

Article

Influence of Organic Fertilization and Soil Tillage on the Yield and Quality of Cold-Pressed Camelina [*Camelina sativa* (L.) Crantz] Seed Cake: An Alternative Feed Ingredient

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Abstract: Camelina [*Camelina sativa* (L.) Crantz] oilseed cake has been identified as an alternative protein feedstuff and as a valuable feed resource. Moreover, over the last decades, there has been an increased interest in the organic production of feed supplements. A 2-year field experiment was conducted in a split-plot design with three replications, two main plots (conventional tillage: moldboard ploughing at 25 cm followed by rotary hoeing at 10–15 cm, and minimum tillage: chiseling at 25 cm depth followed by rotary hoeing at 10–15 cm), and three sub-plots (organic fertilization type: untreated, vermicompost, and compost) to evaluate the fertilization and tillage system effect on the yield and quality of cold-pressed camelina seed cake. Seed yield and cake yield were only affected by organic fertilization, with the highest values observed in the compost treatment. Crude protein was influenced by both factors examined, and the greatest content was found under conventional tillage and compost application. As for the fatty acid composition of oilseed cake, this can be characterized as a major source of polyunsaturated fatty acids (~52% of total FAs), particularly linoleic acid and α -linolenic acid, which were only affected by fertilization, with the highest values found after compost application. To conclude, the cold-pressed cake from camelina seed cultivated under compost fertilization and conventional tillage appears to be an effective alternative to conventionally used protein feed ingredients.

Keywords: α -linolenic acid; compost; crude protein content; linoleic acid; nutritive value; polyunsaturated fatty acids (PUFA); total carbohydrate content

1. Introduction

Modern methods of animal husbandry are designed to address concerns facing the world, including feeding the rising population while simultaneously minimizing environmental pollution and mitigating climate change. This will be accomplished by making more effective use of natural resources, reducing emissions of greenhouse gases, and growing more resilient to changes in the climate. The European Union's Farm to Fork Strategy includes requirements for reducing the adverse effects of environmental and climate change on livestock farming. In addition, it requires transitioning to more environmentally friendly animal husbandry [1]. The European Union imports around 75% of the high plant-based protein sources required to maintain balanced rations for high-producing animals [2]. As

a result, an ecologically sustainable approach can be adopted by lowering reliance on essential feed ingredients such as soybean cultivated on degraded lands. Growing alternative protein crops or other plants that can be used to produce protein by-products is one solution to the problem [3,4].

Camelina [*Camelina sativa* (L.) Crantz] is an oilseed and protein crop of the Brassicaceae family. Several archaeobotanical researches proved that camelina has been cultivated for a long time in Europe and Asia Minor [5–7]. It was used as an agricultural crop in numerous European countries until the mid-twentieth century [4,8]. Over the last decade, camelina has increased in popularity due to its environmental adaptability and nutritional profile, which is comparable to that of widely used oilseeds. Camelina can be successfully cultivated under several climatic patterns since it is characterized by its drought, low temperature, and heat tolerance [9–12]. Moreover, because of its decreased nutrient and water requirements, it is able to grow without irrigation and with little amounts of fertilizers, and it is typically grown on marginal and saline soils [9,13]. This crop seems to be more resilient to numerous pests and diseases in contrast to other plant species of the Brassicaceae family, making its production more ecologically beneficial because of lower herbicide and pesticide use [8,14,15]. In addition to the above-mentioned characteristics, camelina seed oil has a distinct oil composition, abundant in α -linolenic acid (>25%) and tocopherols [16,17], consequently characterizing its oil as a potential alternative source for food or non-food applications such as biodiesel and aviation turbine fuel production [18,19]. Whilst the seed cake is characterized by its high content in proteins (30–40%), its remaining oil (10–15%), carbohydrates, and additional phytochemicals [8,20] have been proposed as a cheap alternative protein feed-stuff and a valuable source in animal nutrition [3,4,8], because camelina byproducts are less expensive than other crop sources, particularly soybean [21].

Agronomic management techniques, such as seed rate, plant density, fertilization, tillage system, sowing time, and irrigation, influence crop environment, which subsequently influences crop growth and, ultimately, yield and quality [9,11–13]. Fertilization plays a critical role in increasing agricultural output by providing the necessary nutrients, particularly nitrogen, that crop plants require to maintain vegetative development in tandem with reproductive growth. Improved crop yield can only be obtained when nutrients are supplied at the optimum dose required by crop plants [12,22]. Furthermore, data from many researchers clearly illustrate the beneficial effects of organic fertilization on the quality characteristics of several crops [23,24]. Tillage is one of the most crucial procedures in the agricultural production system. Tillage methods suppress weeds, provide a proper seedbed for crops, incorporate crop residues into the soil, promote chemical reactivity, and therefore improve all physicochemical soil conditions that affect plant growth, development, and quality. Conservation tillage, including minimum tillage, is an environmentally friendly method of managing soil surface and seedbed preparation. It is used all over the world to conserve soil moisture, reduce soil erosion, and improve soil organic C, plant-available water capacity, aggregation, and soil water transmission [25].

The demand for organically grown products has risen in recent decades because many people are concerned about the environment and believe that organic products are healthier than conventional ones. The most recent modifications to EU legislation for organic animal production [26,27] tightened restrictions on livestock feed source materials by lowering the permitted proportion of conventional feed to zero. Consequently, many livestock farmers are experiencing a scarcity of organic feedstuffs [28]. The increased interest in the organic production of feed supplements enforced the need to evaluate the yield and quality parameters of organically produced camelina oilseed cake. In addition, cold-pressing, involving mechanical pressing without the use of heat, is a low-cost, simple, quick, and environmentally friendly method for producing cakes from small quantities of raw materials [29–32]. The objective of the present research was therefore to evaluate the effects of organic fertilization with compost, vermicompost, and soil tillage systems

(conventional and minimum) on yield and quality parameters of cold-pressed oilseed cakes of camelina.

2. Materials and Methods

2.1. Site Description and Experimental Design

A two-year field experiment was conducted in the Tripoli region (37°30' N and 22°22' E; 660 m altitude), central Peloponnese, southern Greece, during the 2015 and 2016 spring–summer cropping seasons (Figure 1). The primary soil physicochemical parameters (at 0–25 cm soil depth) of the experimental site are the following: the soil was characterized as a clay loam (28.6% clay, 37.8% silt, and 33.6% sand) with a pH (1:2 H₂O) of 6.62, 0.104% total nitrogen (N), 1.52 % total organic carbon, a sufficient supply of phosphorus (Olsen P: 10.7 mg·kg^{−1} soil), potassium (K) of 100.5 mg·kg^{−1} soil, magnesium (Mg) of 182 mg·kg^{−1} soil, and electrical conductivity of 58.2 µS cm^{−1}. The site was certified as organic and managed in accordance with European Union organic agriculture regulations (EC 834/2007) [26]. The meteorological data (mean monthly air temperature and precipitation) for the experimental site over the experimental periods were gathered from an automatic weather station of the Institute for Environmental Research, National Observatory of Athens (IERSD/NOA) [33] situated 4 km from the site; the data are presented in Table 1. Total precipitation in 2015 and 2016 (from April to July) was 142.2 and 216.6 mm, respectively. The mean temperature during the experimental periods was 17.0 °C for 2015 and 18.2 °C for 2016.



Figure 1. Overview of camelina experimental field during the second (2016) experimental year.

Table 1. Weather data for experimental location during the growing periods (April–July 2015 and 2016).

	Mean Temperature (°C)		Precipitation (mm)	
	2015	2016	2015	2016
April	10.4	13.6	6.6	3.4
May	16.0	14.9	49.6	33.0
June	18.3	21.7	78.0	135.0
July	21.7	22.6	8.0	45.2

The experiment was set up on an area of 546 m² according to the split-plot design with three replications, two main plots (conventional tillage: CT, and minimum tillage: MT), and

three sub-plots [organic fertilization type: untreated (control), vermicompost, and compost] (Figure 2). Specifically, the application of conventional tillage was achieved by moldboard ploughing at a depth of 25 cm with a BKD plough (BKD 20003; Kariotakis, Doxato, Drama, Greece) equipped with three M12 type moldboards, followed by one rotary hoeing at a depth of about 10–15 cm with a Maschio Gaspardo rotary tiller (Weekend Warrior SD; Maschio Gaspardo S.p.A, Padova, Italy) equipped with 28 blades; the plots of minimum tillage treatment included chiseling at 25 cm depth with an Alpler chisel plough (Alpler Agricultural Machinery, Aydin, Turkey) equipped with seven shanks, followed by rotary hoeing at 10–15 cm. The total applied organic fertilizer (vermicompost and compost) dose was $2000 \text{ kg} \cdot \text{ha}^{-1}$, and this amount is the general recommended dose of the respective fertilizer type for camelina cultivation in clay–loam soils [34]. In the present study, the two organic fertilizers differed in their composting process [organic waste (wheat straw, maize straw, and farmyard manure at a ratio of 6:3:1) converted into compost under aerobic conditions (a) by microorganisms (thermophilic bacteria): composting and (b) through the interaction of earthworms (*Eisenia foetida* and *Lumbricus rubellis*) and microorganisms (mesophilic bacteria) at room temperature (25°C): vermicomposting and composition (Table 2).

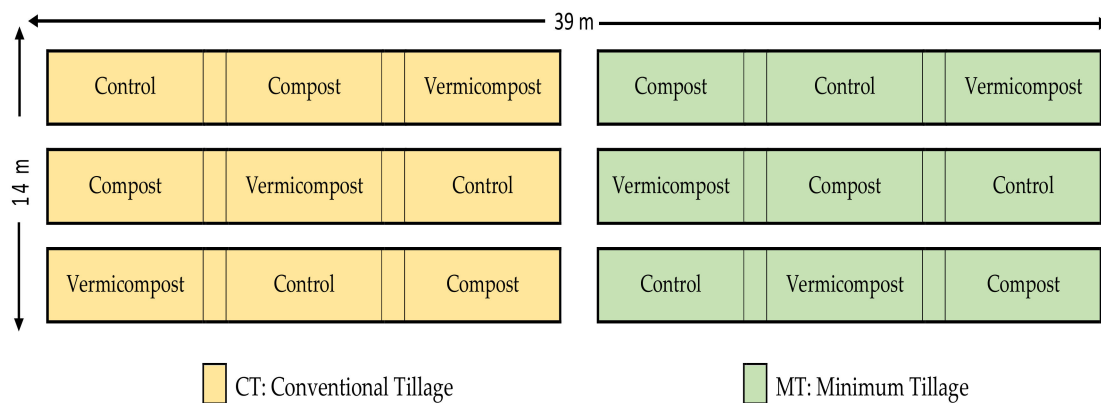


Figure 2. Experimental layout.

Table 2. Main chemical properties of organic materials used in the experimental procedure.

Parameter	Vermicompost	Compost
pH (1:2 H ₂ O)	7.22	6.61
Total organic substance (%)	52.0	32.9
N (g·kg ^{−1})	20.1	70.3
P (g·kg ^{−1})	6.5	17.4
K (g·kg ^{−1})	12.45	58.10
Mg (g·kg ^{−1})	6.03	12.06

The main plot and sub-plot sizes were 76 m^2 ($19 \text{ m} \times 4 \text{ m}$) and 24 m^2 ($6 \text{ m} \times 4 \text{ m}$), respectively (Figure 2). In each experimental year, soil tillage took place three days prior to sowing. Organic fertilizers were manually broadcasted as a basal dressing and integrated into the soil by rotary hoeing. Camelina [*Camelina sativa* (L.) Crantz cv. Midas] seeds were sown by hand in rows 30 cm apart at 2–3 cm depth. The sowing rate was $6 \text{ kg} \cdot \text{ha}^{-1}$, and seed sowing took place on 10 May 2015 and 13 April 2016. The crop was manually harvested on 31 July 2015 and 10 July 2016, once the seeds had attained full maturity (seed moisture was about 7%). There were no pests or diseases in the camelina crop over the cropping seasons. Supplemental irrigation was set up by means of a dripline irrigation system, and the total quantity of water applied during the experiment was 30 mm for each

growing period. In addition, weeds were controlled by hand-hoeing as necessary and prior to the closure of the canopy.

2.2. Sampling Procedures, Measurements, and Methods

To obtain oilseed cake samples, camelina seeds weighing a total of 300 g were harvested from each experimental plot. The seeds were cleaned from foreign materials and then cold-pressed using a cold mechanical screw pressing (TäbyPress Type 20, Örebro, Sweden) operated at a temperature below 50 °C. The press cake was left to dry at room conditions for 24 h before chemical composition analysis. The seed cake extraction rate (%) was determined by dividing the mass of cake extracted with initial weight of camelina seeds and multiplying by 100. The seed cake yield was calculated by multiplying the seed cake extraction rate with the seed yield.

As regards chemical analysis, the oilseed cake samples were crushed to pass through a 1 mm Wiley mill screen (Thomas T4274.E15 Steel Model 4 Wiley Mill; Arthur H. Thomas, Philadelphia, PA, USA). The samples were assessed for dry matter (DM) analysis (method 943.01), crude ash (CA; method 924.05), and crude protein (CP; method 984.13) with a fully automated Kjeldahl analyzer (Kjeltec 8400; Foss Tecator AB, Höganäs, Sweden), as well as crude fat (CF; method 920.39) and crude fiber (CFr; method 978.10) [35]. The crude protein (CP) content was estimated by multiplying the Kjeldahl nitrogen content by 6.25. Concerning the carbohydrate content (CHO), it was calculated as the remainder up to 100% of the sample dry matter (DM) after subtraction of the sum of crude fat (CF), crude protein (CP), and crude ash (CA). The residual oil from the oilseed cake was extracted using the Soxhlet n-hexane method. Specifically, 250 mL of solvent and 10 g of camelina oilseed cake sample were used in order to maintain a solvent to solid ratio of 25:1. The total extraction process was completed within one 1 h. The extracted phase was then distilled to separate the oil from the solvent. The residual oil content (%) was determined by dividing the mass of oil extracted by the initial weight of camelina cake and multiplying by 100.

The quantification and determination of fatty acids (FAs) were also performed in the oilseed cake samples using an Agilent 6890 GC chromatograph (Agilent Technologies, Santa Clara, CA, USA) equipped with a flame ionization detector (FID) and a single capillary column HP-88 GC (60 m × 0.25 mm i.d. × 0.20 µm film thickness; Hewlett-Packard Corporation, Palo Alto, CA, USA) after the transesterification procedure described by Heleno et al. [36]. The temperatures in the initial and final columns were 170 °C and 230 °C, respectively, and the temperature increased at a rate of 4 °C min⁻¹. The temperatures of the injector and the detector were both 230 °C. The FID temperature was set to 260 °C, and the chromatographic analysis included a temperature-programmed run beginning at 120 °C and lasting 1 min. Then, there were two step-ramps, one at 1.25 °C min⁻¹ to 230 °C and another at 10 °C min⁻¹ to 240 °C, each for 3 min. The flame gases were hydrogen (at least >99% purity) and synthetic air. The carrier gas was helium with a linear velocity set at 30 cm s⁻¹. Fatty acid identification was made by comparing the relative retention times from samples with a mix standard of 37 component FA methyl esters (FAME) (Supelco, Sigma-Aldrich, St. Louis, MO, USA). Extra FA standards were also utilized for cis-9, trans-11, C18:2, trans-10, cis-12 C18:2, and trans-11 C18:1 FA (Sigma-Aldrich, St. Louis, MO, USA). The results were processed using a Hewlett-Packard 3365 Chemstation data analysis software (Hewlett-Packard Corporation, Palo Alto, CA, USA). In the present study, the seven major fatty acids (~99%) identified in camelina oilseed cake were studied and expressed as the relative fraction of each individual fatty acid contained in the sample. The seven main fatty acids discovered were as follows: palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1 *n*-9), linoleic acid (C18:2 *n*-6), α-linolenic acid (C18:3 *n*-3), cis-11-eicosenoic acid (C20:1), and erucic acid (C22:1). In addition, the values of saturated fatty acids (SAFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), omega 6 (*n*-6), and omega 3 (*n*-3) were summed from the profiles of identified FAs in camelina oilseed cake samples, and the PUFA/SAFA and *n*-6/*n*-3 ratios were determined.

2.3. Statistical Analysis

This study was statistically analyzed using SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA). A mixed model analysis of variance (ANOVA) was performed, with years and replications as random effects and soil tillage and organic fertilization as fixed effects. In order to estimate whether there were significant differences between the treatments, Tukey's honestly significant difference test (Tukey's HSD) was applied. By using Pearson's correlation analysis, the relationships between yield components and nutritive characteristics were described. All statistical analyses conducted in this study were declared significant at 5% ($p \leq 0.05$).

3. Results

The two-year data analysis demonstrated that the interaction between soil tillage and organic fertilization had only a substantial effect on the crude fat content of camelina oilseed cake (Table 3). Moreover, the year $\times$ soil tillage interaction was also found to be statistically significant for the above-mentioned trait. The main effect of soil tillage was significant on the crude protein content, crude fat content, cis-11-eicosenoic acid (C20:1), erucic acid (C22:1), and total monounsaturated fatty acids (MUFA) of camelina oilseed cake. With the exception of seed cake extraction rate, crude ash content, stearic acid (C18:0), and omega-6 to omega-3 fatty acids ratio ($n-6/n-3$), the main effect of organic fertilization regimes was substantial on seed yield, seed cake extraction rate, and yield, together with nutritional components and fatty acids composition of oilseed cake. In addition, the main effect of the year presented a substantial effect on seed yield, seed cake content and yield, dry matter content, crude fat content, total carbohydrate (CHO) content, residual oil content of oilseed cake, as well as on its fatty acids composition and their combinations, excepting cis-11-eicosenoic acid (C20:1), erucic acid (C22:1), α -Linolenic acid (C18:3 $n-3$), total polyunsaturated fatty acids (PUFA), and $n-6/n-3$ ratio.

Table 3. Combined analysis of variance (F values) for all studied parameters of camelina crop grown under different soil tillage and organic fertilization during the two-year study.

Source of Variance	Df	Seed Yield	Seed Cake Extraction Rate	Seed Cake Yield	Dry Matter Content	Crude Protein	Crude Fat
Year (Y)	1	30.917 ***	15.827 **	18.111 **	14.915 **	1.544 ^{ns}	18.354 **
Tillage (T)	1	3.799 ^{ns}	0.199 ^{ns}	4.057 ^{ns}	0.271 ^{ns}	30.937 ***	37.161 ***
Fertilization (F)	2	241.461 ***	2.063 ^{ns}	214.628 ***	61.134 ***	11.480 **	14.677 ***
Y $\times$ T	1	0.124 ^{ns}	0.090 ^{ns}	0.024 ^{ns}	6.977 *	0.065 ^{ns}	5.047 *
Y $\times$ F	2	0.266 ^{ns}	0.470 ^{ns}	0.129 ^{ns}	1.137 ^{ns}	0.021 ^{ns}	1.041 ^{ns}
T $\times$ F	2	1.373 ^{ns}	0.041 ^{ns}	1.330 ^{ns}	0.127 ^{ns}	0.961 ^{ns}	3.372 *
Y $\times$ T $\times$ F	2	0.267 ^{ns}	0.581 ^{ns}	0.073 ^{ns}	0.223 ^{ns}	0.924 ^{ns}	1.001 ^{ns}
Source of Variance	Df	Crude Fiber	Crude Ash	Total Carbohydrate	Residual Oil Content	Palmitic Acid (C16:0)	Stearic Acid (C18:0)
Year (Y)	1	0.052 ^{ns}	0.242 ^{ns}	19.345 ***	34.744 ***	22.318 ***	5.245 *
Tillage (T)	1	0.976 ^{ns}	0.069 ^{ns}	0.450 ^{ns}	2.959 ^{ns}	0.018 ^{ns}	0.583 ^{ns}
Fertilization (F)	2	20.748 ***	3.044 ^{ns}	29.517 ***	24.982 ***	20.287 ***	0.094 ^{ns}
Y $\times$ T	1	0.786 ^{ns}	0.945 ^{ns}	3.439 ^{ns}	0.005 ^{ns}	0.049 ^{ns}	0.065 ^{ns}
Y $\times$ F	2	0.374 ^{ns}	0.562 ^{ns}	0.901 ^{ns}	4.688 ^{ns}	3.593 ^{ns}	1.058 ^{ns}
T $\times$ F	2	1.459 ^{ns}	0.009 ^{ns}	4.978 *	0.062 ^{ns}	0.111 ^{ns}	1.446 ^{ns}
Y $\times$ T $\times$ F	2	0.585 ^{ns}	0.410 ^{ns}	2.391 ^{ns}	0.144 ^{ns}	0.821 ^{ns}	0.281 ^{ns}

Table 3. Cont.

Source of Variance	Df	Total Saturated Fatty Acids (SAFA)	Oleic Acid (C18:1 <i>n</i> -9)	Cis-11-Eicosenoic Acid (C20:1)	Erucic Acid (C22:1)	Total Monounsaturated Fatty Acids (MUFA)
Year (Y)	1	9.974 **	376.113 ***	1.468 ^{ns}	0.048 ^{ns}	85.196 ***
Tillage (T)	1	0.236 ^{ns}	0.002 ^{ns}	26.996 ***	9.809 **	19.186 ***
Fertilization (F)	2	16.618 ***	10.187 **	24.657 ***	21.363 ***	32.930 ***
Y × T	1	0.007 ^{ns}	0.509 ^{ns}	0.834 ^{ns}	0.334 ^{ns}	0.903 ^{ns}
Y × F	2	2.523 ^{ns}	1.667 ^{ns}	0.078 ^{ns}	0.024 ^{ns}	0.653 ^{ns}
T × F	2	0.802 ^{ns}	0.072 ^{ns}	0.068 ^{ns}	1.422 ^{ns}	0.224 ^{ns}
Y × T × F	2	1.212 ^{ns}	0.540 ^{ns}	0.017 ^{ns}	1.019 ^{ns}	0.148 ^{ns}
Source of Variance	Df	Linoleic Acid (C18:2 <i>n</i> -6)	α-Linolenic Acid (C18:3 <i>n</i> -3)	Total Polyunsaturated Fatty Acids (PUFA)	PUFA/SAFA	<i>n</i> -6/ <i>n</i> -3
Year (Y)	1	17.091 **	0.078 ^{ns}	1.856 ^{ns}	6.542 *	3.681 ^{ns}
Tillage (T)	1	0.323 ^{ns}	2.461 ^{ns}	3.147 ^{ns}	1.720 ^{ns}	0.876 ^{ns}
Fertilization (F)	2	17.138 ***	13.177 ***	26.723 ***	9.590 **	1.650 ^{ns}
Y × T	1	2.159 ^{ns}	0.602 ^{ns}	0.033 ^{ns}	0.069 ^{ns}	1.369 ^{ns}
Y × F	2	8.548 ^{ns}	0.551 ^{ns}	0.344 ^{ns}	0.545 ^{ns}	2.829 ^{ns}
T × F	2	1.278 ^{ns}	2.663 ^{ns}	3.040 ^{ns}	1.227 ^{ns}	1.712 ^{ns}
Y × T × F	2	0.734 ^{ns}	0.475 ^{ns}	1.036 ^{ns}	1.601 ^{ns}	0.095 ^{ns}

F-test ratios originated from analysis of variance. ^{ns}: non-significant; *, **, and ***: significant at the 5%, 1%, and 0.1% levels, respectively. Df: degrees of freedom.

3.1. Seed Yield, Oilseed Cake Extraction Rate, and Yield of Camelina

The present study proved that fertilization only had a significant effect on the seed yield of the camelina crop (Table 4). Specifically, the highest yields were found in compost plots (1083.6 and 955.2 kg·ha⁻¹ in 2015 and 2016, respectively), followed by vermicompost (703.1 and 602.5 kg·ha⁻¹ in 2015 and 2016, respectively), with untreated plants yielding the lowest (558.9 and 462.5 kg·ha⁻¹ for the corresponding growing periods).

Table 4. Seed yield, cake extraction rate, and cake yield as affected by soil tillage system (conventional and minimum tillage: CT and MT, respectively) and fertilization (control, vermicompost, and compost).

Treatment	Seed Yield (kg·ha ⁻¹)	Seed Cake Extraction Rate (%)	Seed Cake Yield (kg·ha ⁻¹)
2015			
Tillage System			
CT	759.4 A	62.20 A	472.3 A
MT	804.3 A	62.16 A	499.9 A
Fertilization			
Control	558.9 c	62.37 a	348.6 c
Vermicompost	703.1 b	62.21 a	437.4 b
Compost	1083.6 a	61.95 a	671.3 a

Table 4. Cont.

Treatment	Seed Yield (kg·ha ⁻¹)	Seed Cake Extraction Rate (%)	Seed Cake Yield (kg·ha ⁻¹)
Source of Variation			
F_{Tillage}	2.410 ^{ns}	0.059 ^{ns}	2.532 ^{ns}
$F_{\text{Fertilization}}$	117.108 ^{***}	1.713 ^{ns}	120.901 ^{***}
$F_{\text{Tillage}} \times \text{Fertilization}$	1.289 ^{ns}	1.362 ^{ns}	1.093 ^{ns}
2016			
Tillage System			
CT	657.8 A	61.07 A	401.7 A
MT	688.9 A	60.84 A	419.1 A
Fertilization			
Control	462.5 c	61.33 a	283.7 c
Vermicompost	602.5 b	61.22 a	368.9 b
Compost	955.2 a	60.31 a	576.1 a
Source of Variation			
F_{Tillage}	1.416 ^{ns}	0.154 ^{ns}	1.617 ^{ns}
$F_{\text{Fertilization}}$	125.452 ^{***}	1.221 ^{ns}	95.586 ^{***}
$F_{\text{Tillage}} \times \text{Fertilization}$	0.247 ^{ns}	0.207 ^{ns}	0.365 ^{ns}

F -test ratios originated from analysis of variance. ^{ns}: non-significant; ^{***}: significant at the 0.1% level. The different upper- and lower-case letters indicate significant differences according to Tukey's HSD test ($p \leq 0.05$) under different soil tillage and organic fertilization regimes, respectively, within a cultivation period.

Concerning the seed cake extraction rate of camelina, there were no significant differences among different soil tillage and fertilization plots (Table 4). Seed cake yield was estimated by multiplying the seed yield of the camelina crop and the content of seed cake residue derived from the crop's seeds after removing the fixed oil. According to the combined analysis (Table 3), seed cake yield was only affected by fertilization. Averaged over soil tillage treatments, the highest values of cake yield were found in plants treated with compost (671.3 and 576.1 kg·ha⁻¹ in 2015 and 2016, respectively), followed by vermicompost (437.4 and 368.9 kg·ha⁻¹ for the respective years; Table 4).

3.2. Nutritional Composition of Camelina Oilseed Cake

The influence of the soil tillage system and organic fertilization on the dry matter (DM) content of camelina oilseed cake is shown in Table 5. During the two-year experiment, DM content was not affected by soil tillage systems; however, the experiment results showed that the mean values of this trait offered strong evidence of the effect of varied organic fertilization treatments. In particular, the highest values were presented for compost fertilizer (93.54% and 93.70% in 2015 and 2016, respectively), followed by vermicompost (93.11% and 93.46% for the corresponding growing seasons).

Both soil tillage and organic fertilization had a significant impact on crude protein (CP) content (Tables 3 and 5). Concerning the soil tillage effect, the CP content mean values in conventional tillage plots (35.60% and 35.18% DM in 2015 and 2016, respectively) were substantially higher than that in minimum tillage plots (33.99% and 33.71% DM for the corresponding growing periods). As regards the fertilization effect, the highest mean values of CP content were discovered in plots with compost (35.53% and 35.16% DM in 2015 and 2016, respectively) and vermicompost (34.91% and 34.64% DM for the respective years) fertilizers, whereas the lowest values (33.94% and 33.54% DM for the corresponding growing seasons) were achieved in the unfertilized (control) plots.

Table 5. Nutritional components of oilseed cake as affected by soil tillage system (conventional and minimum tillage: CT and MT, respectively) and fertilization (control, vermicompost, and compost).

Treatment	Dry Matter Content (%)	Crude Protein (% DM)	Crude Fat (% DM)	Crude Fiber (% DM)	Crude Ash (% DM)	Total Carbohydrate (% DM)	Residual Oil Content (% DM)
2015							
Tillage System							
CT	93.07 A	35.60 A	15.47 B	7.46 A	5.48 A	43.46 A	13.82 A
MT	93.89 A	33.99 B	17.93 A	7.48 A	5.53 A	42.55 A	13.87 A
Fertilization							
Control	92.28 c	33.94 b	15.53 b	7.17 b	5.44 a	45.09 a	13.75 b
Vermicompost	93.11 b	34.91 ab	16.69 ab	7.51 ab	5.50 a	42.91 b	13.86 ab
Compost	93.54 a	35.53 a	17.88 a	7.74 a	5.57 a	41.02 c	13.93 a
Source of Variation							
F_{Tillage}	2.459 ^{ns}	15.786 ^{**}	27.289 ^{**}	0.003 ^{ns}	0.321 ^{ns}	3.526 ^{ns}	2.197 ^{ns}
$F_{\text{Fertilization}}$	42.594 ^{***}	5.217 [*]	8.297 [*]	8.175 [*]	0.706 ^{ns}	20.972 ^{**}	6.503 ^{**}
$F_{\text{Tillage} \times \text{Fertilization}}$	0.133 ^{ns}	0.392 ^{ns}	1.566 ^{ns}	0.407 ^{ns}	0.197 ^{ns}	2.611 ^{ns}	0.066 ^{ns}
2016							
Tillage System							
CT	93.43 A	35.18 A	14.87 B	7.39 A	5.49 A	44.37 A	14.02 A
MT	93.17 A	33.71 B	16.01 A	7.52 A	5.58 A	44.79 A	14.09 A
Fertilization							
Control	92.75 b	33.54 b	14.50 b	7.23 c	5.43 a	46.53 a	13.83 c
Vermicompost	93.46 a	34.64 ab	15.79 a	7.44 b	5.48 a	44.10 b	14.07 b
Compost	93.70 a	35.16 a	16.02 a	7.69 a	5.72 a	43.10 b	14.28 a
Source of Variation							
F_{Tillage}	4.604 ^{ns}	15.173 ^{**}	10.223 [*]	4.117 ^{ns}	0.627 ^{ns}	0.639 ^{ns}	1.160 ^{ns}
$F_{\text{Fertilization}}$	21.482 ^{**}	6.367 [*]	7.087 [*]	19.354 ^{**}	2.508 ^{ns}	10.450 [*]	18.584 ^{**}
$F_{\text{Tillage} \times \text{Fertilization}}$	0.210 ^{ns}	1.579 ^{ns}	3.279 ^{ns}	3.289 ^{ns}	0.217 ^{ns}	4.570 ^{ns}	0.119 ^{ns}

F -test ratios originated from analysis of variance. ^{ns}: non-significant; *, **, and ***: significant at the 5%, 1%, and 0.1% levels, respectively. The different upper- and lower-case letters indicate significant differences according to Tukey's HSD test ($p < 0.05$) under different soil tillage and organic fertilization regimes, respectively, within a cultivation period.

The current study found that soil tillage had a substantial impact on the crude fat (CF) content of camelina oilseed cake during the experimental periods (Table 5), with the minimum tillage plots achieving higher values of this measure (17.93% and 16.01% DM in 2015 and 2016, respectively) in relation to the conventional tillage treatment (15.47% and 14.87% DM for the corresponding growing seasons). As regards organic fertilization, this also had a considerable effect on the CF content, with greater values (17.88% and 16.02% DM in 2015 and 2016, respectively) observed in plots fertilized with compost fertilizer followed by vermicompost (16.69% and 15.79% DM for the corresponding experimental years).

There were no significant variations in crude fiber (CFr) content between the two studied soil tillage systems; nonetheless, the oilseed cake from plants of minimum tillage exhibited slightly higher values (7.48% and 7.52% DM in 2015 and 2016, respectively) in comparison to those of conventional tillage (7.46% and 7.39% DM for the corresponding years) (Table 5). Contrariwise, the organic fertilization impact was determined to be

significant, with the higher values (7.74% and 7.69% DM in 2015 and 2016, respectively) recorded in the compost plots.

As for the crude ash (CA) content, there were no significant differences among the conventional and minimum soil tillage systems; however, the oilseed cake from plants grown under minimum tillage exhibited marginally higher values of this measure (5.53% and 5.58% DM in 2015 and 2016, respectively) than those of the conventional tillage treatment (5.48% and 5.49% DM for the corresponding growing seasons). Likewise, organic fertilization was not found to have a substantial impact, although slightly greater values (5.57% and 5.72% DM in 2015 and 2016, respectively) were achieved in compost plots, whereas the lowest values (5.44% and 5.43% DM for the corresponding growing seasons) were recorded in unfertilized plots.

Total carbohydrate (CHO) content was not influenced by the different soil tillage systems, but it was influenced by the different fertilization treatments (Table 5). In particular, the highest value of CHO was discovered in unfertilized plots, with the values being 45.09% and 46.53% DM in 2015 and 2016, respectively, whilst the lowest values (41.02% and 43.10% DM for the corresponding growing seasons) were recorded in compost plots.

During the two-year research trial, only fertilization had a substantial effect on residual oil content. Specifically, the highest residual oil content values were achieved in the oilseed cake from plants fertilized with compost (19.93% and 14.28% DM in 2015 and 2016, respectively), whilst the lowest values (13.75% and 13.83% DM for the corresponding growing seasons) were found in the oilseed cake from unfertilized plants.

3.3. Fatty Acid Composition and Ratios of Camelina Oilseed Cake

In the current research study, the seven primary fatty acids detected in camelina oilseed cake were studied. They were expressed as the relative percentage of each individual fatty acid present in the seed cake sample. Specifically, the seven major fatty acids observed that accounted for about 99% of total fatty acids were palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1 *n*-9), linoleic acid (C18:2 *n*-6), α -linolenic acid (C18:3 *n*-3), cis-11-eicosenoic acid (C20:1), and erucic acid (C22:1) (Table 6).

The combined analysis of variance (Table 3) revealed that the contents of saturated (SAFA: palmitic and stearic acid), monounsaturated (MUFA: oleic, cis-11-eicosenoic, and erucic acid), and polyunsaturated fatty acids (PUFA: linoleic and α -linolenic acid) were significantly influenced by organic fertilization during the growing seasons of the current study. In particular, averaged over the soil tillage systems, the greatest SAFA values were detected in the oilseed cake from plants fertilized with vermicompost (9.85% and 9.86% DM in 2015 and 2016, respectively) and compost (9.78% and 9.91% DM for the corresponding growing seasons) (Table 6). As regards MUFA content, the highest value was recorded in unfertilized (control) plots, with values of 34.10% and 33.36% DM for the corresponding growing seasons. As for PUFA content, the highest values (52.74% and 52.62% DM in 2015 and 2016, respectively) were observed in compost plots. As regards the soil tillage effect, this also had a significant impact on MUFA content (Table 3). During the experimental periods, the mean values of MUFA (33.85% and 33.08% DM in 2015 and 2016, respectively) were greater in those in the conventional tillage system plots (Table 6).

Palmitic acid presented the highest content between SAFAs. According to the combined analysis (Table 3), seed cake yield was only affected by organic fertilization. In particular, the greatest values of palmitic acid content were recorded in the oilseed cake of plants treated with compost (7.23% and 7.39% DM in 2015 and 2016, respectively) and vermicompost (7.28% and 7.33% DM for the corresponding years) fertilizers (Table 6).

Table 6. Fatty acid components and ratios of oilseed cake as affected by soil tillage system (conventional and minimum tillage: CT and MT, respectively) and fertilization (control, vermicompost, and compost).

	Saturated Fatty Acids (SAFA)			Monounsaturated Fatty Acids (MUFA)				Polyunsaturated Fatty Acids (PUFA)			PUFA/SAFA	<i>n</i> -6/ <i>n</i> -3
	Palmitic Acid (C16:0) (% DM)	Stearic Acid (C18:0) (% DM)	Total SAFA (% DM)	Oleic Acid (C18:1 <i>n</i> -9) (% DM)	Cis-11-EiCosenoic Acid (C20:1) (% DM)	Erucic Acid (C22:1) (% DM)	Total MUFA (% DM)	Linoleic Acid (C18:2 <i>n</i> -6) (% DM)	α-Linolenic Acid (C18:3 <i>n</i> -3) (% DM)	Total PUFA (% DM)		
2015	Tillage System											
CT	7.22 A	2.54 A	9.76 A	18.27 A	13.41 A	2.17 A	33.85 A	22.37 A	29.31 A	51.67 A	5.29 A	0.76 A
MT	7.21 A	2.56 A	9.78 A	18.24 A	13.11 B	2.10 B	33.45 B	22.29 A	29.80 A	52.09 A	5.33 A	0.74 A
	Fertilization											
Control	7.15 b	2.54 a	9.69 b	18.38 a	13.49 a	2.23 a	34.10 a	22.23 b	28.79 b	51.03 b	5.26 a	0.77 a
Vermicompost	7.28 a	2.56 a	9.85 a	18.29 ab	13.20 b	2.04 c	33.53 b	22.33 ab	29.56 ab	51.88 ab	5.27 a	0.76 a
Compost	7.23 ab	2.55 a	9.78 ab	18.09 b	13.09 b	2.13 b	33.31 b	22.42 a	30.32 a	52.74 a	5.39 a	0.74 a
	Source of Variation											
<i>F</i> _{Tillage}	0.002 ^{ns}	0.581 ^{ns}	0.072 ^{ns}	0.172 ^{ns}	11.453 *	8.603 *	9.483 *	4.008 ^{ns}	1.860 ^{ns}	1.273 ^{ns}	0.796 ^{ns}	1.976 ^{ns}
<i>F</i> _{Fertilization}	6.215 *	0.503 ^{ns}	8.101 *	5.812 *	6.865 *	20.167 **	12.732 **	7.786 *	5.865 *	7.053 *	3.597 ^{ns}	3.098 ^{ns}
<i>F</i> _{Tillage} × Fertilization	0.444 ^{ns}	1.016 ^{ns}	1.386 ^{ns}	0.302 ^{ns}	0.033 ^{ns}	3.702 ^{ns}	0.242 ^{ns}	1.649 ^{ns}	0.660 ^{ns}	0.463 ^{ns}	0.315 ^{ns}	0.951 ^{ns}
2016	Tillage System											
CT	7.30 A	2.53 A	9.83 A	17.47 A	13.43 A	2.16 A	33.08 A	21.89 A	29.69 A	51.48 A	5.23 A	0.74 A
MT	7.31 A	2.52 A	9.84 A	17.50 A	13.21 B	2.11 A	32.81 B	22.06 A	29.53 A	51.76 A	5.26 A	0.73 A
	Fertilization											
Control	7.21 b	2.54 a	9.75 b	17.56 a	13.58 a	2.22 a	33.36 a	21.53 b	28.96 b	50.49 c	5.18 b	0.75 a
Vermicompost	7.33 a	2.53 a	9.86 a	17.47 ab	13.24 b	2.04 b	32.75 b	21.84 b	29.82 a	51.66 b	5.24 ab	0.73 a
Compost	7.39 a	2.52 a	9.91 a	17.42 b	13.15 b	2.16 a	32.73 b	22.55 a	30.07 a	52.62 a	5.31 a	0.74 a
	Source of Variation											
<i>F</i> _{Tillage}	0.109 ^{ns}	0.117 ^{ns}	0.186 ^{ns}	0.656 ^{ns}	27.727 **	3.430 ^{ns}	11.721 *	1.093 ^{ns}	0.602 ^{ns}	2.551 ^{ns}	1.243 ^{ns}	0.031 ^{ns}
<i>F</i> _{Fertilization}	26.328 **	0.636 ^{ns}	11.509 **	6.479 *	36.536 ***	7.132 *	28.910 ***	13.112 **	9.680 *	33.163 ***	10.238 *	1.142 ^{ns}
<i>F</i> _{Tillage} × Fertilization	0.521 ^{ns}	0.740 ^{ns}	0.505 ^{ns}	0.326 ^{ns}	0.085 ^{ns}	0.230 ^{ns}	0.018 ^{ns}	0.971 ^{ns}	4.128 ^{ns}	6.809 ^{ns}	5.277 ^{ns}	0.843 ^{ns}

F-test ratios originated from analysis of variance. ^{ns}: non-significant; *, **, and ***: significant at the 5%, 1%, and 0.1% levels, respectively. The different upper- and lower-case letters indicate significant differences according to Tukey's HSD test ($p \leq 0.05$) under different soil tillage and organic fertilization regimes, respectively, within a cultivation period.

Among MUFAs, the highest content was recorded in oleic acid (Table 6). During the two-year research study, oleic acid content was not influenced by soil tillage; however, the experimental results proved a significant effect of different organic fertilization regimes on this trait. Specifically, the highest values were presented in the untreated (control: 18.38% and 17.56% DM in 2015 and 2016, respectively), followed by vermicompost (18.29% and 17.47% DM for the corresponding growing seasons) fertilizers.

In the PUFA category, the greatest content was obtained from α -linolenic acid, and it was the highest content among all the other fatty acids in camelina oilseed cake (Table 6). Diverse soil tillage strategies had no effect on the α -linolenic acid concentration, which was exclusively altered by distinct organic fertilization treatments. In particular, the greatest values were observed under compost fertilization (30.32% and 30.07% DM in 2015 and 2016, respectively), followed by vermicompost (29.56% and 29.82% DM for the corresponding growing seasons).

As for the linoleic acid, which recorded the second highest content among PUFAs and all the other fatty acids of camelina oilseed cake, the effects of the soil tillage system and organic fertilization on its content are shown in Table 6. Concerning soil tillage, there were no substantial differences between the two tested soil tillage systems. Contrariwise, the linoleic acid content presented strong evidence of the effect of varied organic fertilization treatments. The greatest values were recorded in the oilseed cake of plants treated with compost (22.42% and 22.55% DM in 2015 and 2016, respectively).

The ratio of PUFA/SAFA was not influenced by soil tillage, and it was only affected by the different organic fertilization regimes during the second year of the experiment. In particular, during the second experimental period, the highest PUFA/SAFA ratio was recorded in the case of compost (5.31), while the lowest value was obtained from untreated (control: 5.18) plots (Table 6).

Finally, PUFAs consist of two types: omega 3 (n -3) and omega 6 (n -6) fatty acids. In the current research, n -3 fatty acids consisted only of α -linolenic acid, whereas n -6 fatty acids consisted of linoleic acid. Concerning the ratio of n -6/ n -3, there were no significant differences between the two examined soil tillage systems; however, the conventional tillage system plants recorded slightly higher values of the measure (0.76 and 0.74 in 2015 and 2016, respectively) than those of the minimum tillage system (0.74 and 0.73 for the corresponding growing seasons) (Table 6). Likewise, the organic fertilization impact was not determined to be statistically significant in the current trial, although, untreated (control: 0.77 and 0.75 in 2015 and 2016, respectively) presented slightly higher n -6/ n -3 ratio values.

4. Discussion

During the two-year trial, the seed yield of camelina crop was slightly higher in minimum tillage (Table 3). The minimum tillage for camelina crop can generate an equivalent seed yield to conventional tillage and should result in less tillage intensity in the distinctive Mediterranean environment [37,38]. However, there has been some disagreement in previous research studies on how different oilseed crops react to soil tillage systems, with lower yields discovered under conventional tillage compared with minimum [39,40], as well as higher yields observed under conventional tillage [41,42] and little effect of tillage treatment [43]. Considering all the above mentioned, it is possible to conclude that the interaction effect between the tillage method and environment is more essential than the applied tillage method alone [42,44].

In terms of fertilization, the application of different organic amendments had a significant response to the camelina seed yield. The two-year mean value of this trait was considerably greater in compost fertilizer plots (1019.4 kg·ha⁻¹), followed by vermicompost (652.8 kg·ha⁻¹), and the untreated (control: 510.7 kg·ha⁻¹) recorded the lowest yield. The current results of organically grown camelina are equal to those found in conventionally grown camelina in other Mediterranean environments around the world [12,45,46]. In addition, the application of compost seemed to increase seed yield by 56.16% as compared with vermicompost application. This increment could be related to the type of organic

amendment (a greater proportion of compost in nitrogen and other main nutrients than vermicompost) that supplied the specific needs of the camelina crop for nutrients, as well as the improved chemical, hydro-physical, and biological properties of soils where organic amendments were applied [47,48].

Throughout the two-year experiment, the oilseed cake extraction rate was not statistically affected by fertilization; however, the two-year average value of extraction rate was slightly higher in untreated plots (61.85%), whereas the lowest rate was offered by compost fertilizer (61.13%). The present results revealed that organic fertilization seemed to slightly reduce the values of this trait. In addition, the cake extraction rate is inversely proportional to the oil content of the seeds [29]. Consequently, these findings are in agreement with previous studies that confirmed the alternative use of organic fertilization in order to minimize the potential reductions in oil content and quality in comparison with the negative effects of synthetic fertilizers [49,50].

The combined analysis of variance revealed that the seed cake yield of camelina was significantly influenced by organic fertilization regimes (Table 2). Specifically, the highest two-year average value was obtained from compost treatments, with the value being 97.28% higher than that of the control, respectively. The yield of oilseed cake is determined by the crop's seed yield and the residue content, which continues to exist after the significant proportion of the oil has been extracted from oilseeds (seed cake extraction rate). As a result, seed yield and seed cake residual rate correlated strongly with seed cake yield ($r = 0.993$, $p < 0.001$ and $r = 0.769$, $p < 0.001$, respectively) (Figure 3).

Dry matter (DM) content of the oilseed cake was only affected by fertilization, and the highest values were found after the application of organic fertilizers (Table 4). In particular, the compost treatment presented the greatest two-year value (93.62%), followed by vermicompost (93.29%). The available nitrogen raised the DM content in a positive linear relationship. This happened as nitrogen promotes plant maturity and metabolism, causing a substantial increase in photoassimilates' accumulation and transformation into plant tissues [12,51].

The camelina plant constitutes an excellent protein source. The crude protein (CP) content of various camelina feed components varies. According to the literature, camelina seed contains ~25% CP, whilst the seed byproducts, for instance, of seed cake have higher CP content, with values ranging from 30.3 to 39.8% depending on genotype (variety), growing season, and environment (soil and climatic conditions), as well as agronomic practices [4,52]. The current study found that the CP content of camelina oilseed cake was substantially affected by both the soil tillage system and fertilization. Regarding the effect of soil tillage, the two-year mean value of CP content found in conventional tillage plots (35.39% of DM) was higher than that in minimum tillage plots (33.85% of DM). These findings are in accordance with those obtained by Wilhelm and Wortman [53], Spoljar et al. [54], and Cociu and Alionte [55] determined the good effects of crop rotation and more intensive tillage on protein content in the seed of soybean and maize crops. Increasing available nutrient levels generally improves feed quality measures, including CP content. In terms of fertilization effect, compost had the highest two-year average value (35.35% DM), followed by vermicompost fertilization (34.78% DM). The higher CP content following the application of compost fertilizer could be attributed to larger quantities of plants' available nitrogen, which improves and enhances nitrogen uptake and which is critical for protein synthesis [56]. Furthermore, the current results confirmed that the CP content in camelina cake is comparable to that discovered in rapeseed meal (29.7–39.9%); however, it is lower than that in soybean meal (43.0–56.3%) [52,57,58].

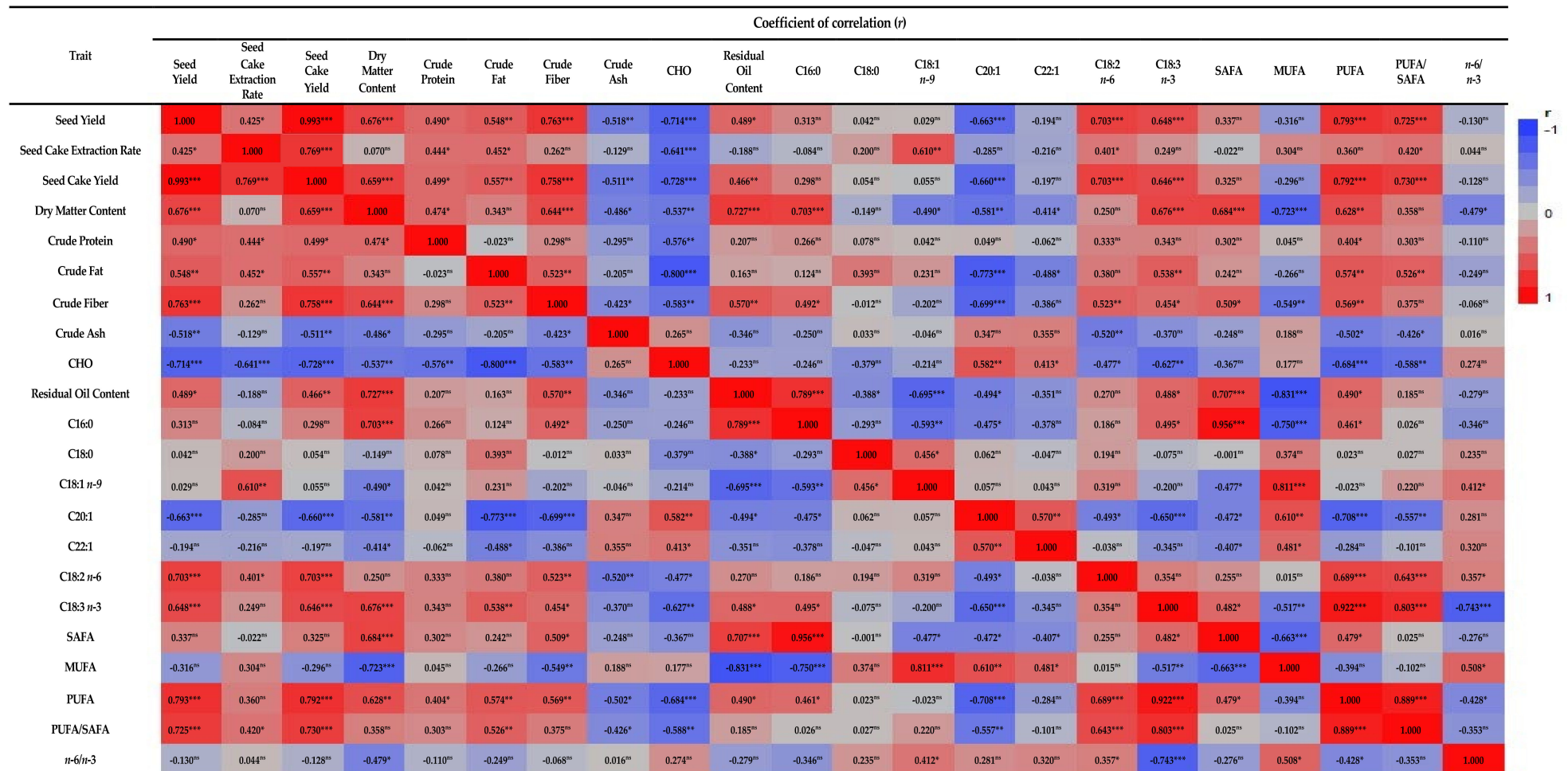


Figure 3. Heatmap of correlation coefficients between evaluated traits. ^{ns}: Non-significant; *, **, and ***: significant at the 5%, 1%, and 0.1% levels, respectively. CHO: total carbohydrate content, C16:0: palmitic acid, C18:0: stearic acid, C18:1 n-9: oleic acid, C20:1: cis-11-eicosenoic acid, C22:1: erucic acid, C18:2 n-6: linoleic acid, C18:3 n-3: α -linolenic acid, SAFA: saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids, n-3: omega-3 fatty acids, and n-6: omega-6 fatty acids.

Crude fat (CF) is constituted of lipids, such as galactolipids, triglycerides, and phospholipids, and several non-polar substances including phosphatides, steroids, pigments, and fat-soluble vitamins, as well as waxes. According to Juodka et al. [52], the CF content obtained from camelina seed is high (36.8%), although the CF content in oilseed cake varies from 6.4% to 22.7%. In the current investigation, the CF content of camelina seed cake was significantly affected by both examined factors. CF content received the highest values in the minimum tillage system, with the 2-year mean value being 11.87% higher in comparison with conventional tillage. Similar results, with increased fat content in soybean seeds as tillage became more minimized, were obtained by Urda et al. [59]. Concerning the organic fertilization effect, the greatest 2-year mean value was obtained from compost (16.95 DM), whereas the lowest was recorded in the untreated (control: 15.02%). The positive effect of compost fertilization on CF content was previously reported by Jariene et al. [60] in pumpkin oil cake. In general, a comparison of our findings to the findings of previous research studies on other oilseed crop species reveals that the CF content in oilseed cake of camelina is greater than that in soybean (0.6–3.3%) and rapeseed (1.4–10.5%) meals [57,58].

A high percentage of fibrous components (crude fiber; CFr) implies that the feed is characterized by low digestibility and energy value [61]. Previous research proved that high CFr content was observed in camelina seed by-products, with the values varying from 9.7% to 17.4%, indicating a higher content in comparison to that in soybean meal and similar to that in rapeseed expellers and meal [62]. CFr content was only influenced by organic fertilization regimes in the current research, and the highest 2-year mean value was reported in compost (7.72% DM), followed by vermicompost (7.48% DM). Barker and Sawyer [63] and Kaur et al. [64] reported that the CFr content in soybean seeds remained unchanged when nitrogen fertilizers were applied.

An increased crude ash (CA) content implies considerable soil pollution, which might raise the content of insoluble fiber components in neutral detergent fiber (total cellulose) solution greatly. In our study, this measure was not affected by the assessed factors, although there was a tendency for CA content to be higher with the increase in available nitrogen, and a slightly greater 2-year value (5.65% DM) was recorded in plots fertilized with compost (Table 5). The CA content of camelina oilseed cake was reported to vary from 4.9% to 6.3% [50]. Bobrecka-Jamro et al. [65] demonstrated that high rates of nitrogen increased the CP content and decreased the content of CF, as well as causing a significant decrease in ash and CFr content in soybean seeds.

Carbohydrates (CHO) represent the principal source of energy for rumen microorganisms, as well as the primary plant energy reserve, comprising 50–80% of total reserves [66]. CHOs offer energy to livestock, with the rumen performing the majority of digestion in the case of ruminants [67]. The CHO of camelina seed meal comprises monosaccharides, disaccharides, oligosaccharides, as well as polysaccharides [4]. The total CHO content declined linearly in the current experiment, with increasing levels of nitrogen supply to the plant (Table 4) due to the increased usage of these carbs to convert available nitrogen into protein as a natural plant reaction [68,69].

Regarding the residual oil content in camelina oilseed cake, the combined analysis of variability showed that organic fertilization only influenced this trait. Specifically, the highest 2-year mean value was discovered in compost treatment (14.11% of DM), while the lowest was obtained from untreated (13.79% DM). The current findings distinctly reveal that a substantial quantity of oil continues to exist in the cake after mechanical screw press extraction of oilseeds. In addition, cold-pressed cakes preserve more oil than solvent-extracted meals [32]. As a result, cold-pressed cakes contribute a substantial quantity of energy to livestock rations due to their high content of residual oil [4,32].

The fatty acid (FA) composition of camelina oilseed cake is presented in Table 6. The results revealed that the cold-pressed cake was distinguished by low quantities of saturated fatty acids (SAFA), of which palmitic acid (C16:0) was the predominant one. During the two experimental years, the contents of SAFA and palmitic acid were only affected by organic fertilization, presenting a similar trend. Specifically, the highest concentrations in the

first year of the study were achieved after vermicompost application, with the maximum average values of SAFA and palmitic acid content being 9.85% and 9.28% DM, respectively, whereas, during the second year, the highest values of SAFA (9.91% DM) and palmitic acid (7.39% DM) were recorded after compost fertilization, with the differences among compost and vermicompost fertilization not being statistically significant. In the present study, this similar response trend of SAFA and palmitic acid content is also confirmed by the very strong and positive correlation among the above-mentioned traits ($r = 0.956$, $p < 0.001$, respectively) (Figure 3). The amount of SAFA and palmitic acid content in camelina seed cake seems to be lower than that found in soybean meal (19.9%) and rapeseed cake (16.3%), although higher compared with that found in hempseed cake (7.7%) [70,71].

Concerning the proportion of monounsaturated fatty acids (MUFA), this was substantially affected by both examined factors. In particular, the conventional tillage system, with a 2-year mean value of 33.47% DM, was significantly higher than that of minimum tillage, with a 2-year mean value of 33.14% DM. In terms of fertilization, the highest 2-year mean value (33.73%) was observed in the untreated plots. Oleic acid (C18:1 *n*-9), which is characterized by its cholesterol-lowering properties [72], was the most dominant acid among MUFA and was negatively affected by organic fertilization application, with the highest two-year average value (13.54% of DM) of its content observed in the unfertilized (control) plots. Hazardous erucic acid (C22:1) was the lowest MUFA in content and presented a similar response to that of total MUFA towards the examined factors' effects. The highest average 2-year values were observed under conventional tillage (2.17% DM) and untreated (2.23% DM). As for the above-mentioned results, similar behavior of MUFA and their consequents was also detected in previous research studying the influence of similar factors (minimum soil tillage and organic fertilization) on the fatty acid profile of camelina seed oil [50,73,74]. The current findings confirmed that camelina cake contains more MUFA than hempseed cake (10%) but less than soybean meal (52.4%) and rapeseed cake (48.7%) [70,71]. Moreover, the erucic acid content in cold-pressed camelina cake seemed to be thirty-six times higher than that in rapeseed cake [71].

Camelina oilseed cake constitutes a major source of polyunsaturated fatty acids (PUFA), particularly linoleic acid (C18:2 *n*-6) and α -linolenic acid (C18:3 *n*-3), which are characterized as essential since they are essential for good health, and must be incorporated into the diet as they are not able to be produced by the body. Omega 6 (*n*-6) and omega 3 (*n*-3) are fatty acids of PUFA, and specifically in the present research, the *n*-6 and *n*-3 omega fatty acids in cold-pressed camelina cake were composed exclusively of linoleic and α -linolenic acid, respectively. According to the results of our study, the total PUFA and their constituents' contents were only affected by organic fertilization, and the highest average 2-year values of their contents were presented in oilseed cake obtained from plants fertilized with compost (52.68%, 22.49%, and 30.20% for total PUFA, linoleic acid, and α -linolenic acid, respectively). In the same manner, in the research study of Martinez et al. [74] evaluating the organic fertilization effect on camelina oil, the application of composted sludge seemed to significantly increase the proportion of linoleic acid, while there was a significant decrease in the proportion of erucic acid with respect to untreated plants. In addition, correlation analysis revealed highly significant correlations between the levels of linoleic and linolenic acids and between these fatty acids and seed cake extraction rate (Figure 3), which is in accordance with the relevant study of Obour et al. [75] on the fatty acid profile of camelina seed oil. As for α -linolenic acid, camelina cake presents a much higher content of this fatty acid in comparison with other feed ingredients, including soybean meal (7.2–8.6%), hempseed cake (15.9–24.7%), and rapeseed cake (10.6–13.1%), but lower than the relevant content recorded in linseed cake (51.5%) [52,71,76,77]. As a result, it is important to remember that camelina is the second highest α -linolenic acid-containing plant that is cultivated in the Northern Hemisphere and utilized as a feed ingredient [50,69]. Furthermore, essential linoleic acid was found to be lower than in other feed ingredients, such as soybean meal (52.4–55.2%) and hempseed cake (52.5–59.5%), but lower than the relevant content recorded in linseed cake (14.60%) [52,71,77].

In response to the fatty acid ratios, the PUFA/SAFA were only affected by organic fertilization during the second year of the study, and the greatest value was found in compost plots, with the average values being 5.31, while the $n-6/n-3$ or linoleic/ α -linolenic ratio was not influenced by either examined factor, and its values ranged from 0.73 to 0.77%. Finally, the $n-6/n-3$ or linoleic/ α -linolenic ratio in cold-pressed camelina cake was found to be lower compared with soybean meal (6.11), hempseed cake (3.76), as well as rapeseed cake (1.66) [52,71,76,77].

5. Conclusions

The results of the present research demonstrated that the seed yield, as well as the seed cake yield of camelina, were significantly affected by organic fertilization, with the highest values observed in the compost treatment, whereas the different tillage systems had no significant effect. In terms of nutritional characteristics, cold-pressed cake from camelina seed cultivated under compost fertilization and conventional tillage seems to be an excellent alternative to commonly used protein feed additives in livestock diets. Camelina cake is characterized by great nutritional properties, as it contains a significant quantity of CP and high CF content, making it a viable protein and energy source for ruminant and non-ruminant animals. In addition, camelina cake has the potential to provide crucial polyunsaturated fatty acids (PUFA) (~52% of total FAs), especially under compost fertilization, which can be utilized for the production of animal products rich in omega 3 ($n-3$) and omega 6 ($n-6$) PUFA, demonstrating several beneficial effects on human health. Finally, special consideration should be given to antinutritional ingredients (e.g., erucic acid) that can decrease feed consumption and nutrient utilization; in consequence, further research studies including various animal species at different growing stages are required in order to determine the appropriate feed supplementation level of camelina oilseed cake without any negative effect on animal performance.

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