Article

Behavior of safflower elite lines high productivity and oil quality in the Yaqui Valley, Sonora, Mexico

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Abstract

The safflower *Carthamus tinctorius* L. it is a crop that has been adopted by a large number of producers, particularly in the Northwest of the country, due to its great adaptability and its little water requirement, due to the great demands presented by the oilseed industry in the country. Since the 1970s it has been worked to generate materials that are highly productive, with good percentage and qualityof oil and with characteristics of resistance to the main diseases present in the region (false mildew and leaf rust). For this reason, the objective of this work was to evaluate the behavior of the elite safflower lines generated by the genetic improvement program in the region (23 oleic and 1 linoleic). These lines were established during cycles 2017-2018 and 2018-2019. Its agronomic behavior was evaluated under the present conditions of the Yaqui Valley. Oleic lines were found that surpassed witnesses Ciano ol and Chey ol, varieties that are widely sown in the region. In addition, it was found that the linoleic type line had better agronomic characteristics, production and oil content than witness RC-1002 which leads to the conclusion that within the evaluated lines there are potential materials to be released as a variety.

Keywords: oilseeds, plant breeding, production.

Reception date: January 2021
Acceptance date: March 2021

Introduction

The safflower *Carthamus tinctorius* L. (Asteraceae) is a species that is cultivated worldwide, is native to the Middle East and was traditionally used to produce dyes from its petals. It is currently used for both medicinal and food purposes (Machewad *et al*., 2012; Asgarpanah and Kasemivash, 2013). Most grain production is used for oil extraction, which is of very good quality and there are two types that contain a high concentration of linoleic acid and those containing oleic acid, which bring benefits for feeding the general population (Borbón *et al*., 2019).

The main safflower producing countries worldwide are: Kazakhstan, Russia, Mexico and the United States, with production of 196 000, 193 000, 96 000 and 90 000 ton respectively (FAOSTAT, 2019). In the world it is generally cultivated in soils that are scarcely fertile or of low-yield due to the 'rustic' conditions that this species presents by this species. However, in southern Sonora due to water deficit conditions, safflower has been adopted by a large number of farmers, who mostly grow it on good quality land (Montoya, 2010). And although Mexico is one of the main world producers of the crop, during 2016 it was only possible to cover 50.5% of the safflower seed required by the national industry (Ramos *et al*., 2019). Situation that is constant since the 90's (Chanda *et al*., 1990).

In Mexico the safflower is grown mainly for the production of edible oil and in recent years experiments have been carried out to evaluate its use as silage or fresh forage for cattle and goats (Landau *et al*., 2004; Reta *et al*., 2017). The production of this species is concentrated in the north of the country within the states of: Sonora, Baja California and Tamaulipas, with an area of 15 000, 2 600 and 1 910 ha sown.

Safflower cultivation generates 0.11% of the national agricultural GDP and covers 15.31% of the national oilseed production (SAGARPA, 2017; SIAP, 2021), its harvest is completely mechanized and the places where the greatest productivity is presented is where it is irrigated, as is the case of Sonora, where most of this area is concentrated within the Yaqui and Mayo Valleys (Silveira *et al*., 2009; Ramirez *et al*., 2017). Being these the most important regions of the state, the Yaqui establishes two cycles in the year, where in autumn-winter the most important crops are wheat and maize and during the summer an important area of soybeans and maize is established depending on the availability by the Yaqui River dam system (Cerutti, 2019).

Safflower is a crop of great importance in northwestern Mexico, thanks to its production capacity with low water levels, compared to wheat cultivation, which predominates in the region; however, due to the effects of climate change there are fewer and fewer water catchments in the Yaqui River dam system (Minjares *et al*., 2010), it is important to note that some of the water contained in these reservoirs is used for human consumption, by the localities of the Yaqui River basin, in addition the insistence by producers to sow wheat has increasingly reduced the planting area of summer crops such as: soybeans, sorghum, among others. This has caused a water deficit for wheat cultivation (Paquini *et al*., 2016).

In the Mayo Valley this problem is more evident because this region is not irrigated with the aforementioned dam system, but with the Mocúzari dam that is supplied by the flow from Mayo River, which does not supply to maintain the agricultural area, so it is very common that government programs are registered that promote the sowing of the safflower crop, which is optimal due to its low water requirement (Khalili *et al*., 2014; Martínez *et al*., 2016; Singh *et al*., 2016).

The safflower genetic improvement program started since the 1970s with the aim of identifying materials that adapt to the conditions of the region and present quality and productivity (Quilantán, 1978). Over time, work has been done to generate materials that meet the needs of producers and thanks to this activity it has been possible to release varieties with resistance characteristics to different diseases of global importance such as safflower rust (*Puccinia carthami*) and Alternaria (*Alternaria carthami*) (Montoya and Ochoa, 2006).

During the agricultural cycle 2000-2001 in the Yaqui and Mayo Valleys, the disease known as false mildew caused by the fungus *R. carthami* was presented (Hostert *et al*., 2006) which during the 2003-2004 cycle presented the greatest damage recorded, during this cycle 107 833 ha had been established in the Valley in the largest area in the last 15 years, of which 2 410 were reported sinister due to the disease (SIAP 2021), it was estimated that in this area the false mildew caused a loss of about 133 000 t equivalent to 440 million pesos, as a result of this, the generation of varieties that presented resistance characteristics and the first results of this work were reflected in 2008 when the first varieties tolerant to this disease were released (Montoya *et al*., 2008; Montoya, 2010; Bourbon *et al*., 2011; JLSVVY, 2019).

Over time the planting area of the crop has varied in the state of Sonora, from 2010 the year with the largest area was 2012 with 56 452 ha, followed by 2011 with 45 202 ha, the constant pressure of the disease, as well as the availability of water and the price of crop have led to the lowest area in 2019 with only 13 397 ha planted in the state (Montoya *et al*., 2008; Ávila *et al*., 2014; SIAP 2021). In addition, weather conditions have been changing and it is necessary to continue generating materials that adapt to this scenario (Padmavathi and Virmani, 2013).

Within the safflower crop there are two types: those that produce a high percentage oil of monounsaturated and oleic acid, and those with high concentration of polyunsaturated acids and linoleic acid (Zapata, 2010; SAGARPA, 2017). Historically within the genetic improvement program varieties that contained oil of the linoleic type, because it was what was required by the industry (Montoya *et al*., 2008; Bourbon *et al*., 2011); however, in recent years, attending to the needs of the edible oil industry, emphasis has been placed on the generation of safflower materials with a high content of oleic acid (Montoya *et al*., 2008) due to the benign properties it has on human food (Montes *et al*., 2016).

But research of linoleic materials is still maintained, with the aim of preventing possible needs of these materials in the near future, by farmers and industry (Montoya *et al*., 2008). Therefore, the objective of this research was to determine the agronomic behavior of the elite lines of the oleic and linoleic type generated by the genetic improvement program and also to identify possible candidate materials to be released as new varieties. based on its productive potential, quality and tolerance to diseases present in the region.

Materials and methods

This work was carried out within the facilities of the Norman E. Borlaug Experimental Field located in block 910 of the Yaqui Valley, during the autumn-winter 2016-17 and autumn-winter 2017-2018 where cycles where a previous irrigation was applied to be able to sow them on land, with planting dates of: December 20, 2017 and January 24, 2019, respectively. 24 elite lines were established (Table 1), from the safflower improvement programme (23 oleics, 1 linoleic), selected for their good agronomic characteristics, as well as their good production and quality of oil, also for presenting tolerance to false mildew and 3 RC-1002 witnesses (linoleic), Chey ol and Ciano ol (oleic), varieties that are widely planted in the region. All materials were generated by the program using traditional methods of improvement (Pedigree) and selection. Throughout their development, they were subjected to different types of stress and recurrent selections were made in order to obtain these materials.

Table 1. Lines and varieties used for the development of this study.

Material	Origin	Type	Material	Origin	Type
0272-12-3-5-OY	Elite line	Oleic	CC1644-1-2-0Y	Elite line	Oleic
0272-3-2	Elite line	Oleic	CCC-1561	Elite line	Oleic
C-27-1Y-2Y(A/N)	Elite line	Oleic	CCC-1564-1-1-1-1-0Y	Elite line	Oleic
C-32-0Y	Elite line	Oleic	CCC-1633-1-1-1-0Y	Elite line	Oleic
C-54-1-OY	Elite line	Oleic	CCC-1651-1-1-1-2-0Y	Elite line	Oleic
C-56-1Y-1Y	Elite line	Oleic	CCC-1651-1-1-1-2Y-1Y	Elite line	Oleic
C-61-1Y-1Y	Elite line	Oleic	CCC-1672-1-1-1-1	Elite line	Oleic
C-63-0Y	Elite line	Oleic	S-518-SEL-PPR’SS10 (A/N)	Elite line	Oleic
C-65-0Y	Elite line	Oleic	CIANO-OL/ CC1658-1-0Y	Elite line	Oleic
C-72-0Y	Elite line	Oleic	S-518-SEL-PPR’SS10 (A/N)	Elite line	Oleic
CC-14-31-5-1-OY. 1-2-0Y	Elite line	Oleic	CHEY-OL	Variety	Oleic
CC1567-1-1-0Y-1C	Elite line	Oleic	CIANO-OL	Variety	Oleic
CC-15-76-1-1-0Y-1C	Elite line	Oleic	RC-1002	Variety	Linoleic
CC1631-1-1-1-1	Elite line	Oleic			
CC1635-1-1-1-1Y	Elite line	Linoleic			

A completely random experimental design was established with four repetitions, on a plot of four grooves at 80 cm of separation and a length of 6 meters (19.2 m^2). These materials were given the agronomic management recommended by INIFAP in the region, which consisted of a fertilization of 150-52-00 (N-P-K), in addition two relief irrigations were carried out during the stage of stem elongation and the formation of flower buttons, insecticides for insect control and no disease control application were carried out.

Weekly sampling was carried out when the plant passed the rosette stage and until the beginning of flowering, in search of the characteristic lesions caused by the false mildew *R. carthami.* And the rust of the leaf caused by *Puccinia carthami.* Similarly, climate data were taken from the automated station located within block 910, recording variables of: average, maximum and minimum temperature, relative humidity and precipitation (REMAS, 2019).

Regarding agronomic variables, the variables of plant height, were recorded, where the measurement of three plants per repetition was taken with the help of a measure of length equivalent to four rods and the values were averaged. To determine physiological maturity, the days elapsed from planting until the plant showed symptoms of senescence were counted. The incidence and severity of the false mildew was determined using the scale proposed by Ramírez *et al*. (2011). Which consisted of visually dividing into lower, middle and upper thirds. To evaluate the severity, an arbitrary and continuous scale from 1 to 100% was used according to the visual estimation of the leaf area affected by the symptoms in each sampled leaf. Data were taken from one leaf per stratum per plant.

For the yield variable, 4 m of the plot were harvested, leaving 1 m headland at the edges, and then being processed with a threshing machine of type 'Pullman', weigh the obtained grain and convert it to kg ha^{-1}. The values obtained from this variable were performed with a variance analysis and a mean test with significant minimum difference (DMS) to determine statistical significances. A sample of 100 g of grain was taken from the harvested product and processed with a FOSS oil analyzer to determine the oil content.

Results and discussion

During the two evaluation cycles the climatic conditions were not favorable for the development of the false mildew, however; during the first evaluation cycle 2017-2018 there were mild symptoms of the disease in the lines, C-54-1-OY, C-27-1Y-2Y(A/N), S-518-SEL-PPR'SS10 (A/N) which did not reach 5% of the affected foliar area on the scale proposed by Ramirez *et al*. (2011) and during the second evaluation cycle there are no symptoms of the disease in any of the lines, nor in regional witnesses

In this regard Ramírez *et al*. (2011); Singh *et al*. (2019) mention that *R. carthami* is a disease that requires very specific conditions of temperature and humidity, in addition to the materials evaluated in the study were selected apart from its agronomic characteristics and oil quality, because it has resistance to that disease. Only one application was carried out for the control of the complex of sucking insects (*Lygus lineolaris* and *Nezara viridula*) present during the button formation and flowering period. This application was carried out with the help of an aircraft, due to the impossibility of making it terrestrial due to the height of the crop. Table 2 shows the variability in the agronomic characteristics of the materials evaluated.

The differences between the variables from days to maturity and height, during the two cycles evaluated is due to the different planting date, the first of December 20, 2019 and the other of January 24, 2019. During both planting periods all the materials completed their vegetative cycle before the time period of 140 to 150 days (Navejas *et al*., 2008; Nikabadi *et al*., 2008); Padmavathi and Virmani, 2013; Ávila *et al*., 2014), for the Northwest. Even during the second year of evaluation some lines such as: C-56-1Y-1Y, CCC-1561, CCC-1672-1-1-1-1.

Table 2. Agronomic data of elite safflower lines cycles 2017-2018, 2018-2019. City Obregón, Sonora.

Genotype	Days to maturity		Height (cm)	
	2017-2018	2018-2019	2017-2018	2018-2019
0272-12-3-5-OY	133	105	137	101
0272-3-2	135	104	142	99
C-27-1Y-2Y(A/N)	137	102	137	98
C-32-0Y	138	109	146	97
C-54-1-OY	135	106	139	96
C-56-1Y-1Y	138	96	138	95
C-61-1Y-1Y	138	100	134	100
C-63-0Y	138	110	146	101
C-65-0Y	138	105	149	95
C-72-0Y	138	107	143	99
CC-14-31-5-1-OY. 1-2-0Y	135	137	165	102
CC1567-1-1-0Y-1C	133	105	142	99
CC-15-76-1-1-0Y-1C	133	103	144	95
CC1631-1-1-1-1	138	101	134	102
CC1635-1-1-1-1Y	138	106	151	93
CC1644-1-2-0Y	137	113	146	107
CCC-1561	137	93	146	91
CCC-1564-1-1-1-1-0Y	137	112	141	96
CCC-1633-1-1-1-0Y	135	111	146	97
CCC-1651-1-1-1-2-0Y	135	116	145	110
CCC-1651-1-1-1-2Y-1Y	138	113	153	105
CCC-1672-1-1-1-1	138	97	141	92
S-518-SEL-PPR’SS10 (A/N)	137	101	143	98
CIANO-OL/CC1658-1-0Y	138	103	165	106
S-518-SEL-PPR’SS10 (A/N)	137	101	143	98
CHEY-OL	138	137	127	94
CIANO-OL	135	137	163	102
RC-1002	135	137	131	96

They managed to complete the cycle before 100 days, far exceeding what was previously reported, coinciding with what was reported by Bellé *et al*. (2012); Navejas *et al*. (2014); Ramonda (2019) which mention that the planting date is a very important factor for the development of the crop, since plants established at an early date tend to enlarge their cycle and produce lush proportions compared to late and intermediate dated plants that shorten their vegetative cycle and height. According to Montoya (2010); Golkar *et al*. (2012) materials with characteristics of precocity, of a compact size, oil content above 38% and good production, are favorable to be released as commercial varieties.

Potential oil production in safflower crop is an extremely complex feature and is the result of multiple growth and development functions, which are controlled by genotype and environmental interaction (Kuruvadi *et al*., 1993; Ashrafi and Razmjoo, 2010). Over time it has always been a primary objective of safflower plant breeders to introduce this characteristic to all the materials that are generated since, although different uses can be given to the crop, its natural vocation is the production of oil for human consumption and, as a result of the search for new energy sources, its potential to produce biofuel has been investigated (Ullah and Bano, 2011; Vosoughkia *et al*., 2012; Eryilmaz and Yesilyurt, 2016).

Over time, the genetic improvement program had been dedicated to generating linoleic materials, which have been grown in different middle eastern countries such as Iran and India (Pourad, 2008; Mahboobeh *et al*., 2011), in recent years research has decreased in this section. Among the materials evaluated of this type is the line: CC1635-1-1-1-1Y which has presented production values and percentage of oil higher than the witness of the type Linoleic RC-1002 (Table 3), Montoya (2008). And to other commercial varieties of the same type such as the variety 'Promesa and Guayalejo' of recent release (Valadez and Cervantes, 2013; Valadez and Gutiérrez, 2017).

Table 3. Production and quality of elite lines of safflower cycles 2017-2018, 2018-2019. Obregón, City Sonora.

Genotype	Oil (%)		Yield (kg ha^{-1})			
	2017-2018	2018-2019	2017-2018		2018-2019	
0272-12-3-5-OY	34.82	36.43	1 575	abcde	1764	abc
0272-3-2	38.01	37.66	1 968	ab	1216	c
C-27-1Y-2Y(A/N)	37.71	37.44	1 548	abcde	1849	ab
C-32-0Y	37.44	37.1	1 473	bcde	1329	bc
C-54-1-OY	37.28	37.62	1 697	abcde	1367	bc
C-56-1Y-1Y	37.8	37.65	1 629	abcde	1271	bc
C-61-1Y-1Y	37.21	38.72	1 314	de	1193	c
C-63-0Y	39.44	38.1	1 665	abcde	1994	a
C-65-0Y	38.97	38.27	1 670	abcde	1292	abc
C-72-0Y	36.49	36.13	2 028	a	1277	bc
CC-14-31-5-1-OY.... 1-2-0Y	39.76	43.32	1 717	abcde	1703	abc
CC1567-1-1-0Y-1C	38.22	37.85	1 479	abcde	1398	abc
CC-15-76-1-1-0Y-1C	36.77	37.66	1 200	de	1174	c
CC1631-1-1-1-1	38.42	36.78	1 214	de	1246	bc
CC1635-1-1-1-1Y	40.45	39.17	1 436	bcde	1215	c
CC1644-1-2-0Y	36.76	36.68	1 362	cde	1213	c
CCC-1561	38.16	36.93	1 704	abcd	1432	abc
CCC-1564-1-1-1-1-0Y	37.13	37.68	1 139	e	1554	abc
CCC-1633-1-1-1-0Y	37.25	37.69	1 488	abcde	1328	bc
CCC-1651-1-1-1-2-0Y	37.96	37.95	1 234	de	1323	bc

Genotype	Oil (%)		Yield (kg ha^{-1})			
	2017-2018	2018-2019	2017-2018		2018-2019	
CCC-1651-1-1-1-2Y-1Y	37.95	36.65	1 647	abcde	1471	abc
CCC-1672-1-1-1-1	42.16	37.95	1 672	abcde	1217	c
S-518-SEL-PPR’SS10 (A/N)	38.22	36.43	1 634	abcde	1183	c
CIANO-OL/CC1658-1-0Y	37.02	36.88	1 276	ded	1288	bc
S-518-SEL-PPR’SS10 (A/N)	38.22	36.43	1 634	abcde	1183	c
CHEY-OL	36.4	36.24	1 614	abcde	1193	c
CIANO-OL	37.76	37.24	1 676	abcde	1500	abc
RC-1002	40.77	37.37	1 892	abc	1319	bc

α = 95% DMS 2017-2018= 571.244 DMS 2018-2019= 624.522.

In recent years, research has focused on generating materials with a high oleic acid content. Within the evaluated lines it can find some that have higher production values and oil content than witnesses Ciano Ol and Chey Ol. among these it can be found: CC-14-31-5-1-OY 1-2-0Y, and CCC-1672-1-1-1-1 with an oil percentage of 43% and 42% respectively. Widely exceeding the aforementioned witnesses which present only 37 and 36% oil (Montoya *et al*., 2008; Ávila *et al*., 2017).

Conclusions

Within the materials evaluated there are lines of the oleic type such as: CC-14-31-5-1-OY. 1-2-0Y and CCC-1672-1-1-1-1. that have agronomic characteristics that make them possible candidates to be released as varieties; however, it is necessary to make assessments in the different producing regions of northwestern Mexico to know their behavior under the different climatic characteristics present in each area.

Although research on linoleic materials has decreased, materials are still being generated in order to satisfy possible needs of the producer and industry. As is the case with line CC1635-1-1-1-1Y which has managed to surpass the linoleic witness RC-1002. And which places it as a candidate to be released as a variety in case linoleic type materials are required.

The results of this work show that the genetic improvement programme for safflower crop has performed good results and although, the generation of materials that have resistance to disease and high productivity and oil content is an incentive for producers to decide to grow safflower, the truth is that the determining factor for the area of safflower to increase is the price.

Acknowledgments

The authors thank the National Council of Science and Technology (CONACYT) for the support in the development of this work and the Genetic Improvement Program for the safflower crop of the Institute of Agricultural and Livestock Forestry Research (INIFAP) for the facilities granted in the preparation of this study.

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