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Unconventional Ingredients from the Industrial Oilseed By-Products in Dairy Goat Feeding: Effects on the Nutritional Quality of Milk and on Human Health

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Abstract: Oilseed by-products (*Cynara cardunculus* and *Camelina sativa*) (CCCS) are rich in bioactive compounds. This study aimed to evaluate the health effects of consuming yogurt made from goat milk fed with CCCS industrial residues in adults. In this randomized, crossover clinical trial, 20 healthy adults (14F; 37.7 ± 14.2 years) consumed either yogurt made from goat milk fed with CCCS or regular goat yogurt (C) daily for 1 month in each phase. Anthropometric parameters and blood samples were collected at the beginning and end of each phase. CCCS yogurt consumption resulted in a significant fat mass reduction (−1.8% and −1.1 kg) and fat-free mass increase (+1.5% and +0.9 kg). Regarding blood parameters, a non-significant decrease in triglycerides, total cholesterol, and LDL cholesterol was observed, particularly after the CCCS intervention. Moreover, creatinine levels exhibited an opposite trend ($p = 0.023$) after CCCS, decreasing in subjects aged ≤30 years (−0.03 mg/dL) and increasing in older subjects (+0.05 mg/dL). Regarding inflammatory parameters, a non-significant trend in increased IL-1ra levels was observed especially after CCCS yogurt consumption compared to the C yogurt (+56.9 vs. +19.1 pg/mL, respectively). The use of unconventional feed derived from oilseed by-products for dairy goat feeding may have potential possible beneficial effects on human health.

Keywords: goat; milk; fatty acids; *Camelina sativa*; *Cynara cardunculus*; sustainable animal production; sustainable development

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1. Introduction

Global population growth has accelerated significantly, increasing food insecurity by exacerbating the degradation of essential resources such as arable land, freshwater and fertile soils, critical resources for agricultural production. These challenges threaten the ability to ensure continued access to sufficient, safe and nutritious food for the entire world population, underscoring the urgency of adopting more sustainable solutions. In this context, the programs of the Food and Agriculture Organization of the United Nations (FAO) and the European Union (EU) play a crucial role, strongly supporting the principles of sustainable development and the circular economy. This innovative economy strategy aims to decouple economic growth from excessive consumption of natural resources, promoting more sustainable production practices to mitigate increasing pressure on resources and ensure a more balanced and resilient future for global food security [1,2].

For all these reasons, the principle of the 3Rs (Reduce, Reuse, Recycle) has become crucially important, especially in productive sectors such as agriculture. In particular, livestock farming has significant potential to benefit from the use of alternative feed resources, using various biomass wastes. These residues not only help to reuse resources and minimize environmental impact, but could also contribute to improving the quality of feed, increasing its nutritional value due to their specific characteristics. In addition, this approach can strengthen food security, ensuring sustainable access to nutritious food and reducing dependence on external resources [3,4].

In this context, the use of *Cynara cardunculus* (CC) meal and *Camelina sativa* (CS) cake in animal feed represents a promising opportunity to support and reinforce the principles of the circular economy [4]. These products derived from the industrial processing of oilseeds, known as by-products, can be reused as livestock feed. This not only contributes to reducing industrial waste generated by agribusiness, but also minimizes the need for alternative resources. In addition to these environmental benefits, emerging research highlights that CC meal and CS cake are nutritionally suitable alternatives for ruminants, such as goats, as well as for poultry and pigs [5–8]. Due to their high nutritional and bioactive properties, these alternative feed products have significant potential to enhance feed composition and, consequently, improve the quality of animal products obtained thanks to their nutraceutical properties. Recent studies have shown that CC meal is particularly rich in protein, fiber, phenolic acids and flavonoids, which can improve not only milk production but also its composition, including fatty acid and antioxidant profiles [9–11]. On the other hand, CS cake is known for its high content of omega-3 fatty acids and tocopherols, compounds that can positively influence animal health and milk composition [12–14]. These bioactive components can be transferred into the final product, such as milk and its derivatives like yogurt, potentially offering nutraceutical benefits to humans who consume them [15].

However, despite the growing interest in the use of non-conventional ingredients like oilseed by-products in animal feeding, the available scientific literature on the use of CC meal and CS cake is still limited. Therefore, further research is needed on the effects of these industrial by-products on the metabolism of dairy goats, as well as on the production and quality of their milk. In addition, it is essential to explore the potential benefits that the consumption of these dairy products may have on human health. To this end, the purpose of the present study is to evaluate the potential nutraceutical effect of consuming yogurt produced from milk of goats fed with CC meal and CS cake in clinically healthy adult subjects. The results obtained from this study will not only contribute to expanding our existing knowledge on the use of CC and CS as alternative feed resources in goat milk production, but will also provide information on their potential effects on consumer health, thereby promoting more sustainable livestock practices.

2. Materials and Methods

2.1. Study Population

In total, 20 healthy volunteers were recruited to participate in this study, of whom 14 were women, with a mean age of 37.7 ± 14.2 years. These volunteers were selected from workers of the University of Florence and their acquaintances. Inclusion criteria for participation in this study included age between 20 and 75 years, absence of major pathologies, food allergies or intolerances, or gastrointestinal problems (such as irritable bowel syndrome, diarrhea or constipation). Pregnant or breastfeeding women were excluded from this study.

2.2. Study Design

The study conducted was a double-blinded, randomized, crossover trial designed to evaluate the potential health effects of consuming yogurt made from goat milk fed with unconventional ingredients derived from industrial residues of CC and CS (CCCS), compared with yogurt made from goat's milk fed with regular feed. Participants who met the eligibility criteria were randomly distributed into one of the two groups, with

10 individuals in each. During the first phase, one group was assigned to consume CCCS yogurt, while the other group consumed the control yogurt, both for one month period. In the second phase, the groups switched yogurt types: those who previously consumed the control yogurts started consuming the CCCS yogurts and vice versa. All participants were asked to avoid consuming any other yogurt products during the intervention phase to ensure the integrity of the study results. Prior to initial screening and randomization, written informed consent was obtained from all participants, ensuring that they understood the objectives of the study and agreed to participate voluntarily. This study was conducted in conformity with the guidelines set out in the Declaration of Helsinki.

2.3. Yogurt Varieties

The yogurt used in this study was produced from milk obtained from chamois goats fed two different diets: a control diet with regular feeding and an experimental diet enriched with CC meal and CS cake. These unconventional ingredients were obtained from two by-products of industrial processing of two oil seeds, CC and CS. CC is mainly grown for oil production, which is used in the manufacture of bioplastics, while CS stands out as a sustainable source of biofuels. Both industry by-products, CC meal and CS cake, present a remarkable nutritional profile thanks to their protein and lipid content. In particular, the lipid profile of CS and CC seeds is high in polyunsaturated fatty acids (PUFAs); CS in particular contains a significant amount of functional fatty acids such as omega-3. They are also a source of fiber and provide functional molecules such as flavonoids. The fatty acid composition of both the CCCS and control yogurts used in this study is provided in Table 1.

Table 1. Fatty acid composition of CCCS and control yogurts.

Fatty Acid Composition of CCCS and Control Yogurts, g kg^{-1} Total Fatty Acids		
Fatty Acid	**CCCS Yogurt**	**Control Yogurt**
C4	2.90	2.83
C6	2.46	2.39
C8	2.01	2.08
C10-1	0.29	0.39
C11	0.14	0.21
C12	3.89	4.48
C12-1	0.06	0.07
C13 iso	0.06	0.05
C13 ante	0.11	0.06
C13	0.10	0.05
C14 iso	9.16	0.08
C14	0.19	0.09
C15 iso	0.12	9.08
C14-1	0.34	0.28
C15 anteiso	0.34	0.15
C15	0.80	0.42
C16 iso	0.36	0.81
C16	24.6	22.40
C16-1	0.61	0.36
C17 iso	0.32	0.51
C17 anteiso	0.49	0.36
C17	0.49	0.45
C17-1	0.24	0.26
C18 iso	0.06	0.05
C18	9.09	11.36
C18:1 trans 5	0.23	0.18
C18:1 trans 6–8	0.33	0.37
C18-1 trans 9	0.79	0.61
C18:1 trans 10	1.91	1.78

Table 1. *Cont.*

Fatty Acid Composition of CCCS and Control Yogurts, g kg^{-1} Total Fatty Acids		
Fatty Acid	**CCCS Yogurt**	**Control Yogurt**
C18-1 trans 11	0.57	0.40
C18-1 trans 12	0.30	0.29
C18-1C9	19.19	21.30
C18-1C7	0.82	0.91
C18-1 cis11	0.63	0.50
C18-1 C12	0.59	0.68
C18-1 C13 + T16	0.40	0.34
C18-1 C14+ C16	0.27	0.21
C18-1 C15	0.10	0.06
C18-2 C9 T12	0.10	0.06
C18-2 T9-C12	1.07	0.57
C18-3 N3 (T9-C12-C15)	0.20	0.03
C18-3 N3 (C9-C12-C15)	0.45	0.40
C20	1.16	1.09
C18:2 C9 T11	0.11	0.08
C20:4 n6	0.31	0.10

CCCS: *Cynara Cardunculus* and *Camelina Sativa.*

2.4. Anthropometric Measurements and Body Composition

Body weight and height were measured using a stadiometer. The body mass index (BMI) was then calculated by dividing the participant's weight in kilograms (kg) by the square of their height in meters (m^2). Body composition, including fat mass, fat-free mass, total body water and extra cellular water, was determined by a bioelectrical impedance analysis device (Akern, model SE 101—Akern s.r.l., Florence, Italy) at baseline and during follow-up visits.

2.5. Blood Samples

Blood samples were taken from participants at baseline and after both interventions, after a required 12 h fasting period. Participants were also instructed to avoid any strenuous physical activity the day before the blood draw. Blood samples were centrifuged at 3000 rpm for 15 min, and aliquoted to obtain serum, which was then stored at −80 °C until analysis. The biochemical parameters measured included a comprehensive set of routine markers, including blood count (white blood cell (WBC), red blood cells (RBCs), hemoglobin (Hb), hematocrit (Ht)), renal function (urea, creatine), liver function (aspartate transaminase (AST), alanine transaminase (ALT), gamma-glutamyl transferase (GammaGT)), fasting glucose, uric acid, lipid (triglycerides, total cholesterol, low-density lipoprotein (LDL) cholesterol, high-density lipoprotein (HDL) cholesterol), mineral (sodium, potassium, calcium, magnesium, iron) and vitamin (folate, vitamin B12) profiles. In addition, cytokine panel and inflammatory parameters (interferon (IFN) alpha, interleukin (IL)1-alpha, IL-1ra, IL-2, IL-6, IL-7, IL-10, IL-15, vascular endothelial growth factor (VEGF)) were measured with the Bio-Plex cytokine assay (Bio-Rad Laboratories Inc., Hercules, CA, USA), according to the manufacturer's detailed protocols and instructions.

2.6. Statistical Analysis

Statistical analysis for this study was conducted using the statistical package IBM® SPSS® Statistics for Macintosh, version 28.0 (IBM Corp., Armonk, NY, USA). The results were reported as frequencies and percentages, means ± standard deviations (SD) or geometric means and 95% confidence intervals (CI), as appropriate. The baseline characteristics of the two groups were compared using the Mann–Whitney *U* test for non-normally distributed continuous data, while dichotomous variables were analyzed using the Chi-square test to assess associations between categorical variables. The data were treated as matched samples of a crossover study. Matched samples were analyzed for all two interventions with the CCCS yogurt and control yogurt, combining the results of both intervention periods of the groups. A general linear model for repeated measures, adjusted for age, sex, BMI at baseline, smoking habit and physical activity, was used to evaluate the effects of the CCCS yogurt and control yogurt. Adjusting for these factors is important, as they can significantly influence the health outcomes measured in this study. Since a normal distribution of the data was assumed for these analyses, data with non-normal distribution were log-transformed by replacing each value with its natural logarithm (ln), to stabilize the variance and reduce the impact of outliers. Subsequent analyses were performed with the transformed data. However, for ease of interpretation, the results were reconverted to the original antilogarithmic scale and presented as geometric means and 95% CI. Subgroup analyses were performed to investigate possible variations in anthropometric measurements, body composition and blood parameters according to participant characteristics, such as sex or age. *p*-values <0.05 were considered statistically significant.

3. Results

3.1. Participants' Characteristics

Twenty healthy adults between 21 and 72 years of age participated in this study, with a higher prevalence of women (70%). Among the participants, two individuals were habitual smokers, and five reported not practicing any type of physical activity on a regular basis. The mean BMI was 22.0 ± 3.7 kg/m^2, and most of the participants were found to be within normal weight category (60%) with no participant found to be categorized as obese (BMI ≥ 30 kg/m^2). Table 2 shows a detailed overview of the sociodemographic characteristics of the participants at baseline, divided into two groups according to the first randomization. No significant differences between the participants of both groups were observed.

Table 2. Characteristics of enrolment participants.

Characteristic	All (n = 20)	CCCS Yogurt (n = 10)	Control Yogurt (n = 10)	*p*-Value
Age, y, median (mean ± SD)	37.7 ± 14.2	34.7 ± 15.1	40.6 ± 13.3	0.130
Female sex, n (%)	14 (70)	6 (60)	8 (80)	0.329
Body weight, kg (mean ± SD)	62.0 ± 13.4	66.7 ± 12.9	57.3 ± 12.8	0.199
BMI, kg/m^2 (mean ± SD)	22.0 ± 3.7	22.9 ± 3.5	21.1 ± 3.8	0.290
Underweight (≥18.5 kg/m^2), n (%)	4 (20)	1 (10)	3 (30)	0.264
Overweight (≥25 kg/m^2), n (%)	4 (20)	2 (20)	2 (20)	1.000
Current smokers, n (%)	2 (10)	1 (10)	1 (10)	1.000
Absent of physical activity, n (%)	5 (25)	2 (20)	3 (30)	0.606

CCCS: *Cynara Cardunculus* and *Camelina Sativa*; SD: standard deviation; BMI: body mass index.

3.2. Body Weight and Body Composition

No significant differences in body weight and BMI were observed in both groups, but modest changes in body composition were observed after CCCS yogurt consumption (Table 3). Specifically, consumption of CCCS yogurt resulted in a significant reduction in fat mass, both in terms of kg (−1.1 kg) and percentage (−1.8%), as well as a significant increase in fat-free mass in terms of kg (+0.9 kg) and percentage (+1.5%). On the other hand, after consumption of CCCS yogurt there was also an increase in total body water (+0.7 kg and +1.4%), as well as in extracellular water (+0.6 kg and +1.2%), which increased especially in men compared to women (+1.4 kg vs. +0.4 kg, p = 0.043).

Table 3. Modifications of anthropometric parameters and body composition.

Variable	CCCS Pre	CCCS Post	*p*-Value	Control Pre	Control Post	*p*-Value	*p* (ΔCCCS versus ΔControl)
Weight, kg	60.6 (56.4–65.2)	60.6 (56.6–64.9)	0.959	60.4 (56.5–65.0)	60.5 (56.3–65.0)	0.465	0.284
BMI, kg/m^2	21.8 (20.3–23.3)	21.7 (20.3–23.2)	0.671	21.8 (20.3–23.2)	21.7 (20.3–23.3)	0.542	0.412
TBW, L	36.6 (34.5–38.7)	37.3 (35.1–39.8)	**0.019**	36.8 (34.6–39.1)	37.2 (35.4–39.1)	0.369	0.551
TBW, %	60.3 (57.1–63.6)	61.7 (58.4–65.2)	**0.014**	60.7 (57.5–64.0)	61.4 (57.9–65.1)	0.369	0.441
ECW, L	15.8 (15.0–16.6)	16.4 (15.4–16.5)	**0.023**	16.1 (15.2–17.0)	16.2 (15.3–17.1)	0.440	**0.021**
ECW, %	43.1 (41.5–44.8)	44.3 (42.4–46.2)	**0.003**	43.7 (42.0–45.6)	43.6 (41.8–45.2)	0.723	**0.010**
FFM, kg	49.9 (47.3–52.5)	50.8 (48.0–53.7)	**0.042**	50.0 (47.3–52.8)	50.5 (48.1–52.9)	0.405	0.424
FFM, %	82.2 (78.0–86.7)	83.7 (79.4–88.1)	**0.047**	82.4 (78.3–86.8)	83.3 (78.7–88.1)	0.391	0.516
FM, kg	9.2 (6.4–13.0)	8.1 (5.6–11.6)	**0.030**	8.8 (6.3–12.4)	8.1 (5.5–12.0)	0.291	0.516
FM, %	15.1 (11.2–20.4)	13.3 (9.7–18.3)	**0.030**	14.5 (10.9–19.5)	13.4 (9.7–18.6)	0.300	0.516
BCM, kg	28.0 (26.0–30.2)	27.8 (25.6–30.2)	0.528	27.7 (25.6–30.1)	28.1 (26.1–30.2)	0.518	0.433
BCM, %	56.2 (54.3–58.1)	54.8 (52.6–57.1)	**0.002**	55.5 (53.4–57.7)	55.7 (53.6–57.9)	0.780	0.465

Data are reported as geometric mean and 95% confidence interval (CI). Adjusted for age, sex, smoking habit and physical activity. Bold values indicate significant *p*-values ($p < 0.05$). CCCS: *Cynara Cardunculus* and *Camelina Sativa*; BMI: body mass index; TBW: total body water; ECW: extra cellular water; FFM: Fat Free Mass; FM: fat mass; BCM: Body Cell Mass.

3.3. Biochemical Parameters

The changes in the biochemical profile are reported in Table 4. Consumption of CCCS yogurt led to a significant (p = 0.002) decrease in sodium levels (−1.5 mEq/L), resulting in a significant difference between the two groups (p = 0.045). In addition, a significant modest decrease in calcium levels was observed after CCCS yogurt consumption (−0.2 mg/dL), which was more pronounced in subjects aged 30 years or younger than in those older than 30 years (−0,47 mg/dL vs. −0.1 mg/dL, p = 0.046). An opposite trend (p = 0.023) was observed in creatinine levels according to participants' age after CCCS yogurt intake, with a decrease in those aged 30 years or younger (−0.03 mg/dL) and an increase in those older than 30 years (+0.05 mg/dL). After consumption of the control yogurt, significantly opposite trends were observed according to the sex and age of the participants for some biochemical parameters—specifically, with respect to urea levels (+0.05 g/L women vs. −0.29 g/L men, p = 0.032), sodium levels (+0.05 g/L $\geq$ 30 years vs. −0.29 g/L <30 years, p = 0.032) and calcium levels (+0.27 mg/dL vs. −0.22 mg/dL, p = 0.035).

Table 4. Modifications of biochemical parameters.

Variable	CCCS Pre	CCCS Post	*p*-Value	Control Pre	Control Post	*p*-Value	*p* (ΔCCCS versus ΔControl)
WBC, $\times 10^9$/L	6.2 (5.7–6.7)	6.2 (5.6–6.8)	0.824	6.2 (5.4–7.0)	6.3 (5.8–6.8)	0.783	0.569
RBC, $\times 10^{12}$/L	4.59 (4.40–4.78)	4.52 (4.36–4.68)	0.251	4.58 (4.42–4.74)	4.56 (4.41–4.72)	0.723	0.405
Hb, g/dL	13.50 (13.1–13.94)	13.4 (12.9–13.85)	0.407	13.52 (13.12–13.93)	13.45 (13.02–13.9)	0.509	0.953
Ht, %	40.7 (39.3–42.2)	39.9 (38.4–41.3)	0.132	40.7 (39.6–41.7)	40.5 (39.4–41.6)	0.684	0.255
Folate, ng/mL	6.7 (5.5–8.2)	7.3 (5.8–9.2)	0.202	7.1 (5.8–8.8)	6.8 (5.8–9.3)	0.617	0.323
Vitamin B12, pg/mL	399.0 (338.3–471.1)	394.3 (334.0–465.5)	0.672	401.8 (339.0–475.8)	391.9 (330.6–465.0)	0.203	0.285
Glucose, mg/dL	83.3 (80.2–86.5)	79.4 (75.7–83.3)	0.153	81.5 (77.3–86.1)	81.2 (77.9–84.8)	0.876	0.364
Urea, g/L	0.29 (0.26–0.33)	0.28 (0.24–0.31)	0.218	0.29 (0.26–0.32)	0.30 (0.27–0.33)	0.447	0.170
Creatine, mg/dL	0.77 (0.70–0.84)	0.79 (0.72–0.86)	0.297	0.78 (0.72–0.84)	0.78 (0.73–0.85)	0.713	0.533
Sodium, mEq/L	141.7 (141.2–142.3)	140.2 (139.5–140.9)	**0.002**	141.2 (140.5–141.7)	141.3 (140.3–142.3)	0.573	**0.045**
Potassium, mEq/L	4.5 (4.3–4.8)	4.3 (4.2–4.4)	0.058	4.5 (4.4–4.6)	4.5 (4.3–4.6)	0.854	0.243
Calcium, mg/dL	9.4 (9.1–9.7)	9.2 (9.0–9.4)	**0.035**	9.4 (9.2–9.6)	9.4 (9.2–9.6)	0.840	0.143
Magnesium, mg/dL	2.05 (2.00–2.11)	2.03 (1.95–2.11)	0.323	2.01 (1.93–2.10)	2.04 (1.97–2.11)	0.203	0.126
AST, U/L	18.6 (16.9–20.5)	19.0 (16.6–21.6)	0.621	18.4 (16.7–20.3)	18.9 (17.0–21.0)	0.486	0.703
ALT, U/L	16.0 (13.2–19.5)	17.0 (15.8–19.5)	0.342	17.2 (14.7–20.1)	16.7 (14.2–19.5)	0.579	0.321
GammaGT, mg/dL	15.1 (12.5–18.2)	14.5 (11.9–17.8)	0.053	15.1 (12.2–18.7)	15.3 (12.5–18.8)	0.757	0.420
Triglycerides, mg/dL	71.2 (61.3–82.5)	69.7 (60.3–80.6)	0.724	74.0 (61.5–89.0)	73.3 (64.3–83.5)	0.906	0.818
Total cholesterol, mg/dL	185.5 (170.9–191.7)	180.9 (170.9–191.7)	0.148	186.0 (176.4–196.4)	184.0 (176.4–194.6)	0.544	0.499
LDL cholesterol, mg/dL	97.9 (91.6–104.7)	96.0 (88.2–104.4)	0.391	98.5 (90.5–107.3)	97.9 (89.8–106.8)	0.827	0.635
HDL cholesterol, mg/dL	69.6 (64.7–74.7)	67.2 (62.9–71.7)	0.232	69.1 (63.9–74.7)	67.6 (63.2–72.4)	0.424	0.725
Iron, microg/dL	92.6 (82.8–103.4)	86.0 (72.2–102.3)	0.436	94.8 (79.6–113.0)	86.3 (72.8–102.3)	0.451	0.705
Uric acid, mg/dL	3.8 (3.5–4.1)	3.9 (3.6–4.3)	0.548	4.0 (3.6–4.3)	3.9 (3.5–4.3)	0.725	0.532

Data are reported as geometric mean and 95% confidence interval (CI). Adjusted for age, sex, BMI at baseline, smoking habit and physical activity. Bold values indicate significant *p*-values ($p < 0.05$). CCCS: *Cynara Cardunculus* and *Camelina Sativa*; WBC: white blood cells; RBC: red blood cells; Hb: hemoglobin; Ht: hematocrit; AST: aspartate transaminase; ALT: alanine transaminase; GammaGT: gamma-glutamyl transferase; LDL: low-density lipoprotein; HDL: high-density lipoprotein.

Regarding the lipid profile, a statistically non-significant downward trend in triglyceride, total cholesterol and LDL cholesterol levels was observed after both interventions, which was more pronounced after the CCCS yogurt consumption compared to control yogurt consumption, with reductions of −1.9 mg/dL vs. −0.9 mg/dL for triglycerides, −4.6 mg/dL vs. −2 mg/dL for total cholesterol and −1.9 mg/dL vs. −0.6 mg/dL for LDL cholesterol, respectively. Additionally, the decrease in LDL cholesterol and total cholesterol levels following the consumption of CCCS yogurt was more pronounced in men than in women, although no statistically significant differences were observed based on sex (Figure 1). HDL levels also showed a downward trend after the consumption of both types of yogurt, with a significantly (p = 0.043) greater decrease in HDL levels in men (−7.7 mg/dL) compared to women (−0.7 mg/dL) after CCCS yogurt consumption.

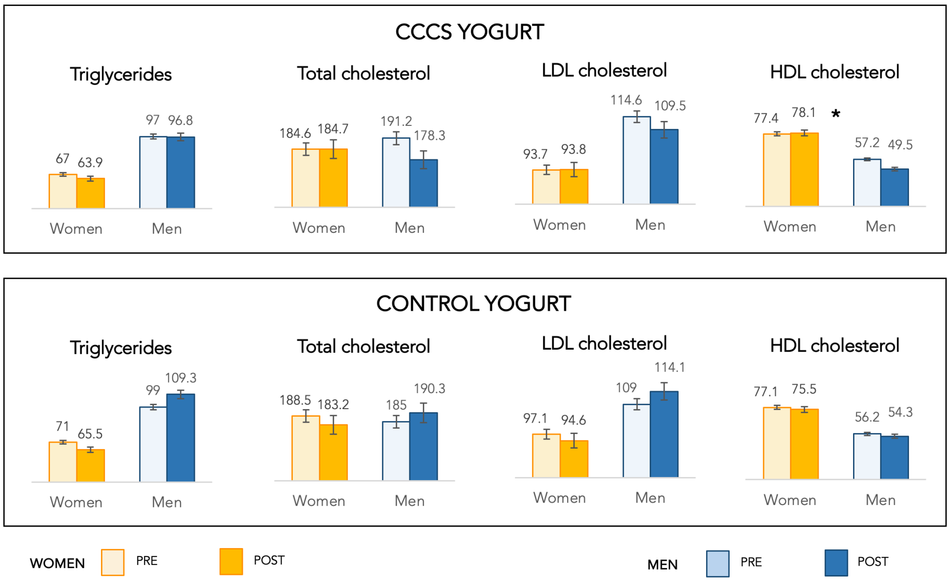

Figure 1. Modifications of lipid profile according to sex. * $p < 0.05$. CCCS: *Cynara cardunculus* and *Camelina sativa*; LDL: low-density lipoprotein; HDL: high-density lipoprotein.

3.4. Inflammatory Parameters

The changes in the inflammatory profile are shown in Table 5. After consumption of both types of yogurt, an increase in VEGF levels was observed (+11.1 pg/mL after consumption of CCCS yogurt and +3.6 pg/mL after intake of control yogurt), which only reached significance in the CCCS group. This increase was significantly (p = 0.039) greater in adults older than 30 years than in the rest of the participants after the CCCS intervention (+8.8 pg/mL and +2.5 pg/mL, respectively). In addition, a non-statistically significant trend of increased of IL-1ra levels was observed after both interventions, especially after the consumption of CCCS yogurt compared to the intake of control yogurt (+56.9 pg/mL and +19.1 pg/mL, respectively). Moreover, an opposite trend (p = 0.047) was observed in IL-1alpha levels according to participants' ages after CCCS yogurt intake, with a decrease in those aged 30 years or younger (−0.11 pg/mL) and an increase in those older than 30 years (+0.04 pg/mL) (Figure 2).

Table 5. Modifications of inflammatory parameters.

Variable	CCCS Pre	CCCS Post	*p*-Value	Control Pre	Control Post	*p*-Value	*p* (ΔCCCS versus ΔControl)
IFN alpha, pg/mL	0.14 (0.05–0.38)	0.16 (0.05–0.50)	0.566	0.19 (0.08–0.50)	0.12 (0.04–0.37)	0.259	0.967
IL1-alpha, pg/mL	1.8 (1.4–2.2)	1.8 (1.5–2.1)	0.756	1.7 (1.4–2.1)	1.5 (1.0–2.2)	0.455	0.684
IL-1ra, pg/mL	180.6 (101.3–321.8)	237.5 (149.8–376.2)	0.211	241.8 (143.2–408.7)	260.9 (196.6–346.2)	0.730	0.651
IL-2, pg/mL	0.06 (0.02–0.22)	0.04 (0.01–0.10)	0.241	0.05 (0.02–0.14)	0.03 (0.01–0.09)	0.247	0.862

Table 5. *Cont.*

Variable	CCCS Pre	CCCS Post	*p*-Value	Control Pre	Control Post	*p*-Value	*p* (ΔCCCS versus ΔControl)
IL-6, pg/mL	0.23 (0.11–0.48)	0.30 (0.13–0.73)	0.368	0.32 (0.13–0.74)	0.17 (0.09–0.32)	0.201	0.357
IL-7, pg/mL	4.8 (3.5–6.5)	4.6 (3.2–6.6)	0.826	4.9 (3.7–6.5)	4.6 (3.4–6.2)	0.612	0.607
IL-10, pg/mL	16.5 (13.8–19.9)	16.1 (10.7–24.1)	0.868	18.1 (11.7–28.0)	15.3 (12.0–19.5)	0.225	0.871
IL-15, pg/mL	1.2 (0.9–1.6)	1.3 (1.0–1.6)	0.691	1.3 (1.0–1.7)	1.2 (1.0–1.5)	0.531	0.871
VEGF, pg/mL	111.4 (78.1–158.9)	122.5 (91.7–163.5)	**0.040**	121.4 (91.1–161.7)	125.0 (106.9–145.9)	0.772	0.088

Data are reported as geometric mean and 95% confidence interval (CI). Adjusted for age, sex, BMI at baseline, smoking habit and physical activity. Bold values indicate significant *p*-values ($p < 0.05$). CCCS: *Cynara Cardunculus* and *Camelina Sativa*; IFN: interferon; IL: interleukin; VEGF, vascular endothelial growth factor.

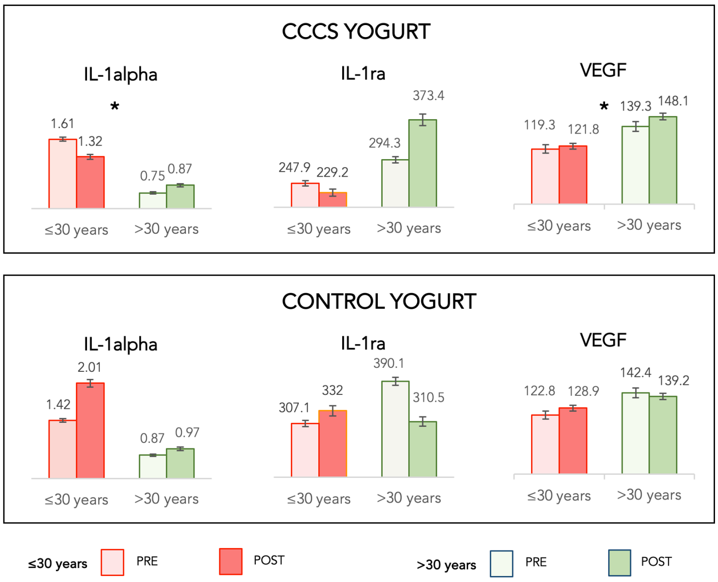

Figure 2. Modifications of inflammatory parameters according to age. * $p < 0.05$. CCCS: *Cynara carduncuclus* and *Camelina sativa*; IL: interleukin; VEGF, vascular endothelial growth factor.

4. Discussion

The continued and accelerated growth of the world's population has greatly intensified concerns about food security due to the depletion of essential and limited resources such as arable land, freshwater and fertile soils. This challenge threatens our ability to ensure continued access to sufficient, safe and nutritious food for all, which has driven the urgent need to adopt more sustainable production practices. As a result, recent research has focused on the use of alternative feed resources that can increase the sustainability of feed production, aligning with the principles of the circular economy, which promotes the use of by-products and waste reduction. In addition, the incorporation of these unconventional ingredients due to their nutritional composition could improve the quality of feed, benefiting both the animals and the products derived from them. In this context, the present study aimed to investigate the potential nutraceutical effects of consuming yogurt produced from the milk of goats that had been fed non-conventional ingredients derived from the by-products of industrial processing of two oil seeds: CC and CS. The results of this research supported the hypothesis that the use of CC and CS for feeding dairy goats reported potential beneficial effects on human health, leading to improved body composition and modulation of the lipid and inflammatory profile of individuals consuming this type of yogurt.

Among the most scientifically recognized characteristics of CC and CS is their lipid composition, particularly their richness in PUFAs. Several studies have shown that the introduction of CS into animal feed can significantly improve the nutritional quality of their products. For example, Colonna et al. demonstrated that dietary supplementation with fresh CS forage resulted in sheep milk having a higher content of PUFAs, particularly of conjugated linoleic acid (CLA) [16]. Similarly, Cais-Sokolinska et al. found that feeding

CS to small ruminants enhanced the fatty acid profile of their raw milk and derived kefir by increasing levels of PUFAs, including both CLA and omega-3 fatty acids [17]. In our study, both types of yogurts showed a non-significant downward trend in triglyceride, total cholesterol and LDL cholesterol levels. However, subjects who consumed the CCCS yogurt showed a more pronounced decrease, especially in total cholesterol and LDL cholesterol levels in men. These results could be due to the higher concentration of PUFAs, such as α-linolenic acid, which have been shown to reduce LDL cholesterol levels and, to a lesser extent, HDL cholesterol levels when substituted for saturated fatty acids (SFAs) [18]. Furthermore, these findings may suggest a positive relationship with cardiovascular health, given that triglycerides are a key biomarker of risk, especially in combination with elevated LDL levels [19].

Following consumption of CCCS yogurt, slight changes in plasma levels of certain minerals, particularly calcium and sodium, were observed. Although CS is a recognized source of calcium, and goat's milk has a higher content of this mineral compared to cow's milk [20,21], serum calcium levels experienced a slight decrease after CCCS consumption. This could be explained by the fact that both CS and goat milk contain significant concentrations of phosphorus, a mineral that can interfere with calcium absorption, reducing its bioavailability and, consequently, its effective absorption [22]. On the other hand, a significant decrease in plasma sodium levels was observed after CCCS yogurt intake. Although the reduction in both calcium and sodium was statistically significant, the changes were small in magnitude. Further long-term studies are required to determine whether these variations could have clinical relevance.

Moreover, this study showed improvements in the inflammatory profile after consumption of CCCS yogurts. In particular, consumption of CCCS yogurt was associated with an upward trend in IL-1ra, which is an important cytokine that mitigates inflammation by inhibiting the activity of the proinflammatory cytokine IL-1. In addition, an upward trend in IFN-alpha was observed only in the intervention group, suggesting further modulation of immune responses by inhibiting proinflammatory cytokines. This modulation of the inflammatory response can be attributed to various hypotheses that deserve to be explored. First, as reported in several previous studies, the use of CC and CS markedly improves lipid composition by increasing PUFA content and reducing SFA content. Consistent with the findings of Colonna et al. [16], CCCS yogurt had a lower concentration of stearic acid (C18:0) and a higher content of arachidonic acid (C20:4 n-6) compared to the control yogurt. The higher concentration of PUFAs, in particular arachidonic acid, plays a crucial role in the regulation of inflammation, as it is a key precursor of eicosanoids, including prostaglandins, thromboxanes and leukotrienes. Conversely, stearic acid is potentially associated with vascular inflammation through inflammation of vascular endothelial cells [23]. Secondly, CC and CS possess bioactive compounds such as phenolic acids and flavonoids, which have been related to anti-inflammatory activity attributed to multiple mechanisms, such as inactivation of the nuclear factor kappa-light-chain-enhancer of activated B cells (NF-kB) and the modulation of mitogen-activated protein kinase (MAPK) [9,23,24]. However, human studies to date on the potential effect of these unconventional ingredients remain limited and present mixed results. For example, a recent study examining the impact of camelina oil-enriched crackers on inflammatory profile found no differences in inflammatory markers after consumption [25]. Despite the variability in study designs, further research is essential to understand how CC and CS use may influence inflammatory markers and the potential long-term implications that could result from these effects.

Finally, although there were no significant changes in body weight and BMI, we observed a modest improvement in body composition after consumption of CCCS yogurt, with a significant reduction in fat mass and a significant increase in lean mass, both in terms of kg and percentage. A groundbreaking study in mouse models was the first to evaluate the effect of supplementation with CC combined with the polyphenolic fraction of bergamot on body weight and body composition, demonstrating an effective reduction in body weight and fat mass. The researchers concluded that this supplementation probably favors weight and body fat loss by decreasing oxidative stress and improving adipose tissue function. This positive effect could be possibly achieved by increasing the circulating half-life of glucagon-like peptide-1 (GLP-1), an incretin hormone that contributes to the regulation of appetite and metabolism [26]. Another possible hypothesis that could explain the observed changes in body composition could be related to the lipid fraction of yogurt. As previously mentioned, CC yogurt has a high content of PUFAs, including omega-3, which play an important role in regulating body weight and reducing abdominal adiposity [27].

While the results of this study are promising and encouraging, the limited sample size presents an important limitation, particularly in evaluating differences related to the sex and age of participants. To draw more definitive and generalizable conclusions about the potential human health effects of consuming dairy products from goats fed CC and CS—non-conventional ingredients derived from industrial oilseed by-products—larger and more comprehensive studies are needed. In addition, it is important to acknowledge that changes in dietary and lifestyle habits could have influenced the parameters investigated in this study. To mitigate this potential confounding factor, all participants received thorough instructions from both physicians and an expert dietician prior to the study's initiation. They were advised to maintain their usual lifestyle habits throughout the duration of the study. Despite these efforts and recommendations, the possibility of unintentional changes cannot be completely ruled out. Therefore, while our findings are encouraging, further research is essential to confirm these results and to explore the effects of these food products in more diverse and larger populations in order to better understand their impact on human health.

5. Conclusions

In conclusion, the present study demonstrates that non-conventional ingredients derived from industrial CC and CS residues can be effectively utilized as an alternative feed for dairy goats. This approach not only offers potential benefits for human health by enhancing body composition and modulating both lipid profiles and inflammatory markers, but also contributes to the sustainability of animal production. Considering that both CC and CS are by-products generated during the oil extraction process, their inclusion in goat feeding strategies represents a valuable and strategic opportunity to reuse resources that would otherwise be wasted. This also promotes more sustainable and environmentally friendly agricultural and livestock practices, helping to reduce the environmental impact of animal production.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Additional data are available from the corresponding author(s) on reasonable request.

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