

Production and chemical composition of milk from sheep supplemented with faba beans and sprouted barley

Producción y composición química de la leche de oveja suplementada con habas y cebada germinada.

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ABSTRACT

Sheep farming plays a vital role in Mediterranean rural economies, but its sustainability is threatened by the high cost of imported protein sources such as soybean meal. This study, carried out in an experimental farm in northeastern Algeria, evaluated locally available alternatives - faba beans and sprouted barley - as substitutes in lactating ewes diet. Thirty Ouled Djellal ewes were randomly assigned to three iso-energetic and iso-nitrogenous diets (16 % crude protein): Three concentrates differing only in protein source: soybean meal, faba beans, or a 50 % faba bean– sprouted barley mix (n =10 per group). Milk yield and composition (fat, protein, lactose, total solids, non-fat solids) were measured, and lamb growth was assessed using average daily gain. Data were analyzed using one-way analysis of variance. No significant differences were observed in milk yield or lamb growth among treatments (P > 0.05). However, milk composition was significantly influenced by diet. Milk protein differed strongly (P < 0.0001), with the (faba beans) group showing the lowest value (4.99 %), significantly lower than (soybean meal) (7.36 %) and the (faba bean– sprouted barley mix) group (6.88 %). Milk fat was higher in the (soybean meal) (6.38 %) and (faba beans) (5.83 %) groups than in the (faba bean– sprouted barley mix) group (5.26 %) (P = 0.043). Lactose was not significantly affected (P = 0.064). Total solids were significantly lower in the (faba beans) group (16.10 %) compared with (soybean meal) (18.09 %) and the mixed diet (faba bean– sprouted barley mix) (18.64 %) (P < 0.002). Non-fat solids were the most sensitive parameter (P < 0.0001): (faba bean– sprouted barley mix) (15.01 %) > (soybean meal) (12.20 %) > (faba beans) (10.68 %). Lamb growth remained stable regardless of treatment. In conclusion, faba beans and sprouted barley can replace soybean meal in lactating ewes without compromising milk yield or lamb growth. The sprouted barley–faba bean mixture is the most balanced option, supporting the use of local legume–cereal combinations as sustainable alternatives to imported soybean meal.

Key words: *Vicia faba*; *Hordeum vulgare*; *Glycine max*; sprouted barley; milk production; lamb growth.

RESUMEN

La cría de ovejas desempeña un papel vital en las economías rurales mediterráneas, pero su sostenibilidad se ve amenazada por el elevado costo de las fuentes de proteína importadas, como la harina de soja. Este estudio, realizado en una granja experimental del noreste de Argelia, evaluó alternativas disponibles localmente — habas y cebada germinada— como sustitutos en la dieta de ovejas lactantes. Treinta ovejas Ouled Djellal se asignaron aleatoriamente a tres dietas isoenergéticas e isonitrogenadas (16 % de proteína bruta): tres concentrados que diferían únicamente en la fuente de proteína: harina de soja, habas o una mezcla al 50 % de habas y cebada germinada (n = 10 por grupo). Se midieron la producción y la composición de la leche (grasa, proteína, lactosa, sólidos totales, sólidos no grasos), y el crecimiento de los corderos se evaluó mediante la ganancia media diaria. Los datos se analizaron mediante análisis de la varianza de una vía. No se observaron diferencias significativas en la producción de leche ni en el crecimiento de los corderos entre los tratamientos (P > 0,05). Sin embargo, la composición de la leche se vio significativamente influida por la dieta. La proteína de la leche difirió notablemente (P < 0,0001), presentando el grupo (habas) el valor más bajo (4,99 %), significativamente inferior al de (harina de soja) (7,36 %) y al del grupo (habas y cebada germinada) (6,88 %). La grasa de la leche fue mayor en los grupos (harina de soja) (6,38 %) y (habas) (5,83 %) que en el grupo (habas y cebada germinada) (5,26 %) (P = 0,043). La lactosa no se vio afectada significativamente (P = 0,064). Los sólidos totales fueron significativamente menores en el grupo (habas) (16,10 %) en comparación con (harina de soja) (18,09 %) y la dieta mixta (habas y cebada germinada) (18,64 %) (P < 0,002). Los sólidos no grasos fueron el parámetro más sensible (P < 0,0001): (habas y cebada germinada) (15,01 %) > (harina de soja) (12,20 %) > (habas) (10,68 %). El crecimiento de los corderos se mantuvo estable independientemente del tratamiento. En conclusión, las habas y la cebada germinada pueden reemplazar la harina de soja en ovejas lactantes sin comprometer la producción de leche ni el crecimiento de los corderos. La mezcla de cebada germinada y habas es la opción más equilibrada, lo que respalda el uso de combinaciones locales de leguminosa y cereal como alternativas sostenibles a la harina de soja importada.

Palabras clave: *Vicia faba*; *Hordeum vulgare*; *Glycine max*; cebada germinada; producción de leche; crecimiento de corderos.

INTRODUCTION

The raising of sheep is important both for the food habits and for the rural economy of the Mediterranean. However, producers in this sector have a permanent constraint, the high cost of feed, and in particular of concentrate feed [1, 2]. A large part of this economic burden can be explained by the reliance on imported feedstuffs, of which soybean meal is the main ingredient. Soybean meal (SBM) is the major source of protein in animal diets, accounting for around 70 % of the world's consumption. Several advantageous qualities can be highlighted to explain the extensive use of the product in dairy ruminant nutrition, such as high crude protein content (44-56 % dry matter (DM)), efficient nitrogen digestibility (80 %), moderate fiber fraction (1.5-6 % DM) and substantial energy density (2.0 Mcal/kg for lactation).

However, the combined pressures of rising market pricing, repeated supply shortages and increasing environmental concerns have led to a re-evaluation of its position in ruminant feeds, either as a partial substitute or as a complete replacement. In this context, the scientific community has increasingly turned its attention to the valorization of locally accessible feed resources and agricultural by-products with the double aim of reducing production costs and enhancing the sustainability of sheep farming systems [3, 4]. Grain legumes, especially *Vicia faba*, are a particularly potential option for soybean meal, because of their high protein and starch portions, of the alternatives now being researched.

Their presence in animal diets benefits simultaneously food security, traceability of the product, soil fertility and a measurable reduction in the usage of synthetic nitrogen fertilizers, as well as a reduced dependency on imported soybean [5]. In the Algerian context, the faba bean is particularly well adapted to the Mediterranean pedoclimatic conditions, notably in the

Northern sections of the nation, where it represents a real chance to reduce the dependence on protein imports. In fact, several studies have shown that the replacement of SBM with legume-based protein sources in the diet of dairy ewes is consistent with the maintenance and sometimes improvement of milk quality, without a decrease in production performance [3].

The use of sprouted barley as a feed alternative for ruminant animals is gaining traction as a sustainable and nutritious option [6]. The germination process increases the general nutritive value of the grain via numerous simultaneous mechanisms, in particular an increase in the crude fibre content [6], chelation of mineral elements [7], and a considerable drop in the concentration of anti-nutritional agents [8]. In beef cattle, its dietary inclusion has been related to positive impacts on growth performance, carcass characteristics and meat quality, as well as an improvement of feed efficiency during the finishing phase [9]. The use of sprouted barley at 11.5 % of dietary DM has been observed to increase milk output by roughly 4.1 %, increase milk protein content, and improve total-tract digestibility of DM and organic matter in nursing dairy cows [10]. Furthermore, production of sprouted barley needs a very small amount of water in comparison to typical forage agriculture, which makes it more sustainable [11].

Meanwhile, Algeria remains significantly dependent on imports of SBM, exposing the national cattle sector to ...

considerable swings on international markets. Prices hit a peak of 85.7 Algerian Dinars (DZD)/kg (647 USD/ton) in March 2022, then dropped to 76.9 DZD/kg (580.7 USD/ton) in November 2023 and finally settled at around 51.4 DZD/kg (388 USD/ton) by the end of 2024 [12]. This instability has been further aggravated by the current geopolitical tensions, especially the Russia-Ukraine war [13], and the seasonal supply and demand patterns, which usually peak in May with the harvest time [14]. Therefore, the development of local protein sources such as faba beans represents a promising strategy for achieving feed self-sufficiency.

Despite the growing interest in alternative protein sources for small ruminants, there exists a paucity of studies that have directly contrasted faba beans and sprouted barley with soybean meal in integrated ewe-lamb systems within Mediterranean conditions.

MATERIALS AND METHODS

This study investigated the effect of including faba beans and barley sprouts on the production, milk quality and growth of lambs.

Study site and climatic conditions

The study was carried out at an experimental farm located in the commune of Messaoud Boudjeriou, in the wilaya of Constantine, northeastern Algeria (36°25'57" N, 6°29'59" E; 640 masl). The commune has long been a fertile agricultural region, thanks to its rich soils (FIG. 1) and abundant water resources, drawn from significant groundwater reserves. Soils are predominantly calcareous brown with a clay-loam texture, characterized by good water retention but a tendency to compaction.

The area is located in a semi-arid Mediterranean climate zone, characterized by cold, wet winters and hot, dry summers, with rainfall concentrated during the cooler months. The farm operates a mixed crop-livestock system managing approximately 500 sheep and goats with barley and wheat as the main forage and grain base.

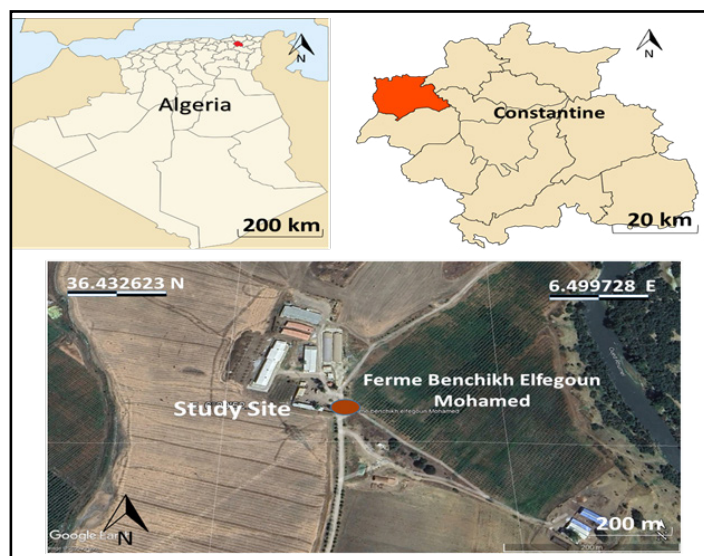


FIGURE 1. Geographic location of the experimental farm (Constantine, Algeria).

Animal management, feeding strategy and experimental design

Thirty clinically healthy Multiparous Ouled Djellal ewes were selected from a flock of 350 based on age and body weight to ensure homogeneity. The animals were 3-4 years old, and weighed 62.92 ± 5.10 kg initially, and 65.15 ± 6.87 kg at allocation after a 15-days (d) adaptation period. Body weight was measured using a digital stainless-steel platform scale 100 kg capacity (model B0DQ8FQF51, France). Ewes were raised and managed under semi-intensive conditions with appropriate housing, hygiene, ventilation and welfare standards. Animals were randomly assigned to three groups (10 ewes each) in a completely randomized design lasting 70 d. Before the trial, ewes were treated with ivermectin (1 mL per 50 kg body weight, given subcutaneously) and given vitamin injections (Multiv-AL®, Vetapharma, Algeria, 3–6 mL per animal, administered intramuscularly). Feed was distributed twice daily (7 AM and 6 PM), with continuous access to water and mineral blocks (ovine mineral supplement, Tromelin Compagnie, France). Average daily gain (ADG) was calculated for the intervals 0–10, 10–30 and 30–60 d.

Three iso-energetic and iso-nitrogenous diets (≈ 16 % CP; 11 MJ/kg DM) were tested: a SBM, a faba bean-based concentrate (F), and a mixed ration of 50 % sprouted barley and 50 % faba bean-based concentrate (FSB). Ewes in (SBM) and (F) received 1200 g concentrate/d; (FSB) ewes received 600 g concentrate plus 1.5 kg fresh sprouted barley (≈ 450 g of original barley grain). Wheat straw was provided *ad libitum* as a fiber.

Sample collection and chemical analysis

Feed samples were collected and pooled by treatment (one composite sample per treatment; three samples in total) and analyzed in triplicate for DM, ash, crude protein (CP), ether extract (EE), and crude fiber (CF) following Association of Official Analytical Chemists (AOAC) procedures [15]; results are expressed on a DM basis.

Nutritive values were estimated using CP and feed evaluation equations of Sauvante *et al.* [16], for energy expressed as feed units for lactation (UFL). The chemical composition of individual ingredients is presented in TABLE I.

TABLE I
Chemical composition of feed ingredients (% of raw feed)

Feed Ingredient	Dry Matter (%)	Ash (%)	Fat (%)	Crude Protein (%)	Crude Fiber (%)
Barley	90.21	5.93	1.89	10.37	6.80
Soybean meal	90.80	7.24	1.50	46.97	3.75
Faba bean	90.29	7.72	1.10	26.72	9.05
Wheat bran	88.45	4.27	1.96	12.78	5.95
Wheat straw	92.40	4.14	0.98	3.73	40.15
Sprouted (germinated) barley	23.00	3.00	2.90	10.43	12.07

The composition of the diets and their calculated nutritive values are summarized in TABLE II.

TABLE II
Ingredient composition (g/kg) and calculated feeding value of the experimental rations.
Feed Unit for Lactation; Crude Protein

Ingredient	(SBM) Group Soybean meal	(F) Group Faba Bean	(FSB) Group 50 % Faba Bean + Sprouted Barley
Barley	700	570	570
Soybean meal	130	0	0
Faba bean	0	260	260
Wheat bran	130	130	130
Mineral-vitamin premix	10	10	10
Limestone	20	20	20
Sodium chloride (NaCl)	5	5	5
Monocalcium phosphate	5	5	5
Sprouted barley	0	0	1500
Feeding			
UFL/kg feed	0.90	0.90	0.95
CP (g/kg feed)	150.3	145.2	145.2

UFL: Feed Unit for Lactation; CP: Crude Protein.

Milk sampling and physicochemical analysis

Milk samples were collected on 0, 30 and 60 day of lactation at 7 AM after foremilk removal. Approximately 20 mL was aseptically collected into sterile tubes and stored at 4 °C until analysis and were transported using a cold-chain transport box (Cold Chain Equipment Company, Algeria). Physicochemical analyses were performed at the Biotechnology Research Center (Constantine, Algeria) using a Milkoscan™ Minor infrared spectrophotometer (FOSS Electric, Hillerød, Denmark), allowing simultaneous determination of fat, protein, lactose, total solids and non-fat solids [17]. Samples were homogenized and ~10 mL of each was deposited on the instrument's sample holder following the manufacturer's recommendations.

Health surveillance and lamb growth performance

The clinical health of ewes and lambs was monitored using a digital veterinary thermometer (GENIA®, 23 cm model, France) and a double-tube veterinary stethoscope (Suprabell®, KaWe, Germany). Lamb body weight (BW) was recorded at birth, 10, 30 and 60 d of age using a calibrated electronic scale (JR5000, Tru-Test Datamars, New Zealand).

Statistical analysis

Data were analyzed by one-way ANOVA using XLSTAT (version 2014, Addinsoft, Paris, France) with diet as fixed effect. Tukey's HSD test was used for post-hoc comparisons. Significance was declared at $P < 0.05$.

RESULTS AND DISCUSSION

The effects of the dietary protein source on milk production, milk composition and lamb growth are summarized in TABLE III and TABLE IV. Analysis of variance showed that milk yield and lamb body weight at 60 d were not significantly affected by treatment, whereas the physicochemical composition of the milk responded strongly: milk protein, fat, total solids and non-fat solids all differed significantly among groups, while lactose was the only component that remained unaffected. Findings are discussed in light of recent international literature, within the framework of improving protein self-sufficiency in Mediterranean livestock systems and reducing dependence on imported protein and to promote the use of locally available resources, such as sprouted barley [18, 19] (TABLE III).

TABLE III

Summary of the effect of dietary protein source on milk production and quality parameters in Ouled Djellal ewes

Parameter	(SBM) Group Soybean meal	(F) Group Faba Bean	(FSB) Group 50 % Faba Bean + Sprouted Barley	P-value
Milk Production (L/day)	1.05 ± 0.09 ^a	1.06 ± 0.06 ^a	1.12 ± 0.06 ^a	0.10
Total solids (%)	18.09 ± 2.95 ^a	16.10 ± 2.11 ^b	18.64 ± 2.23 ^a	0.002
Non-fat solids (%)	12.20 ± 1.54 ^b	10.68 ± 1.39 ^c	15.01 ± 3.25 ^a	0.0001
Milk Protein (%)	7.36 ± 2.23 ^a	4.99 ± 1.26 ^b	6.88 ± 1.72 ^a	< 0.0001
Milk Fat (%)	6.38 ± 1.61 ^a	5.83 ± 1.46 ^a	5.26 ± 1.98 ^b	0.043
Lactose (%)	4.72 ± 0.85 ^a	4.85 ± 0.57 ^a	5.09 ± 0.20 ^a	0.064

Differences among treatments were considered significant at $P < 0.05$, highly significant at $P < 0.01$, and very highly significant at $P < 0.001$. Within each row, means followed by different superscript letters (a, b, c) differ significantly according to Tukey's HSD ($P < 0.05$).

Milk yield

Average daily milk yield did not differ significantly among treatments ($P = 0.10$), showing that replacing SBM under iso-nitrogenous and iso-energetic conditions did not affect daily milk production. Since the mammary gland relies on metabolisable protein absorbed in the small intestine, mostly of ruminal microbial origin, and the three concentrates supplied comparable degradable nitrogen and fermentable energy, microbial protein synthesis and the metabolisable protein flow to the udder remained unchanged. This agrees with previous findings [19, 20], which reported that substituting SBM with legume seeds in such diets does not compromise milk yield, and with Johnston *et al.* [21], who replaced up to 50 % of the protein supplement with F without harming performance.

Milk fat content

Milk fat content was significantly different among the three dietary treatments ($P = 0.043$), with SBM and F showing higher values (6.38 and 5.83 % respectively) compared to FSB (5.26 %). It should be pointed out that all the recorded values are within the physiological range normally reported for sheep milk fat, i.e., between 5 % and 8 % [22]. Contrary to a widespread belief, the polyunsaturated fatty acids (PUFA) delivered by the soy do not stimulate breast lipogenesis on a consistent basis. In dairy calves, these fatty acids are often associated with milk fat depression, which is due to changes in ruminal biohydrogenation pathways and the production of trans-isomers that are known to impede lipid synthesis [23]. Conversely, small ruminants respond differently as PUFA-rich supplements generally maintain or increase milk fat secretion in ewes and goats, essentially due to greater availability of preformed fatty acid precursors (C18:1, C18:2) from plasma to mammary tissue [24], a trend consistent with the results of Zeola *et al.* [25] and Nguyen *et al.* [26]. The lower fat concentration found in the FSB group may be explained in this context by the diluting effect of a more quickly fermentable and energy rich ration, which could alter the ruminal acetate-to-propionate ratio and so, reduce the supply of lipogenic precursors [27].

Milk protein content

Milk protein was the most discriminant variable among all the characteristics considered

($P < 0.0001$). The lowest concentration was found in the F group (4.99 %), which was substantially lower than the SBM (7.36 %) and FSB (6.88 %) groups that did not vary statistically. This result can be explained by the high solubility of faba bean proteins and its rapid degradation in the rumen, which favors nitrogen losses as ammonia when the supply of fermentable energy is insufficient, and reduces the amount of bypass protein available for casein synthesis [28]. Combining sprouted barley with F improves rumen energy–nitrogen synchronization: fermentable starch from barley provides ATP at the same time as degradable nitrogen is released from F, enhancing microbial protein synthesis [29].

Lactose, total solids and non-fat solids

Lactose was the only non-significant parameter (4.72 - 5.09 %, $P = 0.064$), reflecting its role as the main osmotic regulator of milk: its synthesis depends more on genetics and lactation stage than on diet [22, 27]. Total solids were significantly affected ($P = 0.002$). Group (F) showed a lower value (16.10 %) than (SBM) and (FSB) (18.09% and 18.64% respectively), reflecting reduced fat and protein in the (F) diet. Non-fat solids were the most responsive parameter ($P < 0.0001$), with the highest values observed in FSB (15.01 %), followed by SBM (12.20 %) and F (10.68 %), highlighting the synergistic effect of combining sprouted barley and faba beans on the non-fat fraction, mainly driven by improved microbial protein synthesis [29].

Lamb growth performance

Average daily gain during the first 10 d was slightly higher in lambs from FSB ewes than in F and SBM groups, but differences were not significant ($P > 0.05$). Similarly, ADG over 10–30 d tended to be higher in (FSB) (199.0 ± 16.13 g) than in (F) (183.8 ± 15.75 g) and (SBM) (182.3 ± 23.01 g) groups ($P > 0.05$). The dietary protein source provided to ewes during late gestation and lactation therefore had minimal influence on early postnatal lamb growth (TABLE IV).

TABLE IV
Growth and body weight of lambs as a function of maternal dietary protein source.

Parameter	(SBM) Group Soybean meal	(F) Group Faba Bean	(FSB) Group 50 % Faba Bean + Sprouted Barley	P-value
Birth weight	4.41±0.56	5.11±0.62	4.82±0.44	
ADG 0–10 days (g.day ⁻¹)	225.0 ± 31.35	245.5 ± 34.19	256.0 ± 26.18	0.08
ADG 10–30 days (g.day ⁻¹)	182.3 ± 23.01	183.8 ± 15.75	199.0 ± 16.13	0.10
ADG 30–60 days (g.day ⁻¹)	146.86 ± 38.74	115.4 ± 27.40	139.0 ± 32.55	0.211
Body weight at 60 days (kg)	14.62 ± 0.64	14.70 ± 1.04	15.53 ± 1.45	0.427
Differences among treatments were considered significant at P<0.05, ADG: Average daily gain.				

The birth weights differed substantially among treatments F, FSB, and SBM, constituting a major confounding factor. Birth weight is a key determinant of pre-weaning growth in North African and Mediterranean breeds [30], with reported correlations to weaning weight of 0.45–0.70 [31]. Despite a lower initial weight (≈ 1.4 kg difference), lambs from FSB and SBM groups achieved similar or greater 60 d body weight than those of the F group, indicating a compensatory growth effect.

During early growth (0–10 and 10–30 d), ADG did not differ significantly among the three groups. Although the P-values were close to the significance threshold (P = 0.08 and P = 0.10, respectively), the FSB group showed the highest ADG, followed by the F and SBM groups. The trends are biologically plausible and may have been masked by sample size and within-group variability. The advantage of (FSB) can be explained by: (i) improved nutrient digestibility from enzymatic activation during germination [32, 33]; (ii) enhanced rumen microbial activity and volatile fatty-acid production [33]; and (iii) increased bioavailability of vitamins (B-complex, E) and endogenous enzymes, with reduced anti-nutritional compounds [9].

Hydroponic barley reduces feeding costs without compromising milk yield or composition [18, 34] and may improve lamb growth [18], in line with reports that processed legume grain-based supplements in dairy sheep diet and germinated feeds do not negatively affect lamb performance [35, 18].

During the 30–60 d period, a shift occurred: the SBM group showed a trend to a higher ADG, followed by FSB and F groups (P = 0.211). This coincides with the transition phase when lambs consume solid feed while milk production declines after its peak at 21–30 d postpartum [36]. At this physiological stage, milk quality, and especially protein content, becomes a determining element in lamb development. The improved performance observed with the SBM diet can be reasonably explained by the high palatability of this ingredient and by the balance of its amino acid profile, which is characterized by a high proportion of essential amino acids (about 45 %), and particularly lysine and methionine, two amino acids known to be pivotal for the synthesis of milk proteins [37]. Furthermore, increasing the levels of SBM in the diet has been shown to boost both milk supply and protein output, giving a more favorable nutritional substrate for lamb growth during mid-lactation [38].

The relatively lower performance obtained in the F group may be due to the existence of different anti-nutritional compounds such as phytates, tannins, saponins, lectins, oligosaccharides and protease inhibitors, which are known to reduce the utilization of nutrients, to compromise the digestibility of proteins and to generate oxidative metabolites [39]. In ruminant species, however, the microbial activity of the rumen somewhat offsets the detrimental effects, which are further reduced by heat treatment (121 °C for 30 min) [40].

Differences between treatments were observed in the early phase, but the overall zootechnical performance tended to converge: the total BW gain during the 0–60 d interval (9.59–10.71 kg) and the final BW at 60 d (14.62–15.53 kg; P = 0.427) did not differ significantly, which is suggestive of compensatory growth. Indeed, it has been observed that the growth of lambs is more related to the absolute volume of milk supply than to small changes in milk composition [41].

CONCLUSION

The present results show that F and FSB can be utilized successfully as replacement for soybean meal in the diet of Ouled Djellal ewes, without any adverse influence on milk yield or lamb growth performance. Adding sprouted barley helped to improve the levels of milk protein and non-fat solids, but using only F tended to decrease the levels of both milk protein and total solids, unless there was enough extra energy from another source. Of the three regimens tested, the (FSB) ration resulted in the best-balanced response, maintaining an appropriate level of milk fat, bringing protein concentrations back to values similar to those obtained with the (SBM) diet and resulting in the highest content of non-fat solids.

On the other hand, lamb growth was not affected by any treatment, which shows that milk output is much more important than small changes in milk composition in the early days of life after birth. These results also highlight the necessity of taking into account the moisture content of sprouted diets, a characteristic that could have a non-negligible impact on the actual absorption of nutrients.

Overall, the utilization of faba beans and sprouted barley appears to be a practical, economically feasible and environmentally sustainable option to SBM, capable of maintaining milk quality, guaranteeing adequate lamb growth

and contributing to increased protein self-sufficiency in Mediterranean sheep production systems.

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Conflicts of interest

The authors declare no conflict of interest.

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