungal toxins (McWilliam et al., 2005a) are not limiting reproductive performance.

Stubble can be used to sustain reproductive activity, with or without supplementation, according to the nutritional value of the stubble. In ewes grazing oat stubble, supplementation with different levels of sweet lupin (0, 200, 400, 600 g/h/d) during pregnancy had no effect on the number of lambs born, their birth weight, or their growth rate. This suggests that the grazing of oat stubble was adequate to meet the requirements for reproductive function (Brand et al., 1997). However, in Morocco, ewes grazing wheat stubble pastures gave birth to lambs with low birth weight, the lambs grew slowly, and lamb mortality was high (Guessous et al., 1989). The nutrient shortage could be overcome by the addition of sunflower meal and barley (Guessous et al., 1991) or groundnut seed cake (El-Hag et al., 1998). Alternatively, supplementation with a mixture of hay of tall fescue, orchardgrass, alfalfa and white clover can also increase the reproductive performance of ewes grazing stubble (Caballero et al., 1992). When sheep are grazing stubble, which is inherently of low nutritional value, stocking density becomes important and can affect lamb birth weight and lamb growth (Outmani et al., 1991).

The use of feed blocks has been advocated to improve reproductive performance of both sheep and goats, because the blocks preserve well and are easy to use (for review see Ben Salem and Nezzaoui, 2003). Supplementation with urea feed blocks enriched with undegradable protein (cotton seed meal) had a positive effect on the fertility of ewes grazing stubble (Al-Haboby et al., 1999). In lambs going through puberty, semen quality was improved and scrotal circumference was increased by supplementation with molasses–urea blocks (Anindo et al., 1998). However, these effects were dependent on season, reinforcing that not only the quality but the timing of supplementation is crucial for a good return on the nutritional investment. As an alternative to feed blocks, supplementation with urea (8–10 g/day), simply delivered in the drinking water, improved milk yield by 11–32%, and consequently lamb survival by 10%, in merino sheep raised in a dry tropical environment (Stephenson et al., 1981). Feed blocks are a very promising solution to boost reproduction
rate because the composition, quality, and timing of the supplementation can be precisely controlled by producers, thus allowing ease of use of focused feeding to manage flock reproduction (Martin et al., 2004a).

4. Limitation in the use of AFR to improve reproduction

Some AFR contain secondary compounds, produced by the plant as a deterrent to excessive defoliation by herbivores. The nature and the role of some secondary compounds or contaminants are known and, in some cases, their effects on reproductive function have been studied. In the following section, we will discuss some of the most common secondary compounds found in alternative feedstuffs. These compounds can have a negative effect on the reproductive axis either because they are toxic or because they interfere with the system controlling reproductive function (Ben Salem et al., 2001).

A large number of non-conventional feedstuffs contain secondary compounds that are potentially toxic, according to their structure and the rate of intake. Toxic compounds can affect reproduction at almost any level, from attenuation through to inhibition of sperm production in the male, reducing fecundity, increasing embryo loss and inducing abortion in the female, and also having teratogenic effects on the young. In addition, some toxic compounds can affect neonatal development and compromise reproduction in the subsequent adult. The site(s) of action of toxic compound are numerous, from the germ cells to the hypothalamus and pituitary. In the ovary, granulosa cells, thecal cells and oocytes can be impaired by xenobiotics (for review see Mattison, 1993). The toxicity of some plants on specific reproductive organs is well illustrated in a study investigating the effect of supplementation of Ethiopian highland sheep with *Leucaena leucocephala* leaf hay. At 300 g/h/d of Leucaena leaf hay, the sheep gained body weight but the testicular and epididymal size decreased without apparent general toxicity (Dana et al., 2000). The active compound in Leucaena leaf, or its mechanism of action, remains unknown. However, not all secondary compounds are detrimental and some compounds can stimulate reproductive functions, depending on the dose taken and the time when the animal is exposed to them during the reproductive cycle.

4.1. Plant toxins and fungal toxins

Toxic compounds in some AFR, such as alkaloids in lupins and gossypol in cottonseed meal, have a negative effect on reproduction. For example, feeding urea feed block with cotton seed meal reduced semen quality in rams without affecting the libido, suggesting that cotton seed meal (gossypol) has a toxic effect on gametogenesis (Al-Haboby et al., 1999). Also, fungus growing in feed that is contaminated because of a high moisture content (tomato pulp, citrus pulp) could potentially affect the reproductive performance of the flock via mycotoxins. Supplementation with fresh cut poplar (*Populus spp.*) increases reproductive rate, but the effect is inhibited if the feed is contaminated with poplar leaf rust (*Melampsora* spp.) (McWilliam et al., 2004; McWilliam et al., 2005b). Unfortunately, the action of most potentially toxic plant compounds on the reproductive capacity of ruminants has not been studied.
4.2. Phytoestrogens

Many plants and plant products contain phenolic compounds of the flavonoid class that can affect the reproductive performance of herbivores by directly interacting with steroid hormone systems (Oberdorster et al., 2001). These so-called phytoestrogens have structural and functional similarity to estradiol-17β (Jordon et al., 1985) and hence their effects are mediated through interaction with oestrogen receptors (Usui et al., 2002). Negative effects of high levels of certain legume species on mammalian health, and reproduction in particular, have been well documented over the past half a century (Bennett et al., 1946; Morley et al., 1964, 1966; Shutt, 1976; Smith et al., 1979; Smith et al., 1980; Setchell et al., 1987; Adams, 1995, 1998).

Most of the research on infertility due to phytoestrogens (for review see McDonald, 1981) has examined isoflavones in clovers (especially Trifolium subterraneum and T. pratense, red clover), coumestans in medics (especially Medicago sativa, lucerne) and Melilotus albus. The principal isoflavones are formononetin, daidzein, genistein and biochanin A, which can occur in concentrations of up to 5% by weight. For example, mating of ewes grazing on lucerne has been associated with decreased reproductive performance mainly because of the presence of phytoestrogens. Coumestrol (Ramon et al., 1993) and small isoflavones in alfalfa depressed ovulation rate in ewes but did not affect embryonic loss or number of embryos. However, rumen microbes extensively metabolise phytoestrogens and isoflavones, so physiological effects on reproduction are due mostly to the derivative equol. For animals grazing oestrogenic pastures, the effects can be temporary (weeks) if they are moved to non-oestrogenic pasture, or chronic if they graze oestrogenic pastures for longer periods. In the former case, although visible symptoms may not always be present, substantial reductions (up to 20%) in lambing percentage can still occur. In severe cases, permanent infertility can result, with a complete failure of fertilisation, loss of fertilised eggs, and early embryo loss. Oestrus behaviour may also be affected by phytoestrogens; for example, consumption of the shrub Sesbania sesban has a negative effect on the expression of oestrus behaviour in sheep (Melaku et al., 2004), and because the expression of oestrus behaviour is mainly dependent on oestrogen stimulation, it is very probable that Sesbania might contain an anti-oestrogenic compound (Blache and Martin, 1995). Moreover, Sesbania does not seem to act via a metabolic pathway because the body-weight of the ewes was increased by the supplementation with Sesbania (Melaku et al., 2004).

The content of phytoestrogens in alternative feedstuffs needs to be scrutinised before they are utilised, even if they have a good nutritive potential. For example, the grazing of pasture with a high-legume content, or feeding a diet with a high content of grain legume, or grain legume by-products, may be associated with subclinical reductions in fertility (Adams, 1998). Hence, current strategies to avoid infertility have largely been centred on avoiding feeds that are known to be oestrogenic, and the avoidance of high-legume pasture when animals are mated (McDonald, 1981). Another example might emerge shortly from the “miracle tree” (Moringa oleifera), recently described to increase animal productivity (Ben Salem et al., 2001). However, in rats, aqueous extract of Moringa root blocked implantation (Shukla et al., 1988) suggesting that more research on the effect of Moringa leaves on livestock reproduction is required.
4.3. Condensed tannins

Condensed tannins are present in pasture species, trees and shrubs such as willow, poplar, acacia, and lotus. In concentrations greater than 50 g/kg DM, tannins can decrease food intake (Barry and Forss, 1983) and this limits the use of these AFR even though they may have a high protein content suited to improved reproduction. On the other hand, at low or moderate concentrations, tannins can have beneficial effects on reproduction. This positive effect on reproductive performance is not attributed to a reduction in the bioactivity of oestrogenic plant compounds, but to a reduction of protein degradation in the rumen and an increase in amino acid supply to the small intestine (Min et al., 2000; Waghorn et al., 1987). In New Zealand, an alternative pasture species, *Lotus corniculatus* has recently been investigated (Min et al., 1999; Luque et al., 2000; Min et al., 2001; Ramirez-Restrepo et al., 2005). The studies compared ewes grazing *L. corniculatus* with ewes grazing a perennial ryegrass/white clover pasture, and found *L. corniculatus* provided a 5–33% increase in ovulation rate (maximised if *L. corniculatus* was fed for 2–3 oestrus cycles before mating), a 6–39% increase in lambing percentage, and a 14–26% increase in weaning percentage. The effect of *Lotus* on ovulation rate was at least partly dependent on the concentration of active tannins, since the addition of polyethylene glycol to inactivate the tannins decreased the effect of *Lotus* by around 9% (Min et al., 2001). Other effects may include a reduction in the concentration of rumen and plasma ammonia and plasma urea (Min et al., 2001) or changes in the environment of the oviduct and uterus that are conducive to conception, implantation, and fetal development (Ramirez-Restrepo and Barry, 2005).

It is important to stress that the concentration of tannins has to be low to improve reproduction. When present in higher concentrations, tannins can be detrimental to reproduction, but addition of polyethylene glycol alleviates the negative effects of tannins, and offers a simple strategy to improve the effect of plants containing condensed tannins, on ovulation rate, embryo loss (Min et al., 2001) and milk production (Decandia et al., 2000; Gilboa et al., 2000). A more recent study showed that the ovulation rate during the second post-partum cycle was increased by supplementation of polyethylene glycol to goats grazing *Acacia cyanophylla* (Lassoued et al., 2006), a shrub with high tannin content (Ben Salem and Nefzaoui, 2003).

5. Minerals and vitamins

The mineral balance should be considered when feeding goats or sheep with AFR, because dietary deficiency in particular minerals can be detrimental to the reproductive function of both males and females (Table 1). Some alternate forages contain high levels of specific trace elements, for example vitamin E in saltbush (Norman et al., 2004) and selenium in *Astragalus* plants (Pickering et al., 2003), and can be used to compensate the deficiency of some native pastures. However, grazing *Astralagus* species can reduce reproductive performance of the ewe because of the teratogenic effects of selenium on the fetus (Balls and James, 1973; James, 1976).

Some alternative feedstuffs, such as saltbush, contain high concentrations of sodium and potassium (for review Masters et al., 2005). These might not act directly on the
Table 1
Effect of mineral deficiency on reproductive performance of sheep and goat (from Underwood and Suttle, 1999)

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<tr>
<th>Deficiency in</th>
<th>Consequences on reproductive function</th>
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<tr>
<td>Calcium</td>
<td>Milk-fever in ewes</td>
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<td>Poor growth in lambs</td>
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<td>Phosphorus</td>
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<td>Magnesium</td>
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<td>month of lactation in twin-bearing ewes</td>
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<td>Copper</td>
<td>Delayed and depressed oestrus</td>
<td>Effect associated with the presence of molybdenum</td>
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<td>Abortion, dead fetuses</td>
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<td>Iodine</td>
<td>Arrested fetal development</td>
<td>Associated with thyroid dysfunction</td>
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<td>Abortion, stillbirth</td>
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<td>Decline in libido in male</td>
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<td>Post natal mortality</td>
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<td>Growth retardation in the offspring</td>
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<td>Manganese</td>
<td>Depressed or delayed oestrus</td>
<td>Rare occurrence</td>
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<td>Poor conception rate</td>
<td>Effect via reproductive hormone or direct action on the gonads</td>
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<td>Reduction of testicular growth relative to body weight</td>
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<td>Selenium</td>
<td>High level of infertility in ewes</td>
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<td>Increased susceptibility of lambs to cold stress</td>
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<td>Rapid loss of weight in lambs</td>
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<td>Zinc</td>
<td>Block spermatogenesis in lambs</td>
<td>Complete recovery if supplement offer</td>
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<tr>
<td>Chromium</td>
<td>No effect known</td>
<td>Increased insulin sensitivity and glucose utilisation, so could indirectly affect reproductive performance because of misuse of fuel</td>
</tr>
<tr>
<td>Vanadium</td>
<td>No direct effect known</td>
<td>Should not be a problem because sheep are the least susceptible farmed species to vanadium.</td>
</tr>
</tbody>
</table>

reproductive system, but have the potential to affect hormonal systems that link energy balance to reproduction, and so in the long-term inhibit reproduction in sheep and goats. In fact, high intake of NaCl in sheep reduces plasma concentration of insulin (Blache et al., 2007), a hormone known to be involved in the activation of the reproductive system in both males and females (Blache et al., 2006). On the other hand, goats fed on Kallar grass, another salt tolerant plant species that contains high K⁺/Na⁺, showed no change in reproductive performance (Malik et al., 1986). We do not know what caused these differences, but it is possible that the high sugar content of Kallar grass aided...
the maintenance of adequate insulin levels, or that goats tolerated high salt intake better than sheep. However, the effect of high salt intake on reproductive programming has not been studied and requires attention if the use of saltbush is to be increased. Current studies have shown that feeding single-bearing pregnant ewes a high-salt diet to mimic saltbush, with free access to fresh drinking water, did not compromise pregnancy rate or lamb birth weight, but it did affect the physiological responses to salt in the offspring (Digby, Revell, Masters and Blache, unpublished data). Therefore, the use of such alternative feedstuffs during pregnancy should be carefully managed until more information is available on potential effects (positive or negative) on fetal programming (Fowden et al., 2006).

6. Conclusion

The use of alternative feed stuffs is likely to increase because of the need to increase animal production in developing countries and because of the development of sustainable agriculture in countries such as Australia. To use alternative feed sources successfully, the effect of those feed sources on reproduction needs to be seriously considered. More research is required, as has already been pointed out in a recent review on goat production by Morand-Fehr (2005). Alternative feed sources have the potential to either maintain, or even to improve, the reproductive performance of the flock, as exemplified by the use of feed blocks and the use of feedstuffs containing condensed tannins. The key to the successful use of alternative feedstuffs are (1) analysis (and study) of the potential effect of the different components in the feed resource on reproduction (Fig. 4), and (2) management of the supplementation, in terms of both quantity and timing, or rotational grazing of alternative feed sources. Careful management will limit toxicity or other undesirable effects of secondary compounds and allow the exploitation of some unique properties of the secondary compounds, such as exploiting condensed tannins to protect protein from rumen digestion (Makkar, 2005).
References


Oldham, C.M., Lindsay, D.R., 1984. The minimum period of intake of lupin grain required by ewes to increase their ovulation rate when grazing dry summer pasture. In: Lindsay, D.R., Pearce, D.T. (Eds.), Reproduction in Sheep. Australian Wool Corporation, Canberra.


