



Research article

The effect of using diet supplementation based on argane (*Argania spinosa*) on fattening performance, carcass characteristics and fatty acid composition of lambsSana Moutik^{a,b,**}, Aouatif Benali^b, Mohammed Bendaou^b, El Haj Maadoudi^b, Mohammed Rachid Kabbour^b, Abdellah El Housni^b, Nour Eddine Es-Safi^{a,*}^a Mohammed V University in Rabat, LPCMIO, Materials Science Center (MSC), Ecole Normale Supérieure, Rabat, Morocco^b INRA, CRRA-Rabat, P.O. Box 6570, Rabat Institutes, 10101, Rabat, Morocco

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ABSTRACT

The current study was performed in order to evaluate the effect of using argane by-products (oil cake and pulp) as fattening diet of lambs. This was achieved through an experimental lamb fattening investigation using argan by-product as feeding source and the exploration of the fattened lamb performance, carcass characteristics and the chemical fatty acid composition of the quality produced meat.

Twenty fattening Sardi lambs (26 ± 0.5 kg body weight and six months old) were divided into two ($n = 10$) homogenous experimental and control groups. Argane by-products (ABP) and traditional (CF) diets have been used for feeding the experimental and control groups respectively during a period of 75 days. The results obtained for both groups were used to determine the effect of feeding argane by-products on animal weight, average daily gain (ADG), carcass weight, muscle pH values, dressing %, dry matter, ash, ether extract, crude fiber, crude protein, and fatty acid composition.

The obtained results showed that the experimental ABP group lambs had higher average daily gain and meat chemical, crude protein and ash and proportion of C18:0 than the control CF group lambs, while the control CF group had a higher feed conversion ratio, ether extract, mesenteric and perirenal fat. The results obtained for pH₀ and pH₂₄ were similar for both explored groups. The obtained results showed thus that the use of ABP as a diet to fattening lambs increased their performance and lean meat yield.

1. Introduction

The fattening of lambs for slaughter constitutes an important activity in the field of sheep farming in Morocco. This activity is practiced by breeders in order to increase lamb performance such as carcass weight and then improve farmers income. The global objective of any lamb fattening is to produce, in large quantities, profitably, a quality product, sought after by consumers. In a general manner, the fattening can be done in the grass or in a sheepfold, the latter being the most dominant in Morocco. This could be explained by the fact that rainfall is more and more rare in some regions. This could also be explained by the fact that sheepfold fattening gave better results in term of performance and carcass characteristics.

Lambs are generally fed mainly using concentrates and sold after a short period of fattening. The use of food ratios remained however relatively expensive constituting an unstimulating factor for high production (Poncet et al., 2003). According to previously reported data, these diets are also characterized by a low fiber content, a protein level below the norm, a high proportion of commercial foods and a concentrate rich in starch (El Housni et al., 2014). There is therefore a waste of energy, a production of propionic acid, a precursor of fatty deposits, and consequently the production of carcasses which are not very appreciated by consumers. These flaws could be avoided, circumvented or at least limited through the use or the incorporation of alternative and complementary food resources that can meet consumer expectations and maintain the level of production while reserving product quality and animal health.

* Corresponding author.

** Corresponding author.

E-mail addresses: moutik.sanaa@gmail.com (S. Moutik), nour-eddine.es-safi@um5.ac.ma (N.E. Es-Safi).

Among these alternative food resources, agro-industry by-products constitute a good substitute which can be used in the feeding of small ruminants without affecting the production performance (Ben Salem et al., 2008). These wastes constitute sometimes more than the half of the agricultural production, and then are cheap, abundant and accessible feedstocks for small ruminant fattening. Among these agro-resources, we were interested to argane by-products which are produced in the argane oil production process.

Argan tree (*Argania spinosa*, Sapotaceae) is an endemic plant found generally in southwestern Morocco and constitutes the most distinctive species in North Africa (Swenson and Anderberg, 2005). Due to its botanical, social and economic interest in addition to its environmental impact (Charrouf, 1998), argan tree remains an open research area. In Morocco this species covers an area of more than 800 000 ha (Guillaume and Charrouf, 2011) and produce about 350 000 tons of fruits (Charrouf and Guillaume, 2009) used mostly for the extraction of its oil. Beside the famous nutritional and cosmetic argan oil, the production process also yields a huge and a large quantity of by-products consisted mostly of pulp/pericarp (43 %), shells (52.6 %) and meal (2 %). These provided important by-products constituted one of the few alternative drilling resources for livestock in dry areas (Bendaou et al., 2011). Argane oil cake has high levels of dry matter (91%), crude protein (48.4%), crude fiber (17.6%), and fat (18.9%). It presents also significant values of potassium (10.4 g/kg), calcium (6.9 g/kg), and phosphorus (6.4 g/kg) (Charrouf and Guillaume, 2009). The high content of protein represents a best alternative to respond to needs of Moroccan livestock, where protein is a limiting factor for animal production (El Maadoudi et al., 2013). Argan pulp has high levels of carbohydrates (25–50%) (M'hirit et al., 1998), but it is poor in nitrogenous total matter with a rate ranging between 3.5 and 10%. The average dry matter contents of phosphorus and calcium are respectively 0.18% and 0.11% (Charrouf and Guillaume, 2008). The high concentration of carbohydrates makes that the pulp constitutes a food with a high energy value for livestock.

In an ongoing program aimed to the valorization of argan-by products, we were interested to their use as alternative resource for lamb fattening. In this regard and faced with the flagrant lack of research in this direction, a study was carried out on the quality of the milk of sheep fed with argan by-products confirmed the possibility of introducing these resources into the diet of small ruminants without any complications (Moutik et al., 2019). The encouraging obtained results prompted us to explore the possibility of using argan by-products for lamb fattening. This work presents thus new information concerning the effect of diets using argane by-products on fatty acid composition, growth performance, carcass and meat characteristics of lambs.

2. Material and methods

2.1. Experiment site

The study was carried out in a farm at the rural region called "Chiadma" in Essaouira, Morocco, (latitude 31°30'44" N), from January to March 2017. The region area is characterized by a semi-arid Mediterranean climate with an average annual temperature of 17.3 °C and 285 mm average annual rainfall.

2.2. Animals and feeding system

Twenty healthy Sardi male lambs (six months old) with a mean initial body weight of 26.0 ± 0.5 kg, were randomly allotted to two experimental groups of 10 animals each. The test was assayed for 90 days, including 15 days so that the lambs were adapted to the experimental diets and were housed in a well-ventilated area equipped with adequate feed and water facilities. Animals had free access to fresh, clean water during the study. The used animals were clinically examined during the study and all lambs were in good conditions with no obvious signs of any diseases. The use of the animals and the experimental procedures were

approved by the Animal Care Committee, Sheep and Goat Association (ANOC), Provincial Agricultural Directorate of Essaouira (DPAR), and National Institute of Agronomic Research, Rabat, Morocco.

As indicated above, the twenty used lambs were split into two groups of 10 lambs each. The first group received argane by-products (ABP) and the second group was fed with a conventional traditional diet (CF) and constitute the control sample. The argane by-products diet (ABP), which contained argane pulp, argane oil cake, olive cake, ground carob, wheat bran, ground straw and minerals/vitamins complement. The traditional diet (CF) contained barley grain, beetroot pulp, wheat bran, ground straw, trade food and minerals/vitamins complement (Tables 2 and 3). For both groups, a daily ratio of 1.5 kg DM per lamb per day were supplied to the corresponding lambs' group on a two meals basis. Individual feed intake was calculated using daily feed offered and feed refuse averaged over the interval of the performance phase.

2.3. Growth performance and feed conversion ratio

Animal weights were measured by weekly weighting animals at 8:00 a.m. during the performance phase. Average daily gain (ADG) was calculated as the difference between the initial and final weights over the interval of the performance phase (75 days).

2.4. Slaughtering and carcass measurements

At the end of the 75 days trial period, five lambs from each group were slaughtered at the municipal slaughterhouses in order to evaluate carcass characteristics. Lambs were slaughtered at 8:00 a.m., 18 h after last feeding. Fasted live and hot carcass weights were recorded immediately before and after slaughter respectively. Cold carcass weight was recorded after carcasses were chilled at 4 °C for 24 h. The muscle pH values were measured using a pH meter, at slaughter (pH₀) and after 24h refrigeration of the carcass at 4 °C (pH₂₄). The dressing percentages were calculated as the percentage of cold carcass weight/fasted live weight. After slaughter directly, non-carcass edible (head, skin feet and leg, heart, ...) was kidnaped. Lamb carcasses were cut into four parts 24 h after slaughter. Upon cutting, longissimus muscle loin cut kept at -20 °C till meat quality assessment.

2.5. Laboratory analysis

Samples of diets and ingredients were minced using a laboratory mill MF 10 basic IKA WERKE to pass a 1 mm sieve screen and stored in airtight plastic containers for chemical composition analysis according to the AOAC methods (AOAC, 2000), dry matter (DM), ash, ether extract (EE), crude fiber (CF), and crude protein (CP) contents.

2.6. Determination of fatty acid profiles

In order to investigate the fatty acids (FA) composition of the obtained lamb muscle, the latter was thawed (24 h, 4 °C) and its lipids content extracted and further analyzed. Lipids were extracted from samples using a chloroform-methanol (2:1, v/v) mixture as previously described (Folch et al., 1957). The obtained FA mixture were trans-methylated using boron fluoride and methanol according to Morrison and Smith (1964).

The investigated samples fatty acid composition was determined by gas chromatography with a PerkinElmer Clarus 560 gas chromatograph apparatus using a capillary column SP2560 (30 m, 250 μm). The oven temperature was programmed starting at 35 °C for 10 min, then raised to 250 °C at a rate of 8 °C/min and then kept constant at 250 °C for 7 min. Helium was used as a gas carrier at a constant flow rate of 1.0 mL/min with an injected volume of 1 μL. A PerkinElmer Clarus SQ 8 Mass Spectrometer detector equipped with an Electronic ionization source set at 250 °C and operating in the positive ion mode was used. The detected methyl esters were identified through comparison of the obtained MS

spectra with those of a NIST 11 MS data base. The quantitation of the detected compounds (saturated FAs, mono-unsaturated FAs and PUFAs) has been made on the basis of the area % calculation procedure which reports the area of each peak in the chromatogram as a percentage of the total area of all peaks.

2.7. Statistical analysis

The effects of the diets on the meat chemical and fatty acid composition were determined by the repeated measure ANOVA using PROC MIXED of the Statistical Analysis System software (SAS 2004). Once the ANOVA results are significant, differences among means were evaluated using the Duncan's New Multiple Range Test.

Regarding lamb growth, the effect of the two diets on the weight at the two time periods (initial and final weight) as well as on the average daily live weight gain (ADG) was assessed using the Student t test using PROC TTEST of the same software (SAS).

The level of statistical significance was set up to 0.05.

3. Results and discussion

In order to investigate the appropriateness of using argan by-products (ABP) as alternative for fattening, two Sardi 10 lamb groups have been used and fed with ABP and a traditional conventional feed diets (CF). The ingredient used for each diet are indicated in Table 1, the composition of each ingredient is reported in Table 2, while the chemical compositions of both diets are summarized in Table 3.

The used conventional diet contained mineral and vitamins (2 %), ground straw (10 %) and trade food (88 %). While the first two ingredients were maintained in the ABPD, the most main ingredient trade food was replaced by argane oil cake (14 %) as protein source, olive cake (11 %) as a fatty matter source, argane pulp (18 %) and ground carob (14 %) as carbohydrates source, wheat bran (15 %), ground straw (10 %) and barley grain (16 %) as fiber source, and mineral source (2%).

Comparison between the composition of the two used diets showed that ABP diet contained more CP (14.82% vs. 14.71%), CF (17.64 vs. 14.23%) and ash (10.5 vs. 10.15%) compared to the CF diet. From an economic point of view the ABP diet is cheaper than the conventional one (1.83 vs 2.2 MAD/Kg DM).

During the 75 days of study, the animals were observed for every behavioral change. It was observed that the used argane by-products diet was consumed without any trouble. Animals from both groups were also weighed in order to determine the effect of the used diets on the growth factors such as ADG and feed conversion ratio which are presented in Table 4.

Feeding diet with ABP affected DMI, the lambs of this lot consumed more DM than those conventionally fed (Table 4). This can be due to the decrease in the percentages of NDF and ADF (Table 3) of the ABP diet by as NDF concentration has a negative correlation with the voluntary feed intake (Mertens, 2009).

The obtained results showed that starting from an almost similar initial weight for the 2 groups ABP and CF (26.1 kg and 26.07 kg), the final average weights were 36.7 kg and 35.1 kg. The observed difference was reflected with great significance ($p = 0.0001$) in the ADG of the ABP group. It should be noted that the higher final weight of the lambs with the APB diet might be due to a higher DMI.

The feed conversion ratio was 16.49% higher for lambs of the CF diet. These obtained results agree with those previously reported by Waghorn and Barry (1987) where the feed efficiency has been associated with greater body weight gain. The results obtained concerning BW gain suggests that argane-by products could be used as an alternative source for lamb fattening confirming the fact that agricultural by-products can effectively replace concentrates without adversely affecting livestock performance compared to control diets (Martín García et al., 2003; Chiofalo et al., 2004; Sadegui et al., 2009). Due to their relatively cheap cost, the use of such alternative feed in livestock diets will reduce the cost and improve, or maintain, meat quality traits.

The results obtained concerning lamb carcass characteristics and quality measurements are gathered in Tables 5 and 6. The effects of using ABP in the diet on hot and cold carcass weight are shown in Table 5. The use of ABP ($P < 0.05$) increased the hot and cold carcass weights compared to the control group CF. These results are in agreement with the results reported by Soltaninezhad et al. (2016) which showed that using by-products in fattening lamb diet influenced the weights of hot and cold carcasses.

Instrumental and chemical analyses are summarized in Table 6. No significant differences were found when comparing the two diets for pH. Regarding the other parameters CP, EE, and ash, there was a significant difference. Our final pH values are 5.25 and 5.24, these were such to those reported for other breeds (Lestingi et al., 2015; Facciolongo et al., 2015), and support the hypothesis that the lambs were not subjected to pre-slaughter stress (Devine et al., 1993; Lowe et al., 2002). Between 0 min and 24 h after slaughter the pH decreased, this could be due to glycogen conversion into lactate and H^+ (Shija et al., 2013). From hygienic and sanitary point of view, an ultimate pH value greater than 5.8 is considered as undesirable (Young et al., 2004). Therefore, pH values after 24 h of the studied samples with both ABP and CF diets could be considered as acceptable. Lambs fed with the ABP also showed a low fat ($P < 0.05$) compared to those receiving the traditional diet (Table 5). These results are consistent with previously reported studies which showed that lambs under conventional diet had significantly more fat at slaughter (El Housni et al., 2014). This may be due to a slow degradation of carbohydrates in the rumen leading to different pattern or formation of ruminal volatile fatty acid production (Asadollahi et al., 2017).

Table 7 reports the fatty acid composition (as a percentage of total fatty acid methyl esters) of intramuscular lipids. Comparing both ABP and CF, the highest SFAs are in ABP. Note that in both ABP and CF there is the same percentage of C14:0, however; there's more C16:0 (palmitic acid), C17:0 (margaric acid), C18:0 (stearic acid) in ABP, with C16:0 (palmitic acid) and C18:0 (stearic acid) as the main SFAs in both treatments.

Table 1. Chemical composition of diversives ingredients used in the diets.

Ingredients	DM	DM (%)			
		CF	CP	Ash	EE
Argan pulp	98	14.9	7.82	7	6.4
Argan oil cake	90.3	21.4	47	12.4	15.5
Olive cake	91.5	30.2	6.3	8.5	9
Ground straw	88.6	42.7	3.5	8.1	0.4
Wheat bran	88.1	12.2	15.5	7	1.8
Ground carob	91.2	7.5	6.3	5	2.3
Barley grain	88.7	6.6	12.3	7.3	2.1

DM: Dry Matter, CF: Crude fiber, CP: Crude protein, EE: Ether extract.

Table 2. Ingredients of the two used diets.

Ingredients (g/100 g of fresh matter)	Argan by-products diet (ABD)		Traditional diet (CF)
	Argan oil cake	14%	0
	Argan pulp	18%	0
	Olive cake	11%	0
	Ground carob	14%	0
	Wheat bran	15%	0
	Barley grain	16%	0
	Ground straw	10%	10%
	Minerals and vitamins	2%	2%
	Trade Food	0	88%

Table 3. Chemical composition of the two used diets.

Composition	Argan by-products diet (ABP)		Traditional diet (CF)
	Crude protein (%)	14.82	14.71
	Total N (%)	2.3	1.9
	Dry matter (%)	90.6	90.43
	Ash (%)	10.5	10.15
	Crude fiber (%)	17.64	14.23
	Ether extract (%)	4.5	3.7
	P (%)	4.4	3.5
	Ca (%)	7	6.7
	Fatty acid (%)		
	C14:0	0.22	1.2
	C16:0	15.1	18.4
	C16:1	0.12	0.1
	C18:0	6.4	5.9
	C18:1	44.3	38.9
	C18:2	31.2	26.5
	Feed Unit/kg DM	0.81	0.8
	Cost (MAD/Kg DM)	1.83	2.2

Table 4. Dry matter and performance intake of the lambs.

	Diet type		Significance
	ABP	CF	
Dry matter intake (kg/day)	1.3 ± 0.3	1.12 ± 0.19	0.01 (*)
Initial weight (kg)	26.1 ± 1.7	26.07 ± 1.4	0.9 (ns)
Final weight (kg)	36.37 ± 2.4	35.1 ± 1.8	0.001 (**)
Lamb daily gain 0–75 days (g)	137 ± 3.21	120.77 ± 2.9	0.0001 (***)
Feed conversion (kg)	9.7 ± 0.2	8.1 ± 0.5	0.001 (**)

***P < 0.001, **P < 0.01, *P < 0.05, ns: not significant (P > 0.05).

Consonant with other studies (Velasco et al., 2001; Vicenti et al., 2004; Toteda et al., 2011), the important monounsaturated fatty acid (MUFA) was C18:1 n-9c (oleic acid), probably due to Δ9-desaturase enzyme activity allowing lambs to desaturate stearic acid (C18:0) to oleic acid (Pereira et al., 2003), in this trial the CF lambs have more MUFAs than the ABP lambs.

The highest proportion of polyunsaturated fatty acids (PUFAs) is C18:2 n-6 (linolenic acid) in both treatments. It has been reported that n-6 intake is recommended in order to reduce SFAs and increase PUFAs. PUFAs and specifically the n-6 series, whose precursor is linoleic acid, reduce blood cholesterol. However, diets which are rich in these PUFAs decrease LDL, as well as high-density lipoprotein (HDL) which is

Table 5. Carcass characteristics of lambs fed with the two used diets.

	Diet type		Significance
	ABP	CF	
Hot carcass weight (kg)	25.8 ± 1.07	25.6 ± 1.19	0.003 (**)
Cold carcass weight (kg)	25.6 ± 1.18	25.5 ± 1.07	0.003 (**)

***P < 0.001, **P < 0.01, *P < 0.05, ns: not significant (P > 0.05).

Table 6. Chemical composition of the meat of the lambs fed with the two used diets.

	Diet type		Significance
	ABP	CF	
pH ₀	6.2 ± 0.1	6.19 ± 0.1	Ns
pH ₂₄	5.25 ± 0.04	5.24 ± 0.02	Ns
Crude protein (%)	21.2 ± 1.2	20.4 ± 0.9	0.0001 (***)
Ether extract (%)	3.7 ± 1.4	4.3 ± 0.8	0.0001 (***)
Ash (%)	2.84 ± 0.7	2.37 ± 0.4	0.003 (**)

***P < 0.001, **P < 0.01, *P < 0.05, ns: not significant (P > 0.05).

Table 7. Fatty acid composition of the used lambs' meat.

	Diet type		Significance
	ABP	CF	
C14:0, myristic	2.17 ± 0.34	2.2 ± 0.18	ns
C16:0, palmitic	18.4 ± 1.8	17.9 ± 1.45	0.0001 (***)
C17:0, margaric	1.9 ± 0.41	0.6 ± 0.73	0.0001 (***)
C18:0, stearic	27.9 ± 1.06	24.6 ± 1.1	0.0001 (***)
C16:1	0.9 ± 0.31	0.8 ± 0.27	0.001 (**)
C18:1 n-9t	4.3 ± 0.9	4.1 ± 0.87	0.001 (**)
C18:1 n-9c	26.2 ± 3.1	22.8 ± 2.9	0.0001 (***)
C18:1 n-7t	1.15 ± 0.13	1.16 ± 0.17	ns
C18:2 n-3	0.2 ± 0.15	0.4 ± 0.13	0.001 (**)
C18:2 n-6	3.4 ± 1.9	6.6 ± 1.7	0.0001 (***)
C18:3 n-3	0.23 ± 0.17	0.19 ± 0.2	ns
C20:3 n-3	0.02 ± 0.02	0.02 ± 0.01	ns
C20:3 n-6	0.13 ± 0.1	0.12 ± 0.17	ns
C20:4 n-6	1.15 ± 0.71	0.97 ± 0.9	0.001 (**)
C20:5 n-3	0.09 ± 0.08	0.09 ± 0.07	ns
C22:6 n-3	0.02 ± 0.03	0.02 ± 0.02	ns
Total SFA ¹	45.1 ± 2.7	44.8 ± 3.01	0.001 (**)
Total MUFA ²	43.6 ± 3.02	42.9 ± 2.86	0.001 (**)
Total PUFA ³	5.8 ± 0.8	5.7 ± 0.6	ns
PUFA/SFA	0.12 ± 0.07	0.12 ± 0.05	ns

SFA: saturated fatty acid, MUFA: monounsaturated fatty acid, PUFA: polyunsaturated fatty acid.

***P < 0.001, **P < 0.01, *P < 0.05, ns: not significant (P > 0.05).

¹ Sum of C14:0 + C16:0 + C17:0 + C18:0.

² Sum of C18:1 n-7, trans-11 + C18:1 n-9, trans-9 + C18:1 n-9, cis-9 +.

³ Sum of C18:2 cis-9, cis-12 + C18:2 cis-9, trans-11 + C18:3 + C22:5 + C18:3 + C20:3 + C20:4 + C22:5.

protective against Coronary heart disease (CHD) (Ulbricht and Southgate, 1991). The MUFAs have also a same role protective. There were no significant differences in PUFA, and PUFA:SFA ratio between treatments, which is far from the recommended for healthy meat, which is a ratio of 0.4 or more. The hydrogenation action of rumen microorganisms on dietary fatty acids causes the PUFA: AGS ratio of ruminant meats to be low (Enser, 1996).

4. Conclusion

The current study is a part of an ongoing program aimed to explore the use of alternatives sources for lamb fattening. The results obtained (carcass performance and meat quality) were compared to those obtained with a group of lambs which have been fattened with a conventional diet (CF), showed that the use of argan by-products into the diet of lambs, for fattening and meat production, reduced the proportion of fat in the carcass without affecting the quality of the meat. A higher lamb weight daily gain was observed for the animals receiving ABP diet compared to those fattened with the conventional one. When comparing the two diets cost wise (2–2.8 MAD per ABP kg and 3–4 MAD per CF kg), the economic

gain to be made when using ABP compared to CF becomes clear, especially in the context of the absence of adverse effects on the meat quality and the difficulties encountered by breeders to feed their livestock due to an ever-declining rainfall.

This study showed thus that argan-by products represents an interesting potent alternative way for fattening and could be used for lamb fattening.

Declarations

Author contribution statement

Sana Moutik: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Aouatif Benali, El Haj Maadoudi, Mohammed Rachid Kabbour: Contributed reagents, materials, analysis tools or data.

Mohammed Bendaou: Conceived and designed the experiments.

Abdellah El Housni: Analyzed and interpreted the data.

Nour Eddine Es-Safi: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare the following conflict of interests: Nour Eddine Es-Safi; [is an Associate Editor for Heliyon.].

Additional information

No additional information is available for this paper.

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