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Responses to dietary supplementation with field bean (*Vicia faba* var. minor) in production indices, mohair growth and hormonal parameters in transition Angora goats

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ABSTRACT

Twenty-two pluriparous single-foetus-bearing Angora goats, housed 3 weeks pre-partum in mid-December, and in transition from pregnancy to lactation were used to test the efficacy of post-partum supplementation (Group S: 11 goats) or not (Group C: 11 goats) with 300 g/head/day of whole field bean seeds (WFBS) to a diet based on mixed hay ad libitum and natural pasture. The goats were maintained with the suckling of their kids for 90 days. Significant decreases in liveweight (LW) and body condition score (BCS), were documented post-parturition in both groups and were then maintained throughout. These suggest a mobilisation in body tissue that was not mitigated by WFBS supplementation. However, the faster growth of the suckled kids and greater elongation of mohair fibre recorded (Group S > Group C), suggested improvement in partition towards production indices of lactation and hair fibre deposition, respectively. Greater concentrations of total thyroid hormones, T3 and T4 in supplemented does were recorded. Overall mean (pre-prandial) plasma insulin concentrations, not different between treatments, decreased ($p < 0.5$) from pre-partum concentration, and showed a pattern in time, similar to that of LW and BCS. Insulin appeared not to contribute to the suggested lactational and hair growth effects and possibly contributed to transition by a homeorhetic-type reduction in concentration post-partum. Mean plasma insulin-like growth factor-1 (IGF-1) concentrations trended lower due to supplementation from 3 weeks after kidding. It is concluded that WFBS supplementation was efficacious in improving production indices of the transition Angora goats. The feeding of different quantities of WFBS should be investigated.

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Angora goats; transition; lactation; hormones; mohair

HIGHLIGHTS

- Supplementation of transition Angora goats with field bean did not affect the loss of body weight or body condition score occurring after kidding.
- Supplementation with field bean induced higher concentrations of blood thyroid hormones, without affecting post-partum reductions in insulin.
- Supplemented dams had a greater mohair elongation rate and their kids grew more, by likely preferential partition to hair growth and lactation, rather than other body tissues.

Introduction

Inadequate nutrition has been implicated in the poor performance of Angora goat flocks worldwide with feeding allowances poorly defined (McGregor 2021). Nutritional support for transition from pregnancy, parturition and lactation is of particular importance for adult breeding does and for the development of practical systems of husbandry in local environments.

As a guide to lactation potential, daily milk yields peaked at 6 weeks, with an average production of 415–533 g/day under rangeland conditions (Alizadehasl and Ünal 2021). McGregor (2018) reported 45-day yields averaging 1.49 kg/day. The growth of suckling kids was reported by the current authors (Acuti et al. 2009) as an indirect measure of lactational response by dams to supply nutrients.

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Angora goats have been selected principally for essentially continuous growth of the speciality fibre mohair by hair follicles in the skin. There is a particular demand for sulphur-containing amino acids as components of keratins and associated proteins in hair (Galbraith 2000). These cause imbalances which may exacerbate deficiencies in amino acid supply to other tissues. Preferential partition of nutrients towards fibre production has been described even under conditions of nutritional deficit and when secreting milk to contribute to meeting nutritional demands of kids post-partum (Reis and Sahlu 1994).

Dietary energy supplements generally improve live-weight (LW), mohair fibre growth and fibre diameter (McGregor 1998, 2017) and McGregor and Howse (2018). Supplementation with rumen undegradable protein or intestinally-available sulphur-containing amino acids (Shahjalal et al. 1992; Galbraith 1995, 2000) increased yield associated with greater diameter and length of mohair fibres. (Positive responses may be expected where limitations due to individual nutrients are overcome by appropriate additional nutritional supply.

There is particular interest in the use of the nitrogen-fixing legume and field beans (*Vicia faba*) which provide an ecologically and climatically suitable crop in several European countries. O'Kiely et al. (2022) have highlighted particularly the high-quality concentration (e.g. per kg DM and compared with barley grain) of both metabolisable energy (13.4 vs 12.3 MJ) and readily available crude protein (302 vs 116 g). Sauvant et al. (2004) provided data on intestinal protein digestion and supply.

Field beans were the choice of supplement for does and kids described in the earlier report (Acuti et al. 2009). Supplementation after parturition produced greater LWs and improved body condition scores (BCSs) of Angora kids and at weaning at 90 days, for secondary hair follicle activity and mohair staple length, and for diameter at 155 days of age. The impact on does, not yet reported, is needed to advise practical guidance for breeders farming Angora goats under European conditions.

The quantification of internal signalling factors (McElwee and Hoffmann 2000; Galbraith 2010) which regulate development and physiological activity and contribute to the partition of absorbed nutrients and in deficiency, mobilisation of body tissues is also required. Such internal signalling factors may be short term 'acute' affecting homeostasis or longer term 'chronic' and homeorhetic in nature (Bell and Bauman 1997). Examples include the hormones secreted by the thyroid gland as hormonal components of the hypothalamic-pituitary axis, 3-3′-5-triiodothyronine (T3), converted from less active thyroxine (T4) precursor and subsequently inactivated by monodeiodinase enzymes (Rhind and Kyle 2004). Thyroid hormones influence basal metabolism, somatic growth, milk, hair fibre production, biological rhythmicity and the homeorhetic changes during associated physiological transition stages, for example, pregnancy, parturition and lactation (Todini 2007; Todini, Malfatti, et al. 2007; Mancino et al. 2021) foetal hair follicle development and post-natal fibre production (Hopkins and Thorburn 1972; Kenyon et al. 2005). In the data associated with this report (Acuti et al. 2009), significantly greater concentrations of total plasma T4 and T3 were observed in suckling Angora kids with access to lactating dams supplemented with whole field bean seeds WFBS when compared with those unsupplemented. At weaning, T4 values were also negatively correlated ($p < 0.05$) with the secondary fibre diameter, and the T3/T4 ratio was positively correlated ($p < 0.05$) with the secondary to primary hair follicle ratio. Both T3 and T3/T4 values were positively correlated ($p < 0.01$) with staple length at 155 days of age.

Similarly, pancreatic insulin (INS) has a role in the control of nutrient partitioning and metabolic homeostasis in animals (Petersen and Shulman 2018). It binds to receptors on plasma membranes of cells in specific tissues and via signal transduction pathways typically promotes activities such as transporter-mediated glucose transport, glycogen synthesis, lipogenic gene expression and lipogenesis, and suppresses gluconeogenic gene expression and lipolysis. It has a role in the transition of the dairy cow, which typically undergoes rapid changes in nutritional demands for lactation following parturition, particularly where food intake capacity is inadequate, resulting in a change from anabolic to a catabolic state (Bell and Bauman 1997; Kinoshita et al. 2016). In lactating dairy goats, plasma INS levels have been shown to correlate positively with energy intake (Todini, Trabalza-Marinucci, et al. 2007).

While insulin has been ascribed a role as an endocrine peptide hormone, in regulating metabolic fluxes, insulin-like growth factors (IGF-1 and IGF-2) produced by the liver and other tissues, stimulate proliferation and differentiation in a range of cell types (Su et al. 1999; Petersen and Shulman 2018). IGF-1 functions as an important mediator in somatotrophin (ST)-stimulated somatic growth as well as in ST-independent anabolic responses. A role for IGF-1 has been described in the ontogenic development and functional biology of hair follicles and growth of hair by a systemic endocrine-type effect with paracrine action from the local secretion in the dermal papilla (Galbraith 2010). Binding proteins such as IGF binding protein-3 by bovine mammary epithelial cells modulate the availability of IGFs for interaction with receptors on surfaces of cells (Cohick 1998). Exogenous ST mediated by circulating IGF-1 is well recognised to stimulate milk production in dairy cows (e.g. Collier and Bauman 2014), similar to that suggested to occur in lactating dairy goats (Faulkner and Martin 1999) with the additional possibility of paracrine synthesis in mammary tissue (Nielsen et al. 1990; Prosser et al. 1991).

Maintaining appropriate health and welfare is an aim of good nutritional and husbandry practice in successful Angora goat breeding systems involving interdependence of does and kids. The current study tested the hypothesis that supplementation of diets of Angora does with WFBS during the transition from pregnancy to lactation produced efficacious alterations in production indices, which were mediated by changes in certain signalling molecules. Focus is given to body characteristics, mohair fibre growth, and in blood, THs, insulin and IGF-1. It adds to earlier information describing detailed responses of their kids (Acuti et al. 2009).

Materials and methods

Animals and diet

Reference is made to a full description provided by Acuti et al. (2009). Briefly for details, and where methodology differed, the study was carried out in a marginal hilly area of Umbria, Central Italy. 22 oestrus-synchronised and naturally-mated pregnant single foetus-bearing Angora goats, aged 2–5 years with a mean initial LW of 39.5 ± 7.1 kg, were studied. They were housed indoors in mid-December, 3 weeks before expected parturition and were group-fed a basal pregnancy diet of mixed hay *ad libitum*, a mineral-vitamin supplement and shared natural pasture containing leguminous and grass species, on the daily turnout for at least 7 h (Table 1). Following normal pregnancies and after kidding on 7 January ±2 days, the does were allocated into two experimental groups by randomised blocks based on number, age, parity, LW and BCS. They were maintained with natural suckling until their kids attained 90 days of age (4 April). The groups were housed separately and continued to receive the above pregnancy diet either without further supplementation (Control group, C) or with supplementation (Group S) with 300 g/head/day *V. faba* var. minor (WFBS), available during daily housing. The amount of supplementation has been defined following guidance to supplementation of female breeding goats under rangeland conditions (300–500 g) by Santucci et al. (1991). The animals had free access to water.

The hand-plucking technique (Wallis de Vries 1995) was used to collect representative samples of the grass pasture consumed by animals. Dietary intakes of hay and, post-kidding, WFBS were measured daily throughout the study. In the absence of direct measures of herbage intake, estimates were made using recognised methodology for Angora goats (Luo, Goestch, Nsahlai, Moore, et al. 2004; Luo, Goestch, Nsahlai, Sahlu, et al. 2004; American Institute for Goat Research 2020) and confirmed for compliance against calculations of Avondo et al. (2007, 2008) which take into account lactation under Mediterranean conditions and concentration of protein in the dietary concentrate. Samples of all feeds were collected every 15d to measure nutritive value and chemical composition (Association of Official Analytical Chemists 2000) and metabolisable energy (Demarquilly 1981; Table 1). The basal pregnancy diet was designed to meet or to exceed, depending on the stage of growth of pasture, crude protein and metabolisable energy (ME) requirements of lactating Angora goats producing 1 kg milk/day (National Research Council 1981; Luo, Goestch, Nsahlai, Sahlu, et al. 2004; Sahlu et al. 2004; McGregor 2018).

Liveweight, body condition score and hair fibre

Values for goats for LW were recorded monthly and at the same dates, for BCS by 4 trained operators, using

Table 1. Composition of experimental feeds (g/kg dry matter, unless otherwise stated).

Item	Whole field bean	Pasture, Jan–Feb	Pasture, Mar–Apr	Prairie hay
Dry matter, g/kg, as fed-basis	819	347.70	206.80	940.30
Crude protein	252.40	221.80	300.80	62.60
Neutral detergent fibre	188.70	318.50	386.40	621.60
Acid detergent fibre	89.10	158.90	161.80	386
Acid detergent lignin	13.70	20.70	28.50	54.70
Calcium	1.11	5.52	6.01	5.75
Phosphorus	5.21	2.94	5.43	4.01
Metabolisable energy, MJ/kg dry matter	13.06	14.21	13.16	7.16

a 1–5 scale, based on the general aspect of the animal and palpation of the sternum and lumbar vertebrae as described by Santucci et al. (1991). For Score 1, 'sternal fat can be seized with the fingers' and lumbar vertebrae 'with the whole hand'. For Score 5 the 'sternal fat cannot be identified. It cannot be seized' and for the lumbar region, the 'thickness of the tissue mass is so large … that reference marks are list'. The kids were weighed at birth and at 5, 10, 15, 20, 30, 40, 55, 70 and 90 days of age.

Mohair fibre samples were collected from a marked (5 × 5 cm) patch on the mid side of the body, within 1 week after parturition, mid-February, and mid-March.

Thirty randomly selected individual fibres were straightened and measured to the nearest 1 mm of length, using a plastic ruler. Diameter values were determined by an optical fibre diameter analyser (OFDA 100, BSC Electronics Pty Ltd., Western Australia, Australia) on at least 4000 fibres in samples collected in January and March.

Kemp and other large diameter medullated fibres were allocated to a separate category that contained diameter values in excess of 40 μm.

Blood sampling and assays

Blood samples (pre-prandial) were collected from does at 9.00am by jugular venepuncture, at 2 weekly-intervals, from 3 weeks prior to kidding (18 December) to 12 weeks post-kidding (4 April). Samples were collected into 10 mL sodium ethylenediaminetetraacetic acid (EDTA)-containing Vacutainer® tubes, centrifuged at 2500 *g* for 15 min to separate plasma, for aliquoting and storage at −20 °C until assayed, within a few weeks after the completion of samplings. All the hormone concentrations were determined as the average of duplicate determinants. Hormonal assays were validated for precision, accuracy and linearity as described in detail by Acuti et al. (2009). Assays using commercial enzyme immunoassay kits were performed using the automated processor Brio 2 reader (Seac, Firenze, Italy). Absorbance was measured at 450 nm wavelength. For TH, microplates were read also at 405 nm wavelengths, to better fit the calculation of sample concentrations within the first two lowest calibrators. Total concentrations of T3 and T4 in plasma were assayed using kits for use in humans (T3KT1EW and T4KT2EW; Radim, Rome, Italy). Plasma INS was determined using the sheep insulin enzyme-linked immunosorbent assay (ELISA) kit (EIA-2339; DRG Diagnostics, Marburg, Germany). Plasma total IGF-1 concentrations were determined by the IGF-I 600 ELISA kit (EIA-4140, DRG Diagnostics, Marburg, Germany). Intra- and inter-assay coefficients of variation (CVs, %) were, for T3, 2.5 and 3.1; for T4, 3.8 and 4.1; for INS, 3.6 and 5.6 and for IGF-1, 6.3 and 11.1, respectively. The assay sensitivities (detection limits), as declared by manufacturers, were: 0.16, 4.5, 0.025 and 1.29 ng/mL, for T3, T4, INS and IGF-1, respectively.

Statistical analysis

Statistical analysis was performed using the IBM SPSS Statistics for Windows, Version 25.0 software package (IBM 2017). Normality of distribution and homogeneity of variance of data were examined by Shapiro–Wilk and Levene's tests, respectively. Log transformations were applied where necessary to satisfy requirements for a constant variance. A mixed model with repeated measures considering diet (S and C) and time (sampling date) as fixed factors were used for all measured parameters. The goat was considered a random factor. Interaction between the two factors (diet × time) was included in the model when found to be significant in the ANOVA. Values recorded at the beginning of the study were included as a covariate in the LW and BCS models, as was LW at birth in the model for the growth of kids. Models used for the analysis of mohair fibre included values measured at first sampling, as covariates. Pairwise comparisons, post-hoc, utilised Tukey's HSD (honestly significant difference) test. Correlations were estimated by means of Pearson's correlation coefficient (Sokal and Rohlf 1995). Significance was at $p < 0.05$, unless otherwise stated. Tendencies were recognised when $0.05 < p \leq 0.10$.

Results

The composition of the feeds is reported in Table 1. Dietary intakes of hay by does were not affected by the FWBS supplementation for Group S and averaged (daily dry matter ± SD) 750 ± 65 g in both groups C and S. Also, the amount of WFBS concentrate (246 g dry matter) offered to the S goats was always entirely consumed.

Estimates for daily intake of pasture herbage (dry matter) were 810 and 1016 g (C group) and 736 and 942 g (S group) for the periods January–February and March–April, respectively. The impact of consuming the WFBS concentrate was to reduce estimated dry matter intake of pasture by 74 g in both time periods for Group S compared with Group C. Based on the above estimations, values for daily ME intake, were 16.9 and 18.7 MJ for C group does and 19.0 and

21.0 MJ for does in Group S, and for daily ingested crude protein 226.6 and 352.6 g (C group) and 272.2 and 392.3 g (S group) for the same periods, respectively.

Significant decreases ($p < 0.05$ or $p < 0.01$) for LW and BCS between values before, and after, kidding were recorded for does in both groups (Figure 1(a,b)). Subsequent differences in time were not significant. Similarly, there were no effects ($p > 0.05$) due to field bean supplementation between groups C and S at all time points.

Mean LW of kids (Figure 2(a)) was affected by time and diet ($p < 0.001$), being higher in kids of supplemented does ($p < 0.05$), at subsequent time points from 15 days of age for daily LW gain up to weaning (Figure 2(a)).

Mohair fibre length, but not diameter, was greater in samples from the S group (4.86 cm) than those obtained from the C group (3.74 cm) after 2 months of the study (Table 2). Similarly, the percentage of kemp fibres did not differ between treatments. (5.1% vs 5.3% in samples from C and S group does, respectively).

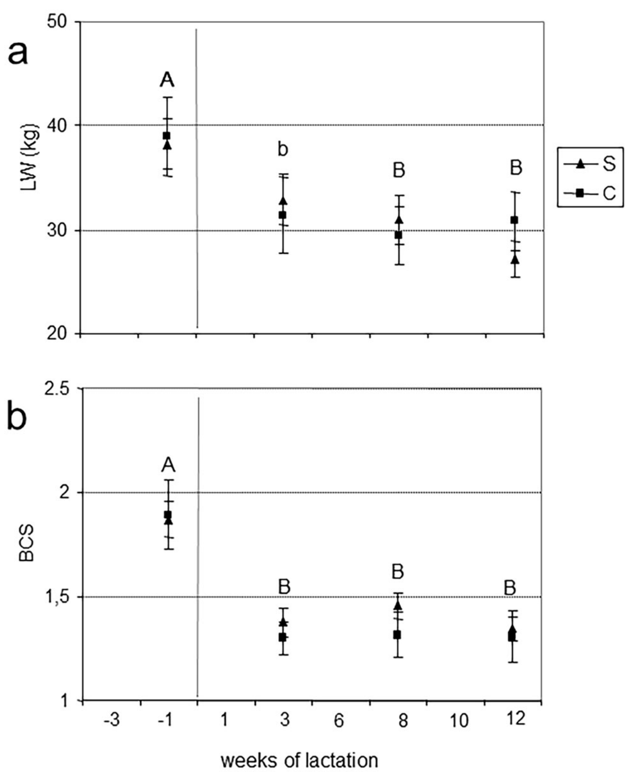

Figure 1. Liveweight (LW) (a) and body condition score (BCS) (b) (mean ± SEM) in lactating Angora goats supplemented (S, $n = 11$) or not (C, $n = 11$) with 300 g/head/day of whole field bean. Different letters indicate significant differences by time. Lowercase letters = $p < 0.05$; capital letters = $p < 0.01$.

Mean total concentrations in plasma of both THs were affected by dietary supplementation and were greater for S compared with C groups. Overall mean (± SEM) concentrations for T3 were 1.81 ± 0.12 and 2.74 ± 0.23 ng/mL and for C and S groups, respectively ($p = 0.02$) (Figure 3(a)). Mean (±SEM) concentrations of T4 were 115.2 ± 5 and 92.3 ± 2.2 ng/mL for S and C groups, respectively ($p < 0.01$) (Figure 3(b)). No statistical effect by time, nor diet × time interaction was observed. Concentrations of plasma T3 and T4 were strongly correlated ($r = 0.75$; $p < 0.001$).

The overall mean (±SEM) for plasma concentration of INS (Figure 3(c)) was 0.08 ± 0.01 ng/mL. No significant differences between dietary treatments nor interaction between dietary treatment and time were found. In the C group, INS concentrations were lower ($p < 0.05$) in samples collected after kidding than in the last week of pregnancy. Plasma INS values were moderately correlated with BCS ($r = 0.5$; $p < 0.05$).

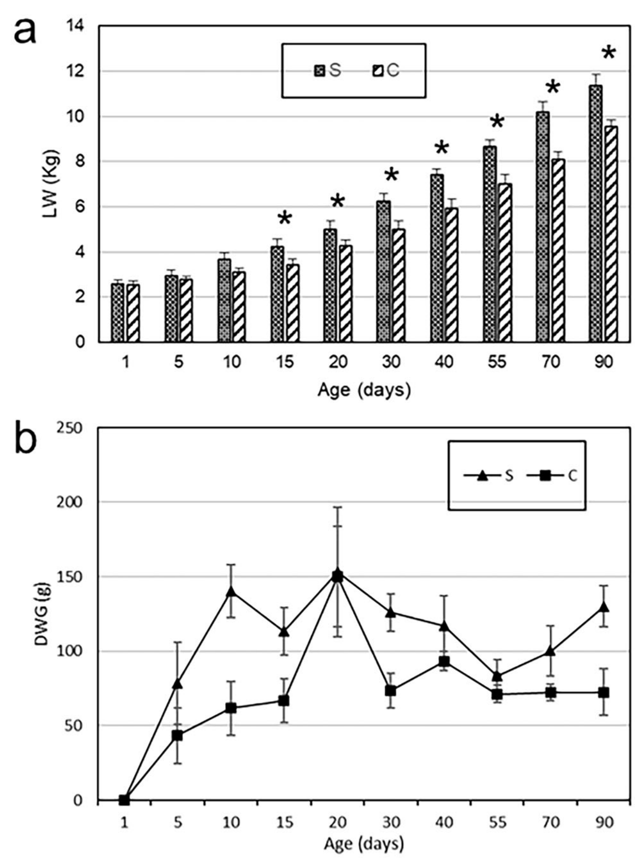

Figure 2. Liveweight (LW) (a) and daily weight gain (DWG) (b) (mean ± SEM) in suckling Angora kids. Diet of the respective dams from kidding was supplemented (S, $n = 11$) or not (C, $n = 11$) with 300 g/head/day of whole field bean. *Significant differences ($p < 0.05$) between groups. Overall daily weight gain means are significantly different ($p < 0.05$) between groups.

Table 2. Fibre length and diameter (mean ± SEM) in lactating Angora goats supplemented (S, $n = 11$) or not (C, $n = 11$) with 300 g/head/day of whole field bean.

Item	Mid-February, 4 weeks after kidding	Mid-March, 8 weeks after kidding
Fibre diameter, μm		
Group S		28.96 ± 2.89
Group C		28.76 ± 1.68
Length, cm		
Group S	1.97 ± 0.05	4.87 ± 0.04 A
Group C	1.85 ± 0.06	3.74 ± 0.06 B

Note. Period of fleece growth from parturition until 4 or 8 weeks after kidding. Where the pre-experimental covariate for the same physical property is significant, the values shown are adjusted for that covariate. Different letters within columns = $p < 0.001$.

For total plasma IGF-1 concentrations (Figure 3(d)), variations and overlap in mean values from −3 to +3 weeks of lactation in both groups, which then diverged, were particularly evident. Values of the supplemented group were consistently lower than for the unsupplemented group at the remaining time points from +3 up to +12 weeks. Overall mean values (±SEM) were 299 ± 59 ng/mL and 246 ± 43 ng/mL for groups C and S, respectively. However, statistical significance due to dietary treatment was not achieved ($p > 0.05$) when tested by conventional ANOVA with repeat measures, although significance ($p < 0.05$) was attained by alternative, paired *t*-test methodology on the values from +3 to +12 post kidding.

Discussion

A challenge in diversifying animal agriculture is the development of successful husbandry and breeding practices for non-traditional species in local environments. The present study investigated the effectiveness of a forage-based diet to supplement with the nitrogen-fixing legume WFBS, on Angora does and their kids in a controlled on-farm environment. The results complement those of a detailed earlier report describing selected responses exclusively in kids (Acuti et al. 2009).

The composition of the feeds (Table 1) was consistent with expected values from previous analyses (Sauvant et al. 2004). The quantities of components of the diets calculated as being consumed, met or exceeded published requirements, for pregnancy and lactation (American Institute for Goat Research 2020) and were well accepted by the goats. These included fibrous prairie hay averaging 760 g/day DMI which was not affected by the inclusion of the WFBS supplement of 246 g/day DMI. Changes in the composition of the grazed herbage gave rise to estimates for the greater intakes of pasture DM, total DM, crude protein and

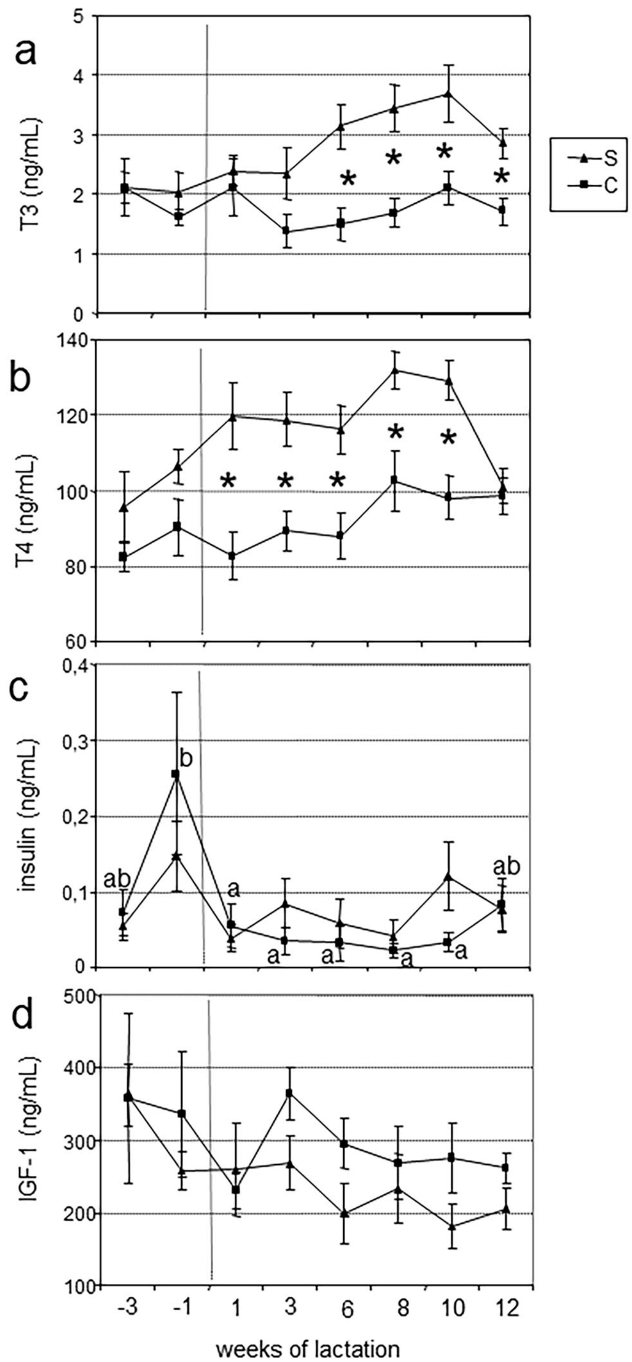

Figure 3. Plasma 3-3′-5-Triiodothyronine (T3) (a), thyroxine (T4) (b), insulin (c), insulin-like growth factor-1 (IGF-1), (d) concentrations (mean ± SEM) in lactating Angora goats supplemented (S, $n = 11$) or not (C, $n = 11$) with 300 g/head/day of whole field bean. *Significant differences ($p < 0.05$) between groups. Different lowercase letters indicate significant differences by time ($p < 0.05$).

ME in both groups of does in comparing January–February and March–April sample collections. Similarly, in comparisons within the individual time periods, the estimated DMI of grazed herbage was reduced by an estimated 74 g for Group S compared with Group C, due to the inclusion of WFBS. The nutritional impact of WFBS included improvement in intakes of ME (11.2%) and CP (20%) during January and February and 12% and 11%, respectively for March and April for Group S, compared with does in Group C. These dietary inputs contributed to the differences in production and physiological parameters observed in does and in the consistent greater growth of kids, from 15 days post-partum, responding to milk output by the does as their major sources of nutrition (Figure 2). Additional information on the response of kids is presented by Acuti et al. (2009).

As expected, removal at the birth of both kid and reproductive tissues from the body of does give rise to reductions in LW measured at week 3 compared with 1 week before parturition and which were not reduced further. Similar reductions in BCS in both groups were also observed which may relate to the mobilisation of body tissues to support lactation such as observed by Santucci et al. (1991) in breeding goats under extensive conditions. These authors also report a similar reduction in BCS at kidding although with a more evident recovery in spring. The lack of difference for LW and BCS between the groups of does, suggests that the improved nutrition provided by WFBS did not produce a benefit in production in addition to that observed in support of the growth of kids and in mohair yield.

In the present study, greater values ($p < 0.05$) in the length of mohair, but not diameter, for Group S compared with Group C, were evident in samples collected at 8 weeks after parturition, suggesting a positive response to supplementation and preferential partitioning to hair follicle synthesis. Interestingly, a marked trend towards greater growth of fibre was evident in the mid-March compared with mid-February sampling, in both groups perhaps reflecting improved nutritional intakes in both groups. In contrast, a change in the partition of consumed nutrients towards LW and body deposition was not apparent.

Conclusions for practical husbandry, of supplementation with WFBS in the present study, suggest benefits in support of growth of kids, via lactation response, and mohair production by breeding does, with possible additional benefit from seasonal improvements in quality of grazed herbage. The response to the higher energy and protein concentration in the diet in early lactation is consistent with the reports of preferential partitioning of nutrients towards the mammary gland and increased milk production although with lesser effect on mohair fibre production (Thornton 1987; Sahlu et al. 1999).

In contrast, in non-lactating animals such as castrate male Angora goats (Galbraith 2000), positive responses were demonstrated to supply good quality protein supplements or intestinally available methionine, but not energy, in yield and diameter of mohair fibre. Both dietary protein and energy supplements increased LW gain, food conversion efficiency, and partitioning of nutrients into body and carcase weights. Similar observations have been made in a range of reports (e.g. Sahlu et al. 1992; Shahjalal et al. 1992; McGregor 1998). Additional considerations relating metabolic adaptations to nutrition and lactation for goats include genotype (e.g. dairy vs fibre-producing: mohair vs cashmere-bearing), physiological state (pre-partum and post-partum conditions) and photoperiod (Russo et al. 2013). However, it is recognised that energy and protein requirements for milk production remain poorly studied and, in review, McGregor (2018) concluded that proposed energy requirements, and potential milk yield by lactating Angora goats, should be revised upwards.

In considering physiological mechanisms and internal chemical signalling, the greater concentrations of both total T3 and T4 in blood plasma of lactating dams in the present study (Group S > Group C) are of interest. Similar results were previously reported (Acuti et al. 2009) in the kids of the study in which those supplemented from weaning with 80 g/head/day of WFBS had greater concentration of the THs than those unsupplemented. Elevated plasma thyroid hormone concentrations have been implicated in the positive responses to supplementary maize grain during pregnancy in dairy goats (Todini, Malfatti, et al. 2007). Khan and Ludri (2002) observed greater concentration in blood of T3 and T4, during the periparturient period, in single-foetus vs twin-bearing cross-breed does. Such data indicate a positive relationship between nutrient sufficiency for does in pregnancy and lactation and concentrations of thyroid hormones in the blood. The context includes interactions with the free form at the cellular level with the main effects produced by T3 (Rhind and Kyle 2004). In a study in 5-month-old wether and doeling Angora goats, exogenous daily T4 administration was shown to stimulate mohair growth rate while decreasing fibre diameter (Puchala et al. 2001).

Considering insulin, the results from the present study indicated an increase in blood concentration (9 h samples) between weeks 3 and 1 pre-partum and a significant decrease by week 1 post-partum. The lower concentrations were similar in both groups and were maintained thereafter although a trend for the increase was apparent by weeks 10–12 particularly in Group S possibly in a late response to the nutritional supplementation. A similar pattern was reported by Ghavipanje et al. (2021), in untreated transition dairy goats in a study to investigate treatment with the alkaloid, berberine. The changes in 'chronic' concentration of insulin in such studies, suggest a role in the longer-term homeorhetic events occurring in the transition from pregnancy to lactation and affecting tissues and organs in the body. The results of lowered concentrations in early lactation are consistent with other reports for other ruminants (e.g. Faulkner and Martin 1999) in which insulin contributes a general anabolic influence during pregnancy. Hence, where chronic INS secretion decreases along with reduced responsiveness (insulin resistance) of non-mammary tissues, this allows mobilisation of catabolic processes, such as lipolysis, to increase the supply of fatty acids, glucose and amino acids to the mammary gland during lactation (Bell 1995; Bell and Bauman 1997). While the capacity for glucose uptake in the mammary gland is increased, this appears to be facilitated by the expression of the non-insulin-dependent GLUT1 transporter and not the insulin-responsive GLUT 4 glucose transporter (Komatsu et al. 2005). The reduction in BCS evident from 1 week before, to 1 week after, parturition and remaining relatively unchanged for subsequent weeks in the present study is consistent with such mobilisation, particularly of adipose tissues. Ghavipanje et al. (2021) report a similar reduction in BCS post-partum in transition dairy goats concomitant with elevated concentrations in blood non-esterified fatty acids.

A general increase in plasma INS concentration has been described (Brockman and Laarveld 1986) in homeorhetic-type response to improved nutrient intake as reductions in competing physiology states occur such as in later phases of lactation (Sibbald and Rhind 1997; Archer et al. 2002). Insulin may also act homeostatically, to reduce glucose concentrations short-term in blood and to stimulate metabolism towards lipogenesis and deposition in adipose tissue. The results may be seen more generally in the context of other studies in ruminant animals in which insulin concentrations responded positively to dietary energy intake (e.g. dairy-breed goats: Magistrelli et al. 2005; Todini, Trabalza-Marinucci, et al. 2007; Celi et al. 2008), and protein (e.g. lactating dairy cows: Blauwiekel and Kincaid 1986; Wheeler et al. 1995).

Considering IGF-1, variable concentrations and overlap for both supplemented and unsupplemented groups were evident from −3 to +1 weeks of lactation with evidence for a reducing trend for the remaining +3 to +12 weeks of the study. This reducing trend was associated with consistently smaller mean values for the supplemented, compared with the control group at all time points of sampling and in which statistical significance by paired *t*-test, but not conventional ANOVA, was attained. The reductions towards parturition in overall profiles of plasma IGF-1 found in the present study have similarities with those reported by Dehnhard et al. (2000) in breeding goats and Gulay et al. (2004) in Holstein cows in which consistently low concentrations were described for the subsequent 4 weeks of lactation. An interpretation of the present results suggests that the dietary supplementation with WFBS did not increase plasma IGF-1 but may be more associated with reduced concentrations compared with unsupplemented controls. This result may be considered inconsistent with the positive correlations between IGF-1 and the level of nutrition reported in goats (Magistrelli et al. 2005) and sheep (Adams et al. 2000), and when related to Somatotropin (ST)-dependent and independent mechanisms (Breier and Gluckman 1991). Elevated concentrations of plasma ST are recognised to increase concentrations of IGF-1, typically from hepatic secretion. Secretion of IGF-1 is also known to become refractory to stimulation by increasing concentrations of ST under conditions of nutritional insufficiency in which reductions in IGF-1 concentrations may occur such as reported in male castrate sheep (Pittroff et al. 2006; Adams et al. 2000). In contrast, Taguchi et al. (2021), report lower values for IGF-1 in the blood of Japanese black heifer calves provided (per day) with 9 L of milk replacer when compared with those given a lesser nutritional input of 7 L/day. In other studies on Merino rams, fed supplements of different legume seeds, variations in hormonal secretions including IGF-1, have been attributed to more subtle differences in chemical constituents and not simply to the content of total energy and protein in the diet (Blache et al. 1996). Furthermore, in breeding ewes, Scaramuzzi et al. (2006), report that plasma IGF-1 concentrations in blood were not affected by nutritional 'flushing', which increased circulating concentrations of INS and leptin and decreased those for ST. The lack of any relationship between circulating IGF-1 and mohair growth supports previous findings in Angora goats treated with bovine ST which had elevated concentrations of both ST and IGF-1 (Davis et al. 1999). In ovine species, systemic endocrine actions of IGF-1 appear to be of limited importance for wool growth (Adams et al. 2000), while its fundamental role in supporting cellular function in the hair follicle, is thought to be paracrine (Su et al. 1999). Interactions with IGFBPs may contribute by retaining IGFs at local sites of synthesis (Breier and Gluckman 1991) with sensitivities of tissues dependent on the presence of active receptors. In the present study, the contribution of similar or lower plasma concentrations of IGF-1, to the response of transition does to the dietary supplement (increased LW gain of kids from apparent increases in milk production, increased hair fibre growth) while maintaining LW and BCS similar to untreated controls, remains unclear.

Conclusions

In conclusion, although dietary supplementation with 300 g/day WFBS and improvement in nutritional supply, had no effect ($p > 0.05$) on LW and BCS reductions post-partum in transition Angora goats, increases were recorded in mohair fibre elongation and in the growth rate of kids. These results support the hypothesis that supplementation with WFBS was effective in improving these production indices under the farm conditions tested. Preferential partitioning of the supplementary nutrition appeared to occur towards the mammary gland and lactation, and integumental hair follicles respectively. Such effects were accompanied by significant increases in plasma thyroid hormone concentrations, while insulin concentrations between Groups C and S, were not significantly different. Insulin possibly contributed to transition after parturition by a homeorhetic-type reduction in concentration which was maintained essentially to the end of the study. Mean plasma insulin-like growth factor-1 concentrations trended lower during lactation due to supplementation.

Further studies could usefully investigate the feeding of greater quantities of WFBS to underpin practical advice on farms concerning nutrition/production relationships and nutrient partitioning in breeding goats.

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Ethical approval

Predating the transposition of European Directive 2010/63/EU into Italian law (Legislative Decree 26/2014), the care and the handling of the animals were in accordance with the guidelines of Italian law on the protection of animals used for experimental and other scientific purposes, in force at that time (DL n.116/1992) and the principles of the Declaration of Helsinki. meeting the Animals in Research: Reporting In Vivo Experiments (ARRIVE) guidelines. The study was planned and performed according to the guidelines of the Animal Ethics Committee of the University of Camerino, Italy. All mandatory laboratory health and safety procedures were complied with during the conduct of the experimental work reported in this paper.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data associated with this paper are available from the corresponding author [LT] upon reasonable request.

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