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Validation of elite lines and varieties of safflower (*Carthamus tinctorius* L.) in southern Sonora, Mexico

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Abstract

In Mexico, the main safflower-producing states in 2024 were Sinaloa, Sonora, and Tamaulipas. The safflower breeding program at the Norman E. Borlaug Experimental Station (CENEB) has focused its research on developing lines resistant to Ramularia leaf spot and of the oleic type. Therefore, the objective of this study was to evaluate and identify elite lines with good yield and oil quality that could be candidates for commercial varieties. The experimental plot was established in block 910 of the Yaqui Valley, during the 2023-2024 fall-winter crop season at CENEB. Sowing was carried out in moist soil, on December 5, 2023, in a randomized block design with four replications. Six commercial varieties and eight advanced lines were evaluated. The variables measured in the field were days to flowering and to physiological maturity, plant height, grain yield (kg ha^{-1}), and quality (percentage of oil and oleic acid). The analysis of variance was performed using the SAS statistical package, and the LSD test ($\alpha = 0.05$) for mean comparison. Significant differences in grain yield were found between treatments. The line with the highest yield was C-45-2-MOC with 2,971 kg ha^{-1}, which was statistically similar to the varieties S-323 and Huatson OL. The elite line M-CW-3268 had an oil percentage greater than 40, while the lines C-62-MOC and CC-1777-1-1-1-0Y had an oleic acid content of 79.78 and 79.56 %, respectively.

Keywords: Safflower; *Carthamus tinctorius*; Leaf Spot; *Ramularia carthami*; Oleic Acid; Elite Lines

1. Introduction

Safflower (*Carthamus tinctorius* L.) is an annual oilseed crop belonging to the Asteraceae family [1]. It is the only cultivated safflower species that contains 2n = 24 chromosomes. It has been traditionally grown in various countries, including India, Mexico, China, Australia, Turkey, and Iran [2]. In 2024, Mexico ranked as the fourth largest producer of

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this oilseed worldwide with a production of 65,760 tons; Sonora, Sinaloa and Tamaulipas being the main producing states [3]. This crop has a wide adaptability to diverse agroecological conditions, developing optimally in conditions of low water availability, soils with low fertility and in places with different temperatures, since it is considered tolerant to cold, drought, and salinity conditions, compared to other oilseeds [4,5]. Safflower is primarily used for cosmetics, food, and medicinal purposes. It also has potential as a forage crop in Mediterranean farming systems. Currently, researchers' interest in this species stems mainly from its high-quality vegetable oil, which has nutritional and industrial applications. The nutritional value of safflower oil is very similar to that of olive oil, which is why it has become relevant in recent years as a result of human consumption in arid and semi-arid areas [1]. Safflower oil contains two unsaturated fatty acids: oleic acid (Cys, Omega-9) and linoleic acid (Cys, Omega-6), which make up approximately 90 % of the total fatty acids. The remaining 10 % consists of palmitic acid and stearic acid [6,7]. The main biotic factors that hinder the production of this crop are fungal diseases transmitted by seed, soil, and air, such as wilt caused by *Fusarium oxysporum* (Schlechtend) f. sp. *carthami* (Klisiewicz and Houston) and *Verticillium dahliae* Kleb., leaf spots caused by *Cercospora* spp., *Alternaria carthami* Chowdhury, *Alternaria alternata* Fr. Keissler, *Ramularia carthami* Zaprom., *Ramularia cercosporelloides* U. Braun and Crous, and *Septoria* spp. Root and stem rots caused by *Botrytis cinerea* Pers.:Fr., *Macrophomina phaseolina* (Tassi) Goidanich, *Phytophthora cactorum* (Lebert and Cohn) J. Schröt, and *P. cryptogea* Pethyb. and Laff., *P. drechsleri* Tucker, *Pythium* spp., *Rhizoctonia solani* Kühn, and *Sclerotinia sclerotiorum* (Lib.) de Bary are also present. Rust caused by *Puccinia carthami* Corda and powdery mildew caused by *Leveilla taurica* (Lév.) G. Arnaud have also been reported [8,9,10,11]. Safflower breeding has focused on improving yield, oil content, and associated agronomic characteristics, especially resistance to diseases, insects, and abiotic stresses. This improvement has concentrated on taking advantage of the variability existing in commercial varieties, but also on interspecific crosses [12]. In Northwest Mexico, experimentation with safflower began in 1958, with adaptation and performance tests [13], while the genetic improvement program began in the 1970s, whose objective was to identify materials that adapted to the conditions of the region and that presented good quality and productivity [14]. The main disease in this region that affects the crop is Ramularia leaf spot caused by *Ramularia carthami* (Figure 1), which appeared from the fall-winter agricultural crop season 2000-2001 [15].

Figure 1 Symptoms of leaf spot on safflower caused by *Ramularia carthami*

This disease is endemic in southern Sonora and is currently considered a limiting factor in safflower production. The best way to control the disease is to use tolerant varieties, as this contributes to environmental protection and reduces production costs. For this reason, it is necessary to develop new varieties through breeding and selection methods among existing genetic resources [4]. The main problems with safflower are low yields, low oleic oil content, and genotypes susceptible to Ramularia leaf spot. Therefore, the objective of this work was to evaluate and identify elite lines with good yield and oil quality characteristics that could be candidates for release as varieties.

2. Materials and methods

This study was conducted in southern Sonora during the 2023-2024 fall-winter crop season at the Norman E. Borlaug Experimental Station (27° 36’ 97 29’’ N Latitude, 109° 92’ 55 30’’ W Longitude, and 39 m above sea level), on a clay soil with compaction problems, known locally as compacted clay. Fourteen safflower genotypes were evaluated: eight elite oleic-type lines and six commercial varieties used in the region (Table 1). A population density of 15 plants per linear meter was used; the agronomic management of the crop was carried out according to the recommendations of INIFAP for the region [13]. A randomized block design with four replications was established, with a usable plot size of 6.4 m^2. Sowing was carried out in moist soil on December 5, 2023. Three complementary irrigations were applied and fertilization was done with the formula 150-52-00.

Table 1 Lines and commercial safflower varieties evaluated at the Norman E. Borlaug Experimental Station, during the 2023-2024 fall-winter crop season, in the Yaqui Valley, Sonora, Mexico

Safflower experimental lines
C-63-0Y
M-CW-3268
C-63-1-MOC
CCC-1651-1-1-1-2-MOC
C-45-2-MOC
C-62-MOC
PALO ROJO LIMPIA
CC-1777-1-1-1-0Y
Safflower commercial varieties
HUATSON-OL
S-323
CHEY OL
AS-23
AS-3427 OL
CW-3268

For weed control, mechanical cultivation and manual weeding were carried out, and an application of Bifexam insecticide at the rate of 250 mL of commercial product/ha [16] was made for the control of pests (bed bugs and aphids) in the phenological stage of branch and bud formation, while for disease control it was not necessary to make any fungicide application. The daily average temperature (°C), the maximum and minimum, and the relative humidity were recorded from November 15, 2023 to June 30, 2024 by the weather station CIANO-910, located in block 910 in the Yaqui Valley [17]; this station belongs to the automated weather station network of Sonora [18]. Likewise, the variables measured were days to flowering and physiological maturity, plant height, reaction to Ramularia leaf spot (using a visual scale from 0 to 10, where 0 = 0 % damage and 10 = 100 % damage), grain yield (kg ha^{-1}), and quality (percentage of oil and oleic acid). The analysis of variance was performed using the SAS statistical package, and the LSD test ($\alpha = 0.05$) for mean comparison.

3. Results and discussion

Table 2 presents the agronomic variables of the evaluated lines and varieties. It shows that the days to flowering vary among the materials from 103 to 116 days after sowing (das), with genotypes C-63-0Y and C-45-2-MOC being the earliest and M-CW-3268, C-63-1-MOC, CCC-1651-1-1-1-2-0Y, and CW-3268 being the latest. Mousavi *et al.* [4] evaluated 127 safflower genotypes in two agricultural crop seasons in Iran, of which 23 were of Mexican origin and these presented the flowering start stage between 214 and 225 days; the number of days contrasts considerably with those presented in this study. Plant height ranged from 128 to 165 cm among the materials; Beyyavas *et al.* [19] reported average plant heights from 99.5 cm to 120.5 cm, which are lower than those observed in the genotypes of this study. The lines M-CW-3268 and CCC-1651-1-1-1-2-0Y were the tallest at 165 cm, while C-62-MOC was the shortest at 128 cm. Days to physiological maturity ranged from 153 to 160 das. Ramularia leaf spot was not observed during this growing season.

Table 2 Agronomic characteristics of safflower lines and varieties, evaluated at the Norman E. Borlaug Experimental Station, during the 2023-2024 fall-winter crop season, in the Yaqui Valley, Sonora, Mexico

	Days to flowering	Height (cm)	Days to physiological maturity
Lines			
C-63-0Y	103	158	155
M-CW-3268	116	165	158
C-63-1-MOC	116	159	160
CCC-1651-1-1-1-2-0Y	116	165	155
C-45-2-MOC	103	142	160
C-62-MOC	114	128	155
PALO ROJO LIMPIA	110	132	160
CC-1777-1-1-1-OY	109	135	155
Varieties			
HUATSON-OL	110	151	158
S-323	110	129	156
CHEY-OL	115	152	160
AS-23	115	139	160
AS-3427-OL	113	151	153
CW-3268	116	149	158

Figure 2 shows the maximum, minimum, and average temperatures, as well as the average relative humidity, recorded during the crop season. The maximum temperature reached its highest value in May, averaging 39.6 °C, while January showed the lowest minimum temperature at 1.1 °C. February recorded the highest average relative humidity at 74.06 %.

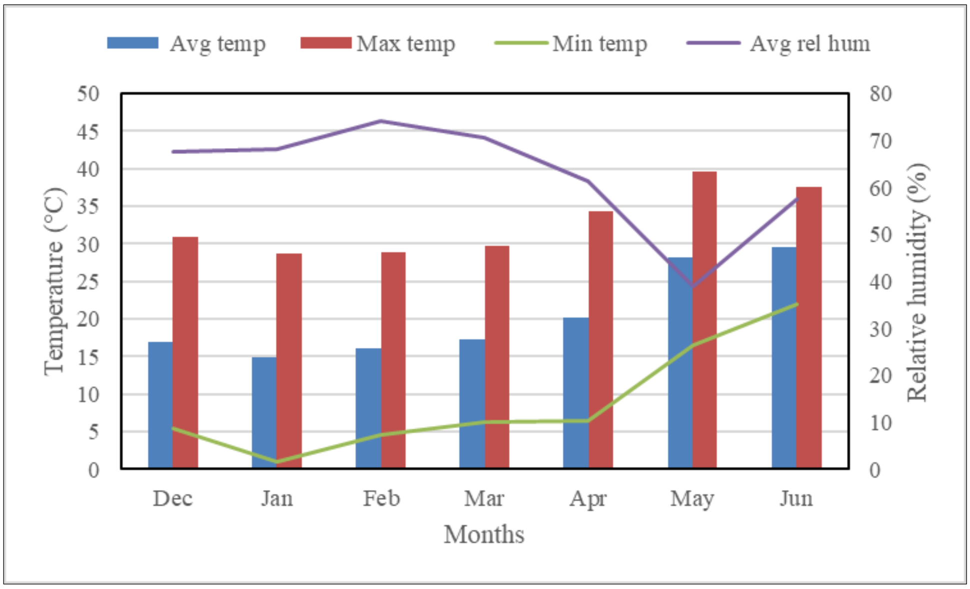

Figure 2 Temperature and relative humidity during the 2023-2024 safflower crop season, recorded by the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

Ramírez *et al*. [20] concluded that the favorable conditions for the occurrence of Ramularia leaf spot are minimum temperatures of 9.2 to 11.6 °C, maximum temperatures between 25.3 to 29.9 °C, with relative humidity of 73.0 to 81.5 %. The disease did not appear, even though the growing season had conditions conducive to its development. Oliver [21] mentions that for a disease to occur, a susceptible host, a virulent pathogen, and favorable environmental conditions are required; however, the possible lack of primary inoculum, as well as the extreme temperature conditions that occurred, could have influenced the absence of the disease. The greatest damage caused by Ramularia leaf spot in the state of Sonora occurred during the 2003-2004 crop season, on an area of 107,698 ha, with yield losses estimated at 55 %, which represented a reduction of 133,000 t with an estimated value of 30.324 million dollars [22,23].

Regarding grain yield, the statistical analysis showed significant differences between treatments, with a coefficient of variation of 24 %. The elite line C-45-2-MOC with 2,971 kg ha^{-1} was the genotype that showed the highest production of all the materials evaluated, being statistically similar to the varieties S-323 and Huatson OL (Table 3).

Table 3 Yield and quality characteristics of safflower lines and varieties, evaluated at the Norman E. Borlaug Experimental Station, during the 2023-2024 fall-winter crop season, in the Yaqui Valley, Sonora, Mexico

Lines and varieties	Yield (kg ha^{-1})	Oil (%)	Oleic acid (%)
C-45-2-MOC	2,971 a*	34.9	47.28
S-323	2,707 ab	39.4	80.79
HUATSON-OL	2,669 ab	38.5	77.43
AS-23	2,526 bc	36.2	71.22
C-63-0Y	2,455 bc	37.5	59.8
C-63-1-MOC	2,450 bc	37.7	62.41
AS-3427-OL	2,293 c	42.2	81.84
CHEY-OL	2,272 cd	35.79	76.43
C-62-MOC	2,255 cd	36.6	79.78
M-CW-3268	1,970 de	40.7	63.92
PALO ROJO LIMPIA	1,789 e	39.1	67.45
CW-3268	1,475 f	40.4	75.95
CCC-1651-1-1-1-2-0Y	1,475 f	36.0	54.98
CC-1777-1-1-1-OY	1,098 g	37.7	79.56

LSD=183.6, *Numbers with different letters show a significant difference

These yields do not differ much from those reported by Aguilera *et al*. [24], in December and January sowings that fluctuated between 1,200 to 2,028 kg ha^{-1} of different advanced lines in the same area. Mousavi *et al*. [4] indicated that out of the 23 Mexican genotypes evaluated, 10 of them obtained yields from 3,125 to 5,500 kg·ha^{-1}, being considerably higher than those evaluated in the present study. The remaining genotypes showed yields ranging from 125 to 2,792 kg ha^{-1}, exhibiting results similar to those presented in this study. The CC-1777-1-1-1-OY line showed the lowest yield at 1,098 kg ha^{-1}.

Regarding the percentage of oil, the AS-3427-OL and CW-3268 varieties were above 40 %, as was the M-CW-3268 line. The rest of the lines and varieties presented a range of 34.9 to 39.4 %. The concentration of oil in safflower seed varies between 35 % and 50 %, with 90 % unsaturated fatty acids [25]. Beyyavas *et al*. [19] evaluated different traits of 26 varieties, lines and populations of safflower in two agricultural crop seasons; within the oil content they obtained average values from 26 % to 34.8 %, respectively. These values are below those obtained in the present study where the line that obtained the lowest oil content was C-45-2-MOC with a value of 34.9 %. Oil content can be affected by varieties, location, and the interaction of both [19]. The AS-3427-OL variety had the highest percentage of oleic acid at 81.84 %, followed by S-323 at 80.79 %, while the C-45-2-MOC line had the lowest at 47.28 %.

4. Conclusion

The earliest genotypes for days to flowering were C-63-0Y and C-45-2-MOC with 103, while for days to physiological maturity AS-3427-OL with 153, followed by C-63-0Y, CCC-1651-1-1-1-2-0Y, C-62-MOC, and CC-1777-1-1-1-0Y with 155.

The tallest genotypes were M-CW-3268 and CCC-1651-1-1-1-2-0Y at 165 cm, while C-62-MOC was the shortest at 128 cm.

The varieties with the highest percentage of oil above 40 %, were AS-3427-OL and CW-3268, as well as the M-CW-3268 line, while the C-45-2-MOC line presented the lowest percentage with 34.9 %.

The AS-3427-OL variety showed the highest percentage of oleic acid at 81.84 %, followed by S-323 at 80.79 %, while the C-62-MOC and CC-1777-1-1-1-0Y lines showed percentages of 79.78 % and 79.56 %, respectively. On the other hand, the C-45-2-MOC line showed the lowest at 47.28 %.

The elite line C-45-2-MOC presented the highest yield with 2,971 kg ha^{-1}, being statistically similar to the varieties S-323 and Huatson OL.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that No conflict of interest.

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