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Effect of the Short-Term Incorporation of Different Proportions of Ensiled Artichoke By-Product on Milk Parameters and Health Status of Dairy Goats

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Abstract: The use of local agricultural by-products for animal feed is an alternative that reduces livestock production costs and allows food production of greater environmental sustainability. The aim of this experiment was to study the effect of the inclusion in the dairy goat ration of artichoke by-product silage (ABS) at three levels (25%, 40% and 60%, on a dry matter basis) on the milk yield, composition and quality, and on the metabolic profile of dairy goats. Thirty-six Murciano-Granadina dairy goats in mid-lactation were divided into four groups with homogeneous characteristics. Each group was assigned a diet: a control treatment (C) that consisted of a conventional diet of alfalfa hay and concentrate, and three other treatments that included 25, 40 and 60% ABS: ABS25, ABS40 and ABS60. Small differences were observed in the milk yield and quality and the health status of the animals. Only ABS60 presented a slightly lower milk yield (−20% compared to control group), without relevant differences in the milk composition and mineral profile. Regarding the lipid profile, ABS40 was the treatment with the best milk quality, due to a higher content of polyunsaturated fatty acids (4.37%) and lower atherogenicity (1.90) and thrombogenicity indices (3.05), without differences from C. It was concluded that the maximum inclusion level of ABS in dairy goats' diet should be equal to 40%.

Keywords: lipid profile; CLA; mineral profile; silage by-products; metabolism

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1. Introduction

Animal feeding represents 50–65% of the costs of a livestock farm [1]. Food production for livestock involves a high consumption of limited natural resources, such as land, water and fossil fuels. Moreover, some ingredients of animal rations, such as soybean, often come from far away, with the consequent costs and risk of contamination from transport. All of these activities have a negative impact on the animal production sector, both economically and environmentally. One solution to these problems could be the use of local by-products for animal feeding.

Spain is one of the main artichoke-producing countries worldwide. Production is concentrated in the southeast region of the Iberian Peninsula, where in 2018, artichoke production exceeded 260,000 tons [2]. Only 50% of the harvested artichoke is used for human consumption, as the rest is made up of the bracts, stems of flower buds and inedible parts [3]. The farming of artichoke for the food market entails a great availability of these by-products, which can be used in animal feed.

In general, the composition of these by-products is similar to bean pods, characterized by a moderate content of neutral detergent fiber (NDF; 400-600 g/kg) and metabolizable

energy (ME; 1.72–1.90 Mcal/kg DM) and a medium-high crude protein concentration (CP; 160–200 g/kg; [4]), so the by-products could partially replace forages and protein concentrates in the diet, such as alfalfa or soybean cake. Artichoke by-product silage (ABS) has the appropriate fermentative conditions to ensure the nutritional quality and safety necessary to be part of the small ruminant ration [5,6], and can be preserved for long periods of time (up to 200 days according to Monllor et al. [6]). The references found in the literature about the effect of ABS consumption on milk quality and composition, as well as on the health status of the animals, are scarce [7–9]. Only Monllor et al. [10] and Muelas et al. [11] published studies about the use of ABS in dairy goats, where they observed that the inclusion of up to 25% in the diet had no effect on the milk yield and quality or on the sensory properties of yogurt made with milk from those animals. Jaramillo et al. [8] observed the same effects in Manchega ewes fed with this by-product silage at up to 30% of the TMR. Moreover, it is noted that the addition of agroindustrial by-products in the ruminant diet can affect the lipid profile of milk [12–18], contributing to its improvement by increasing polyunsaturated fatty acids (PUFA), such as vaccenic and rumenic acid [16].

The objective of this experiment was to study the effect of the inclusion of 25, 40 and 60% of ABS in the ration of Murciano-Granadina dairy goats on the milk yield, composition and quality, along with the health status of the animals, to determine the best level of inclusion of this by-product without harming the performance and health of the animals.

2. Materials and Methods

2.1. Animals and Facilities

Murciano-Granadina lactating goats used in this experiment were housed in the teaching and experimental farm of the Miguel Hernández University, with straw litter, access to outdoor pens, free access to water and an adequate feeding space for all animals (at least 35 cm/animal). The animals were fed twice a day, at 8:00 and 14:00, and milked once a day (Casse milking parlor, 2 × 12 × 12, GEA, Bönen, Germany), as is usual in the region. This study was approved by the Ethical Committee of Experimentation of the Miguel Hernández University (code UMH.DTA.GRM.01.15).

2.2. Experimental Design

From a group of 100 goats that were in mid-lactation (fourth month) fed with a conventional diet (control, C), pre-experimental sampling was carried out and 36 animals were selected, with an average body weight (BW) of 41.9 ± 6.24 kg, a parity of 2.5 ± 0.484 lactations, an average milk yield of 2.25 ± 0.71 kg/day and a somatic cell count (SCC) of 5.63 ± 0.39 Log cells/mL. The animals were divided into four groups with homogeneous characteristics in terms of the cited variables.

A short-term experiment was carried out to study the effect of including ABS in the ration at three levels: 25% (ABS25), 40% (ABS40) and 60% (ABS60), expressed on a dry matter basis of the total ration. Artichoke by-product came from the canning industries of the region. All rations were calculated according to the formulation recommendations of Fernández et al. [19], with a calculated intake level of 2.2 kg DM/day, so that the four rations were isoenergetic and isoproteic. Table 1 shows the amounts of the ingredients in each diet, as well as their composition. The experiment lasted four weeks. It began with the pre-experimental control, which served to prepare four homogeneous groups. The first two weeks served as an adaptation phase to the diets, and in the following two weeks, three controls were carried out in the beginning, middle and end of the experiment, where BW, intake and milk yield were recorded, in addition to the collection of milk and blood samples.

Table 1. Ingredients and chemical composition of experimental diets.

Item	Diets			
	C	**ABS25**	**ABS40**	**ABS60**
Ingredients (g/100 g DM)				
Alfalfa hay	37.5	13.2	4.83	-
Grain mix	62.5	61.8	55.8	29.0
Oats	-	-	-	10.2
ABS	-	24.7	38.7	60.0
Premix vitamins/minerals	-	0.311	0.696	0.880
Chemical composition				
DM (g/kg FM)	872	422	322	231
g/kg DM				
OM	932	936	936	920
EE	65.3	57.7	58.5	48.9
CP	162	160	157	145
NDF	399	321	371	459
ADF	218	183	205	294
ADL	63.1	40.8	36.2	116
TP	3.87	7.95	7.75	14.7
IVDMD	715	739	804	769
[1] ME	2.66	2.13	2.51	2.44
VFA and fermentative metabolites (g/kg DM)				
Lactate	n.d.	3.99	23.5	3.66
Acetate	n.d.	2.63	3.12	8.74
Propionate	n.d.	3.70	n.d.	n.d.
Butyrate	n.d.	9.80	n.d.	23.7
Ethanol	n.d.	2.49	4.13	8.85
Ammonia N	n.d.	4.01	4.01	8.95
Fatty acids profile (g/100 g total fatty acids)				
C6:0	0.061	1.49	0.163	7.94
C12:0	0.183	0.156	0.225	0.057
C14:0	0.440	0.500	0.435	0.251
C16:0	17.2	18.4	16.8	14.0
C16:1 cis9	0.300	0.388	0.303	0.235
C18:0	3.25	3.25	3.05	1.54
C18:1 cis9	26.4	23.0	27.0	18.6
C18:1 cis11	1.06	0.962	1.16	0.798
C18:2n6	44.0	41.5	41.9	29.4
C18:3n3	4.07	2.83	4.48	4.85
C20:0	0.463	0.440	0.431	0.327
C20:1n9	0.323	0.297	0.373	0.375
C22:0	0.457	0.439	0.449	0.121
C24:0	0.336	0.368	0.457	0.439
SFA	23.3	30.5	23.9	45.1
MUFA	28.2	25.0	29.1	20.3
PUFA	48.7	44.5	47.2	34.8
Mineral profile				
Na (g/kg DM)	2.89	2.59	3.28	3.11
Mg (g/kg DM)	2.66	2.57	2.62	2.86
K (g/kg DM)	13.5	17.7	19.7	23.5
Ca (g/kg DM)	5.90	6.24	5.64	5.33
P (g/kg DM)	2.76	3.95	3.64	4.00
S (g/kg DM)	2.89	2.94	2.71	2.89
Se (mg/kg DM)	0.198	0.288	0.119	0.100
Zn (mg/kg DM)	49.4	73.8	55.4	46.5
Cu (mg/kg DM)	6.15	7.42	6.63	8.20
Fe (mg/kg DM)	129	230	133	160
Mn (mg/kg DM)	42.1	51.5	31.7	28.3

C: Control diet; ABS: Artichoke bracts silage; DM: Dry matter; FM: Fresh matter; OM: Organic matter; EE: Ether extract; CP: Crude protein; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin; TP: Total polyphenols; IVDMD: In vitro dry matter digestibility; ME: Metabolizable energy; VFA: Volatile fatty acids; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; n.d.: Not detected. [1] [20].

2.3. Variables Analyzed

The BW of the animals (kg) was determined by weighing on a scale with a precision of 100 g (APC, Baxtran, Spain). The composition of the rations was determined on a dehydrated sample at 60 °C according to the procedures included in the AOAC [21] for dry matter (DM, g/kg; method 930.5), organic matter (OM, g/kg DM; method 942.05), ether extract (EE, g/kg DM; method 920.39) and CP (g/kg DM; method 984.13). The contents of NDF (g/kg DM), acid detergent fiber (ADF, g/kg DM) and acid detergent lignin (ADL, g/kg DM) were analyzed following the method of Van Soest et al. [22]. The content of total polyphenols (TP, g/kg DM) present in the rations was analyzed by the Folin-Ciocalteu method reported in Kim et al. [23] on fresh samples. The determination of volatile fatty acids (VFA) such as acetic, propionic and butyric acid, as well as other metabolites of silage fermentation, such as lactic acid and ethanol, was carried out according to the method proposed by Feng-Xia et al. [24], using HPLC liquid chromatography (Agilent 1200, Santa Clara, CA, USA), with a C610H column of 30 cm and 7.8 mm ID (Supelcogel, Saint Louis, MO, USA) on fresh ration samples. The apparent in vitro dry matter digestibility (IVDMD, g/kg DM) was analyzed in duplicate using the method of Menke and Steingass [25]. Analysis of the fatty acid profile in the diets was carried out by direct methylation on the lyophilized samples, without prior extraction of the fat, according to Kramer et al. [26], using methylated C19:0 as the internal standard (Sigma-Aldrich, St. Louis, MO, USA). The identification and quantification of the fatty acid methylated esters (FAMEs) was carried out with a flame ionization detector (FID) coupled to a GC-17A gas chromatograph (Shimadzu, Kyoto, Japan), equipped with a CP Sil 88 column of 100 m, 0.25 mm ID and 0.20 mm internal coverage (Agilent, Santa Clara, CA, USA). As standard, a mixture of FAME (18912-1AMP, Sigma-Aldrich, Saint Louis, MO, USA) was used. The feed consumption was calculated by the difference between the feed offered and refused, determining the dry matter by dehydration in an oven at 105 °C for 48 h of a representative sample of the feed rejected by the animals of each treatment.

For the analysis of minerals in the diets and milk, previous digestion of the samples was carried out according to González Arrojo et al. [27]. ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) Agilent 7700x (Santa Clara, CA, USA) ORS (Octapole Reaction System) equipment was used to determine the concentrations of Na, Mg, K, Ca, P, S, Se, Zn, Cu, Fe and Mn. An internal standard was used to correct for physical and/or matrix interferences from the ICP-MS equipment.

The milk yield of the goats was measured with a Lactocorder device (WMB, Balgach, Switzerland) attached to the long milk tube of the milking equipment. The same Lactocorder also collected 100 mL of representative milk sample from the entire milking of each animal, for subsequent analysis of SCC and macrocomposition. The SCC of the milk samples was determined by a DCC item of equipment (DeLaval Cell Counter, DeLaval, Tumba, Sweden), using an electronic fluoro-optical method. The results were transformed to Log10 (LSCC) to get a normal distribution. The analysis of the milk macrocomposition and urea content was carried out by mid-infrared spectroscopy equipment (MilkoScan FT2, FOSS, Hillerød, Denmark) calibrated for goat milk. The variables analyzed were fat, protein, true protein, casein, whey protein, lactose, total solids (TS), non-fat total solids (NFTS), useful total solids (fat + protein, UTS), ash and urea. The milk yield corrected for fat was calculated, according to the equation of Gravert [28]: FCM (3.5%) = 0.433 × Yield (kg/day) + 16.218 × Fat yield (kg/day), and the milk yield corrected for fat and protein by: FPCM = Yield (kg/day) × (0.337 + 0.116 × Fat (%) + 0.06 × Protein (%) [29].

Analysis of the milk fatty acid profile was carried out by extracting the fat by the Folch method with some variations, as detailed in Romeu-Nadal et al. [30]. The fatty acids were methylated according to the method of Nudda et al. [31]. The equipment, column and mix of fatty acid standards were those previously described in the analysis of the lipid profile of the ration samples. Atherogenicity (IA) and thrombogenicity (IT) indices were calculated, according to Ulbricht and Southgate [32], and desaturation indices (ID) for C14: 0, C16:

0 and C18: 0, according to Lock and Garnsworthy [33]. The mineral analysis method for milk samples was the same as that used for feed samples.

Blood samples were analyzed by enzymatic spectrophotometry for the determination of glucose (mg/dL), urea (mg/dL) and β-hydroxybutyrate (BHB, mmol/L).

2.4. Statistical Analysis

The variables were analyzed according to a mixed linear model with repeated measures (PROC GLIMMIX. SAS v9.2, 2012), introducing in the model the covariate of the data obtained in the pre-experimental sampling, according to the following equation:

$$Y = \mu + Di + Sj + DixSj + covY0 + Ak + e,$$

where Y is the dependent variable, μ is the intercept, Di is the fixed effect of the diet (i = C, ABS25, ABS40, ABS60), Sj is the fixed effect of the sampling (j = 1, 2, 3), DixSj is the interaction of the diet with the sampling, covY0 is the effect of the value of Y in sampling 0, Ak is the random effect of the animal and e is the residual error. For each variable, the covariance model that presented better modelling of the data (lower Akaike Information Criterion and Bayesian Information Criterion) was used.

3. Results

3.1. Body Weight and Milk Yield

The goats from group C presented a higher BW throughout the experiment, which led to a higher mean value ($p < 0.05$) than those from the ABS treatments, with no differences between them, as shown in Table 2. The feed consumption was similar in all groups, although slightly higher in C (2.21 ± 0.006 kg DM/day). The feed intake of ABS treatments was 1.84 ± 0.099 kg DM/day for ABS25, 1.73 ± 0.069 kg DM/day for ABS40 and 1.91 ± 0.153 kg DM/day for ABS60.

Table 2. Body weight, milk yield and composition and SCC, according to the effects considered.

Variable	Diets					Significance		
	C	ABS25	ABS40	ABS60	SEM	Diet	Sampling	Diet × Sampling
Average body weight (kg)	44.2 a	42.4 b	42.3 b	42.2 b	0.565	*	*	***
Milk yield (kg/day)	2.39 a	2.33 a	2.26 ab	1.91 b	0.139	*	ns	*
LSCC (Log_{10} cell/mL)	5.57	5.71	5.58	5.59	0.103	ns	**	ns
FCM (kg/day)	2.55 a	2.46 ab	2.50 a	2.00 b	0.163	*	ns	ns
Fat (%)	3.74	3.97	4.04	4.20	0.205	ns	ns	ns
Protein (%)	3.35	3.33	3.40	3.41	0.079	ns	ns	ns
FPCM (kg/day)	2.37 a	2.30 a	2.30 a	1.87 b	0.142	*	ns	ns
UTS (%)	7.12	7.31	7.44	7.57	0.223	ns	ns	*
True protein (%)	3.12	3.10	3.16	3.17	0.070	ns	ns	ns
Casein (%)	2.66	2.64	2.73	2.70	0.062	ns	ns	ns
Whey protein (%)	0.462	0.470	0.433	0.457	0.018	ns	**	**
Lactose (%)	4.24	4.22	4.33	4.25	0.045	ns	*	***
Total solids (%)	12.0	12.2	12.4	12.3	0.227	ns	ns	ns
NFTS (%)	8.72	8.72	8.84	8.71	0.099	ns	ns	*
Ash (%)	0.618 ab	0.656 a	0.598 ab	0.568 b	0.032	*	ns	ns
Milk urea (mg/L)	597	549	533	542	24.4	ns	ns	ns

C: Control diet; ABS: Artichoke bracts silage; SEM: Standard error of the mean; LSCC: Log_{10} somatic cell count; FCM: Fat-corrected milk (3.5%); UTS: Useful total solids (fat + protein); TS: Total solids; NFTS: Non-fat total solids; ab: Least square means within a column with different letters that differ significantly. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: non signficant.

The milk yield was lower ($p < 0.05$) in animals fed with the higher level of inclusion of ABS, with no differences between c and ABS25 and ABS40. Similarly, FCM and FPCM also presented a lower value in ABS60 ($p < 0.05$). Regarding the milk's macrocomposition, only the ash content presented significant differences ($p < 0.05$), although of little magnitude,

ABS25 being the one that held the highest value (0.656%) and ABS60 the lowest (0.568 %). The inclusion of ABS in the diet of dairy goats did not affect the urea milk content ($p > 0.05$).

3.2. Milk Mineral Profile

As can be observed in Table 3, only minor differences were found in the Mn milk content. The Mn content was higher in ABS40 and ABS60 ($p < 0.05$).

Table 3. Milk mineral profile according to the effects considered.

Mineral	Diets				SEM	Significance
	C	ABS25	ABS40	ABS60		
Na (g/kg MS)	2.59	2.44	2.50	2.96	0.314	ns
Mg (g/kg MS)	0.888	0.896	0.864	0.921	0.069	ns
P (g/kg MS)	6.00	5.98	6.38	5.91	0.437	ns
S (g/kg MS)	2.45	2.43	2.60	2.41	0.118	ns
K (g/kg MS)	12.0	12.5	11.4	11.5	0.724	ns
Ca (g/kg MS)	8.85	8.79	8.87	8.39	0.533	ns
Mn (mg/kg MS)	0.203 b	0.236 b	0.328 a	0.316 a	0.017	**
Fe (mg/kg MS)	2.95	2.27	2.72	2.34	0.304	ns
Cu (mg/kg MS)	0.697	0.522	0.474	0.378	0.066	ns
Zn (mg/kg MS)	28.3	23.3	25.9	21.3	3.54	ns
Se (mg/kg MS)	0.102	0.104	0.112	0.094	0.009	ns

C: Control diet; ABS: Artichoke bracts silage; SEM: Standard error of the mean; ab: Least square means within a column with different letters that differ significantly. ** $p < 0.01$; ns: non-significant.

3.3. Lipid Profile of Milk

The milk lipid profile of the animals in this experiment is detailed in Table 4. C presented a higher value than the rest in C18:2 cis9, trans13, C18:2 trans8, cis13, C20:0 and C18:3n3. A higher level of C18:1 trans9 was also found in C, whereas the lower the percentage of ABS included in the diet, the lower was the content of this fatty acid. In contrast, the C15:0, isoC16:0, C16:1 trans5 and C17:1 cis9 contents increased in line with the quantity of ABS present in the diet. ABS25 presented a similar value to C ($p > 0.05$) in C12:0, C18:0, C18:1 trans15, 16, C18:1 cis12 and C18:2n6 fatty acids, with the proportion of these fatty acids in milk decreasing as the ABS inclusion level became higher. ABS40 presented a higher content of C18:1 trans6-8, C18:1 trans11, C18:1 trans12, C18:2 trans11, cis15 and C20:2n9 than the rest of the treatments.

Table 4. Fatty acid composition (g/100 g total fatty acids) measured in milk according to the effects considered.

Fatty Acid	Diets				SEM	Significance
	C	ABS25	ABS40	ABS60		
C4:0	2.20	2.75	2.79	2.75	0.239	ns
C6:0	3.10	3.58	3.78	3.48	0.361	ns
C7:0	0.053	0.043	0.071	0.054	0.007	ns
C8:0	4.25	4.41	5.18	4.00	0.882	ns
C9:0	0.064	0.068	0.083	0.080	0.007	ns
C10:0	13.3	14.8	15.3	14.4	2.02	ns
C10:1 c9	0.039	0.035	0.040	0.034	0.006	ns
C11:0	0.186	0.172	0.168	0.186	0.008	ns
C12:0	3.20 a	2.94 ab	2.77 b	2.66 b	0.144	**
C12:1 c9	0.032	0.027	0.025	0.025	0.004	ns
iso C13:0	0.017	0.021	0.021	0.021	0.003	ns

Table 4. *Cont.*

Fatty Acid	Diets				SEM	Significance
	C	ABS25	ABS40	ABS60		
anteiso C13:0	0.025	0.029	0.023	0.030	0.003	ns
iso C14:0	0.055	0.051	0.052	0.070	0.007	ns
C14:0	7.61	7.07	6.63	6.98	0.334	ns
iso C15:0	0.167	0.162	0.139	0.162	0.026	ns
anteiso C15:0	0.233	0.192	0.199	0.213	0.012	ns
C14:1 c9	0.074	0.050	0.061	0.072	0.012	ns
C15:0	0.653 ab	0.566 c	0.605 bc	0.689 a	0.028	*
C15:1	0.072	0.048	0.063	0.054	0.009	ns
iso C16:0	0.165 c	0.201 b	0.194 b	0.240 a	0.013	***
C16:0	21.6	20.7	20.0	23.3	2.03	ns
C16:1 t4	0.038	0.000	0.008	0.050	0.019	ns
C16:1 t5	0.024 b	0.000 b	0.000 b	0.053 a	0.013	*
C16:1 t6–7	0.106	0.072	0.115	0.092	0.062	ns
C16:1 t9	0.200	0.156	0.207	0.159	0.043	ns
C16:1 t10	0.028	0.015	0.029	0.001	0.016	ns
C16:1 t11–12	0.009	0.026	0.029	0.036	0.014	ns
C16:1 c7	0.201	0.180	0.184	0.153	0.022	ns
C16:1 c9	0.428	0.401	0.442	0.483	0.049	ns
C16:1 c10	0.029	0.000	0.028	0.024	0.017	ns
C16:1 c11	0.000	0.000	0.003	0.003	0.002	ns
iso C17:0	0.243	0.246	0.271	0.204	0.029	ns
anteiso C17:0	0.280	0.228	0.267	0.224	0.022	ns
C17:0	0.566	0.455	0.495	0.552	0.031	ns
C17:1 c6–7	0.040	0.054	0.050	0.049	0.007	ns
C17:1 c8	0.000	0.000	0.005	0.000	0.002	ns
C17:1 c9	0.095 b	0.104 b	0.116 b	0.174 a	0.014	*
iso C18:0	0.032	0.036	0.046	0.048	0.010	ns
C18:0	14.0 a	13.8 a	13.3 ab	12.3 b	0.657	*
C18:1 t4	0.070	0.048	0.068	0.060	0.010	ns
C18:1 t5	0.029	0.025	0.031	0.027	0.006	ns
C18:1 t6–8	0.197 a	0.148 b	0.187 a	0.128 b	0.013	***
C18:1 t9	0.273 a	0.232 b	0.212 bc	0.183 c	0.017	***
C18:1 t10	0.289	0.2000	0.110	0.167	0.079	ns
C18:1 t11	1.32 b	1.22 b	2.20 a	0.881 b	0.250	*
C18:1 t12	0.478 ab	0.419 b	0.510 a	0.282 c	0.024	***
C18:1 t13–14	0.060	0.148	0.124	0.000	0.059	ns
C18:1 t15–16	0.425 a	0.407 a	0.350 b	0.331 b	0.014	***
C18:1 c9	18.5	16.5	17.4	18.1	2.56	ns
C18:1 c11	0.056	0.051	0.042	0.007	0.044	ns
C18:1 c12	0.582 a	0.537 a	0.565 a	0.462 b	0.026	**
C18:1 c13	0.128	0.114	0.124	0.104	0.010	ns
C18:1 c15	0.207	0.204	0.195	0.178	0.009	ns
C18:2 c9.t13	0.268 a	0.189 b	0.194 b	0.193 b	0.015	**

Table 4. *Cont.*

Fatty Acid	Diets				SEM	Significance
	C	ABS25	ABS40	ABS60		
C18:2 t8.c13	0.100 a	0.081 b	0.071 b	0.074 b	0.006	*
C18:2 c9.t12	0.157	0.101	0.095	0.093	0.017	ns
C18:2 t11.c15	0.011 b	0.006 b	0.027 a	0.012 b	0.004	**
C18:2n6	2.62 a	2.56 ab	2.88 a	2.25 b	0.171	*
C20:0	0.229 a	0.214 b	0.187 c	0.209 b	0.007	**
C18:3n6	0.017	0.026	0.026	0.025	0.006	ns
C20:1 c9	0.013	0.001	0.007	0.007	0.006	ns
C20:1 c11	0.037	0.061	0.057	0.049	0.006	ns
C18:3n3	0.182 a	0.146 b	0.151 b	0.134 b	0.012	*
CLA c9.t11	0.446	0.433	0.631	0.401	0.187	ns
CLA t9.c11	0.044	0.041	0.041	0.037	0.006	ns
CLA t10.c12	0.025	0.020	0.018	0.033	0.010	ns
CLA t12.14	0.016	0.013	0.014	0.022	0.006	ns
C20:2n6	0.031	0.040	0.036	0.038	0.007	ns
C20:2n9	0.000 b	0.000 b	0.003 a	0.000 b	0.001	*
C20:3n9	0.073	0.073	0.054	0.057	0.008	ns
C22:0	0.024	0.026	0.018	0.024	0.007	ns
C20:4n6	0.146	0.145	0.142	0.164	0.011	ns
C23:0	0.025	0.030	0.023	0.028	0.006	ns
C22:2n6	0.000	0.016	0.015	0.005	0.008	ns
C24:0	0.048	0.0144	0.026	0.057	0.063	ns

C: Control diet; ABS: Artichoke bracts silage; SEM: Standard error of the mean; abc: Least square means within a column with different letters that differ significantly. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$;ns: non-significant.

These differences in the lipid profile translated into a higher content of PUFA and n6 acids in the milk of goats fed with the C and ABS40 diets compared to the ABS60 group (Table 5; $p < 0.05$). Regarding the indices related to the quality of the lipid profile in terms of the prevention of cardiovascular diseases, ABS40 presented a higher quality due to the lower values of AI and IT (1.90 and 3.05, respectively; $p < 0.05$). ABS60 showed higher desaturation activity of 18-carbon fatty acids compared to the C and ABS25 groups ($p < 0.001$).

3.4. Plasma Metabolite Profile

Table 6 shows the plasma metabolite values analyzed in the goats of the present experiment. Whereas no significant differences were found in glucose levels, there were in the plasma urea and BHB levels. Regarding urea, the animals from C presented a higher value than the rest (52.5 mg/dL; $p < 0.001$), and the urea content decreased as the ABS level of inclusion in the diet increased, so the animals from ABS60 presented the lowest value. Regarding the BHB content, the animals from the ABS25 treatment presented higher levels than those from C and ABS60 ($p < 0.05$).

Table 5. Grouped fatty acids (g/100 g total fatty acids) and indices related to cardiovascular health and desaturation activity in milk according to the effects considered.

Variable	Diets				SEM	Significance
	C	ABS25	ABS40	ABS60		
SFA	72.5	73.3	72.1	72.7	1.80	ns
MUFA	23.5	22.0	23.1	23.0	2.23	ns
PUFA	4.13 ab	3.93 b	4.37 a	3.53 c	0.192	*
UFA	27.3	26.1	27.4	26.7	1.86	ns
SFA/UFA	2.65	2.83	2.68	2.74	0.255	ns
SCFA	23.1	25.6	27.1	24.8	3.57	ns
MCFA	36.4	34.2	33.4	36.7	1.44	ns
LCFA	39.9	40.1	39.2	37.9	2.77	ns
OBCFA	2.84	2.51	2.67	2.84	0.128	ns
∑CLA	0.596	0.543	0.592	0.505	0.117	ns
n3	0.179	0.145	0.153	0.136	0.011	ns
n6	2.80 a	2.77 ab	3.06 a	2.44 b	0.173	*
n6/n3	16.1	19.2	20.2	18.7	1.16	ns
AI	2.07 a	2.09 a	1.90 b	2.10 a	0.080	**
TI	3.26 ab	3.36 a	3.05 b	3.29 ab	0.154	**
DI C14:0	0.009	0.007	0.009	0.011	0.002	ns
DI C16:0	0.051	0.041	0.050	0.045	0.004	ns
DI C18:0	1.56 b	1.47 b	1.66 ab	1.78 a	0.106	***

C: Control diet; ABS: Artichoke bracts silage; SEM: Standard error of the mean; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids (MUFA + PUFA); SCFA: Short-chain fatty acids (C6:0 to C10:0); MCFA: Medium-chain fatty acids (C11:0 to C17:0); LCFA: Long-chain fatty acids (C18:0 to C24:0); AI: Atherogenic index; TI: Thrombogenic index; DI: Desaturation index; abc: Least square means within a column with different letters that differ significantly. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: non-significant.

Table 6. Plasmatic profile according to the effects considered.

Variable	Diets				SEM	Significance		
	C	ABS25	ABS40	ABS60		Diet	Sampling	Diet × Sampling
Glucose (mg/dL)	44.8	46.3	47.0	44.5	1.44	ns	***	**
Urea (mg/dL)	52.5 a	44.0 b	39.5 bc	35.1 c	1.73	***	**	**
BHB (mmol/L)	0.319 b	0.524 a	0.444 ab	0.318 b	0.054	*	ns	*

C: Control diet; ABS: Artichoke bracts silage; SEM: Standard error of the mean; BHB: β-hydroxybutyrate; abc: Least square means within a column with different letters that differ significantly. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: non-significant..

4. Discussion

4.1. Body Weight and Milk Yield

Goats fed with ABS diets presented a slightly lower feed intake than those from C. This can be explained by the presence of fermentation metabolites in ABS diets and a higher TP content (Table 1), which reduced the food intake [34,35]. Another factor that could affect the outcome was the greater volume of the diet, as the inclusion of ABS increased the moisture content, as occurred in Monllor et al. [14] with a broccoli by-product and artichoke plant silages in dairy goats' diet. However, as these differences in feed consumption were small, the differences in BW were not relevant.

Relative to milk yield, ABS60 presented a significant lower yield value (1.91 kg/day), without varying the fat and protein content, which led to lower FCM and FPCM contents ($p < 0.05$) in ABS60 than in the other treatments with ABS (2.00 and 1.87 kg/day). With the lowest levels of ABS (25 and 40%), significant differences versus C for milk yield, LSCC, FCM and FPCM were not observed, as occurred in Monllor et al. and Monllor et al. [10,36], with 25% of ABS or artichoke plant silage in the diet of dairy goats, respectively. The lack of effect of the ABS diet on milk composition is as reported by Muelas et al. [14].

4.2. Milk Mineral Profile

Although ABS40 and ABS60 had a higher level of Mn in milk, these differences were biologically irrelevant in comparison to C and ABS25. The milk mineral profile of the goats used in this experiment coincided with that shown by Stergiadis et al. [37] for typical goat milk.

4.3. Lipid Profile of Milk

Odd and branched chain fatty acids (OBCFA) are biomarkers of ruminal activity and have potential activity against metabolic diseases [38]. A higher OBCFA content in goat milk was observed as the ABS consumption rose. This was due to the higher concentration of NDF in these diets, which according to Patel et al. [39], entails a greater generation of ruminal VFA, which is a precursor of the synthesis of OBCFA. On the other hand, the higher content of other fatty acids in milk, such as linoleic (C18:2n6) in C and ABS25, was related to a higher content of those fatty acids in the diet [40].

ABS40 was the treatment with the best milk lipid profile because of a higher content of vaccenic acid (C18:1 trans11) in milk, due to a higher content of oleic acid in the diet, which acts as a precursor for the activity of Δ9-C18-desaturase in vaccenic acid synthesis [40]. The higher TP concentration in the ABS40 diet also helped to reach higher values of vaccenic acid and PUFA due to the inhibitory effect on ruminal fatty acids' biohydrogenation [41]. Considering that, the milk from ABS40 treatment showed the lowest AI and TI, so a better quality in terms of prevention of cardiovascular diseases was reached with this ABS inclusion [42].

4.4. Plasma Metabolite Profile

The plasma metabolite profile observed in the animals of this study was adjusted to that considered optimal for the goat species [43]. The lower blood urea content in goats fed with a higher dose of ABS in the diet was due to the higher TP content, which reduces the protein rumen digestibility by forming non-degradable complexes [44], thereby reducing ruminal N ammonia production and consequent urea synthesis in the liver [45]. Another reason why the blood urea content was lower in ABS groups was the slightly lower level of CP content of those diets [46].

5. Conclusions

The use of ABS in the diet of dairy goats is a potential alternative because it does not have negative effects on the milk yield and quality, or the health status of the animals. Of the three levels of inclusion studied in this experiment, 40% was the one that represented a greater inclusion of the by-product without penalizing the milk yield. In addition, the milk lipid profile quality improved with the diet with 40% ABS due to higher PUFA and n6 contents and lower AI and TI. In conclusion, the maximum inclusion level of ABS in dairy goats' diet should be 40%. More studies carried out over a longer period and including its use in different stages of lactation are required.

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