

Article

Effects of Dietary Red Grape Pomace Silage Inclusion Levels on the Nutritional and Technological Traits of Goat Milk

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Simple Summary

Grape pomace, the main residue produced during winemaking, is rich in natural compounds such as antioxidants, fibre and healthy fats. Using this by-product as animal feed can reduce waste and offer a more sustainable alternative to conventional ingredients. This study evaluated whether adding different amounts of ensiled red grape pomace (0, 6, 12 and 18% of the diet) to dairy goat feed could influence the nutritional quality and technological properties of their milk. Seventy-two goats were fed these diets for eight weeks, and their milk was regularly analysed. Overall, the inclusion of grape pomace did not change the basic composition of the milk or its antioxidant activity. However, it reduced milk urea and somatic cell count—two variables commonly associated with metabolic status and udder health—and improved the milk's fat profile in ways considered nutritionally desirable. Small changes in milk colour were detected, but these were too minor for consumers to notice. Some minerals, such as calcium, potassium and phosphorus, increased in milk from goats fed grape pomace. Overall, these results indicate that grape pomace can be included in goat diets without compromising milk quality, while supporting more sustainable livestock production and generating milk with compositional changes that may be of interest from a nutritional perspective.

Abstract

Grape pomace represents the main by-product generated during winemaking and is characterised by its richness in polyphenols, dietary fibre, residual sugars, lipids, and triterpenes. These bioactive compounds derived from grapes are known to positively influence oxidative status, metabolic balance, and animal productivity, positioning grape pomace as a promising, environmentally and economically sustainable alternative feed ingredient for conventional feed components. This research evaluated the effects of incorporating different inclusion rates (0, 6, 12, and 18% DM) of ensiled red grape pomace (RGP) into isoenergetic and isoproteic diets on the nutritional and technological characteristics of goat milk. Seventy-two Murciano-Granadina dairy goats were selected and distributed into eight homogeneous groups ($n = 9$ per group) based on physiological traits. Each diet was randomly assigned to two groups, and the feeding trial extended over eight weeks. After a two-week adaptation to the experimental diets, four biweekly milk samplings were performed to obtain representative bulk tank samples from each treatment group. Milk samples were analysed for gross composition, pH, mineral profile, fatty acid com-

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position, coagulation properties, colourimetric parameters, and antioxidant capacity. The collected data were analysed using a general linear model, considering the effect of the treatment, sampling days, and their interaction (Proc. GLM, SAS v9.4). Dietary RGP inclusion had no significant effect on milk gross composition or on the antioxidant activity of the milk. However, it led to a significant reduction in milk urea content and somatic cell count, alongside improvements in the lipid profile from a human health perspective. The magnitude of the effects observed in the colourimetric parameters (<0.5 units) fell below the threshold of human visual perception and was therefore not considered relevant. RGP-fed milk also showed increased calcium and potassium concentrations, while RGP_12 milk exhibited the highest phosphorus content. In addition, the lowest RGP levels (RGP_6) reduced the rennet coagulation time while increasing milk curd aggregation rate. Despite these targeted effects, the overall milk composition remained stable, which is critical for maintaining its technological functionality.

Keywords: by-products; fatty acids; lipid profile; health index; functional properties; coagulation properties

1. Introduction

Grape pomace is the main by-product of the winemaking industry [1]. It consists of a heterogeneous mixture of seeds, skins, and pulp residues [2] and is characterised by high levels of polyphenols, dietary fibre, residual sugars, lipids, and triterpenes [3]. Its valorisation in ruminant feeding represents both sustainability and nutritional opportunity, aligning with circular economy principles by reducing agro-industrial waste while providing functional nutrients to livestock [4–6]. The strategic integration of agro-industrial by-products and non-conventional forages into livestock feeding systems is increasingly acknowledged as a sustainable pathway to reduce dependency on imported feed resources and to enhance regional feed autonomy. This approach is particularly relevant for production systems that rely heavily on conventional feed crops—such as cereals, legumes, and standard forages—which are progressively constrained by declining economic competitiveness and intensifying limitations in land, water, and other critical inputs [7]. When diets are carefully formulated to meet nutritional requirements, the inclusion of such by-products does not compromise animal performance or product quality [8–11]. The dietary inclusion of agro-industrial by-products has proven effective in small ruminant feeding systems [12–14].

Nevertheless, the seasonal nature of agro-industrial by-products and their elevated moisture content pose challenges for year-round use and preservation. Silage represents a technically and economically viable preservation method for these resources, enabling the retention of their nutritional and hygienic integrity while maintaining the stability of their bioactive compound content [5,15,16]. Notably, grape pomace retains a substantial fraction of the grape's bioactive compounds—such as phenolics, flavonoids, and tocopherols—and polyunsaturated fatty acids [17–20], that are not transferred to the wine [21]. Polyphenols present in grape pomace—particularly flavanols and proanthocyanidins—exert systemic bioactivities, including ruminal modulation, improved hepatic function, regulation of nitrogen metabolism, and enhanced antioxidant capacity [22]. Moreover, dietary polyphenols may also influence milk yield and composition, with milk increasingly recognised as a sensitive biosensor of metabolic adaptation in response to nutritional interventions [23].

Goat milk, recognised for its high total solids and favourable digestibility [24–26], has attracted increasing attention in developed countries for its nutritional profile and the

growing prevalence of cow's milk protein intolerance and allergy. Globally, it ranks as the third most consumed milk type after cow and buffalo milk, with Europe accounting for approximately 20% of total global production [27]. Although studies on sheep fed silage derived from agro-industrial by-products are limited, the available evidence supports their suitability for maintaining milk quality and animal health [28–31]. However, in goats, the inclusion of plant by-products in the diet results in variable effects on milk composition and technological properties, with evidence indicating a trend that is both dose-dependent and influenced by dietary exposure duration. For instance, Monllor et al. [14] demonstrated that 25% DM of ensiled artichoke plant silage improved the lipid and mineral profile of goat milk, and a 40% DM inclusion increased polyunsaturated fatty acids (PUFA) and n-6 levels and reduced atherogenic and thrombogenic indices [32]. In a full-lactation trial, the same inclusion level of artichoke silage reduced the n-6/n-3 ratio, whereas broccoli silage at 40% DM induced selective feeding and reduced intake [33]. Arco-Pérez et al. [34] reported that diets containing 20% DM of ensiled tomato or olive by-products did not affect milk yield or gross composition, but altered the fatty acid profile, increasing C18:1 trans-11, C20:2, and CLA. Prolonged feeding of tomato silage, however, led to elevated saturated fatty acids (SFAs) while reducing monounsaturated fatty acids (MUFAs) and conjugated linoleic acid (CLA). Muelas et al. [35] found no significant changes in milk composition when Murciano-Granadina goats were fed up to 25% DM of artichoke by-product silage, although colourimetric shifts were observed at this level, whereas a lower dose (12.5% DM) did not elicit this effect. However, evidence regarding the use of red grape pomace in dairy goats remains limited, and the few available studies have exclusively assessed dehydrated red grape pomace [36,37].

The hypothesis proposed is that feeding dairy goats with diets containing red grape pomace silage could beneficially modulate the nutritional and technological characteristics of milk, and that the valorisation of this agro-industrial by-product may contribute to more sustainable dairy production systems in the present context.

Therefore, this study aimed to assess the effects of varying inclusion levels of red grape pomace silage (RGP) in dairy goat diets on milk composition, mineral and fatty acid profiles, coagulation properties, colourimetric parameters, and antioxidant activity. A further objective was to determine the most favourable inclusion level among those tested that optimises milk nutritional and technological traits.

2. Materials and Methods

2.1. Animals and Facilities

The study was carried out at the teaching and research farm of Miguel Hernández University in Spain, utilising a dairy goat herd. The experimental period lasted 56 days, starting in late January immediately after the baseline sampling and a one-week acclimation phase, and extending through the end of March. The facility maintains Murciano-Granadina goats housed in straw-bedded enclosures under a free-stall system. Each animal was allocated 1.5 square metres of personal space, 35 centimetres of linear access to the feeding area, and continuous availability of clean drinking water. Feeding routines were implemented twice daily, at 9:00 a.m. and 3:00 p.m., while milking was performed once per day using a Casse milking parlour (2 × 12 × 12 configuration, GEA, Düsseldorf, Germany), following regional standard management protocols. This study was approved by the Office of Responsible Research at Miguel Hernández University in accordance with European institutional guidelines for animal welfare (code UMH.DTA.JDS.03.21).

2.2. Experimental Design

Out of an initial herd of 120 dairy goats, in the five weeks postpartum stage of lactation—maintained on a conventional feeding regimen—72 individuals were selected based on uniformity in parity, body weight (42 ± 2 kg), daily milk production (2 ± 0.16 kg), and logarithmic somatic cell count (LSCC, 2.62 ± 0.14 Log10 cells/mL). These goats were evenly allocated into eight groups of nine animals each—3 primiparous and 6 multiparous each—ensuring consistency across the selection parameters. From this point onward, each group was considered an experimental unit. After a one-week acclimation period within their new groupings, a baseline sampling was performed. Subsequently, each dietary treatment was randomly assigned to two of the eight groups (two groups per diet): a control diet (standard feed without by-products), 6_RGP (standard feed with 6% dry matter of red grape pomace silage), 12_RGP (12% DM of red grape pomace silage), and 18_RGP (18% DM of red grape pomace silage). Following a two-week adaptation to the newly assigned diets, four additional biweekly milk samplings were carried out to collect representative bulk tank samples, using eight independent tanks (one per experimental unit). For each experimental unit, a representative volume was then collected and immediately partitioned into uniform aliquots. Bulk tank milk was kept at 4 °C under continuous agitation during sampling to ensure complete homogenization. Gross composition, somatic cell count (SCC), milk coagulation properties, pH, and colourimetric traits were determined immediately. The remaining aliquots were stored at −20 °C until the analysis of mineral content, fatty acid composition, and antioxidant capacity. All analytical determinations were performed in duplicate.

Milk samples were collected sequentially as lactation advanced, following the predetermined weekly schedule. To clearly distinguish the influence of lactation stage from that of dietary intervention, two complementary methodological measures were adopted: a control group fed the standard diet was maintained unchanged throughout the study, and the statistical interaction between sampling week and dietary treatment was formally assessed. This combined strategy allowed the detection of diet-related effects that varied with lactation stage while minimising confounding associated with the temporal structure of the experimental design.

The experimental diets were formulated according to the recommendations of Fernández et al. [38] for goats producing 2 kg of milk/day, ensuring isoenergetic and isoproteic rations tailored to their production level. The adjustment of ingredient proportions, including the incorporation of the ensiled red grape pomace, was carried out using a commercial feed formulation software (BESTMIX®—version 4.02, Bestmix Software, Maldegem, Belgium). Each experimental unit received the fixed amount of feed assigned to it twice daily. Details on ingredients, chemical composition, and daily feed offered (Table 1) are provided below, following the same diets described in the published study [39]. The RGP incorporated into the experimental diet corresponded to silage previously characterised by Romero et al. [5]. It had undergone a 180-day storage period in 300 kg commercial plastic bales, resulting in a material with a pH of 4.2 and a dry matter content of 53.8%. Its chemical composition—approximately 55% DM, 8.5% EE, 10.5% CP, 50% NDF and 40% ADF—confirmed its classification as a high-fibre ingredient supplying a moderate energy contribution to ruminant diets.

Table 1. Ingredients and chemical composition of experimental diets containing different inclusions of red grape pomace by-product for dairy goat feeding.

Item	Diets			
	Control	RGP_6	RGP_12	RGP_18
Ingredients (% DM)				
RGP	0.0	6.0	12.0	18.0
Barley straw	4.3	2.4	1.1	2.1

Alfalfa hay (16% CP)	33.7	33.2	28.5	10.4
Concentrate feed	62.0	58.4	58.4	69.5
Kg DM offered/animal/day	1.99	2.06	2.07	2.00
Chemical composition (g/kg DM)				
DM (g/kg FM)	886	872	841	797
OM	917	912	921	921
CP	152	158	156	156
EE	27	31	36	40
CF	195	180	186	133
NDF	387	383	374	340
ADF	226	223	233	196
ADL	41	47	47	49
Starch	214	212	210	208
Total sugar	33	34	35	40
Total polyphenols (GAE eq.)	7.5	7.1	7.2	7.1
ME ¹ (Mcal/kg DM)	2.65	2.66	2.63	2.74
Mineral content (g/kg DM)				
Ca	11.7	11.9	11.4	11.6
Na	5.1	4.7	4.3	4.0
K	13.7	13.9	13.7	13.1
P	3.7	3.9	3.8	4.2
Fatty acid profile ²				
C4:0	0.05	0.10	0.07	0.05
C6:0	0.03	0.03	0.07	0.02
C12:0	0.14	0.17	0.20	0.14
C14:0	0.56	0.56	0.46	0.43
C16:0	17.92	18.36	15.51	16.26
C16:1c9	0.61	0.58	0.62	0.57
C18:0	3.98	4.02	4.18	3.99
C18:1c9	23.79	21.89	21.39	22.42
C18:1c11	1.31	1.24	1.48	1.20
C18:2n6	44.57	44.58	49.44	49.80
C18:3n3	4.24	5.30	4.12	2.79
C20:0	0.37	0.39	0.38	0.32
C20:1n9	0.38	0.34	0.27	0.32
C22:0	0.28	0.33	0.25	0.25
C24:0	0.27	0.34	0.15	0.22
SFA	24.50	25.38	22.21	22.25
MUFA	26.24	24.21	23.68	24.63
PUFA	49.21	50.38	54.11	53.08
UI	129.35	130.67	136.75	134.13
Antioxidant activity (mg Trolox eq/g DM)				
ABTS	2.6	2.3	2.6	2.8
DPPH	2.9	3.0	3.4	3.3

RGP: red grape pomace; RGP_6: diet with 6% of RGP; RGP_12: diet with 12% of RGP; RGP_18: diet with 18% of RGP. DM: dry matter; FM: fresh matter; OM: organic matter; CP: crude protein; EE: ether extract; CF: crude fibre; NDF: neutral detergent fibre; ADF: acid detergent fibre; ADL: acid detergent lignin; GAE eq.: gallic acid equivalents; ME: metabolic energy: ¹ [40]; ² percentages of the methylated fatty acid area in the fatty acid profile; SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid; UI: Unsaturation Index.

2.3. Variables Analysed

The composition of the diets (Table 1) was determined according to AOAC (1999) methods [41]: 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), crude protein (CP, g/kg DM; method 984.13), and total sugars (g/kg DM; method 974.06). Neutral detergent fibre (NDF, g/kg DM), acid detergent fibre (ADF, g/kg DM), and acid detergent lignin (ADL, g/kg DM) were ana-

lysed according to Van Soest et al. [42]. Starch content was determined using the polarimetric method of Ewers [43]. Total polyphenol content (PT, g GAE eq./kg DM) was analysed using the Folin–Ciocalteu method as described by Kim et al. [44]. The mineral content in the diets was determined using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS; Agilent 7700x, Santa Clara, CA, USA) following acid digestion of the samples according to González-Arrojo et al. [45]. The lipid profile, including the separation of polyunsaturated fatty acid isomers, was determined by direct methylation of the lyophilised sample, without prior fat extraction, according to Kramer et al. [46]. The identification of fatty acid methyl esters (FAMES) was performed using a GC-2030 gas chromatograph equipped with a flame ionisation detector (FID). The system included a CP Sil 88 capillary column (100 m × 0.25 mm, 0.20 µm particle size; Agilent, Santa Clara, CA, USA) and an automatic injector model AOC-20i (Shimadzu, Kyoto, Japan). For peak identification within the fatty acid profile, a commercial FAME mixture (catalogue number 18912-1AMP; Sigma-Aldrich, Saint Louis, MO, USA) was employed as the reference standard. To evaluate the antioxidant activity, ABTS and DPPH reducing power were determined. For the ABTS analysis (reduction of the 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonate radical), the method described by Leite et al. [47] was followed. The DPPH analysis (reduction of the 1,1-diphenyl-2-picrylhydrazyl radical) was conducted following the modified protocol by Cheng et al. [48], developed initially by Brand-Williams et al. [49].

Gross composition of bulk tank milk—including fat, crude protein, lactose, useful dry matter (UDM), non-fat dry matter (NFD), and milk urea—was analysed using mid-infrared spectroscopy (CombiFoss™ 7 DC, Foss, Hillerød, Denmark). Moreover, somatic cell count (SCC, cells/mL) was determined via flow cytometry (CombiFoss™ 7 DC, Foss, Hillerød, Denmark). Total cholesterol content was determined following saponification and methylation of milk samples. Quantification was performed using high-performance liquid chromatography (HPLC 1200, Agilent Technologies, Santa Clara, CA, USA) equipped with a diode array detector (DAD) set at 208 nm. The separation was carried out under isocratic conditions using a mobile phase of 2-propanol-hexane (2:98, v/v) at a flow rate of 1 mL/min, according to the method described by Domínguez et al. [50].

The mineral content in the milk was determined following acid digestion of the samples according to González-Arrojo et al. [45]. Quantification was performed using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS; Agilent 7700x, Santa Clara, CA, USA) equipped with an Octopole Reaction System (ORS). To account for potential physical and matrix interferences, an internal standard was employed throughout the analysis.

The milk fatty acid profile was determined following the fat extraction method described by Romeu-Nadal et al. [51], and fatty acid methylation was performed according to Nudda et al. [52]. Fatty acid methyl esters (FAMES) were separated using a gas chromatograph (GC) Shimadzu GC-2030 coupled with a flame ionisation detector (FID), and an automatic injector AOC-20i was used. The GC was equipped with a capillary column (CP Sil 88 100 m × 0.25 mm, 0.20 µm particle size, Agilent, Santa Clara, CA, USA). The injector and detector temperatures were 240 °C and 250 °C, respectively. The programmed temperature was 45 °C for two minutes, increasing to 165 °C in a range of 8 °C/min, maintained at 165 °C for 35 min, increasing to 210 °C in a range of 5.5 °C/min. Helium was used as carrier gas, and nitrogen as a make-up gas (40 mL min⁻¹). FID used hydrogen and air, at rates of 35 mL min⁻¹ and 350 mL min⁻¹, respectively. The fatty acids were individually identified by comparison with the relative retention times of a standard mix of external standards (37FAME mix, Supelco, Bellefonte, PA, USA). Results were calculated as a percentage of each fatty acid in the total fatty acid profile. Nutritional and health-related indices of fatty acids were calculated following the methodology proposed by Chen and Liu [53].

To assess milk coagulation properties, samples were equilibrated in a water bath at 32 °C for 15 min. Recombinant chymosin (Larbus S.A., Madrid, Spain) was prepared by

diluting it 1:100 in distilled water. For each measurement, 10 mL of milk was dispensed into the wells of the Optigraph device (Ysebaert, Frépillon, France), followed by the addition of 100 µL of the diluted enzyme. The assay was conducted at 32 °C, monitoring optical changes over a 50 min period. Based on these readings, the rennet coagulation time (RCT, min), aggregation rate (min), and curd firmness (mm) were determined under standardised conditions using the Optigraph system. Additionally, pH values were recorded using a pH/Ion 510 m (Eutech Instruments Pte Ltd., Singapore).

Colour evaluation was performed using the CIE 1976 L*a*b* (CIELab) coordinate system with a spectrophotometer (CM-700, Minolta Camera Co., Osaka, Japan), set to a 10° standard observer angle and D65 illuminant under SCI (Specular Component Included) mode. To minimise measurement interference, a low-reflectance glass cube (Minolta CR-A51/1829-752) was used as a measuring instrument. The measured CIELab parameters included lightness (L*), red/green coordinate (a*), and yellow/blue coordinate (b*). Based on these values, the psychophysical attributes hue angle (h*) and chroma (C*) were calculated using the following equations [54]:

$$h^* = \tan^{-1} (b^*/a^*)$$

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

Moreover, whiteness (WI) and yellowness (YI) indices were determined according to the following equations [55]:

$$WI = 100 - \sqrt{[(100 - L^*)^2 + a^{*2} + b^{*2}]}$$

$$YI = 142.86 \times (b^*/L^*)$$

To evaluate the antioxidant activity by ABTS and FRAP reducing power were determined. For the ABTS analysis (reduction of the 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonate) radical), the method described by Leite et al. [47] was followed. The FRAP analysis (ferric reducing antioxidant power, which measures the reduction of ferric ion to the ferrous state) was conducted according to the protocol by Oyaizu [56]. The results of these reactions were measured by spectrophotometry using a UV-visible spectrophotometer (Zuzi 4255/50, Auxilab, Arlegui, Navarra, Spain) at wavelengths of 734 and 593 nm for ABTS and FRAP, respectively. The antioxidant capacity value of the sample was expressed in mg Trolox eq/100 mL of milk.

2.4. Statistical Analysis

The SCC values were log₁₀-transformed prior to analysis. Milk variables were analysed using a general linear model (PROC GLM, SAS v9.4). The experimental unit was the group, as goats were managed and fed collectively within each dietary treatment (two groups per diet). Accordingly, the statistical model included diet, sampling time, and their interaction as fixed effects, following the equation:

$$Y = \mu + D_i + T_k + (D_i \times T_k) + e$$

where Y is the dependent variable, μ is the intercept, D_i represents the fixed effect of diet (i = control, 6-RGP, 12-RGP, 18-RGP), T_k is the fixed effect of sampling k = 0, 1, 2, 3, 4), $D_i \times T_k$ represents the interaction between both effects (20 levels), and e is the residual error.

In addition to the fixed-effect tests, orthogonal polynomial contrasts were used to evaluate the dose-response pattern associated with increasing dietary RGP inclusion (0, 6, 12, and 18%). Linear and quadratic contrasts were applied to the main effect of diet to characterise potential monotonic or curvilinear responses. Although diet $\times$ sampling interactions were significant for several variables, these interactions were attributed to the physiological evolution of milk composition across mid-lactation rather than to treatment-

dependent effects. Therefore, polynomial contrasts were evaluated on the overall dietary effect, consistent with the primary objective of assessing the impact of RGP inclusion level. Statistical significance for linear and quadratic contrasts was declared at $p < 0.05$.

Least square means (LSMEANS) were obtained to estimate model-adjusted means for each level of the fixed effects. Pairwise comparisons between LSMEANS were performed using the t -test associated with the PDIF option in PROC GLM. The null hypothesis tested was:

$$H_0: \text{LSMean}(h) = \text{LSMean}(j)$$

where h and j represent different levels of the fixed effect. Statistical significance was assessed using $\text{Pr} > t$, with $p < 0.05$ considered significant.

3. Results

3.1. Gross Composition

The inclusion of RGP in the diet significantly influenced lactose, milk urea, and LSCC, as detailed in Table 2. The RGP_12 milk showed the highest lactose content (4.70%), significantly higher than both control and RGP_6 and RGP_18 milk ($p = 0.0068$). Milk urea concentration declined progressively with increasing levels of RGP inclusion. Specifically, RGP_12 (554.30 mg/L) and RGP_18 (540.10 mg/L) milk samples presented significantly lower urea concentrations compared to the control group (586.10 mg/L). Furthermore, LSCC was significantly reduced in the RGP_18 milk (2.89 Log10 cells/mL) relative to the control (3.05 Log10 cells/mL) ($p = 0.0205$). No treatment-related effects were detected for fat, protein, NFD, UDM, or cholesterol content ($p > 0.05$). Sampling effects were included mainly to adjust for lactation-stage progression; their significance reflects the expected physiological changes across weeks rather than treatment-related trends.

Table 2. Results of statistical analysis (p -values) and least square means ($\pm$ SEM) comparison for gross milk composition and total cholesterol content of milk across dietary treatments.

Item	Diet					p -Value		
	Control	RGP_6	RGP_12	RGP_18	SEM	Diet	Sampling	Diet x Sampling
Fat (%)	5.22	5.46	5.42	5.37	0.117	ns	0.0001	ns
Protein (%)	3.80	3.82	3.83	3.68	0.045	ns	<0.0001	ns
Lactose (%)	4.64 ^a	4.62 ^a	4.70 ^b	4.64 ^a	0.015	0.0068	<0.0001	ns
NFDM (%)	9.32	9.34	9.42	9.23	0.057	ns	<0.0001	ns
UDM (%)	9.02	9.28	9.25	9.05	0.150	ns	<0.0001	ns
Urea (mg/L)	586.10 ^a	576.40 ^{ab}	554.30 ^{bc}	540.10 ^c	5.640	0.0011	<0.0001	ns
LSCC (Log10 cells/mL)	3.05 ^{ac}	3.11 ^a	2.94 ^{bc}	2.89 ^b	0.050	0.0205	0.0112	ns
CHOL (mg/100 g)	18.70	19.33	18.46	18.74	0.247	ns	<0.0001	ns

RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; NFDM: non-fat dry matter; UDM: useful dry matter (% fat + % protein); LSCC: Log10 somatic cell count; CHOL: total cholesterol content. SEM: standard error of the mean; a–c: different letters within the same row indicate significant differences between diets according to the LSMEANS t -test (PDIF) in PROC GLM; ns: non-significant ($p > 0.05$). p -values are reported for the significant effects.

Increasing RGP inclusion produced a dose–response effect on milk urea concentration. A significant linear decrease was observed as dietary RGP level increased ($p = 0.0004$). In addition, a quadratic trend was detected ($p = 0.0599$), suggesting a slight curvature in the response, with the greatest reduction occurring at the highest inclusion levels. LSCC

also showed a dose–response pattern. A significant linear decrease was detected with increasing RGP inclusion ($p = 0.0227$), whereas no quadratic effects were observed ($p = 0.3627$).

3.2. Mineral Profile

As shown in Table 3, the Ca concentration in milk from RGP-fed goats was significantly higher than that of the control group, with RGP_12 exhibiting the peak value (0.171 g/100 g) ($p < 0.001$). K increased in the RGP milk compared with the control ($p < 0.001$), although no differences were observed between the RGP_12 and RGP_18 groups ($p > 0.05$). RGP_12 also yielded the highest P content (0.152 g/100 g) ($p < 0.001$), while RGP_18 showed the greatest magnesium concentration (0.015 g/100 g) ($p < 0.001$).

Table 3. Results of statistical analysis (p -values) and least square means ($\pm$ SEM) comparison for mineral profile of milk across dietary treatments.

Item	Diet					p -Value		
	Control	RGP_6	RGP_12	RGP_18	SEM	Diet	Sampling	Diet x Sampling
Ca (g/100 g)	0.144 ^a	0.161 ^b	0.171 ^c	0.160 ^b	0.002	<0.0001	<0.0001	<0.0001
P (g/100 g)	0.121 ^a	0.120 ^a	0.152 ^b	0.122 ^a	0.005	<0.0001	0.0001	0.0054
K (g/100 g)	0.108 ^a	0.122 ^b	0.131 ^c	0.132 ^c	0.002	<0.0001	<0.0001	<0.0001
Na (g/100 g)	0.035	0.036	0.035	0.036	0.001	ns	<0.0001	<0.0001
Mg (g/100 g)	0.013 ^a	0.014 ^{bc}	0.014 ^{ab}	0.015 ^c	0.000	<0.0001	0.0092	0.0034
Ca:P	1.22 ^b	1.39 ^a	1.19 ^b	1.33 ^a	0.045	0.0104	0.0219	0.0182

RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; SEM: standard error of the mean. a–c: different letters within the same row indicate significant differences between diets according to the LSMEANS t -test (PDIFF) in PROC GLM; ns: non-significant ($p > 0.05$). p -values are reported for the significant effects.

Dietary RGP inclusion significantly affected the mineral profile of milk. Ca concentration showed a strong dose–response pattern, with both linear ($p < 0.0001$) and quadratic ($p < 0.0001$) components being highly significant. This indicates a pronounced curvilinear response, with the greatest increases occurring at intermediate inclusion levels. P concentration exhibited a different pattern: no linear effect was detected ($p = 0.1244$), whereas the quadratic contrast was significant ($p = 0.0040$). This suggests a non-monotonic response, with changes driven primarily by curvature rather than by a progressive increase or decrease across RGP levels. K concentration increased consistently with dietary RGP inclusion, as shown by a highly significant linear effect ($p < 0.0001$). A significant quadratic component was also observed ($p = 0.0001$), indicating that although the overall trend was increasing, the magnitude of the response varied across inclusion levels. Mg concentration also displayed a linear increase with rising RGP inclusion ($p < 0.0001$), while the quadratic effect was not significant ($p = 0.8302$), confirming a predominantly monotonic dose–response pattern.

3.3. Fatty Acid Profile

The major milk fatty acids quantified in this experiment are listed in Table 4. C14:0 ($p < 0.0001$), C18:3n3 ($p < 0.0001$), C22:0 ($p = 0.006$), SFA ($p < 0.0001$), IA ($p < 0.0001$), IT ($p < 0.0001$), HFA ($p < 0.0001$) and OBCFA ($p < 0.0001$) significantly decreased as the proportion of RGP in the diet increased. Conversely, C18:1c11 ($p = 0.0009$), MUFA ($p < 0.0001$), PUFA ($p < 0.0001$), UI ($p < 0.0001$), HH ($p < 0.0001$) and HPI significantly increased with higher dietary inclusion of RGP. C18:0, C18:1c9, C18:2n6, C20:1n9, n6n3, and LAALA ($p < 0.0001$)

were significantly higher in RGP milks compared to the control; at the same time, RGP_12 milk exhibited the highest individual values for C18:0 and C18:1c9 ($p < 0.0001$). C12:0, C16:0 and C16:1c9 were significantly reduced in the RGP milk relative to the control ($p < 0.0001$). In contrast, C18:1t11 and CLA c9,t11 increased in the RGP milk, with the RGP_12 milk exhibiting the highest levels ($p < 0.0001$). CLAVACCs were significantly higher on RGP_12 and control milk.

Table 4. Results of statistical analysis (p -values) and least square means ($\pm$ SEM) comparison for fatty acid profile (percentages of the methylated fatty acid area in the fatty acid profile) and nutritional and health-related indices of milk across dietary treatments.

Item	Diet					p -Value		
	Control	RGP_6	RGP_12	RGP_18	SEM	Diet	Sampling	Diet x Sampling
C4:0	0.89	0.99	0.90	0.92	0.030	ns	ns	ns
C6:0	1.50	1.58	1.43	1.47	0.038	ns	ns	ns
C12:0	5.042 ^a	4.292 ^b	4.383 ^b	4.100 ^c	0.077	<0.0001	<0.0001	0.01
C14:0	9.455 ^a	9.023 ^b	8.854 ^{bc}	8.807 ^c	0.068	<0.0001	<0.0001	0.0022
C16:0	29.863 ^a	28.173 ^b	28.598 ^b	27.322 ^c	0.325	<0.0001	<0.0001	ns
C16:1c9	0.831 ^a	0.746 ^b	0.761 ^b	0.680 ^c	0.009	<0.0001	<0.0001	ns
C18:0	7.065 ^d	7.762 ^c	8.684 ^a	8.088 ^b	0.156	<0.0001	<0.0001	0.0003
C18:1c9	15.248 ^c	16.698 ^b	17.031 ^a	16.176 ^b	0.222	<0.0001	<0.0001	0.0479
C18:1c11	0.472 ^b	0.503 ^{ab}	0.514 ^a	0.540 ^a	0.011	0.0009	<0.0001	ns
C18:2n6	3.471 ^c	3.768 ^b	3.631 ^b	3.906 ^a	0.046	<0.0001	<0.0001	ns
C18:3n3	0.236 ^a	0.221 ^b	0.215 ^b	0.179 ^c	0.004	<0.0001	<0.0001	0.0115
C18:1t11	1.880 ^d	2.744 ^a	2.027 ^c	2.468 ^b	0.095	<0.0001	ns	ns
CLAc9t11	1.068 ^d	1.328 ^a	1.164 ^c	1.216 ^b	0.037	<0.0001	<0.0001	ns
C20:0	0.15	0.16	0.15	0.15	0.007	ns	<0.0001	ns
C20:1n9	0.050 ^a	0.057 ^b	0.059 ^{bc}	0.066 ^c	0.003	0.0071	<0.0001	ns
C22:0	0.040 ^a	0.038 ^a	0.037 ^a	0.030 ^b	0.002	0.006	<0.0001	0.0124
C24:0	0.02	0.03	0.02	0.02	0.004	ns	<0.0001	ns
SFA	68.926 ^a	66.510 ^b	66.846 ^b	64.255 ^c	0.366	<0.0001	<0.0001	0.0011
MUFA	24.760 ^c	26.616 ^b	26.956 ^b	28.890 ^a	0.321	<0.0001	<0.0001	0.0008
PUFA	5.674 ^b	6.202 ^a	6.209 ^{ab}	6.222 ^a	0.077	<0.0001	<0.0001	ns
n6n3	15.622 ^c	18.198 ^b	18.556 ^b	23.729 ^a	0.276	<0.0001	<0.0001	<0.0001
LAALA	14.739 ^c	17.190 ^b	17.090 ^b	22.621 ^a	0.269	<0.0001	<0.0001	<0.0001
UI	34.405 ^c	36.995 ^b	36.640 ^b	39.272 ^a	0.419	<0.0001	<0.0001	0.028
IA	2.434 ^a	2.102 ^b	2.115 ^b	1.904 ^c	0.034	<0.0001	<0.0001	<0.0001
IT	3.155 ^a	2.841 ^b	2.838 ^b	2.599 ^c	0.054	<0.0001	<0.0001	0.0012
HFA	44.360 ^a	41.487 ^b	41.385 ^b	40.227 ^c	0.337	<0.0001	<0.0001	0.0026
HH	0.498 ^c	0.568 ^a	0.579 ^a	0.583 ^a	0.012	<0.0001	<0.0001	0.0678
HPI	0.421 ^c	0.482 ^b	0.497 ^b	0.527 ^a	0.009	<0.0001	<0.0001	0.0047
OLESTE	2.25	2.26	2.09	2.07	0.064	ns	<0.0001	ns
CLAVACC	0.612 ^a	0.528 ^b	0.625 ^a	0.533 ^b	0.015	<0.0001	<0.0001	0.0234
OBCFA	3.341 ^a	3.094 ^b	3.011 ^b	2.895 ^c	0.038	<0.0001	0.0003	0.0034

RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; CLA: conjugated linoleic acid; SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid; n6n3: ω -6/ ω -3 Fatty Acid Ratio; LAALA: Linoleic Acid/ α -Linolenic Acid Ratio; UI: Unsaturation Index; IA: Index of Atherogenicity; IT: Index of Thrombogenicity; HFA: Hypercholesterolemic Index; HH: Hypocholesterolemic/Hypercholesterolemic Ratio; HPI: Health-Promoting Index; OLESTE: Oleic to Stearic Acid Ratio; CLAVACC: Conjugated Linoleic Acid to Vaccenic Acid Ratio; OBCFA: Odd- and

Branched-Chain Fatty Acids. SEM: standard error of the mean. a–c: different letters within the same row indicate significant differences between diets according to the LSMEANS *t*-test (PDIFF) in PROC GLM; ns: non-significant ($p > 0.05$). *p*-values are reported for the significant effects.

Several fatty acids exhibited a curvilinear dose–response pattern to increasing RGP inclusion, with both linear and quadratic components being significant. This behaviour was observed for C12:0 (linear $p < 0.0001$; quadratic $p = 0.0036$), C14:0 (linear $p < 0.0001$; quadratic $p = 0.0067$), C18:0 (linear $p < 0.0001$; quadratic $p = 0.0001$), C18:1c9 (linear $p = 0.0026$; quadratic $p < 0.0001$), C18:3n3 (linear $p < 0.0001$; quadratic $p = 0.0249$), C18:1 t11 (linear $p = 0.0160$; quadratic $p = 0.0290$), PUFA (linear $p = 0.0002$; quadratic $p = 0.0120$), n6n3 (linear $p < 0.0001$; quadratic $p < 0.0001$), LAALA (linear $p < 0.0001$; quadratic $p < 0.0001$), and HH (linear $p < 0.0001$; quadratic $p = 0.0007$). These results indicate that the response of these fatty acids was not strictly monotonic, but followed a curved trajectory, with changes in slope across inclusion levels. A consistent linear response to increasing RGP inclusion was observed for several fatty acids and nutritional and health-related indices, including C16:0 ($p < 0.0001$), C16:1c9 ($p < 0.0001$), C18:1c11 ($p < 0.0001$), C18:2n6 ($p < 0.0001$), C22:0 ($p = 0.0010$), SFA ($p < 0.0001$), MUFA ($p < 0.0001$), UI ($p < 0.0001$), IA ($p < 0.0001$), TI ($p < 0.0001$), HFA ($p < 0.0001$), HPI ($p < 0.0001$), CLAVACC ($p = 0.0448$), and OBCFA ($p < 0.0001$). For these traits, the absence of a quadratic component indicates a predominantly monotonic dose–response pattern, with changes occurring progressively across RGP levels. A purely quadratic response to increasing RGP inclusion was observed for CLAc9t11 ($p = 0.0071$) and C20:1n9 ($p = 0.0047$).

3.4. Milk Coagulation Properties

Regarding milk coagulation properties, RGP_6 milk exhibited the shortest rennet coagulation time (7.88 min) ($p = 0.0022$) and the highest aggregation rate (2.51 mm/min) ($p = 0.0270$) (Table 5). No significant differences were observed between the RGP_12 and RGP_18 milks and the control milk for either variable. Sampling effects were consistently significant across all variables, indicating a measurable influence of lactation-stage progression.

Table 5. Results of statistical analysis (*p*-values) and least square means ($\pm$ SEM) comparison for milk coagulation properties and pH across dietary treatments.

Item	Diet					<i>p</i> -Value		
	Control	RGP_6	RGP_12	RGP_18	SEM	Diet	Sampling	Diet x Sampling
Rennet coagulation time (min)	8.65 ^a	7.88 ^b	9.21 ^a	9.21 ^a	0.443	0.0022	0.0033	ns
Aggregation rate (mm/min)	2.06 ^a	2.51 ^b	2.34 ^{ab}	2.20 ^a	0.224	0.0270	<0.0001	ns
Curd firmness (mm)	16.12	15.53	14.86	16.43	1.052	ns	<0.0001	0.0030
pH	6.73	6.73	6.74	6.73	0.050	ns	0.0007	ns

RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; SEM: standard error of the mean. a–b: different letters within the same row indicate significant differences between diets according to the LSMEANS *t*-test (PDIFF) in PROC GLM; ns: non-significant ($p > 0.05$). *p*-values are reported for the significant effects.

Rennet coagulation time showed a significant linear response to increasing RGP inclusion ($p = 0.0158$), indicating a progressive increase in coagulation time at higher dietary levels. No quadratic effects were detected ($p = 0.1785$), confirming a predominantly monotonic dose–response pattern. The aggregation rate showed a purely quadratic response to increasing RGP inclusion ($p = 0.0079$), with no linear effect detected ($p = 0.7312$).

3.5. Colourimetric Parameters

Colourimetric parameters are summarised in Table 6. The inclusion of RGP in the diet significantly influenced milk colour, as evidenced by changes in the a^* , b^* , h^* , C^* coordinates and YI. Milk from the RGP_6 (−1.34) showed significantly lower a^* values compared to RGP_12 (−1.23) and RGP_18 (−1.23) ($p = 0.0056$), but not significantly different from the control. Similarly, h^* values in RGP_6 milk (104.88) were significantly higher than RGP_12 milk (103.11), with no significant difference observed relative to control and RGP_18 milk. In contrast, b^* and C^* values decreased significantly in RGP_18 milk compared to both the control and RGP_12, but showed no significant differences when compared to RGP_6. The YI decreased significantly in the RGP_12 and RGP_18 milks relative to the control ($p = 0.0058$), whereas no differences were observed when compared with RGP_6 milk. Sampling effects were consistently significant across all variables, indicating a measurable influence of lactation-stage progression.

Table 6. Results of statistical analysis (p -values) and least square means ($\pm$ SEM) comparison for colourimetric parameters across dietary treatments.

Item	Diet					p -Value		
	Control	RGP_6	RGP_12	RGP_18	SEM	Diet	Sampling	Diet x Sampling
L*	84.78	84.57	84.76	84.56	0.002	ns	<0.0001	ns
a^*	−1.30 ^{ab}	−1.34 ^a	−1.23 ^b	−1.23 ^b	0.024	0.0056	<0.0001	ns
b^*	5.33 ^a	5.17 ^{ab}	5.33 ^a	5.05 ^b	0.060	0.0046	<0.0001	ns
h^*	103.87 ^{ab}	104.88 ^b	103.11 ^a	103.86 ^{ab}	0.371	0.0179	<0.0001	ns
C^*	5.49 ^a	5.35 ^{ab}	5.47 ^a	5.20 ^b	0.056	0.0026	<0.0001	ns
WI	83.79	83.65	83.79	83.70	0.066	ns	<0.0001	ns
YI	8.97 ^a	8.72 ^{ab}	8.68 ^b	8.52 ^b	0.099	0.0058	<0.0001	ns

RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; L*: lightness; a^* : red/green coordinate; b^* : yellow/blue coordinate; h^* : angle; C^* : chroma; WI: whiteness indices; YI: yellowness indices. SEM: standard error of the mean. a–b: different letters within the same row indicate significant differences between diets according to the LSMEANS t -test (PDIFF) in PROC GLM; ns: non-significant ($p > 0.05$). p -values are reported for the significant effects.

Moreover, milk colour parameters showed a consistent linear response to increasing RGP inclusion: a^* ($p = 0.0084$), b^* ($p = 0.0158$), C^* ($p = 0.0050$), and YI ($p = 0.0191$), with no quadratic component detected. Overall, these results indicate a predominantly monotonic dose–response pattern, with colour intensification decreasing progressively as RGP inclusion level rose.

3.6. Antioxidant Activity

The ABTS radical scavenging potential and the ferric reducing antioxidant power (FRAP) of milk did not show significant differences between RGP levels, as shown in Table 7. However, ABTS showed a significant diet $\times$ sampling interaction, indicating that differences among diets occurred only at specific sampling times.

Table 7. Results of statistical analysis (*p*-values) and least square means ($\pm$ SEM) comparison for antioxidant activity of milk across dietary treatments expressed in mg Trolox eq/100 mL.

Item	Diet					<i>p</i> -Value		
	Control	RGP_6	RGP_12	RGP_18	SEM	Diet	Sampling	Diet x Sampling
ABTS	8.560	8.260	8.190	8.540	0.183	ns	<0.0001	0.025
FRAP	4.030	4.010	4.040	3.840	0.099	ns	<0.0001	ns

RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP. SEM: standard error of the mean; ns: non-significant ($p > 0.05$). *p*-values are reported for the significant effects.

The temporal evolution of variables exhibiting a significant diet $\times$ sampling interaction is presented in the Supplementary Materials (Figure S1; Figure S2; Figure S3; Figure S4 (A), (B), (C), where their trajectories across the study period can be examined.

4. Discussion

Slight numerical increases in milk gross composition—lactose, NFD, UDM—were detected in goats receiving up to 12% DM of RGP; nevertheless, these variations were too small to have any practical impact on the technological properties of the milk. These findings are consistent with those reported by [8–11], who noted that the use of agro-industrial by-products in small ruminant feeding is feasible, provided that diets are properly balanced and tailored to the energy requirements of the production stage.

Although the literature addressing the inclusion of grape pomace and its effects on milk quality and composition remains heterogeneous, most studies support its suitability as a feed ingredient. Increasing the supply of structural carbohydrates is generally associated with enhanced milk fat synthesis [57]; however, in the present experiment, the incorporation of RGP silage led to a reduction in dietary fibre content—opposite to the response reported by Gálvez-Lopez et al. [58], who observed higher fibre levels when including up to 15% DM of ensiled white grape pomace in dairy goat diets. Those authors also documented a progressive increase in milk fat concentration with rising levels of white grape pomace inclusion. This pattern is consistent with the results of Antunović et al. [59], who reported increases in both milk fat and protein in goats supplemented with up to 10% grape seed cake, although—as in the current study—these changes were not considered technologically meaningful. Conversely, Nudda et al. [60] and Manso et al. [61] found no enhancement in milk fat content when supplementing diets with 300 g/day of grape seeds or up to 100 g/kg of grape pomace, respectively. More recent evidence from Renna et al. [37] also supports this lack of response, showing that the inclusion of 60 g/kg DM of dehydrated grape pomace in dairy goat diets did not modify milk macrocomposition. In contrast, Baghsiyah et al. [36] reported reductions in both milk fat and protein percentages in Saanen goats fed diets containing 10% dried grape pomace.

Lower milk urea concentrations observed with increasing levels of RGP silage in the diet may reflect a physiological adjustment potentially associated with improved nitrogen utilisation, possibly arising from a better synchrony between rumen-degradable protein and fermentable carbohydrate supply. Even so, several factors may influence this response. Crude protein intake and the dietary protein-to-energy ratio are recognised as the primary drivers of milk urea formation [57], and in the present experiment, both diets were formulated to be isoenergetic and isoproteic, thereby limiting confounding effects from these variables. Although this study did not specifically determine the tannin content of the experimental diets, the literature consistently reports that RGP contains substantial amounts of tannins [2,10], which may interact with ruminal proteins to form com-

plexes that can reduce their degradability [17,21]. This mechanism lowers the production of ruminal ammonia (NH_3), which is subsequently converted to urea in the liver as the main excretory product of nitrogen metabolism [1,62]. These bioactive compounds are also associated with immunomodulatory and anti-inflammatory activities [20,59,63,64], properties that may help explain the lower LSCC values observed in animals receiving higher levels of RGP silage. Similar responses have been reported previously: Alba et al. [65] documented a reduction in SCC when dairy ewes were supplemented with 20 g/kg DM of dehydrated grape pomace. Other by-products rich in comparable phenolic compounds have shown analogous effects, reinforcing this potential mechanism. For instance, the inclusion of 36% hazelnut skins led to a marked decrease in somatic cell count, an outcome attributed to their high polyphenol and tannin content—compounds with well-recognised anti-inflammatory activity [66]. In the same direction, Monllor et al. [33] reported lower SCC in dairy goats fed diets containing 40% ensiled broccoli by-product or ensiled artichoke plant compared with a standard control diet.

With respect to the milk mineral profile, although a significant dietary effect was detected, the magnitude of the differences was too small to have any practical relevance and did not lead to measurable changes in the technological performance of the milk. All measured values were within the expected range for goat milk as described by Guo [67], and closely matched those reported by Gálvez-Lopez et al. [58] and Monllor et al. [9] for the same species and breed. Taken together, these results indicate that the inclusion of ensiled red grape pomace (RGP) did not materially alter the mineral composition of the milk.

The fatty acid composition of milk from goats receiving RGP closely reflected the lipid profile of the corresponding RGP-based diets, consistent with the relationships previously reported by Ianni et al. [68], Correddu et al. [69] and Renna et al. [37]. Higher concentrations of specific fatty acids, such as linoleic acid (C18:2 n-6), may reflect their greater abundance in the RGP diets [70], supporting the hypothesis that the lipid composition of RGP can influence milk fatty acid patterns. In addition, the progressive increase in the n-6/n-3 and LA/ALA ratios with higher levels of RGP inclusion suggests the direct diet–milk transfer previously described for goats. Importantly, the values observed fall within the range commonly reported for caprine milk under diverse feeding conditions [9,36,71], indicating that these ratios remain within the expected physiological variability for this species. An elevated LA/ALA ratio should not be interpreted as inherently detrimental, as the increase is primarily driven by linoleic acid (LA), an essential polyunsaturated fatty acid that must be obtained from the diet and serves as a precursor for longer-chain omega-6 fatty acids such as arachidonic acid. LA is widely recognised as nutritionally beneficial, and in adults, the physiological relevance of the dietary LA/ALA ratio is considerably lower than in infants, where endogenous synthesis of long-chain n-3 PUFAs is limited [53,71]. Therefore, the higher ratios observed here should be understood in the context of dietary composition rather than as indicative of adverse nutritional implications. Moreover, RGP₁₂ supplementation enhanced the concentration of vaccenic acid (C18:1 t11), likely due to the higher oleic acid content, which provides the substrate for Δ^9 -C18-desaturase activity involved in vaccenic acid synthesis [72]. Additionally, the elevated total polyphenol content of RGP diets likely contributed to the increase in vaccenic acid and polyunsaturated fatty acids (PUFAs), given the inhibitory effect of polyphenols on ruminal fatty acid biohydrogenation as reported by Correddu et al. [73]. The lower proportion of saturated fatty acids and the higher content of unsaturated fatty acids in RGP milk compared with the control further corroborate this improvement in the lipid profile [53,74,75]. Considering that RGP milk exhibited lower IA, IT, and HFA values, along with higher UI, HH, and HPI scores, the results indicate a more favourable fatty-acid profile and improved nutritional lipid indices, suggesting a potentially more desirable composition from a cardiovascular and metabolic standpoint [76–78]. These interpre-

tations, however, refer solely to compositional and index-based improvements. These effects showed a dose-dependent tendency, becoming more evident as the level of RGP inclusion increased. This pattern is consistent with previous studies incorporating grape pomace into ruminant diets, which similarly reported improvements in milk lipid profile with potential implications for human nutrition and health [37,68,79–81]. Overall, the fatty acid profile observed in this study remained within the range described by Stergiadis et al. [82] for typical goat milk.

The observation of a shorter rennet coagulation time (RCT), together with a higher aggregation rate in RGP_6 milk, indicates that both the initial κ -casein cleavage phase and the subsequent micellar aggregation step were facilitated. This pattern is typically associated with greater rennet reactivity and faster gelation kinetics [83]. Although these mechanisms were not directly evaluated in the present study, research on goat milk coagulation indicates that parameters such as pH, temperature and the redistribution of colloidal Ca-phosphate can modulate RCT and aggregation rate, accelerating coagulation when pH and temperature decrease and when the Ca:P ratio increases [83–85]. From a technological standpoint, a shorter RCT and a higher aggregation rate are generally associated with improved protein and fat recovery in the curd and, consequently, with enhanced cheese yield [83,86]. In the context of the present study, these aspects should be considered as potential technological implications based on established relationships reported in the literature, as neither cheese yield nor curd recovery were directly measured. However, final gel firmness and water retention also depend on milk fat and protein composition and on processing conditions (cutting temperature, pressing time), meaning that improvements in coagulation kinetics do not automatically guarantee optimal texture without appropriate technological adjustments.

Milk colour is determined by several physicochemical factors, including the dispersion state of fat globules [87] and the concentration of endogenous pigments [88]. Because the L^* coordinate is mainly governed by structural attributes—particularly the distribution of casein micelles and fat droplets [89]—the inclusion of RGP did not modify milk luminosity. In contrast, the a^* and b^* coordinates reflect the abundance of natural pigments in goat milk, chiefly riboflavin (green hue), β -carotene (yellow tones) and, to a lesser extent, lutein [89]. The characteristic whiteness of goat and sheep milk arises from the near-complete conversion of β -carotene into retinol [87]. Accordingly, the slight differences detected in a , b and chroma (C) values among dietary treatments are likely linked to minor variations in pigment concentration. The reduction in the b coordinate and in colour saturation (C^*) observed in RGP milk explains the lower YI values recorded for RGP_12 and RGP_18. These results indicate that substituting conventional feed ingredients with RGP can subtly modulate expected milk pigmentation. This interpretation is consistent with recent findings showing that feeding conditions can modify carotenoid content and colour indices in goat milk [90]. Nevertheless, the magnitude of these changes (<0.5 units) remains below the threshold of human visual perception and is therefore irrelevant from an organoleptic perspective.

No clear effect of the RGP diets was detected on the antioxidant potential of the milk, despite the naturally high polyphenol content of grape pomace [2,17,19]. These bioactive compounds are well known for their strong antioxidant properties [18–20] and, as noted earlier, can be transferred to animal-derived products through dietary intake [24,91,92]. However, the relatively conservative inclusion level of RGP used to avoid potential antinutritional effects [70,93,94] may have limited the expression of this antioxidant potential in the diet and its subsequent transfer to milk [95].

Most studies evaluating agro-industrial by-products in ruminant feeding report only minor or negligible changes in the composition of commercial milk, supporting their suitability as alternative feed ingredients and highlighting their potential to reduce produc-

tion costs and promote circular-economy strategies [96,97]. The magnitude of the effects observed generally depends on the degree of dietary substitution achieved with these by-products [93]. When compositional changes are minimal, the technological properties of milk are typically preserved, indicating that product functionality remains stable even under feeding systems incorporating agro-industrial residues.

The significant variations observed in milk parameters across sampling times are most likely related to the inherent physiological progression of lactation. This process is well known to affect both the compositional and physical properties of milk, independently of the feed strategy [98]. In this context, the significant diet $\times$ sampling interactions detected for some variables are consistent with normal lactation dynamics rather than with treatment-dependent responses. Because the aim of the study was to evaluate the dietary effect of increasing RGP inclusion, and the temporal pattern reflects physiological changes intrinsic to mid-lactation, linear and quadratic contrasts were applied exclusively to the main dietary effect. Consequently, diet $\times$ sampling interactions were not decomposed by sampling period, as they do not represent biologically meaningful treatment-specific responses but rather the expected evolution of milk traits as lactation advances. The dose–response evaluation therefore focused on the overall dietary effect, which aligns with the primary objective of the study.

5. Conclusions

Among the tested treatments, diets containing up to 12% DM inclusion of red grape pomace silage resulted in an overall stable milk profile. The presence of both linear and quadratic components suggests that the response to RGP inclusion was not strictly proportional to dose but exhibited curvature consistent with a more favourable intermediate inclusion level. These findings support the effective integration of red grape pomace silage into nutritionally balanced diets for dairy goats, enabling the partial replacement of conventional feed ingredients under the tested conditions without inducing major alterations in milk composition or in the technological properties evaluated. The minimal variations observed in the milk profile are relevant for maintaining its general characteristics for dairy processing. In parallel, the inclusion of red grape pomace silage promoted favourable shifts in the milk fatty acid composition, particularly through an increased degree of unsaturation, which may be considered a positive nutritional-health attribute. These results, however, should be interpreted strictly at the compositional level, as the study did not evaluate direct implications for human health. To deepen our understanding, future research should investigate higher inclusion levels and assess long-term effects, with the aim of generating robust scientific evidence on the role of these agro-industrial by-products in improving the nutritional and functional characteristics of milk and its derivatives.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/ruminants6030057/s1>, Figure S1: Evolution of the milk mineral profile across sampling weeks for each dietary treatment (Least Squares Means $\pm$ SE). RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; Figure S2: Evolution of the curd firmness (mm) across sampling weeks for each dietary treatment (Least Squares Means $\pm$ SE). RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; Figure S3: Evolution of antioxidant activity by ABTS across sampling weeks for each dietary treatment (Least Squares Means $\pm$ SE). RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP; Figure S4 (A), (B), (C): Evolution of fatty acid profile (percentages of the methylated fatty acid area in the fatty acid profile) and nutritional and health-related indices of milk across dietary treatments. across sampling weeks for each dietary treatment

(Least Squares Means $\pm$ SE). RGP: red grape pomace; RGP_6: experimental diet with 6% of RGP; RGP_12: experimental diet with 12% of RGP; RGP_18: experimental diet with 18% of RGP. SFA: Saturated Fatty Acid; MUFA: Monounsaturated Fatty Acid; n6n3: ω -6/ ω -3 Fatty Acid Ratio; LAALA: Linoleic Acid/ α -Linolenic Acid Ratio; CLAVACC: Conjugated Linoleic Acid to Vaccenic Acid Ratio; OBCFA: Odd- and Branched-Chain Fatty Acids; UI: Unsaturation Index; IA: Index of Atherogenicity; IT: Index of Thrombogenicity; HFA: Hypercholesterolemic Index; HH: Hypocholesterolemic/Hypercholesterolemic Ratio; HPI: Health-Promoting Index.

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Abbreviations

ABTS	2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonate)
ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
AOAC	Association of Official Analytical Chemists.
CHOL	Cholesterol
CIELab	CIE L*a*b* Colour Space *
CLA	Conjugated Linoleic Acid
CLAVACC	CLA/Vaccenic Acid
CP	Crude Protein
DM	Dry Matter
DPPH	2,2-Diphenyl-1-picrylhydrazyl
EE	Ether Extract
FAMES	Fatty Acid Methyl Esters
FID	Flame Ionisation Detector
FM	Fresh Matter
FRAP	Ferric Reducing Antioxidant Power
GAE	Gallic Acid Equivalents
GC	Gas Chromatography
HFA	Hypercholesterolemic Fatty Acids
HH	Hypocholesterolemic/Hypercholesterolemic Ratio
HPI	Health-Promoting Index
HPLC	High-Performance Liquid Chromatography
IA	Atherogenic Index
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IT	Thrombogenic Index
ISO	International Organisation for Standardisation

LAALA	Linoleic/Alpha-Linolenic Ratio
LSCC	Log10 Somatic Cell Count
MUFA	Monounsaturated Fatty Acids
NDF	Neutral Detergent Fibre
NFDM	Non-Fat Dry Matter
OBCFA	Odd- and Branched-Chain Fatty Acids
OM	Organic Matter
OLESTE	Oleic Acid/Stearic Acid
PUFA	Polyunsaturated Fatty Acids
RCT	Rennet Coagulation Time
RGP	Red Grape Pomace
SCC	Somatic Cell Count
SEM	Standard Error of the Mean
SFA	Saturated Fatty Acids
TS	Total Solids
UDM	Useful Dry Matter
UI	Unsaturation Index
VFA	Volatile Fatty Acids
WI	Whiteness Index
YI	Yellowness Index

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