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Research Article

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Tillage intensity and compost application effects on organically grown camelina productivity, seed and oil quality

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Abstract

The importance of *Camelina sativa* has lessened substantially over the last half century, however its unique oil composition and the beneficial agronomic attributes with regard to sustainable agriculture have recently reignited interest in this oilseed crop. Notwithstanding the great interest in camelina, the potential to be cultivated organically has not received prominent attention from researchers. The objective of this study was to evaluate the response of organic camelina to different tillage systems and compost types, based on differences in yield parameters, oil content, seed crude protein and fatty acid profile. The field experiments, conducted during the 2014, 2015 and 2016 growing seasons, were laid out in a split plot design with three replicates, two main plots (conventional tillage and minimum tillage) and three sub-plots (vermicompost, compost, unamended control). It is consequential from the results that the effect of the type of organic amendment was highly significant on camelina's productivity. Particularly, compost treatment resulted in higher seed and oil yield (1132 and 446 kg ha^{-1}, respectively) compared to the vermicompost (682 and 269 kg ha^{-1}, respectively) and the unamended control (554 and 220 kg ha^{-1}, respectively). Regarding the fatty acid profile, both organic amendments increased linoleic and palmitic acids, while they presented disparate effects on a-linolenic acid. Furthermore, tillage system influenced significantly only thousand seeds weight, protein content and gondoic acid, enabling the use of reduced tillage to be comparably effective on organically grown camelina performance. Further experimentation is needed to match crop needs with the appropriate cropping techniques in order to ensure an effective organic cultivation.

Keywords: Camelina; compost; oil content; organic; tillage system; yield

Introduction

Camelina (*Camelina sativa* L. Crantz) is an annual oilseed plant belonging to the Cruciferae family, native to Mediterranean region and Central Asia (Falasca *et al.*, 2014). The name camelina derived from Greek words chamai (dwarf) and linion (flax) and archaeological evidence suggests its cultivation in Europe dating back to the Bronze Age (Bouby, 1998). Cultivation decreased during the Middle Ages was gradually displaced

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by higher-yielding crops such as rapeseed, but was still reported as late as the middle of the 20th century (Zubr, 1997).

In recent years, is being considered as a novel alternative oilseed crop with distinguishing features and a unique and versatile oil profile that could make it a competitive contender against the dominant global vegetable oils, for nutritional and industrial applications (Chaturvedi *et al.*, 2017). Oil content of camelina seeds can range from 30% to 49% (Zubr, 2003; Vollmann *et al.*, 2007; Vollmann and Eynck, 2015) and oil yield is estimated to be 106 to 907 L ha^{-1} which is significantly higher than soybean (347 to 562 L ha^{-1}) and sunflower (505 to 750 L ha^{-1}) (Moser, 2010). The major part of camelina fatty acid composition consists of unsaturated fatty acids(~90%), with a percentage of alpha-linolenic acid about 35% (18:3;n-3) and linolenic acid (18:2;n-6) about 15% which make camelina oil unique among the common vegetable oils, such as soy oil, sunflower oil, canola oil and olive oil (Dharavath *et al.*, 2016). Parallel with the increased concern for camelina oil occurred the exceptional interest for the crop. Competitive edges in agronomic performance of camelina make its cultivation for oil production in temperate regions favorable, primarily due to its very short growing season (85 to 100 days), tolerance to drought and low temperatures, compatibility with cover crops, adequate resistance to common cruciferous pests and pathogens and its ability to be grown in marginal lands and environmentally friendly with low fertilizer and pesticide requirements (Putnam *et al.*, 1993; Vollmann *et al.*, 2007). The aforementioned agrotechnical benefits make *C. sativa* an ideal crop that can be easily adapted to sustainable agricultural practices and systems, such as organic farming (Akk and Ilumäe, 2005).

As a low input crop camelina is reported to have modest nutritional requirements for nitrogen (N), phosphorus (P), potassium (K), and sulfur (S), nonetheless nutrient management is a crucial factor in camelina growing technology as it affects growth, yield and seed quality (Waraich *et al.*, 2013; Obour *et al.*, 2015). Substantial quantities of nutrient elements and notable contents of organic matter, which can contribute to support crop productivity, agricultural sustainability and improve soil quality, can be provided by addition of organic amendments (Diacono and Montemurro, 2010). The application of organic amendments is common in organic farming systems and include wastes or byproducts from agricultural, industrial, and municipal operations such as animal manures, compost and green manures (Goss *et al.*, 2013). Several studies have focused on the response of different oilseeds crops to the use of organic soil amendments and their beneficial effects on crop yield and seed quality (Pasricha *et al.*, 1988; Ogbonna and Umar-Shaaba, 2011, Khan *et al.*, 2016), whereas limited information exists concerning the response of camelina to organic fertilization. Regardless fertilization, tillage operations play an important role in sustainable farming systems. Tillage reduction and organic amendments input are two common practices which are considered essential for soil organic matter content, carbon sequestration, nutrient and water availability, microbial biomass and activity under Mediterranean climate (Laudicina *et al.*, 2010). Recently, a shift toward in conservation tillage systems, including no-tillage and minimum tillage, in contrast to conventional tillage has occurred due to the fact that reduces water and soil erosion, labor requirements and saves fuel costs (Blevins and Frye, 1993). According to Keshavarz-Afshar et al. (2015, 2016) camelina tended to yield 26% more in conventional tillage than no-tillage system but the energy input was 5 and 8% lower in no-tillage system at the environmental condition of Montana. However, limited data is available (Angelopoulou *et al.*, 2020) regarding the performance of camelina under different tillage systems in combination with organic amendments application in Mediterranean conditions. The objective of this study was to quantify single and combined effects of different compost inputs and tillage systems on yield, seed and oil properties of organically grown camelina.

Materials and Methods

Site specification

The field trials were conducted in 2014, 2015 and 2016 growing seasons at Tripoli region (37° 30′ 30” N, 22° 22′ 30″ E; 660 m altitude), central Peloponnese, Southern Greece. The soil at the experimental site was characterized as Clay Loam with low organic matter, total N, Olsen P and extractable K^+ (Table 1). Soil samples were collected to a depth of 0-25 cm, then were air-dried and sieved to 2 mm prior to analysis. Soil pH and soluble salts were determined in a 1:2 saturated paste soil extract (Bates, 1964). Organic carbon was determined by the Walkey-Black method (Walkey and Black, 1934) and the total nitrogen was determined by the Kjeldahl method (Bremmer, 1960). Exchangeable cations were determined using an ammonium acetate extraction method (Thomas, 1982).

Table 1. Pre-seeding selected soil (0- 25 cm) physical and chemical properties at the experimental site

Soil characteristics	2014	2015	2016
Sand %	32.4	33.6	30.2
Silt %	38.1	37.8	38.3
Clay %	29.5	28.6	31.5
pH	6.9	6.6	6.5
Total organic carbon (%)	1.9	1.5	1.6
Electrical conductivity (μS/cm)	63.5	58.2	61.8
Total Nitrogen (%)	0.11	0.10	0.10
P-Olsen (mg kg^{-1})	10.8	10.7	10.8
K (mg kg^{-1})	106.1	100.5	98.3
Mg (mg kg^{-1})	195.3	182.5	175.8

The average monthly precipitation and air temperature during the period of the experimental trial (April-July) for three consecutive growing seasons, in relation to the long-term averages (1957-2010) are presented in Figure 1. The cumulative growing degree days (GDD) were calculated based on the maximum daily air temperature (Tmax) and the minimum daily air temperature (Tmin) for each growing season and the period between sowing and harvest time (Table 2) as follows:

$$GDD = \sum 〚(\mathrm{Tmax} - \mathrm{Tmin}/2) - \mathrm{Tbase}〛$$

For camelina, a base temperature (Tbase) of 5°C were used for the calculation (Gesch, 2014; Sintim *et al.*, 2016).

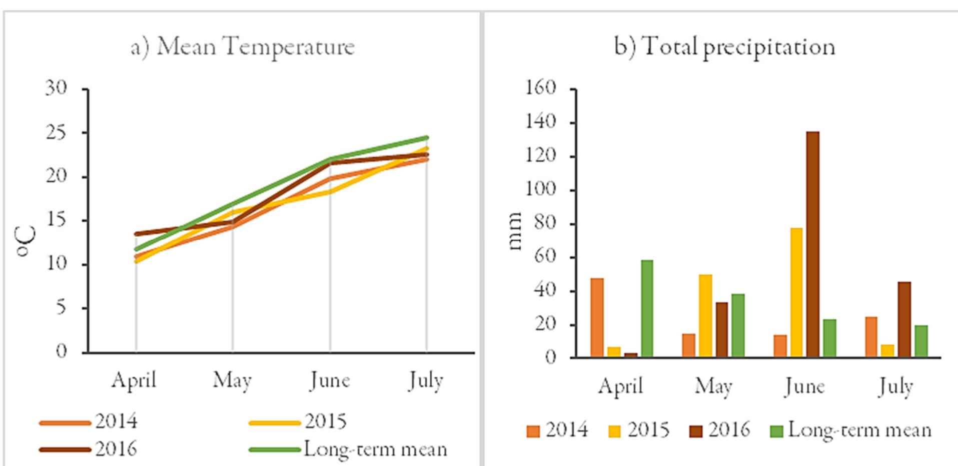

Figure 1. Monthly mean temperature (a) and total precipitation (b) during the experimental period and long-term averages at Tripoli, central Peloponnese

Experimental design and plot management

The study was established in a field certified as organic and the experimental design was a split-plot with three replicates, two main plots and three sub-plots. Experimental units consisted of plots 24 m^2 (6 m long and 4 m wide), spaced 30-cm apart and were managed according to organic agricultural guidelines (EC834/2007).

The main plot was characterized by two different tillage systems: conventional tillage and minimum tillage. The conventional tillage treatment included moldboard plowing at 25 cm depth followed by one rotary hoeing and minimum tillage treatment included chiseling at 10-15 cm depth followed by one rotary hoeing in order to prepare a proper seedbed, according to the environmental annual conditions. Within each tillage treatment, the following compost amendments were applied: vermicompost and compost, compared with an unamended control. The two composts differing in their composting process (organic waste converted into compost under aerobic conditions i. by microorganisms: composting, ii. through the interaction of earthworms and microorganisms at room temperature: vermicomposting) and composition (Table 2). The compost treatments were applied manually at rates of 2 tons ha^{-1} and immediately incorporated with rotary hoeing, before the sowing. Camelina was sown between early April to early May (03/04/14, 10/05/15, 13/04/16), at a rate of 6 kg ha^{-1}, while harvesting took place on early to late July (09/07/14, 31/07/15, 10/07/16). Supplemental irrigation was set up by means of a dripline irrigation system (the water quantity was 50 mm in 2014, 30 mm in 2015 and 30 mm in 2016).

Table 2. Main characteristics of the organic amendments: Vermicompost (VC); Compost (CM)

	Unit	VC	CM
pH		7.2	6.6
Total organic substance	%	52	33
N	g kg^{-1}	20	70
P	mg kg^{-1}	6500	17400
K	mg kg^{-1}	12450	58100
Mg	mg kg^{-1}	6030	12060

Data collection and evaluations

For the computation of plant height ten randomly selected plants in each plot were measured after flowering and prior to swathing maturity. At full maturity, plants from a 1m^2 area within each plot, were harvested and used to estimate harvest index (HI). The HI was calculated as seed dry weight divided by the dry weight of total above ground biomass. After harvesting the 1m^2, grain harvest separately for each plot using a plot combine. Then the seeds were cleaned and weighed to determine seed yield. 1000-seed weight (TSW) was recorded by taking three representative samples, each of 100 seeds, from each experimental unit, then weighing on the electrical balance and converted to TSW in grams. Both, seed yield and TSW were reported based on 7% (w/w) moisture content.

Camelina seed and fatty acid analysis

Representative seed samples of experimental plot were analyzed for dry matter (DM; Official Method 7.007), crude protein (CP; Official Method 7.016) and so rather than ether extract (EE; Official Method 7.060) according to AOAC (1984). Seed oil and crude protein (CP) content are reported on a dry weight basis as a percentage of whole seed. To obtain the *Camelina sativa* oil, from a representative seed sample of each experimental unit, a mechanical screw press (TäbyPress Type 20, Sweden) was used. Subsequently, Camelina oil were analyzed for fatty acids (FA) profile according to the method of O' Fallon *et al.* (2007). For the determination of FA profile, an Agilent 6890 N gas chromatograph equipped with an HP-88 capillary column (60m×0.25mm i.d. with 0.20 μm film thickness, Agilent, Santa Clara, USA) and a flame ionization detector (FID) was used. The FID temperature was set at 260 °C and the chromatographic analysis involved a temperature programmed run starting at 120 °C held for 1 min. Then followed by 2 step- ramp, one of 1.25 °C/min to 230 °C, and another of 10 °C/min to 240 °C, and each held for 3 min. The flame gases were hydrogen (purity at least>99%) and synthetic air. Helium was used as the carrier gas with a linear velocity set at 30 cm/s. Each peak was identified and quantified using a 37 component FA methyl esters (FAME) mix standard (Supelco, Sigma-Aldrich, St. Louis, MO, USA). Extra FA standards were used for the cis-9, trans-11, C18:2, trans-10, cis-12 C18:2 and trans-11 C18:1 FA (Sigma-Aldrich, St. Louis, MO, USA).

Statistical analysis

Data were subjected to statistical analysis using STATISTICA 7.0 logistic package, considering the years and replications as random, while fertilization and tillage treatments as fixed factors. The experimental data were subjected to multi analysis of variance (MANOVA) and differences between means were determined according to Tukey's test. Correlation analyses were used to describe the relationships between seed quality and yield parameters. The significance level of the Pearson's correlation coefficient (r) was tested for $P<0.05$.

Results and Discussion

Climatic conditions and camelina development

The average air temperatures during the process of this 3-year study were generally in accordance with the multiyear average Figure 1. The only exception was observed in April 2016, which air temperature was slightly greater than the long-term mean. Annual crop-year (April -July) precipitation varied substantially from year to year but averaged 153mm which slightly exceeded the long-term average annual precipitation of 140mm at the site. The distribution of precipitation has the greatest fluctuations between the experimental years during the months of April and June compare to the monthly long-term mean. High precipitation at the end of June in 2016 and near to harvest time, occurred by a heavy storm which caused approximately a 50% yield loss without affecting the seed quality traits. Low precipitation in April 2015 and 2016 resulted in delayed seeding in both years because of the too dry soil conditions. Due to delayed sowing, the number of days to harvest decreased for spring camelina as growing season temperatures increased but the number of accumulated GDD differed only slightly among sowing dates (Table 3). These results come in agreement with Gesch (2014) who reported that harvest time seems to be dependent on the accumulation of thermal time and these findings will be useful for camelina producers in order to predict harvest date depending on sowing time.

Spring camelina plants, at the specific agroclimatic conditions, required on average 89 days and 1130 °C d thermal time from seeding to harvest. The range of cumulated GDD are reported in Table 3. Similar results were reported in USA (Gesch, 2014) while average values of GDD in Europe and Canada reached 1205 °C d and 1276 °C d respectively, with a range from 993 to 1520 GDD (Zanetti *et al.*, 2017; Krzyżaniak *et al.*, 2019).

Table 3. Dates of sowing and harvest, cumulative growing degree days (GDD) and mean maximum and minimum temperatures of growing season from seeding to harvest, during three consecutive experimental growing seasons (2014-2016)

Year	Sowing date	Harvest date	Mean Tmax (°C)	Mean T min (°C)	GDD (°C d)
2014	03/04	09/07	25.5	8.8	1097
2015	10/05	31/07	27.3	11.1	1124
2016	13/04	10/07	27.6	9.6	1170

Organic camelina performance

The main effects and interactions among fixed factors on camelina's productive performance are shown in Table 4. In particular, the effects of tillage and compost treatments were highly significant on all measured parameters except for oil content. Furthermore, there were no significant interactive effects among the experimental factors and each factor affected independently camelina's productive and quality features. Beside treatments effects, climatic conditions strongly affected camelina's productivity and seed quality (Table 4). Mean values of the investigated seed and yield quality parameters were higher during the first year compare to the second and third year (Table 5). These observed variations could partially be explained by higher air temperatures in 2015 and 2016 in relative to 2014. Warmer growing season temperatures, especially during seed development, have been reported to decrease seed yield and oil content in oilseed crops (Canvin, 1965; Yaniv *et al.*, 1995).

Table 4. Combined ANOVA table of the effects of tillage and composts treatments on camelina productive and quality performance

Source of variation	PH	TSW	SY	HI	CP	OC	OY	C16:0	C18:0	C18:1	C20:1	C22:1	C18:2n-6	C18:3n-3
Year (Y)	**	**	**	*	**	**	**	**	**	**	**	**	**	**
Tillage (T)	ns	*	ns	ns	**	ns	ns	ns	ns	ns	**	ns	ns	ns
Composts (Cs)	**	ns	**	**	ns	ns	**	**	ns	**	**	**	**	**
T x Cs	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y x T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
Y x Cs	*	ns	ns	ns	ns	ns	*	**	ns	**	**	**	**	**
Y x T x Cs	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Plant height (PH), Thousand seed weight (TSW), Seed yield (SY), harvest index (HI), Crude protein content(CP), Oil content (OC), Oil yield (OY), palmitic (C16:0), stearic (C18:0), oleic (C18:1), gondoic (C20:1), erucic (C22:1), linoleic (C18:2n-6), a-linolenic(C18:3n-3).

non-significant (ns); * and **, significant at 5%, and1% probability levels, respectively.

Effect tillage system on yield and seed qualitative traits

No conclusive data is currently available on camelina's yield and quality with respect to tillage practices. The results of this study indicated that different tillage treatments influenced significantly the TSW ($P<0.05$), gondoic acid ($P<0.01$) and the CP content ($P<0.01$), while the plant height, HI, seed yield, oil content and oil yield were not affected (Table 4). In conventional tillage system camelina reached on average the highest CP content and TSW compared to minimum tillage (Table 5). Many studies (Laudicina *et al.*, 2010; Fernandez *et al.*, 2019) in different agroclimatic conditions confirmed that intensive tillage led to a higher soil moisture, aeration, organic substrates accessibility and NO_3-N content than reduced tillage. Moreover, nitrogen availability might increase the absorbed nitrogen by plant root which raise protein metabolism and subsequently the CP content in seeds (El-Nakhlawy and Bakhashwain, 2009). Beside the increase in CP content the oil content did not differ, potentially at the expense of other seed components. On spring camelina, Afshar et al. (2016) found that tillage system did not affect oil and protein content whereas seed yield increased significantly in conventional tillage compared to no-till. Concerning the FA profile, tillage system did not exert a significant effect on the proportion of FAs apart from gondoic acid ($P<0.01$), the concentration of which was greater in minimum tillage system (Table 7). Gesch and Cermak (2011) also reported on fall-seeded camelina that tillage system had not a significant effect on FA content, besides of gondoic acid, while seed yield and oil content did not differ constantly among the surveyed tillage systems in that study.

The findings of this research indicated that minimum tillage for camelina can give comparable seed and oil yields to conventional tillage, and should result in reducing the intensity of the soil tillage in the specific Mediterranean conditions. Minimum tillage treatment can be suitable for high density crops (Kisic *et al.*, 2010) and parallel can give greater soil strength and quality in order to solve soil erosion problems, mitigate the climate harms and reduce energy consumption (Holland, 2004). However, there has been a discordance in the research on the responses of various oilseed crops to tillage system with lower yields have been reported under conventional tillage compare to minimum (Bilalis *et al.*, 2010; Abdullah, 2014; Seddaiu *et al.*, 2016) as well as higher yields under conventional tillage (Kasap and Coskun, 2006; Torabi *et al.*, 2008) and little effect of tillage treatment on yield (Hocking *et al.*, 2003). Taking in account this variance it could be concluded that the interaction between the tillage method and the environment is more important that the tillage method alone (Rasmussen, 1999; Roper *et al.*, 2013).

Table 5. The effect of year, tillage system and composts application on camelina yield and seed quality characteristics

Parameter	Plant height (cm)	TSW(g)	Seed yield (kg ha^{-1})	HI	CP content (% DM)	Oil content (% DM)	Oil yield (kg ha^{-1})
Year							
2014	76.57 a	0.96 a	912.77 a	0.24 a	26.13 a	41.54 a	378.48 a
2015	71.22 b	0.91 b	781.90 b	0.28 b	28.75 b	37.82 b	295.01 b
2016	65.13 c	0.87 b	673.26 b	0.30 b	27.47 c	39.05 c	262.31 b
Tillage system, average of years							
CT	70.20	0.93 a	770.57	0.28	27.87 a	39.28	303.24
MT	71.77	0.89 b	808.05	0.27	26.98 b	39.66	320.62
Composts treatments (kg ha^{-1}), average of years							
Control	65.60 a	0.91	554.04 a	0.25 a	27.32	39.75	220.41 a
VC	70.10 b	0.90	681.80 b	0.27 ab	27.55	39.49	269.40 b
CM	77.24 c	0.92	1132.10 c	0.30 b	27.67	39.16	445.98 c

Mean values in each column followed by a different letter are significantly different according to Tukey's test ($p < 0.05$). CT: conventional tillage, MT: minimum tillage, VC: vermicompost, CM: compost, harvest index (HI).

Effect of compost treatments on yield and seed qualitative traits

Compost application influenced highly ($P<0.01$) camelina's productivity and seed chemical composition (Table 4). Regardless of the tillage system, the type of compost treatment had a significant influence on plant height, HI, seed yield and oil yield, but did not influence oil and CP content (Table 5).

The maximum height of camelina plants obtained on soil amended with compost (77.24 cm) compare with plants grown on soil amended with vermicompost (70.10 cm) or unamended soil (65.60 cm). Plant height is an important plant characteristic which is correlated highly significant to seed yield ($r= 0.75$, $P<0.01$) and oil yield ($r = 0.77$, $P<0.01$) and is mostly influenced by agroclimatic conditions, as reported by Katar et al. (2012). These findings are in agreement with the present study, in which the effects of organic amendments on plant height were associated with agroclimatic conditions during the experimental years (Table 4). In the third year of the experiment when average daily temperature exceeded the long-term average during April, significant differences were obtained between compost (74.44 cm), vermicompost (63.92 cm) applications and the unamended control (57.05 cm). While, in the first and second year of the experiment plant height peaked in response mainly to compost application with the highest value being observed in the first year (82.39 cm).

The yield potential of organically grown camelina reported in the present study was evaluated to 1132.10 kg ha^{-1} (Table 5), which is equal to what is found in conventionally grown camelina in other locations of Greece (Zanetti *et al.*, 2017) and in Mediterranean environments around the world (Campbell *et al.*, 2013; Schillinger, 2019). Addition of compost and vermicompost showed, on average, 104% and 23% greater camelina yield respectively, compared to unamended control. The HI was also increased by compost application compared to control, while HI values obtained with vermicompost applications did not significantly differ from those of the compost and control (Table 5). These increases might be attributed to the: i) type of organic amendment (richer composition of compost compare to vermicompost) that supplied specific camelina's nutrient requirements (Duong *et al.*, 2012; Nkoa *et al.*, 2014) and ii) improved chemical, hydro-physical and biological properties of treated soils (Adugna, 2018). Consequently, oil yield was also significantly higher in compost and vermicompost amended soil than in unamended (Table 5), a result that was expected due to the high positive correlation with seed yield (Table 6), as both traits are closely related. Furthermore, oil yield was significantly ($P<0.05$) affected by interaction among year and the type of organic amendment (Table 4). In years characterized by high air temperatures (2015 and 2016), oil yields induced a significant decrease relating to compost amendment (401.90 kg ha^{-1} and 368.84 kg ha^{-1}, respectively) in comparison with the first year of the experiment (567.21 kg ha^{-1}).

Similar results of organic amendments on plant growth and productivity were obtained by other researchers (Sharma, 2017; Joshi *et al.*, 2017). However, there is a considerable variability of results in the literature due to various experimental techniques, climate, soil type and organic material characteristics.

Notwithstanding that compost's application did not influence significantly the oil content, it caused some alteration on the content of saturated and unsaturated acids in relation to growing season (Table 4, Table 7). Other studies in oilseeds crops and camelina have also shown that FA profile did not consistently differ among experimental years between the same fertilization treatments (Urbaniak *et al.*, 2008; Gao *et al.*, 2010; Aytac *et al.*, 2017). The interaction of year and organic amendment was significant on a-linolenic, linoleic, oleic, palmitic, erucic and gondoic acids content (Table 7). The application of vermicompost tended to be less effective than compost as regards the improving of a-linolenic acid content, which is essential for camelina's oil nutritional quality, while both organic amendments tend to increase the content of palmitic and linoleic acids. Kirkhus *et al.* (2013) also referred that organic fertilization influenced camelina's oil profile although seasonal variations were larger than variations observed by fertilization.

Table 6. Correlation coefficients between yield and quality traits of camelina

Variable	Plant height	TSW	Seed yield	CP content	Oil content	Oil yield	C18:2n-6	C18:3n-3
Plant height	1							
TSW	0.37^{*}	1						
Seed yield	0.75^{**}	0.32^{*}	1					
CP content	0.22^{ns}	0.36^{*}	0.16^{ns}	1				
Oil content	0.24^{ns}	-0.47^{**}	-0.23^{ns}	-0.82^{**}	1			
Oil yield	0.77^{**}	0.36^{*}	0.90^{**}	-0.19^{ns}	0.28^{ns}	1		
C18:2n-6	0.26^{ns}	-0.39^{*}	-0.28^{ns}	0.54^{**}	-0.75^{**}	-0.25^{ns}	1	
C18:3n-3	-0.24^{ns}	0.30^{ns}	0.18^{ns}	-0.58^{**}	0.69^{**}	0.32^{ns}	-0.88^{**}	1

ns: non-significant, *, ** and ***, significant at 5%, 1% and 0.1% probability levels, respectively

Seed chemical composition

In the present study the oil content ranged from 39 to 41.5% and CP content ranged from 26 to 27% which were greater or equivalent to values reported by other researches on conventionally grown camelina in similar climatic conditions (Angelini *et al.*, 1997; Zanetti *et al.*, 2017). Both oil and CP contents were not affected by the significant increasing of seed yield among composts application (Table 5). These findings may present a useful resource for improving seed yields without an impact on the quantity of produced oil. The negative influence of inorganic fertilization on oil content was underlined by many authors also in camelina who reported that the increase of nitrogen rate resulted in higher seed yield and CP content but lower oil content in the seeds (Jiang *et al.*, 2013; Jiang *et al.*, 2014; Sintim *et al.*, 2015). Studies on canola that compared inorganic and organic fertilization confirmed the need for prudent use of nitrogen fertilization to minimize the potential reductions on oil content and quality and support the organic applications as an alternative to negative effects of synthetic fertilizers (Gao *et al.*, 2010; Ali *et al.*, 2011). Whereas, a promising alternative in sustainable and productive farming in oilseed crops such as camelina, which may mitigate the disparity of yield and quality, could be the combination of organic and inorganic fertilization (Mohammadi and Rokhazdi, 2012; Joshi *et al.*, 2017).

Concerning the FA composition presented in this study (Table 7), the range of FA profile are consistent to previous studies (Vollmann and Eynck, 2015; Righini *et al.*, 2019). Notwithstanding, a-linolenic (27.94-28.51%) and linoleic (21.63-22.42%) acids remained the most abundant FAs featuring the uniqueness of camelina oil. Pearson correlation analysis revealed highly significant correlations between the levels of linoleic and linolenic acids and between these FAs and oil content (Table 6) which is consistent with the research performed by Obour et al. (2017). Growing organic camelina in the specific agroclimatic conditions increased mainly saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs) at the expense of polyunsaturated fatty acids (PUFAs), which constitute 52.9% of the total FAs in camelina oil and is in line with Zanetti *et al.* (2017). A high number of days with maximal temperature above 25 °C during grain development has referred to reduce a-linolenic acid content and PUFAs and increase MUFAs due to their negative correlation (Leclère *et al.*, 2021). Several days, in the present study, during seed feeling had maximum temperatures above 25 °C, which could explain the reduction of a-linolenic acid proportion and PUFAs. These results come also in agreement with Rodríguez-Rodríguez et al. (2013) who mentioned that warmer climates favor lower levels of PUFAs than cooler climates. This profile may be more desirable for biodiesel production since higher contents of SFAs and MUFAs can influence in positive way the quality of biodiesel compare to PUFAs (Pinzi *et al.*, 2009).

Table 7. The effect of year, tillage system and compost application on fatty acid profile of camelina. Main and total polyunsaturated (PUFA), monounsaturated (MUFA), and saturated fatty (SFA) acids in camelina seed as a percentage of aggregate oil

Parameter	SFA (%)		MUFA (%)			PUFA (%)	
	C16:0	C18:0	C18:1	C20:1	C22:1	C18:2n-6	C18:3n-3
Year							
2014	6.04 a	2.58 a	18.78 a	13.28 a	2.57 a	21.63 a	28.51 a
2015	6.22 b	2.55 b	18.25 b	13.39 b	2.79 b	22.42 b	27.94 c
2016	6.29 b	2.54 b	17.56 c	13.35 b	2.84 c	22.07 c	28.25 b
Tillage system, average of years							
CT	6.19	2.55	18.20	13.39 a	2.74	22.10	28.23
MT	6.16	2.57	18.19	13.45 b	2.71	22.02	28.27
Composts treatments (kg ha^{-1}), average of years							
Control	6.11 a	2.56	18.24 a	13.50 a	2.76 a	21.84 a	28.31 a
VC	6.24 b	2.55	18.22 a	13.39 b	2.69 b	22.11 b	28.19 b
CM	6.21 b	2.54	18.12 b	13.35 b	2.75 a	22.17 b	28.37 a

Mean values in each column followed by a different letter are significantly different according to Tukey's test ($p < 0.05$). Fatty acids: palmitic (C16:0), stearic (C18:0), oleic (C18:1), gondoic (C20:1), erucic (C22:1), linoleic (C18:2n-6), a- linolenic(C18:3n-3). CT: conventional tillage, MT: minimum tillage, VC: vermicompost, CM: compost.

Conclusions

The present study demonstrates that spring camelina seems to be well suited under organic production while satisfactory seed yields and desirable quality traits can be obtained. The present results highlighted the importance of the type of the organic amendment on plant growth and yield in contrast to tillage system which did not reveal such a strong effect. Moreover, the effect of organic amendments on fatty acid profile was strongly related with the specific climatic conditions of each growing season, than the effect of the application of organic amendments alone. Compost application combined with minimum tillage was found suitable for achieving optimal seed yields without adverse effects on the quality of produced seeds. Further research is needed to achieve a successful organic camelina cultivation under different agroclimatic conditions.

Authors' Contributions

Conceptualization: FA and DB; Data curation: FA; Formal analysis: FA; Methodology: DB and ET; Resources: ET, DB and FA; Software: FA and DB; Supervision: DB; Writing-original draft: FA; Writing-review and editing: ET and DB. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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