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Article

Effects of Pre-Emergence Herbicides on Weed Control and Yield of Safflower (*Carthamus tinctorius* L.) in Central Italy

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Abstract: Safflower is a multipurpose crop with several uses that can offer benefits to rainfed cereal-based cropping systems due to its tolerance to cold, drought, salinity, and its reduced need for agricultural inputs. Safflower requires good weed control for optimum yields because it is a very poor competitor with weeds, especially at the early growth stage, but registered pre-emergence herbicides are not available. This research investigated the effects of several pre-emergence herbicides on weed control and the yield of safflower in central Italy, through two field experiments in 2019 and 2020. Aclonifen, metazachlor, s-metolachlor, propyzamide, and metribuzin were applied as pre-emergence herbicides. The main weeds were the following: *Papaver rhoeas* L., *Conyza canadensis* (L.) Cronq., and *Ammi majus* L. in experiment 1, and wild sunflower (*Helianthus annuus* L.) in experiment 2. Metazachlor and metribuzin gave the highest phytotoxicity on safflower in both experiments, with values ranging from 48% to 75% and from 30% to 75% (in a scale of 0–100%), respectively, and seem to be not advisable as pre-emergence herbicides. Aclonifen, s-metolachlor, and propyzamide can be considered selective and safe to the safflower, showing the lowest values of phytotoxicity that ranged from 0 to 10%. Metazachlor and s-metolachlor gave the highest total weed control with values of 92% and 97%, respectively.

Keywords: safflower; weed control; herbicides; s-metolachlor; weed competition; minor crop; phytotoxicity

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1. Introduction

Safflower (*Carthamus tinctorius* L.) is an annual crop belonging to the *Asteraceae* family that is cultivated mainly for its seeds, which are used to produce vegetable oil characterized by a nutritionally desirable high percentage of unsaturated fatty acid [1]. However, it is a multipurpose crop with several uses, such as the extraction of dyes, food and cosmetics coloring, forage, medical purposes, and the production of biofuel and industrial oil [2,3]. Furthermore, safflower may offer several benefits to rainfed cereal-based cropping systems due to its tolerance to cold, drought, salinity, and its reduced need for agricultural inputs [4]. Compared to sunflower, safflower has the highest resistance to bird predation and diseases, and has recently received increased attention for all the reasons cited above, as well as for the interesting properties of its oil for food and non-food uses [4]. In fact, although it is still considered a minor, underutilized crop, it has potential in the Mediterranean area for several purposes, including nutritional and industrial applications [5]. Based on their seed oil composition, which is mostly made up of unsaturated fatty acids (linoleic, oleic, and linolenic) and a low proportion of saturated fatty acids (palmitic and stearic), safflower varieties are grouped in either high linoleic or high oleic acid types, with the latter being able to replace sunflower and olive oil [4]. Safflower is cultivated in more than 60 countries, with major productions concentrated in India, Kazakhstan, China, Turkey, Mexico, Russia, and United Republic of Tanzania; Europe has increased significantly its surface and production in the last 20 years [5,6]. Safflower has shown great adaptability to the arid and semi-arid areas of the Mediterranean regions, thanks to its deep root system and xerophytic spine attributes, both in autumn and spring sowing, including in rotation with winter wheat or annual legumes [4].

Safflower requires good weed control for optimum yields because the seedlings grow slowly for several weeks after emergence (at the rosette stage and before stem elongation), during which safflower is a very poor competitor with weeds; later in the growing season, many weeds may surpass safflower in height, effectively shading the crop [7]. The beginning–end of the critical period for weed control in safflower was 11–71, 13–110, and 17–120 days after emergence, for three consecutive years, at 5% acceptable yield loss, and increased to 8–77, 10–130, and 14–142, respectively, at 2,5% acceptable yield loss, showing the importance of early weed control in this crop [8]. The main effect of weed competition results in a yield loss; safflower grown under weed-free conditions yielded more than 2000 kg $\cdot$ ha^{-1}, but a poor weed management system significantly reduces crop yield and makes it difficult to harvest [9]. The weeds in safflower fields resulted in severe yield losses, reaching 63% in Turkey with *Sinapis arvensis* L. at a density of 16 plants $\cdot$ m^{-2} or 73%, depending on the weed species in Canada [7,8]. In the 1980s, in the USA, trifluralin was the principal herbicide used in pre-sowing, with soil incorporation, for weed control in safflower [9]. It controls most annual weeds, especially grasses, but does not adequately control several mustard species (*Sinapis* spp.) [9]. Pronamide (=propyzamide) was also used in safflower to control grasses, but it does not control broadleaf weeds [9]. After the discovery of sulfonylurea herbicides, chlorsulfuron was found to be nontoxic to safflower when applied post-emergence, and was allowed to eliminate broadleaf weeds, like *Amaranthus retroflexus* L., *Tribulus terrestris* L., and *Helianthus annuus* L. (common sunflower), that were not controlled by soil-applied trifluralin, thus ensuring safflower production and reducing harvesting difficulties [9]. Blackshaw et al. [10] found that safflower exhibited an acceptable tolerance to trifluralin, ethalfluralin, sethoxydim, fluazifop-p-butyl, clethodim, diclofop-methyl, difenzoquat, imazamethabenz, chlorsulfuron, thiameturon, metsulfuron, and ethametsulfuron-methyl (Ref: DPX-A7881) over three years and two locations, offering to the grower the option of pre-sowing incorporated, post-emergence herbicide application, or a combination of the two. On the contrary, a mixture of thiameturon plus tribenuron-methyl (Ref: DPX-L5300) caused severe injury to safflower, reducing the yield, oil content, and seed weight, whereas desmedipham, phenmedipham, and mixtures of these herbicides injured safflower only in one location [10]. Due to the sowing time both in spring and autumn, safflower can be infested by winter and summer weeds, that in the Mediterranean area may cause large and abundant infestations [11,12]. Perennials weeds can be a serious problem; safflower should not be grown on fields with heavy infestations of perennial weeds. Yau and Haidar [11] reported that the pendimethalin–pronamide mixture in pre-emergence gave the best weed control, with the absence of weed plants, and without any negative effect on the safflower plants, showing that pre-emergence herbicides may provide an effective control of early season weeds and are more economical than other weed management tools. However, as observed for other minor crops in Europe, also for safflower the main problem is the scarce availability or absence of registered herbicides, especially for pre-emergence applications, not available now in safflower; nevertheless, non-chemical weed management practices can be used, mostly in organic agriculture [11]. For this reason, the authors of the present study have selected some pre-emergence herbicides, suitable for the control of commonly occurring weeds in safflower in the Mediterranean area, based on those registered for use in sunflower or tested previously on safflower in Italy [12,13]. Therefore, the objective of this research was to investigate the effects of the selected pre-emergence herbicides on the weed control and yield of safflower, in both autumn and spring sowing in central Italy. The results of this study can be useful to support the authorization for the use of these herbicides in safflower.

2. Materials and Methods

Two field experiments on safflower were carried out in 2019 (experiment 1—Autumn sowing) and 2020 (experiment 2—Spring sowing) in central Italy (Experimental Station of Papiano, 42°57′ N, 12°22′ E, 165 m a.s.l.) in the same field, on a clay-loam soil (25% sand, 30% clay, and 45% silt, pH 8.2, 0.9% organic matter). The experiment was designed as a randomized block with three replicates and a plot size of 9.6 m^2 (1.6 m width). The main agronomic practices are shown in Table 1. The trials were carried out in accordance with the recommended management practices in this area, as concerns soil tillage and seedbed preparation [11–13]. In each trial, herbicides were used in pre-emergence applications at the selected doses in order to assess weed control ability and selectivity to the crop (Table 2).

Table 1. Agronomic practices in the field experiments.

Agronomic Practices	Experiment 1 (Autumn Sowing)	Experiment 2 (Spring Sowing)
Preceding crop	wheat	wheat
Sowing date	22 October 2019	2 April 2020
Safflower cultivar	CW99-OL (semfor s.r.l.)	CW99-OL (semfor s.r.l.)
Density (plants · ha^{-2})	50	50
Emergence date	2 November 2019	17 April 2020
Herbicide treatments date	24 October 2019	3 April 2020
Fertilization (kg · ha^{-1}):		
P_2O_5 (pre-sowing time application)	75	75
N (post-emergence application)	100	100
Harvest	3 August 2020	11 August 2020

Table 2. Experimental treatments on safflower in 2019 and 2020.

Code	Herbicides	HRAC Group/MoA	Product Information	Dose (g a.i. · ha^{-1})
A	untreated control	-	-	-
B	aclonifen	32/Inhibition of Solanesyl Diphosphate Synthase	Challenge (60% a.i., Bayer CropScience)	1800
C	metazachlor	15/Inhibition of Very Long-Chain Fatty Acid Synthesis	Butisan S (50% a.i., BASF Italia)	1000
D	s-metolachlor	15/Inhibition of Very Long-Chain Fatty Acid Synthesis	Dual Gold (96% a.i., Syngenta Crop Protection)	960
E	propyzamide	3/Inhibition of Microtubule Assembly	Kerb Flo (40% a.i., Corteva Agriscience Italia)	1000
F	metribuzin	5/Inhbition of Photosynthesis at PSII-Serine 264 Binders	Mesozin 70 WG (70% a.i., Corteva Agriscience Italia)	245

The doses were selected according to those labeled for sunflower or used in safflower previously in Italy [12,13]. Herbicide treatments were applied with a backpack plot sprayer fitted with four flat fan nozzles (Albuz APG 110—Yelow) and calibrated to deliver 300 L · ha^{-1} of aqueous solution at 200 kPa. Untreated plots were always added as controls. In both experiments, one irrigation (150 m^3 · ha^{-1}) was carried out one day after pre-emergence treatments in order to improve crop emergence and pre-emergence herbicides activity.

The phytotoxicity of the herbicides towards safflower was rated visually 45 and 90 days after emergence (DAE) in exp. 1 and 25 DAE in exp. 2, on a 0–100% scale (0—no visible injury; 100%—plant death; with equal steps in the scale). Weed ground cover (%) was rated visually 150 DAE for exp. 1 and 75 DAE for exp. 2 by using the Braun-Blanquet cover-abundance scale [14]. In exp. 2, the weed density was also recorded, counting the number of weed plants per plot. Data on weed ground cover were used to calculate the weed control efficacy (*WCE*) of different treatments relative to the untreated check, according to the following Equation (1) [15]:

$$WCE(\%) = \frac{W_U - W_T}{W_U} \times 100 \quad (1)$$

where W_U: weed ground cover in untreated plots; *WT*: weed ground cover in treated plots.

Safflower plant density was measured twice in exp. 1 (40 DAE and 160 DAE) and once in exp. 2 (25 DAE) in order to evaluate the effects of both, herbicides phytotoxicity and weeds competition, on safflower plant emergence and survival. Safflower grain yield was determined by harvesting the central part of each plot (7.5 m^2). The safflower seeds were mechanically cleaned from the straw and adjusted to 9% moisture.

Meteorological data (daily maximum and minimum temperature and rainfall) were collected from a nearby station. Ten-day averages were calculated and compared with multiannual averages (Figure 1).

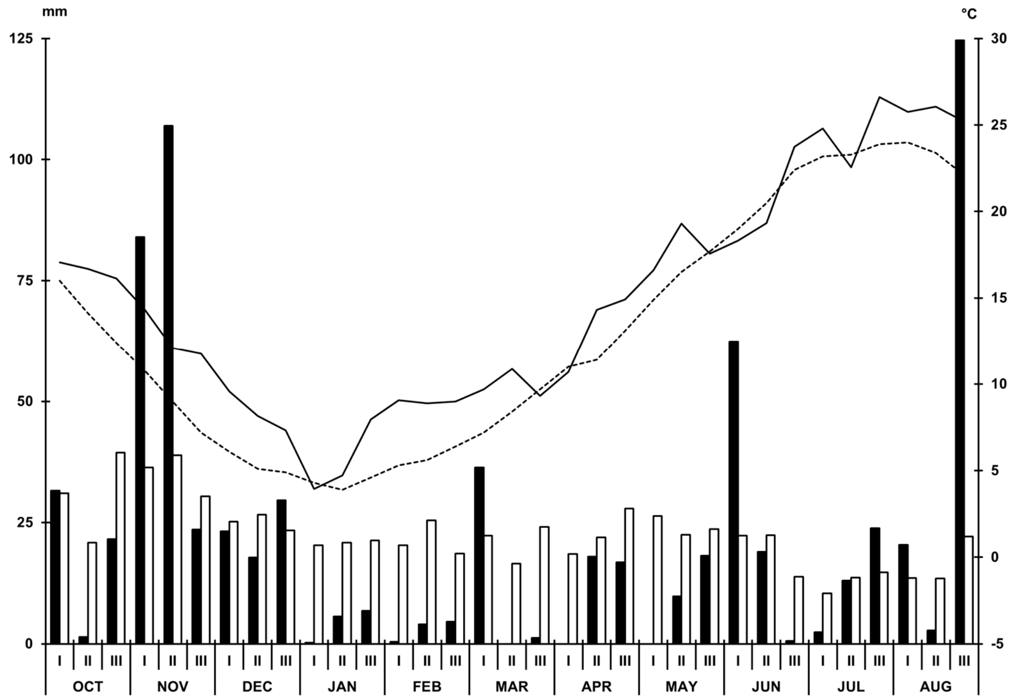

Figure 1. Average 10-day values (I, II, III) of rainfall (mm; bold bar) and temperature (°C; solid line) recorded during the two experiments (from October 2019 to August 2020), compared to multi-annual (from 1921) averages (rainfall: mm, empty bar; temperature: °C, sketched line).

Prior to ANOVA, all data were checked for the basic assumptions for ANOVA, and no transformation of data was required. The means were separated by Fisher's protected LSD test at $p = 0.05$. The ANOVA and check for the basic assumptions were performed with the EXCEL® Add-in macro DSAASTAT [16].

The two experiments were characterized by a different weed flora composition. A combined analysis of data showed that the interactions "years × treatments" were significant ($p < 0.001$); therefore, the results were shown and discussed separately for each year.

3. Results

3.1. Weed Control Efficacy of Herbicide Treatments

In exp. 1, weed flora, in the untreated control, was mainly composed of *Papaver rhoeas* L. (PAPRH, 43% of ground cover), *Conyza canadensis* (L.) Cronq., (CONCA, 5% of ground cover), *Ammi majus* L. (AMIMA, 14% of ground cover), and other sporadic weed species (9%) (*Helianthus annuus* L., *Chenopodium album* L., *Picris echioides* L., *Lolium multiflorum* Lam., *Lactuca serriola* L.), with 71% of total ground cover in the untreated control. Considering the herbicides applied in exp. 1, metazachlor and s-metolachlor gave the highest total weed control with values of 92% and 97%, respectively, and not significantly different between them (Table 3). On the other side, aclonifen, propyzamide, and metribuzin showed the lowest total weed control efficacy, ranging from 40% to 47%, due to the scarce efficacy of aclonifen against *C. canadensis*, propyzamide against *P. rhoeas,* and metribuzin against *P. rhoeas* and *C. canadensis* (Table 3).

Table 3. Exp. 1—Weed control efficacy (%) of herbicide treatments.

Treatment	Code	Weed Control Efficacy (%)				
		PAPRH	CONCA	AMIMA	Other	Total
aclonifen	B	100 a	0 b	66	38	46 b
metazachlor	C	100 a	99 a	100	33	92 a
s-metolachlor	D	100 a	82 a	100	90	97 a
propyzamide	E	24 b	99 a	94	81	47 b
metribuzin	F	34 b	0 b	94	81	40 b
S.E.M. (df = 14)		13	7	15	22	11
LSD (p = 0.05)		43	23	n.s.	n.s.	34

In each column values followed by the same letter are not significantly different according to the Fisher's protected LSD test (p = 0.05); n.s.= non significance.

Considering exp. 2, the weed flora in the untreated control was composed only by one weed species, such as wild sunflower (*Helianthus annuus* L.) (HELAN, 11.3% of ground cover and 1.3 plant m^{-2}) (Table 4). In this case, no herbicide efficacy values towards wild sunflower were reported, as no significant differences were found among the treatments in terms of density and ground cover (Table 4). In particular, the density and ground cover values of wild sunflower were quite small (from 1 to 2 plants m^{-2} and from 6.3% to 22.5% ground cover), proving to be not significantly different from each other. It's evident that the herbicides did not control wild sunflower, as showed by its plant density and absence of other weed species that could not compete and could not affect *H. annuus* emergence and growth.

Table 4. Exp. 2—Density and ground cover of wild sunflower (HELAN).

Treatment	Code	HELAN	
		Density (plant · m^{-2})	Ground Cover (%)
untreated control	A	1.3	11.3
aclonifen	B	1.1	6.3
metazachlor	C	1.1	11.3
s-metolachlor	D	1.3	9.2
propyzamide	E	2.0	22.1
metribuzin	F	1.0	22.5
S.E.M. (df = 17)		0.4	8.1
LSD (p = 0.05)		n.s.	n.s.

n.s.= non significance.

3.2. Phytotoxicity to Safflower

In experiment 1, data on % of phytotoxicity revealed that aclonifen, s-metolachlor, and propyzamide can be considered relatively safe to the safflower, with the lowest values ranging from 0 to 10% at 45 DAE and 90 DAE, with symptoms very low and transitory (Table 5). Metribuzin showed high phytotoxicity on safflower with a value of 43%, which was significantly higher than those of the other herbicides. The highest phytotoxicity value of 75% was observed with metazachlor (Table 5). Phytotoxic symptoms included plant growth reduction, while not significant effects were observed on the safflower crop stand, as shown by the data of safflower plant density at 40 DAE (Table 5; Figure 2). Although in Figure 2 safflower plants seem to be reduced in plot treated with metazachlor (plot delimited in red), actually, looking carefully, you can see that safflower plants were very small but were emerged, as also reported in the figure caption. At 160 DAE, safflower density was reduced to values ranging from 17 to 25 plants m^{-2} due to the plants dying because of the died of cold in January 2020 (Table 5); however, safflower density was not significantly different among treatments.

Table 5. Exp. 1—Herbicide phytotoxicity (scale 0–100%) and density of safflower at different DAE.

Treatment	Code	Herbicide Phytotoxicity (Scale 0–100%)		Safflower Density (plant · m^{-2})	
		45 DAE	90 DAE	40 DAE	160 DAE
untreated control	A	0 d	0 c	49	17
aclonifen	B	0 d	5 c	66	21
metazachlor	C	75 a	75 a	53	17
s-metolachlor	D	0 d	5 c	56	25
propyzamide	E	10 c	5 c	59	17
metribuzin	F	30 b	43 b	57	21
S.E.M. (df = 17)		$4 \cdot 10^{-7}$	3.1	4.3	3.3
LSD (p = 0.05)		$1 \cdot 10^{-6}$	9.6	n.s.	n.s.

In each column values followed by the same letter are not significantly different according to the Fisher's protected LSD test (p = 0.05); n.s.= non significance

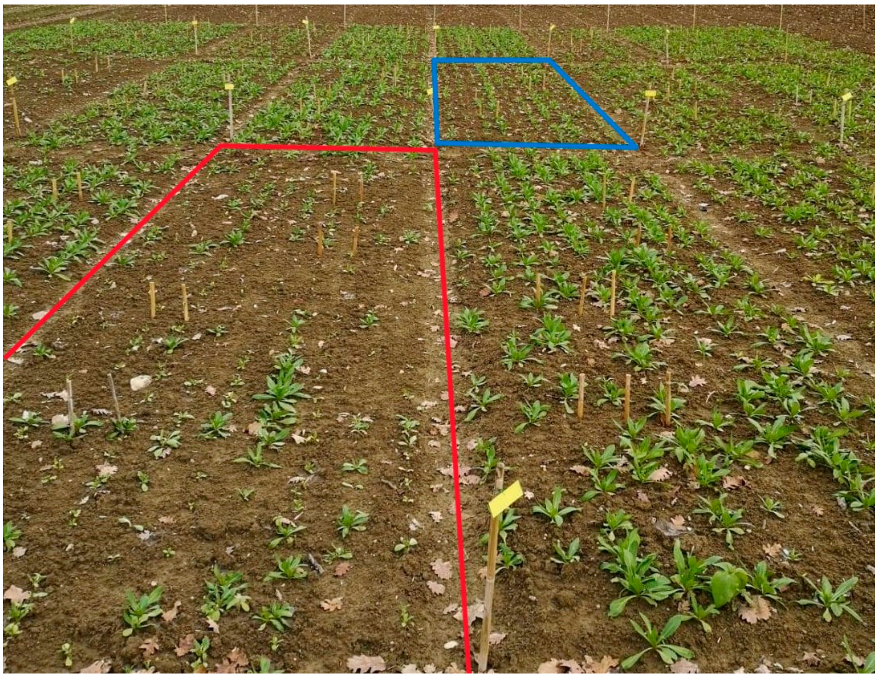

Figure 2. Exp. 1 (45 DAE): phytotoxic effects of metazachlor (plot delimited in red) and metribuzin (plot delimited in blue) in the plots of a block. Phytotoxic symptoms were due to a reduction in plant growth, without effects on plant emergence (looking carefully, in plot delimited in red, the plants were very small but were emerged).

In exp. 2, the herbicides caused a reduction in the safflower crop stand, as shown by values of visual phytotoxicity and plants density observed among treatments (Table 6). In particular, metazachlor and metribuzin were the most harmful herbicides with 48% and 75% of phytotoxicity and a reduction in the safflower density, with respect to untreated control, of 44% and 75%, respectively (Table 6; Figure 3). These herbicides caused a reduction in the emergence and growth of safflower plants, confirming the results obtained in exp. 1. On the other hand, the lowest phytotoxicity and the highest safflower plant density were observed with s-metolachlor and aclonifen, at values of 0 or 5% and of 53 plants m^{-2}, which is not significantly different to that of the untreated control (48 plants m^{-2}) (Table 6). Propyzamide data were similar to that of the untreated control, showing that this herbicide likewise did not affect significantly the safflower plants' emergence and growth (Table 6), as observed by Montemurro and Fracchiolla [9].

Table 6. Exp. 2—Herbicide phytotoxicity (scale 0–100%) and density of safflower at 25 DAE.

Treatment	Code	Herbicide Phytotoxicity (Scale 0–100%)	Safflower Density (Plant · m^{-2})
untreated control	A	0 d	48 a
aclonifen	B	5 cd	53 a
metazachlor	C	48 b	27 bc
s-metolachlor	D	0 d	53 a
propyzamide	E	8 c	41 ab
metribuzin	F	75 a	12 c
S.E.M. (df = 17)		1.6	5.6
LSD (p = 0.05)		5.2	17.6

In each column values followed by the same letter are not significantly different according to the Fisher's protected LSD test (p = 0.05)

Figure 3. Exp. 2 (25 DAE): phytotoxic effects of metazachlor (plots delimited in red) and metribuzin (plots delimited in blue) in the plots of two blocks. Herbicide phytotoxicity included reduction in crop stand and in crop growth.

3.3. Safflower Grain Yield

In exp. 1, grain yield levels were higher than those in exp. 2 (Table 7). On average, the grain yield in exp. 1 was 1984 kg · ha^{-1} and significantly higher ($p < 0.001$) than that in exp. 2 (1316 kg · ha^{-1}), showing that the grain yield was higher in autumn sowing than in spring sowing. In detail, in exp. 1, the highest grain yield obtained by aclonifen (2442 kg · ha^{-1}), s-metolachlor (2444 kg · ha^{-1}) and metazachlor (2317 kg · ha^{-1}) did not statistically differ. A lower production was observed with metribuzin, with 1756 kg · ha^{-1} of grain; however, the lowest values were found in plots treated with propyzamide (1516 kg · ha^{-1}) and an untreated control (1429 kg · ha^{-1}), not significantly different between them (Table 7). These results were in relation to different weed control of the pre-emergence herbicide; higher weed control corresponded to higher grain yield due to the deletion of weed competition (Table 7). Furthermore, phytotoxic symptoms did not affect safflower seed production, as demonstrated by the grain yield obtained with metazachlor (Table 7). In fact, phytotoxic symptoms included only plant growth reduction and not a reduction in crop density, as shown by the data of safflower plant density at 40 DAE (Table 5). In particular, although in Figure 2 safflower plants seem to be reduced in plot treated with metazachlor (plot delimited in red), actually, looking carefully, you can see that safflower plants were very small but were emerged, as also reported in the figure caption. However, after winter, the reduction in plant density revealed at 160 DAE was not affected by the phytotoxicity of herbicides, but was simply due to the low temperatures that occurred in January 2020 (Table 5). In the spring, the safflower plants that survived to winter had also recovered the growth reduction symptoms, but during the subsequent stem elongation phase, were more or less subjected to the weed competition, depending on the different herbicides weed control efficacy (Table 3), so affecting their grain yield (Table 7).

Table 7. Safflower grain yield in both experiments.

Treatment	Code	Grain Yield (kg · ha^{-1})	
		Exp. 1	Exp. 2
untreated control	A	1429 c	1536 a
aclonifen	B	2442 a	1493 a
metazachlor	C	2317 ab	1108 b
s-metolachlor	D	2444 a	1517 a
propyzamide	E	1516 c	1430 a
metribuzin	F	1756 bc	810 c
S.E.M. (df = 17)		212	94
LSD (p = 0.05)		669	295

In each column values followed by the same letter are not significantly different according to the Fisher's protected LSD test (p = 0.05).

In exp. 2, no significant different yield was observed in the untreated control (1536 kg · ha^{-1}) or aclonifen- (1493 kg · ha^{-1}), s-metolachlor- (1517 kg · ha^{-1}), and propyzamide- (1430 kg · ha^{-1}) treated plots, whereas high herbicide injury, due to a reduction in crop stands and crop growth, was observed in plots treated with metazachlor (1108 kg · ha^{-1}) and metribuzin (810 kg · ha^{-1}) (Table 7). In exp. 2, since there was no significant weed competition by only sporadic plants of wild sunflower, the grain yield obtained was mainly affected by herbicides' phytotoxicity rather than by their efficacy against weeds, as revealed with the high injury of the metazachlor and metribuzin.

4. Discussion

The results of this research showed that s-metolachlor, aclonifen, and propyzamide were the less injurious herbicides for safflower, confirming the results obtained in previous studies [9–12,17,18]. However, s-metolachlor seemed to be the best option to obtain a good efficacy against the main weeds in the trials, whereas aclonifen and propyzamide failed to control some weeds. Jha et al. [17] have determined that pendimethalin and s-metolachlor at 1064 and 433 g a.i. ha^{-1} did not cause any injury on the safflower, while they moderately and poorly controlled *Kochia scoparia* (L.) Schrad and *Salsola tragus* L., respectively. The weed control efficacy of pendimethalin has declined throughout the growing season, but s-metolachlor has relatively remained stable, continuing throughout the safflower growth cycle, as observed also in our study. Furthermore, s-metolachlor had no adverse effects on the safflower, even if it was applied at a dose (2745 g a.i. ha^{-1}) higher than that recommended; however, its control ability against *Sinapis arvensis* L. was limited [18]. Since s-metolachlor has a strong efficacy on grass weeds, but is limited on some broad-leaves weeds, the mixture of s-metolachlor + aclonifen may be worth of testing in further experiments in order to evaluate its selectivity to safflower, increasing its efficacy against broadleaf weeds, due to aclonifen activity, making it more useful to manage the more complex weed infestations typical of the Mediterranean areas. Concerning propyzamide, Anderson [9] found that this herbicide did not cause safflower injury but failed to control *Panicum capillare* L. and *A. retroflexus*, which reduced safflower grain yield due to competition. In the same way, propyzamide caused low safflower injury (1, in a scale of 1–9) but poor weed control, ranged from 46% to 78% efficacy, and had grain yield losses due to the competition of uncontrolled weeds [12]. On the other hand, metazachlor and metribuzin, independently to their efficacy on weeds, caused high phytotoxic effects on the safflower, and so they seemed to be not advisable to use as pre-emergence herbicides for weed control in this crop, as observed also by Krenchinski et al. [19] and Montemurro and Fracchiolla [12]. These two latter authors found that metribuzin, in a location of south Italy, gave a high safflower phytotoxicity (7, in a scale of 1–9), an efficacy of 61% against a weed infestation of *Avena ludoviciana* Durieu (23% of ground cover), *Galium aparine* L. (8% of ground cover), and *Sinapis arvensis* L (5% of ground cover), and the lowest grain yield (1.18 t ha^{-1}) [12]. Krenchinski et al. [19] reported that metribuzin, at 360 g a.i. ha^{-1}, had injured safflower more when applied in pre-emergence (96% of phytotoxicity at 4 weeks after treatment) than when used pre-planting incorporated (41% of phytotoxicity). In this study, the two experiments gave similar results in terms of the phytotoxicity of the herbicides on safflower, but not in terms of efficacy, because in exp. 2, any herbicides were able to control wild sunflower, due to their ineffectiveness against this species. This is well known because both pre-emergence and post-emergence herbicides registered on sunflower, like those in this study, are selective on cultivated sunflower, but, at the same time, are not effective against wild sunflower [13]. The above-mentioned research and our study showed that the weed control ability of herbicides is important to reduce weed competition and avoid safflower yield losses; however, in the absence or in cases of reduced weed competition, the selectivity of herbicides prevailed on their efficacy against weeds in influencing the grain yield in safflower. Despite some herbicides can cause transitory phytotoxic effects in safflower, it is important to choose the most selective herbicides in order to avoid crop injury and yield loss. In our research, s-metolachlor and aclonifen were the most selective herbicides; not by chance, s-metolachlor was also authorized as a pre-emergence herbicide for safflower in some countries, like Australia and the U.S. [20–22]. In the U.S., s-metolachlor is registered for use on safflower in pre-plant incorporated or pre-emergence and recommendations on the correct dose to select, depending on the soil texture are labelled [21].

5. Conclusions

For chemical weed control, selective pre-emergence herbicides are needed to avoid weed competition at the early growth stage of safflower. S-metolachlor gave the best performance in terms of efficacy against weeds, selectivity towards safflower and crop yield. Propyzamide and aclonifen were also selective on safflower, and the latter herbicide should be evaluated in mixture with s-metolachlor in further experiments in order to enlarge the weed control spectrum against some broadleaf weeds. However, also based on our results, these three herbicides should be considered in the authorization process for use in safflower. Metazachlor and metribuzin seem to be inadvisable as pre-emergence herbicides due to the low selectivity towards safflower.

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References

1. Fernández-Martinez, J.; del Rio, M.; de Haro, A. Survey of safflower (*Carthamus tinctorius* L.) germplasm for variants in fatty acid composition and other seed characters. *Euphytica* **1993**, *69*, 115–122. [CrossRef]
2. Zehra, E. Resurgence of Safflower (*Carthamus tinctorius* L.) Utilization: A Global View. *J. Agron.* **2005**, *4*, 83–87. [CrossRef]
3. Ilkılıç, C.; Aydın, S.; Behcet, R.; Aydin, H. Biodiesel from Safflower oil and its application in a diesel engine. *Fuel Process. Technol.* **2011**, *92*, 356–362. [CrossRef]
4. Abou Chehade, L.; Angelini, L.G.; Tavarini, S. Genotype and Seasonal Variation Affect Yield and Oil Quality of Safflower (*Carthamus tinctorius* L.) under Mediterranean Conditions. *Agronomy* **2022**, *12*, 122. [CrossRef]
5. Rocchi, L.; Farneselli, M.; Paolotti, L.; Falcinelli, B.; Guiducci, M.; Boggia, A. Life Cycle Inventory for Safflower Production in Southern Europe. *Environ. Clim. Technol.* **2022**, *26*, 862–870. [CrossRef]
6. Food and Agriculture Organization (FAO) of United Nations. The Food and Agriculture Organization Corporate Statistical Database Production Quantities of Safflower Seed and Plantains. 2021. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 10 July 2023).
7. Helm, J.L.; Riveland, N.; Schneiter, A.A.; Sobolik, F. *Safflower Production*; Crop Extension Service, North Dakota State University: Fargo, ND, USA, 1985; p. 4.
8. Budak, I.; Serim, A.; Asav, Ü. The Critical Period for Weed Control in Safflower Fields of Turkey. *C. R. Acad. Bulg. Sci.* **2023**, *76*, 1935–1942. [CrossRef]
9. Anderson, R.L. Chlorsulfuron for weed control in safflower (*Carthamus tinctorius*). *Weed Sci.* **1985**, *33*, 840–842. [CrossRef]
10. Blackshaw, R.E.; Derksen, D.A.; Muendel, H. Herbicides for weed control in safflower (*Carthamus tinctorius*). *Can. J. Plant Sci.* **1990**, *70*, 237–245. [CrossRef]
11. Yau, S.K.; Haidar, M.A. Evaluation of Weed Management Practices for Rain-Fed Safflower Production in a Semiarid Mediterranean Environment. *Agron. J.* **2008**, *100*, 1430–1435. [CrossRef]
12. Montemurro, P.; Fracchiolla, M. Further results of research on chemical weed control in safflower (*Carthamus tinctorius* L.). In *Safflower: A Multipurpose Species with Unexploited Potential and World Adaptability, Proceedings of the IV International Safflower Conference, Bari, Italy, 2–7 June 1997*; Corleto, A., Mündel, H.H., Kalpana Sastry, R., Riveland, N., Tanaka, D.L., Fernández-Martínez, J., Zhang, L.P., Esendal, E., Hill, A.B., Eds.; Adriatica Editrice: Bari, Italy, 1997; pp. 132–135. Available online: https://docplayer.net/76561821-Safflower-a-multipurpose-species-with.html (accessed on 15 December 2023).
13. Pannacci, E.; Graziani, F.; Covarelli, G. Use of herbicide mixtures for pre and post-emergence weed control in sunflower (*Helianthus annuus*). *Crop Prot.* **2007**, *26*, 1150–1157. [CrossRef]
14. van der Maarel, E. Transformation of cover-abundance values in phytosociology and its effects on community similarity. *Vegetation* **1979**, *39*, 97–114. [CrossRef]
15. Chinnusamy, N.; Chinnagounder, C.; Krishnan, P.N. Evaluation of weed control efficacy and seed cotton yield in glyphosate tolerant transgenic cotton. *Am. J. Plant Sci.* **2013**, *4*, 1159–1163. [CrossRef]
16. Onofri, A.; Pannacci, E. Spreadsheet tools for biometry classes in crop science programmes. *Commun. Biometry Crop. Sci.* **2014**, *9*, 3–13.
17. Jha, P.; Kumar, V.; Lim, C.A.; Yadav, R. Evaluation of Preemergence Herbicides for Crop Safety and Weed Control in Safflower. *Am. J. Plant Sci.* **2017**, *8*, 2358–2366. [CrossRef]
18. Budak, I.; Serim, A.T.; Asav, U. Determination of the efficacy of some herbicides on the weeds in safflower. *Plant Prot. Bull.* **2020**, *60*, 81–87. [CrossRef]
19. Krenchinski, F.H.; Pereira, V.G.C.; Giovanelli, B.F.; Mattiuzzi, M.D.; Albrecht, A.J.P.; Wagner, F.G. Seletividade de herbicidas na cultura do cártamo. *Rev. Bras. De Herbic.* **2019**, *18*, 636-1. [CrossRef]
20. Heuston, P.; Macpherson, M. Weed Control in Winter Crops 2024. NSW Department of Primary Industries, Management Guide. Pages 159. Available online: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops (accessed on 20 February 2024).
21. US EPA, Pesticide Product Label, S-Metolachlor EC Herbicide, 01/09/2023. Available online: https://www3.epa.gov/pesticides/chem_search/ppls/082542-00036-20230109.pdf (accessed on 15 December 2023).
22. Rosenfeld, P.E.; Feng, L.G.H. *Risks of Hazardous Wastes*; William Andrew: Norwich, NY, USA, 2011; pp. 127–154. [CrossRef]