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Camelina as a Rotation Crop for Weed Control in Organic Farming in a Semiarid Mediterranean Climate

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Abstract: Crop rotation in winter cereals in semiarid Mediterranean climates is highly desirable to prevent weed infestations, but the climatic conditions make it difficult to implement alternative crops to winter cereals. Camelina (*Camelina sativa* (L.) Crantz) is an interesting option, as it is able to produce profitable yields thanks to its tolerance to cold and drought. In this work, three autumn–winter sowing dates (SD1, October; SD2, December; SD3, January) and two sowing rates (R1, 8 kg ha^{-1}; R2, 11 kg ha^{-1}) were chosen to evaluate the effectiveness of these cultural methods to control weeds over three seasons, and to determine effects on camelina seed yield. Results showed that a significant reduction of weed coverage was obtained by delaying the sowing date. Sowing rates did not show differences in weed coverage. In contrast, no apparent yield penalty was observed among sowing dates and rates. These results show that the introduction of camelina as a rotational crop in semiarid Mediterranean climates is a feasible option for helping to suppress winter weeds, as well as to provide productive seed yield in these climatic conditions.

Keywords: oilseed crop; sowing date; sowing rate; winter weeds; yield

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1. Introduction

Crop rotation is among the most useful tools in order to control weeds [1] and contribute to Integrated Pest Management (IPM). It allows varying the management of fields, creating an unstable and inhospitable environment that prevents weeds from proliferating [1] as well as disrupting weed population dynamics [2]. This is of special interest in organic farming, where no chemicals can be applied for their control. However, the range of crops used in rotation with cereals in Mediterranean semiarid dryland systems is scarce. Rotation with pea (*Pisum sativum* L.) and sunflower (*Helianthus annuus* L.), which intrinsically imply a sowing delay, have proven to be effective for weed control in these climatic conditions [3,4]. Nevertheless, the limited rainfall in semiarid drylands hampers the integration of some of these crops [3].

In the driest part of the Ebro Basin, in northeastern Spain, annual rainfall is about 350 mm [5] and usually presents an erratic distribution [6], which highly affects cereal yields. The future projection of climate change is expected to increase evapotranspiration and decrease rainfall [7]. For this reason, new drought-tolerant crops with the ability to optimize water efficiency and production are being promoted by the Spanish Government [8].

Camelina is one such crop that may well fit with these requirements. Although it is an ancient crop [9,10], it was minimally produced for centuries until the last decade [11]. Its unique oilseed composition has been widely highlighted [12] and is useful for either industrial purposes, such as biodiesel [13,14], or for human consumption [15–17]. It can be considered either as a winter [18] or summer crop [19,20]. It has a short life cycle [21], which varies from 58 to 134 days as a summer crop [22,23] and from 209 to 298 days as a winter crop [15,24]. Moreover, the hardiness of the crop [24] makes it suitable for cropping in low input agricultural fields, such as organic systems. The capability of camelina to adapt to different environments [11] makes it suitable for changing sowing dates for its production. In this respect, many studies have been performed in North America [19,25–27], but all these sowing dates (SD) are for spring-sown experiments done under temperate continental climates. By contrast, Berti et al. [21] compared different autumn and winter SDs in humid Mediterranean climates and found that significant differences in yield and yield components were dependent on environment and latitude. Whether this also happens in a semiarid Mediterranean climate for autumn- and winter-sown camelina in Spain is unknown.

The objective of this work was to study the effect of different sowing dates of camelina on the control of weeds and its effect on camelina seed yield, so that the inclusion of this crop in rotation with organic winter cereals in the Mediterranean semiarid region of Spain could be evaluated.

2. Material and Methods

2.1. Site Description

The experiment was carried out in a field at the University of Lleida, 41°37′ N–0°35′ E, at 180 m above the sea level. The soil was a clay loam soil, with 31% sand, 38% silt, and 31% clay, pH 8.4, 0.95% of organic matter, and 155 mg kg^{-1} of N. The climate in Lleida is considered as Mediterranean semiarid and semicontinental [28], although according to the Köppen classification it is considered as a tropical and subtropical steppe climate (BSk). The mean annual temperature over the last four years (2014–2017) was 16.0 °C and total yearly precipitation averaged 291 mm [5].

2.2. Experimental Design

The experiment was carried out over three seasons: 2015–2016, 2016–2017, and 2017–2018. Seeds of *Camelina sativa* cultivar GP204 from Great Plain Soil & Exploration were provided by Camelina Company Spain. The crop was sown at a rate of 8 kg ha^{-1} (R1), as recommended by the company, and at 11 kg ha^{-1} (R2) in the first two seasons, while after observing the results of the first two seasons, it was decided to sow the crop only at R1 in the third season. Three SD were chosen: Late October (SD1), according to the usual cereal SD in the area, early December (SD2), according to late sowing in the area, and January (SD3). These approximate SDs slightly varied depending on the climatic conditions. The exact SDs in each season are shown in Table 1. One to two days before each sowing, the soil was tilled to a depth of 10 cm to prepare it for sowing as well as for killing all emerged weeds.

Sowing was performed with a Plotseeder TC (Wintersteiger AG, Ried im Innkreis, Austria) in a randomized complete block design with three replicates. Plots were 1.5 m wide and 15 m long, with six rows per plot. Plots were neither irrigated nor fertilized, so that the only water and nutrient supply was each season's precipitation and the previous crop's residue (barley) (*Hordeum vulgare* L.).

2.3. Weed Sampling and Removing

On 3 March 2016, 21 March 2017, and 20 March 2018, weed species surveys were performed in five 0.25 m^2 quadrats per plot and weed species and weed coverage (percentage of soil covered by weeds within the quadrat) were recorded. After the assessment, the weeds were removed by hand, so that no herbicide was applied in the plots. Those weeds emerging in autumn and winter were classified as winter (WW) and those emerging in spring were considered as summer weeds (SW). There were some species that typically emerged in late winter–early spring, and these were included in the WW group.

At the end of the season, harvest of the entire plots was performed with a Wintersteiger plot combine. The number of days from sowing to harvest was counted, as well as the growing degree days (GDD) using a base temperature (T_b) of −0.7 °C, which was found to be the mean T_b for germination for most camelina varieties [29].

2.4. Statistical Analysis

Results of weed coverage and yield were analyzed with a two-way analysis of variance (ANOVA) followed by a least significant difference (LSD) test, considering the sowing date and growing season as fixed factors, while replicate was considered as a random effect. For yield analysis, a two-way ANOVA was performed for the first and second season separately, with the sowing date and rate as fixed factors. Analysis between seasons was performed for only R1 with a two-way ANOVA, with the season and sowing date as fixed factors, followed by an LSD test. Data were square root transformed if necessary to satisfy the normality assumption. The analyses were performed with SPSS 15.0. (SPSS Inc, Chicago, IL, USA).

3. Results

3.1. Climatic Conditions

Overall temperatures from September to June were similar during the three growing seasons, being 15.9 °C in both 2015–2016 and 2016–2017 and 16 °C in 2017–2018. The only anomaly observed occurred in January 2018, which was warmer than December and February for that particular season (Figure 1). Similarly, total precipitation from September to June did not differ between seasons. The highest rainfall was recorded in 2015–2016 (288 mm), followed by 2017–2018 (278 mm) and 2016–2017 (270 mm). Despite this, the distribution of the precipitation throughout the growing season differed substantially from one season to the next and with the average historical values (Figure 1). Autumn 2015 was very dry, and the precipitation received in November mostly occurred in one day (70 mm), while the end of winter and spring (February through May) were wet. In 2016–2017, a wet autumn was followed by a dry winter and spring, except in March 2017, when over 80 mm of precipitation fell. In 2017–2018, there was severe drought in autumn, but after January, precipitation was evenly distributed throughout late winter and spring.

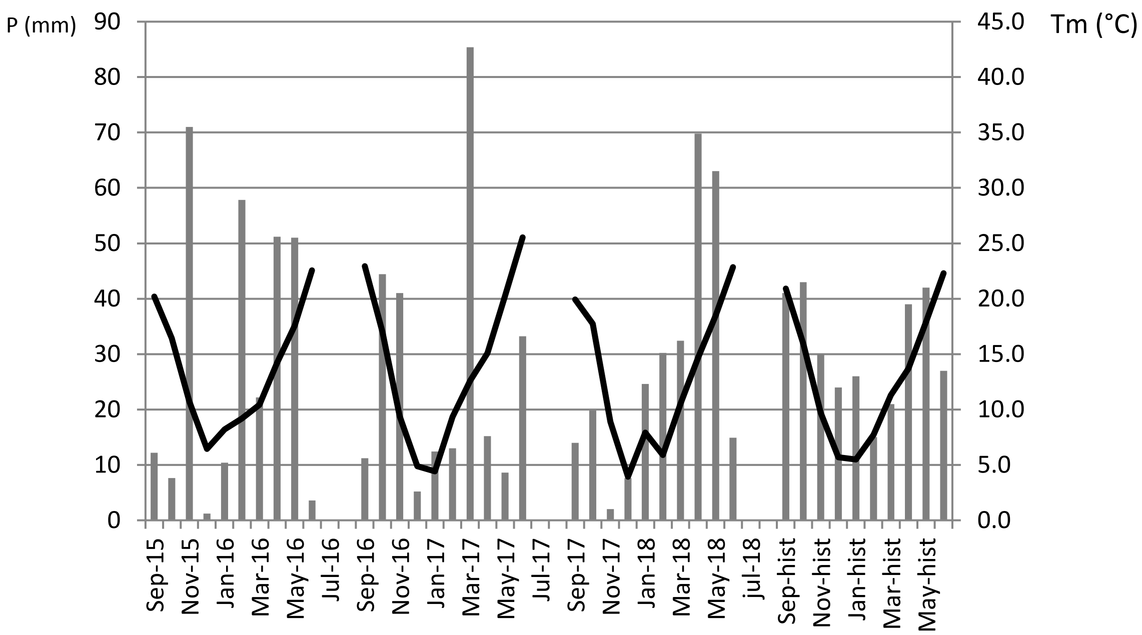

Figure 1. Climatic conditions for each of the three growing seasons (2015–2016, 2016–2017, and 2017–2018), from sowing (September) to harvest (June). The black line indicates the mean monthly temperature (Tm) and the grey bars show total precipitation (P) in each month. The last graph (right) corresponds to monthly average temperatures and precipitations for the period 1983–2010 (AEMET).

3.2. Crop Cycle

Camelina emerged soon after sowing, in 2 to 10 days depending on the soil moisture at each SD, and there were no noticeable changes in the crop density due to winter or drought losses. As explained in the Material and Methods, the three sowing dates each season were in October (SD1), December (SD2), and January (SD3) (Table 1). This affected the time required to reach crop maturity, which happened in all three seasons between 11 May and 20 June. Harvest was always two weeks earlier in SD1 than SD2 and SD3, and one to two months earlier than typical cereal harvest in the study area. Conversely, the crop cycle was always shorter for SD3 (123–150 days) than for SD2 (163–202 days) and SD1 (190–219 days). On average, SD3 required 45 and 71 fewer days to complete its life cycle than SD2 and SD1, respectively. In terms of GDD, SD1 needed between 1959 and 2653 GDD from sowing to harvest (Table 1), which was about 63–173 more GDD than that of SD2 each season. Compared to SD1 and 2, SD3 always required considerably less GDD to reach maturity, which ranged from 1720 to 2174 (Table 1).

Table 1. Calendar dates and the number of days (*N*) and growing degree days (GDD) from sowing to harvest for the first, second, and third sowing date in October, December, and January. T_b for GDD estimation was considered at −0.7 °C [29].

Year	Sowing	Harvest	*N*	GDD
		SD1		
2015–2016	29 Oct 15	06 June 16	221	2653
2016–2017	02 Nov 16	11 May 17	190	1959
2017–2018	15 Oct 17	22 May 18	219	2319
		SD2		
2015–2016	01 Dec 15	20 June 16	202	2575
2016–2017	13 Dec 16	25 May 17	163	1897
2017–2018	04 Dec 17	08 June 18	186	2146
		SD3		
2015–2016	22 Jan 16	20 June 16	150	2174
2016–2017	22 Jan 17	25 May 17	123	1720
2017–2018	16 Jan 18	08 June 18	143	1889

3.3. Weed Species Number and Coverage

Due to the historical use of the field, several weed species which usually do not appear in winter cereal fields were recorded (Tables 2–4). Therefore, the analysis of number and coverage was done for the total of all the species and separately for the winter weed species.

The number and coverage of weeds, considering all species, was greater in SD1 than in SD2 and SD3 in 2015–2016 and 2017–2018, but not in 2016–2017 (Table 5). However, in 2016–2017, when winter/spring weeds were separated from summer ones, their coverage was also significantly greater in SD1 than in SD2 and SD3. No significant differences were detected in the number and coverage of weeds, either for total or winter weeds between R1 and R2 (2015–2016 and 2016–2017). With regard to the differences between seasons for R1, no differences were found for SD1, but the coverage in SD2 and SD3 was greater in 2016–2017 than in the other two seasons (Table 5).

The most abundant winter weed was *Diplotaxis erucoides* (L.) DC., also a member of the *Brassicaceae*, followed by *Hordeum murinum* L. in 2015–2016 (Table 2), then by *Sisymbrium irio* L. in 2016–2017 (Table 3), and *Senecio vulgaris* L. in 2017–2018 (Table 4). It should be noted that there was a presence of *Kochia scoparia* (L.) Schrad. and *Polygonum aviculare* L., which emerge in late winter and spring, and although they compete less with the crop, they can cause harvesting problems. Among the summer weed species, *Chenopodium opulifolium* Schrad. was the most abundant, mainly in 2016–2017, followed by *Chenopodium. album* L. and *Convolvulus arvensis* L.

Table 2. Weed coverage (%) by species in 2015–2016 for each sowing date and sowing density. SD1, first sowing date in late October; SD2, second sowing date in December; SD3, third sowing date in January. R1, sowing dose of 8 kg/ha; R2, sowing dose of 11 kg/ha.

	Weed Species		**2015–2016**					
			SD1R1	**SD2R1**	**SD3R1**	**SD1R2**	**SD2R2**	**SD3R2**
1	*Capsella bursa–pastoris* (L.) Medicus	WW				3		
2	*Chenopodium album* L.	SW	0.10	0.03	0.37			
3	*Chenopodium opulifolium* Schrad.	SW	1.20	0.02			0.10	0.05
4	*Convolvulus arvensis* L.	SW	0.30					
5	*Diplotaxis erucoides* (L.) DC.	WW	17.50	0.10	0.08	21.20	0.14	
6	*Euphorbia helioscopia* L.	WW				0.30		
7	*Fumaria officinalis* L.	WW			0.06	2		
8	*Geranium molle* L.	WW				0.10		
9	*Hordeum murinum* L.	WW	4.90			5.80		0.20
10	*Kochia scoparia* (L.) Schrad.	WW	0.10		0.02		0.02	0.08
11	*Lactuca serriola* L.	WW	0.30					
12	*Lolium rigidum* Gaudin	WW	0.30					
13	*Polygonum aviculare* L.	WW						0.08
14	*Rumex obtusifolius* L.	SW	0.10					
15	*Scorzonera laciniata* L.	WW	0.20					
16	*Senecio vulgaris* L.	WW	0.40			0.20		
17	*Sonchus oleraceus* L.	WW	0.50			0.37		
18	*Trifolium repens* L.	WW	0.20					

Table 3. Weed coverage (%) by species in 2016–2017 for each sowing date and sowing density. SD1, first sowing date in late October; SD2, second sowing date in December; SD3, third sowing date in January. R1, sowing dose of 8 kg/ha; R2, sowing dose of 11 kg/ha.

	Weed Species	**2016–2017**					
		SD1R1	**SD2R1**	**SD3R1**	**SD1R2**	**SD2R2**	**SD3R2**
1	*Capsella bursa–pastoris* (L.) Medicus	0.83	0.15	0.11	0.77	0.57	0.05
2	*Chenopodium album* L.		1.97	2.89	0.03	0.12	0.21
3	*Chenopodium opulifolium* Schrad.	0.19	4.47	7.69	0.23	22.54	9.76
4	*Convolvulus arvensis* L.		0.01	0.02	0.02	0.01	
5	*Diplotaxis erucoides* (L.) DC.	8.1	1.98	2.63	5.60	1.17	0.89
6	*Euphorbia peplus* L.	0.02					
7	*Fumaria capreolata* L.		0.27				
8	*Fumaria officinalis* L.					0.28	0.02
9	*Kochia scoparia* (L.) Schrad.	0.02	0.88	0.19	0.02	0.88	0.40
10	*Lactuca serriola* L.	0.07	0.01		0.01		0.01
11	*Malva sylvestris* L.		0.07				
12	*Papaver rhoeas* L.	0.87	0.07		0.2		
13	*Polygonum aviculare* L.			0.07		0.23	0.2
14	*Scorzonera laciniata* L.						
15	*Senecio vulgaris* L.	0.13					
16	*Rumex obtusifolius* L.	0.07				0.01	
17	*Sonchus oleraceus* L.	0.20	0.02	0.02		0.05	0.01
18	*Sisymbrium crassifolium* Cav.	0.47	0.33		0.33		
19	*Sisymbrium irio* L.	0.67	0.07	0.43	3.80	0.51	0.58
20	*Xanthium spinosum* L.					0.01	

Table 4. Weed coverage (%) by species in 2016–2017 for each sowing date and sowing density. SD1, first sowing date in late October; SD2, second sowing date in December; SD3, third sowing date in January.

	Weed Species	2017–2018		
		SD1R1	SD2R1	SD3R1
1	*Chenopodium album* L.	0.04	0.05	0.07
2	*Convolvulus arvensis* L.	0.58	0.30	0.12
3	*Diplotaxis erucoides* (L.) DC.	8.97	0.06	0.01
4	*Fumaria capreolata* L.			0.05
5	*Fumaria officinalis* L.			0.01
6	*Kochia scoparia* (L.) Schrad.	0.01	0.01	0.01
7	*Lactuca serriola* L.		0.01	0.01
8	*Lolium rigidum* Gaudin		0.01	
9	*Papaver rhoeas* L.			0.01
10	*Polygonum aviculare* L.	0.06	0.09	0.03
11	*Senecio vulgaris* L.	0.43	0.02	
12	*Sonchus oleraceus* L.	0.68		
13	*Veronica hederifolia* L.		0.06	0.01
14	*Veronica persica* Poir.	0.03		
15	*Xanthium spinosum* L.			0.01

Table 5. Number and coverage for all weed species and separately for winter weeds (WW) and summer weeds (SW). Results of two-way ANOVA + LSD are provided for total weed coverage and WW coverage: Low case letters, comparisons between sowing dates and sowing densities within seasons (in 2017–2018 only sowing dates); capital letters, comparison between seasons for each sowing date within R1.

Number and Coverage of Weed Species	2015–2016					
	SD1R1	SD2R1	SD3R1	SD1R2	SD2R2	SD3R2
Total weed species	13	3	4	8	3	4
Total weed coverage	26.1 aA	0.2 cC	0.5 bB	33.0 a	0.3 c	0.4 b
Number WW/SpW	9	1	2	8	2	3
WW/SpW coverage	24.4 aA	0.1 bB	0.2 bB	33.0 a	0.2 b	0.3 b
Number SW	4	2	2	0	1	1
SW coverage	1.7	0.1	0.4	0.0	0.1	0.1
	2016–2017					
Total weed species	12	13	9	10	12	10
Total weed coverage	11.6 aA	10.3 aA	14.1 aA	11.0 a	26.4 a	12.1 a
Number WW/SpW	10	10	6	7	7	8
WW/ SpW coverage	11.5 aA	3.9 bA	3.4 bA	10.7 a	3.5 b	2.0 b
Number SW	2	3	3	3	5	2
SW coverage	0.2	6.5	10.6	0.3	22.7	10.1
	2017–2018					
Total weed species	8		9		11	
Total weed coverage	10.8 aA		0.6 bB		0.3 bB	
Number WW/SpW	6		7		8	
WW/ SpW coverage	10.1 aA		0.2 bB		0.1 bC	
Number SW	2		2		3	
SW coverage	0.6		0.4		0.2	

Different letters show significances at $p < 0.05$.

3.4. Seed Yield Results

Seed yield of camelina highly depended on the climatic conditions each season (Table 6), but generally not on SD or *R*. In 2015–2016, significant differences were observed between SDs, but without any clear tendency. For instance, in R1, the highest yield was obtained in SD3, followed by SD1, while in R2, the highest yield was obtained in SD1, followed by SD3. In both cases, SD2 obtained the lowest yield. In 2016–2017, no differences were found among SD or between R, and in 2017–2018, there was no difference among SD. By contrast, significant differences were found between seasons across all SDs, obtaining the highest yield in 2017–2018, followed by 2016–2017 and 2015–2016.

Table 6. Seed yield (kg ha^{-1}) results (+SE) for each sowing date (SD) and rate (R) in each season (Y). SD1, first sowing date in late October; SD2, second sowing date in December; SD3, third sowing date in January. R1, sowing rate of 8 kg ha^{-1}; R2, sowing rate of 11 kg ha^{-1}. The comparisons between SDs and *R* are shown for 2015–2016 and 2016–2017 (lower rows), as well as the comparison between Y and SD for R1 (last columns).

Seed Yield Results	**2015–2016**		**2016–2017**		**2017–2018**		
	R1	**R2**	**R1**	**R2**	**R1**		
SD1	766 ± 210	1026 ± 262	1768 ± 250	1476 ± 186	2369 ± 136	Y	$p \leq 0.001$
SD2	598 ± 133	557 ± 131	1374 ± 95	1941 ± 320	2426 ± 163	SD	$p = 0.451$
SD3	1382 ± 135	950 ± 163	1473 ± 183	1482 ± 153	2135 ± 242	Y × SD	$p = 0.082$
SD	$p = 0.032$		$p = 0.939$				
R	$p = 0.662$		$p = 0.378$				
SD × *R*	$p = 0.240$		$p = 0.827$				

4. Discussion

The hardiness of camelina to abiotic stresses, such as drought and low temperature, makes it a potential crop [11,12] for rotating with cereals, and thus, camelina may be highly beneficial for agricultural systems in semiarid climates, such as the Ebro Basin. Moreover, the high degree of weed suppression obtained in SD2 and SD3 with respect to SD1 in the present study indicates the potential of this crop to be used in organic farming.

In our work, weed coverage was effectively reduced with camelina SD, but no differences were observed with *R*. In R1, WW coverage was reduced by up to 99.6% in 2015–2016 by delaying the SD from late October (SD1) to December (SD2), while the reduction was 98% in 2017–2018 and 66% in 2016–2017. The delay of SD to January (SD3) did not significantly improve weed coverage reduction, which was of 99.2%, 70.4%, and 99% respectively for 2015–2016, 2016–2017, and 2017–2018. Most WW emerge from October to February, depending on the species and the season; thus, the greatest amount of these weeds was killed with the soil tillage for late SDs. Although the WW species were not the most problematic in the area (*Avena sterilis* and *Bromus diandrus* were lacking, while *Lolium rigidum* and *Papaver rhoeas* were scarcely represented), the presence of mainly *D. erucoides*, as well as *S. irio* and *Hordeum murinum* could be representative of a WW community, giving validity to the obtained results. Similarly, Garcia et al. [30] also obtained 80–99% weed control with SD from October to December in *B. diandrus* in the same area. In our conditions, these control levels would have been 0.0–79.4% in SD1, 9.1–37.7% in SD2, and 12.9–81.9% in SD3, depending on the season. Other emergence models already published for *A. sterilis* [31], *L. rigidum* [32], and *P. rhoeas* [33] indicate the usefulness of the SD in the control of the most important weeds in this area: In our climatic conditions, up to 83.9%, 46.9%, and 6.9% of *A. sterilis*., *L. rigidum*., and *P. rhoeas* emergences would have been killed by SD1, while these values would go up to 86.2%, 62.4%, and 17.8% respectively in SD2, and up to 91.9%, 77.7%, and 42.3% in SD3. Moreover, the competitive capacity of camelina, which was not studied in this work, is likely to have contributed to weed suppression. For this reason, camelina can be a good option to alternate with cereals, but this depends on the annual climatic conditions that highly affect the emergence of these weeds.

Not only did delaying SD contribute to the control of weeds, but it also delayed the harvest date. In our experiment, harvest was done between 11 May and 6 June for SD1 and between 25 May and 20 June for SD2 and SD3 (Table 1). These time laps from sowing to harvest (120–220 days) are similar to those obtained by Berti et al. [21] in Chile for autumn–winter sown camelina. Weeds are adapted to the cereal cycle, and most of them release seeds at harvest [34]. This happens in the Ebro Basin from mid-June to July. Therefore, hastening the harvest of camelina by one month to mid-May would prevent weed seeds from maturing, thus avoiding the seed rain that contributes to the management of the seed bank. In this respect, camelina's short life cycle coincides with that obtained by Gutiérrez and Albalat [24] for SD1, while it was considerably shortened in SD2 and especially in SD3, in the present study.

Contrary to Berti et al. [21], in the present study no significant yield loss was suffered by delaying the sowing date to SD2 or SD3 in any season. The differences with respect to Berti et al. [21] could be partly explained by the climatic differences between the Chilean sites and Lleida Spain. Both winter (Dec–Feb/Jun–Aug) temperatures (6.7 °C < 7.3–8.8 °C) and rainfall (54 mm < 472–747 mm) were lower in Lleida, which could have slowed down the growth of SD1 and SD2, while in Chile the early SD could take advantage of the milder and wetter winter compared with the late SD. There was only some irregular yield in 2015–2016 between SDs. Rainfall in November 2015 was 71 mm, but 70 mm fell in only one day (with a lot of runoff), almost one month before SD2, followed by a December and January that were very dry. This could have contributed to the low yields obtained in SD2 that season. However, this reason does not fully explain yield results in SD2. The lowest yields in 2015–2016 were similar to those obtained by Gutiérrez and Albalat [24] in the nearby county of Aragon, or those by Gesch & Archer [18] and Obour et al. [35] (0.5 Mg ha^{-1}), while others approximated more to French et al. [36] (1Tn ha^{-1}), or even to McVay and Khan [19] and Obour et al. [35] (1.5 Mg ha^{-1}), as yields of 2016–2017. Meanwhile, yields from 2017–2018 were more like those from Gesch [25] (2.3 Mg ha^{-1}) or Zubr [37], who obtained yields of 2.6 to 3.3 Mg ha^{-1} in Denmark. These differences in yield between seasons are the usual ones for a semiarid region, where climatic conditions can easily vary the productivity of the crop from one season to the next [38], like in barley [39].

In this study, seed oil content was not analyzed. Sowing date 1 plants matured before SD2 and SD3, which means that the climatic conditions for the seed maturation process were different between SDs. This could have affected oilseed quality. Gesch et al. [40] observed higher seed mass, oil content, total carbon, and unsaturated fatty acid content for *Thlaspi arvense* seeds produced in Spain than in Minnesota, and Pavlista et al. [26] also found differences in oil content and quality in spring camelina, being the highest when sown in April. Whether this also happens in our conditions and how autumn–winter SD affects camelina seed oil content will require further study.

The lack of yield differences between SDs is a great advantage, because, depending on the climatic conditions of each season, mainly precipitation, weeds can significantly vary their emergence period. The flexibility of sowing of camelina without a yield penalty can be used as a strategy to contribute to better weed control. This sowing flexibility also allows for a wider window of opportunity to make decisions. Despite this, some productivity decreases have been reported [35] in winter wheat the following season when it follows camelina in rotation. This aspect should also be studied to better understand this issue.

5. Conclusions

Camelina presents clear favorable characteristics to be implemented in rotation with winter cereals. Its tolerance to abiotic stresses, low fertility requirement, and its short life cycle make it a good option for obtaining effective coverage reduction over winter weeds. Moreover, apparently, no yield penalties occur, thus providing farmers income, in contrast to fallow lands. However, all these results have been obtained in an experimental field and, although there are many studies confirming their validity, new experiments in commercial fields could help to strengthen the results and contribute to the integration of this useful crop in rotation in agricultural systems in Mediterranean semiarid regions.

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