Agronomic and technological evaluation of a world safflower collection under Moroccan conditions

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Abstract

Safflower (Carthamus tinctorius L.) is a minor crop well adapted to semi-arid regions worldwide. In Morocco, a breeding program has been launched and the objective is to release new spineless and productive safflower varieties with high technological value characterized by shorter vegetative cycle and higher seed yield and oil content than the existing varieties. In 2006, a total of 212 accessions from different origins were collected and evaluated in 2 different locations, Allal Tazi and Douyet, for agronomic and technological characters. The locations differ for climatic conditions, and during the experiment growing season, Allal Tazi was more favourable than Douyet. From 212 accessions, 181 completed their growth and development cycle. The results of this study showed a large variability among these accessions for spinelessness, plant height, earliness, plant branching, resistance to leaf rust, thousand seed weight (TSW), seed yield per plant and seed oil content. Location and location x accession interaction effect was significant. The germplasm exhibited, for all traits, the highest performance in favourable environment (Allal Tazi) than in less favourable one (Douyet). Some accessions showed higher seed yield per plant and oil content than those of the check cultivars, and could be suitable for use in a breeding program. Genotypes with high seed yield per plant were also characterized by a high TSW and were, in general, early flowering, dwarf and spiny. Genotypes having relatively high seed oil content (> 35%) were those that had small seeds often associated with reduced hull. Accessions were grouped into 5 pools on the basis of the following traits: seed yield per plant, seed oil content, spinelessness, earliness and resistance to leaf rust. The nature and the composition of such pool should be confirmed after assessing the accessions for one more year. Selected genotypes from each pool will be used as elite parents in our safflower crossing programme.

Key words: Safflower, *Carthamus tinctorius*, Morocco, accessions, germplasm, evaluation, pools.

تقييم زراعي وتكنولوجي لمجموعة عالمية من انضمامات القرطم بالمغرب

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ملخص

تعتبر زراعة القرطم واحدة من الزراعات الملائمة للمناطق شبه الجافة عبر العالم. بالمغرب، بدأ المعهد الوطني للبحث الزراعي برنامج تحسين وراثي لهذه الزراعة بهدف استنباط أصناف جديدة غير شائكة، مبكرة وذات انتاجية ونسبة زيت أعلى من الأصناف الموجودة حاليا بالمغرب. هذا، وقد تم تجميع وتقديم 212 انضماما من أصول جغرافية مختلفة عبر العالم بموقعين مختلفين من ناحية المعطيات المناخية : علال التازي (منطقة الغرب) والضويات (منطقة سايس) ومن خلال مجموعة من الخاصيات الزراعية والتكنولوجية.

181 انضماما استطاعت أن تكمل دورتها الزراعية وأظهرت تباينا كبيرا فيما بينها على أساس غياب الأشواك، القامة، الابكار، التشعب، مقاومة مرض الصدأ، وزن ألف بذرة، مردودية النبتة ونسبة الزيت. من ناحية أخرى، أظهرت النتائج أن هناك أيضا مفعولا معبرا لكل من الموقع والتفاعل بين الموقع والانضمام على هذه الخاصيات. مقومات هذه الانضمامات كانت أكثر تجلية في علال التازي منه في الضويات. وقد سجلنا أن مجموعة من الانضمامات تتميز بمردودية ونسبة زيت أحسن من الصنفين الذين استعملا كشاهدين وبالتالي يمكننا أن نستغلهما في برنامج الاصطفاء. الأطرزة العرقية ذات المردودية العالية تختص كذلك بوزن بذرة كبيرة، بازهار مبكر، بقصر القامة وبوجود أشواك. أما الأطرزة العرقية ذات نسبة الزيت العالية فتتميز ببذور ذات حجم صغير.

وفي الأخير، تمكنا من تجميع الانضمامات داخل خمس مجموعات جينية على أساس بعض الخاصيات المفيدة وهي المردودية، نسبة الزيت بالبذرة، غياب الأشواك، الازهار المبكر ومقاومة مرض الصدأ. هذا وسيتم تأكيد طبيعة وماهية هذه المجموعات الخمس بعد اعادة تقديم الانضمامات في سنة اضافية أخرى. من خلال هذه المجموعات، يمكن اصطفاء بعض الأطرزة من أجل استعمالها في برنامج التحسين الوراثي لزراعة القرطم ببلادنا.

الكلمات المفتاح : القرطم، المغرب، انضمامات، تقييم، مجموعات.

Evaluation agronomique et technologique d'une collection mondiale de carthame dans les conditions marocaines

Résumé

Le carthame (Carthamus tinctorius L.) est une culture mineure bien adaptée aux zones semi-arides à travers le monde. Au Maroc, un programme d'amélioration de cette culture a été initié avec l'objectif de développer des variétés inermes, productives, plus précoces et ayant un rendement grain et une teneur en huile plus élevés que les variétés existantes. En 2006, 212 accessions de différentes origines géographiques à travers le monde ont été collectées et évaluées sous deux environnements différents (sites), Allal Tazi et Douyet, pour des caractères agronomiques et technologiques. Les deux sites diffèrent par les conditions climatiques et Allal Tazi est plus favorable que Douyet. Seules 181 accessions, de cette collection, ont pu compléter leur cycle de croissance et développement. Les résultats de cette étude ont montré qu'il existe une grande variabilité entre ces accessions pour la présence/absence des épines, la hauteur des plantes, la précocité, la ramification des plantes, la résistance à la rouille, le poids de mille graines (PMG), le rendement grain par plante et la teneur en huile. L'effet du site et de l'interaction accession x site était aussi significatif. Le germoplasme évalué a montré une plus grande performance à Allal Tazi qu'à Douyet, pour tous les caractères étudiés. Quelques accessions ayant exprimé un rendement grain par plante et une teneur en huile plus élevés que les valeurs moyennes enregistrées chez les témoins sont utiles pour le programme d'amélioration du carthame. Les génotypes à rendement grain par plante élevé sont également caractérisés par un PMG élevé, une précocité à la floraison, une hauteur des plantes réduite et une présence d'épines. Les génotypes ayant une teneur en huile relativement élevée (> 35%) possèdent de petites graines souvent associées à une coque réduite. L'ensemble des accessions ont pu être regroupées dans 5 pools sur la base des caractères suivants : rendement grain par plante, teneur en huile, absence des épines, précocité et résistance à la rouille. La nature et la composition de chaque pool devraient être confirmées après l'évaluation des accessions durant une autre année. Les génotypes sélectionnés de chaque pool seront utilisés comme parents élites dans le programme de croisements.

Mots clés : *Carthame, Carthamus tinctorius, Maroc, accessions, germoplasme, évaluation, pools.*

1. Introduction

Even though safflower (*Carthamus tinctorius* L) is an ancient crop well adapted to semi-arid regions and a suitable alternative crop for cultivation in marginal areas, it still remains a minor and underutilized oilseed crop. In 2006, world safflower acreage was around 735,000 ha, which constitute less than 0.5% of total area planted by oilseed crops (FAO, 2007). Safflower is a multi-purpose plant cultivated for edible oil, birdseed, spices, dye of its flowers, medicinal properties and ornamental use (Mündel *et al.*, 1992; Johnston *et al.*, 2002; Uher, 2005).

In Morocco, safflower cultivation, for oil production, was initiated in 1965 by planting 20 ha and the highest acreage ever registered was 3342 ha, reached in 1990. Between 1973 and 1981, the safflower crop was abandoned because the spineless local varieties showed some limitations such as the low oil content in the kernel (< 30%) and the high hull percentage in the whole seed. The introduced American varieties had higher oil content (about 40%), however they were unsuccessfully grown in Morocco because of harvesting and processing problems due to their spiny character. Between 1992 and 2005, the safflower crop was abandoned again for commercial reason. In fact, the production sale prices were not fixed and guaranteed as was the case for sunflower and rapeseed (Nabloussi and Boujghagh, 2006). In all cases, and during safflower cultivation, seed yield and oil content remained very low due to the lack of adapted cultivars and poor management techniques used by farmers.

A safflower selection program was initiated in Morocco in the 60's at INRA (National Institute for Agricultural Research) and abandoned in the beginning of the 1990's. The first breed Moroccan cultivar was Zitghani, developed in 1972 (Rohrmoser, 1975). Later, the selection work carried out by a private company led to the release of two new varieties, Cartafri (a spiny type) and Cartamar (a spineless type), which were registered in 1999 (Hossini, 2002).

Recently, the Moroccan Ministry of Agriculture has called for the development of safflower through a global action plan. Thus, a new safflower breeding programme was launched in 2006. The objective of this program was to release new spineless and productive safflower varieties with high technological value characterized by a shorter vegetative cycle and higher seed yield and oil content than the existing varieties. Only three varieties have been registered, two of them are spineless, and could produce a quite high seed yield between 1.60 and 2.00 t/ha (Nabloussi and Boujghagh, 2006). However, all these varieties have a low oil content < 30%. The expected varieties should have an oil content close to 40%. Furthermore, they must be early to avoid a late season drought and spineless to be suitable to traditional management practices such as hand-harvesting. In this context, a safflower collection has been obtained to constitute the initial germplasm for evaluation in two locations for agro-morphological and technological characters useful for our new safflower breeding program in Morocco.

Materials and Methods

Germplasm

A safflower collection was obtained in 2005. It consisted of 199 accessions provided by the United States Department of Agriculture-Agricultural Research Service, 13 accessions from the gene bank of INRA-Settat (Morocco), 1 variety provided by CSIC-Cordoba (Spain) and 1 variety introduced from India. The Spanish variety (Rancho) and the Indian one (GK-7001) were used as checks. Table 1 summarizes the country of origin, the number of accessions per origin, and where the accessions were obtained.

Methods

The germplasm was planted at autumn (on 21 November 2005) in two locations representing different climatic zones (INRA-experimental station of Allal Tazi in the Gharb region and INRA-experimental station of Douyet in the Saïs region) for morphological, agronomic and technological evaluation. The Allal Tazi station is located at 30 km from Kenitra city (34°31' N, 6° W) at an elevation of 10.5 m and with a rainfall average of 550 mm. The soil is a limestone clay. The Douyet station is located at 10 km from Fez city (34°04' N, 5°07' W) at an elevation of 416 m and receives an average rainfall of 425 mm a year. The soil is a cracking clay with vertic properties. This station is also characterized by a frequent sirocco wind which could be to some extent harmful for crop growing. For all these considerations, Allal Tazi seems more favorable than Douyet. The field experiment was conducted during 2005/06 using a completely randomized design. Each accession was grown in a single 3 m-length row. Inter and intra row spacing were 80 cm and 30 cm, respectively. Both checks were systematically planted after each 10 rows to control the field heterogeneity and to have a comparison basis. Data were collected on morphological traits (initial vigour, spinelessness level, plant height and branching), phenological trait (days from sowing to flowering), agronomic traits (seed yield by plant and thousand seed weight), technological trait (seed oil content by plant) and pathologic trait (leaf rust resistance). For computation of these parameters, a randomized sample of 5 plants by accession was taken. The initial vigour (IV) was defined on the accession basis following scoring scale from 1 (less vigorous) to 5 (most vigorous). The spinelessness level (SL) was determined on the plant basis following scoring scale from 1 (very spineless) to 4 (very spiny). The plant height (PH), measured from the ground to the top of the plant at the maturity, was expressed in cm and branching indicates the number of principal branches per plant. The seed yield per plant (SYP) and the thousand seed weight (TSW) were expressed in g. The seed oil content (SOC), expressed in % of dry matter, is determined by resonance magnetic nuclear (RMN). Like the initial vigour, the leaf rust resistance (RR) was evaluated on the accession basis following scoring scale from 1 (very resistant) to 5 (very susceptible). The data gathered were statistically analyzed using univariate GLM Procedure of SAS statistical package (SAS Institute, 2001). The accession was taken as a fixed factor whilst the site was considered as a random factor.

Table 1. Origin, number and seed source of the safflower collection accessions evaluated in Allal Tazi and Douyet, Morocco, during 2006.

Country of origin	Number of accessions	Seed source (1)
Iran	63	USDA
Egypt	33	USDA
USA	28	USDA
India	23	USDA
Morocco	13	MGB
Afghanistan	12	USDA
Pakistan	7	USDA
Palestine	5	USDA
Australia	5	USDA
China	5	USDA
Iraq	3	USDA
Kazakhstan	2	USDA
Ethiopia	2	USDA
Spain	2	USDA
Turkey	2	USDA
Canada	2	USDA
Kenya	1	USDA
Sudan	1	USDA
Syria	1	USDA
Kuwait	1	USDA
Unknown	1	USDA
Total	**212**	

(1) USDA: United States Department of Agriculture; MGB: Moroccan Gene Bank.

Results and Discussion

From the 212 planted accessions, only 181 completed their growth and development cycle. The others did not emerge. Analysis of variance showed very high significant differences ($P<0.001$) between the accessions for all traits, except the initial vigor (Table 2). There was also a very high effect ($P<0.001$) of location and location x accession interaction on all studied characters except TSW, for which both locations were comparable. A similar result was found in a previous study in Kenya evaluating 36 exotic safflower accessions for agro-morphological characters such as yield per plant, branching and 100 seed weight (Mahasi *et al.*, 2005). In the present work, a large variability was observed for all the characters (Table 3). The initial vigor was higher at Allal Tazi (score 3.98) than at Douyet (score 2.80) with a score variation from 2 to 5 at Allal Tazi and from 1 to 5 at Douyet. In the studied collection, we had very spiny accessions (score 4), spiny accessions (score 3), sparsely spiny accessions

(score 2) and spineless accessions (score 1). The mean value was 1.90 and 2.40 at Allal Tazi and Douyet, respectively, exhibiting a preponderance of sparsely spiny accessions in the collection. Both checks, Rancho and GK7001, were very spiny. All the germplasm showed a high stature (146 and 122 cm at Allal Tazi and Douyet, respectively) and a long vegetative cycle (153 up to 182 days from sowing to flowering at Allal Tazi and 160 up to 185 days at Douyet). The values exhibited by the checks for these traits, respectively, were 138 cm and 167 days for Rancho and 133 cm and 169 days for GK7001.

Table 2. Analysis of variance (Mean square and significance level of differences) for agro-morphological and technological traits of 181 safflower accessions evaluated in Allal Tazi and Douyet during 2006.

Source of variation	IV(1)	SL	PH	DSF	NBP	LRR	TSW	SYP	SOC
Location	597.75	38.74	223640	5434.25	10128	48.91	86.18	46314.51	2893.07
(L)	***(2)	***	***	***	***	***	ns	***	***
Accession	3.04	10.79	1477.43	160.81	157.13	6.32	457.41	1497.59	60.55
(A)	ns	***	***	***	***	***	***	***	***
S x A	3.15	1.26	253.35	31.31	56.85	3.82	64.66	1241.34	12.96
	***	***	***	***	***	***	***	***	***
Plant (A)		0.34	104.48	3.48	34.75		36.74	779.63	9.64
		***	ns	Ns	*		ns	Ns	**

(1) IV initial vigor, SL spinelessness level, PH plant height, DSF days from sowing to flowering, NBP number of branches per plant, LRR leaf rust resistance, TSW 1000 seed weight, SYP seed yield per plant, SOC seed oil content.

(2) *, ** and *** significant at 0.05, 0.01 and 0.001 levels, respectively. ns not significant.

Table 3. Means and ranges for different traits of 181 safflower accessions evaluated in Allal Tazi and Douyet during 2006.

	Allal Tazi			Douyet		
Trait	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
IV (1)	2.00	3.98	5.00	1.00	2.80	5.00
SL	1.00	1.90	4.00	1.00	2.40	4.00
PH	107.00	146.15	177.80	80.00	122.00	147.00
DSF	153.00	172.09	182.00	160.00	175.37	184.80
NBP	18.60	28.80	46.00	10.33	23.82	34.00
LRR	1.00	2.82	5.00	1.00	3.04	5.00
TSW	17.47	34.34	57.40	23.45	36.61	55.15
SYP	1.43	44.26	119.38	10.43	32.00	74.41
SOC	23.36	31.06	47.53	19.90	27.15	46.21

(1) IV initial vigor, SL spinelessness level, PH plant height, DSF days from sowing to flowering, NBP number of branches per plant, LRR leaf rust resistance, TSW 1000 seed weight, SYP seed yield per plant, SOC seed oil content.

For the USDA safflower core collection evaluated in USA, the overall mean was 76.5 cm for plant height and 89.9 days for days to flowering, with a high range for both traits, 65.5 and 20.5, respectively (Johnson *et al.*, 2001). The mean values were too much lower than those of our study, because of the difference in the germplasm background and the date and location of planting (April 1996 in USA vs November 2005 in Morocco). More recently, in a study across 45 exotic and indigenous pure lines, the observed range for plant height was 61 to 86 cm while that for days from sowing to flowering was 116 to 134 days (Alizadeh and Carapetian, 2006). In our study and for Allal Tazi, the mean number of branches per plant was 29, varying from 19 to 46, while for Douyet, it was 24, varying from 10 to 34. Rancho had 27 and GK7001 had 25. Regarding the reaction to leaf rust, the accessions expressed, in general, an intermediate level of resistance to this disease (score 2.82 for Allal Tazi and 3.04 for Douyet). However very resistant (score 1) and very susceptible (score 5) genotypes were identified. Both checks were resistant (score 1.8 and 1.9 for Rancho and GK7001, respectively). Under Allal Tazi conditions, the mean TSW was 34 g whilst the seed yield per plant was almost 44 g with a very large variation from 1.43 up to 119.38 g. The seed oil content ranged from 23.36 to 47.53%, having a mean value of 31%. Under Douyet conditions, the mean TSW was 36.61 g whilst the seed yield per plant was almost 32 g with a large variation from 10.43 up to 74.41 g. Rancho had a TSW of 41.4 g and a SYP of 62.95 g while GK7001 had 38.3 g and 54.4 g for these characters, respectively. The seed oil content ranged from 19.90 to 46.21%, having a mean value of 27.15%,

compared to 34% for Rancho and 31.1% for GK7001. The large variation observed for oil content and seed yield per plant in both locations could be explained by the fact that the evaluated germplasm contained high performance cultivars as well as landraces, with lower performance. In the USDA core collection, the mean TSW was 40.9 g, with a range of 34.1g and the mean SYP was 7.3 g, with a range of 11.2 g (Johnson *et al.*, 2001). The mean oil content of this core collection was 26.8%, with a variation from 14 to 44% (Johnson *et al.*, 1999). In other studies, the observed range for oil content was 27 to 40% (Cazzato *et al.*, 2001), 23 to 34% (Alizadeh, 2005) and 21.4 to 31.7% (Alizadeh and Carapetian, 2006). Because of the more favourable conditions in Allal Tazi, as described above in Material and Methods section, the accessions exhibited higher potential in this location than in the other (Douyet). Nevertheless, in all cases, a large genetic variability was found across these accessions for the traits measured, allowing selection possibilities. In fact, for all these traits, some accessions had values much higher than those of the check cultivars, Rancho and GK-7001. Furthermore, significant differences were observed, in our study, between plants among accessions for spine level, plant branching and seed oil content, revealing the heterogeneity of the accessions and the possibility to select genotypes for these traits within the accessions.

Coefficients of correlation as well as their significance level for studied characters are given in Table 4. These coefficients were significant between several traits but were, in general, less than 0.50. This demonstrates that a large part of the observed variation was not explained by correlation between studied traits.

Table 4. Correlations between different traits of 181 safflower accessions evaluated in Allal Tazi and Douyet during 2006.

	IV	SL	PH	DSF	NBP	RR	SYP	TSW	SOC
IV(1)	1.00	0.07ns(2)	-0.11ns	-0.18*	-0.12ns	-0.03ns	0.06	0.15*	-0.02
SL		1.00	-0.52***	-0.38***	-0.36***	0.11ns	0.22**	0.30***	0.06
PH			1.00	0.67***	0.38***	-0.15*	-0.12ns	-0.38***	0.10ns
DSF				1.00	0.32***	-0.19**	-0.28***	-0.42***	0.14ns
NBP					1.00	-0.08ns	0.00ns	-0.43***	0.05ns
RR						1.00	-0.10ns	0.10ns	0.04ns
SYP							1.00	0.36***	-0.04ns
TSW								1.00	-0.16*
SOC									1.00

(1) IV initial vigor, SL spinelessness level, PH plant height, DSF days from sowing to flowering, NBP number of branches per plant, LRR leaf rust resistance, TSW 1000 seed weight. SYP seed yield per plant, SOC seed oil content.

(2) *, ** and *** significant at 0.05, 0.01 and 0.001 levels, respectively. ns not significant.

Johnson *et al.* (2001) reported a similar result, evaluating their core collection in American conditions. The higher coefficient was that existing between plant height and days to flowering (0.67), indicating that the high genotypes may be late. This finding is in perfect concordance with that of Johnson *et al.* (2001). In the current study, such genotypes were generally spineless and had a low TSW. In fact, there was a negative and significant correlation between plant height and spines level (-0.52) and between plant height and TSW (-0.39). There was also a negative and significant association between TSW and branching (-0.43) and between TSW and days to flowering (-0.42). The late genotypes exhibited a high vegetative development traduced by a high branching. However, the late flowering might reduce the seed filling time period, which is showed by a low TSW. The TSW exhibited the higher positive and significant association with the SYP (0.36). Number of days from sowing to flowering was negatively and significantly associated with the SYP (-0.28). This indicates that the early material is often characterized by a high seed yield which is explained by a high TSW. However, TSW showed a negative and significant association with seed oil content (-0.16), indicating that this latter might decrease with seed size. Seed yield was affected positively by TSW, which is in concordance with a finding of Bidgoli *et al.* (2006). These authors reported that TSW had a substantial direct effect on enhancement of seed yield. The significant negative relationship between SYP and days to flowering suggests that seed yield was higher for early material than for late one. This correlation was also reported by Alizadeh and Carapetian (2006). Previous studies showed that the early material was often shorter with high seed weight than taller material (Pascual-Villalobos and Alburquerque, 1996; Alizadeh and Carapetian, 2006). This was also observed in our experiment. This preliminary result, which should be confirmed next year, suggests that seed yield could be improved by selecting for early flowering and shorter genotypes. Unfortunately, such genotypes are in general spiny, which forces an additional effort to introduce the spineless character into this interesting material. The spineless trait is recessive and controlled by 4 genes (Narkhede and Deokar, 1990). However, a recent study has showed that a recessive single gene was involved in the control of this character (Pahlavani *et al.*, 2004). Consistently, spineless genotypes have low seed yield and low oil content and, in USA, efforts to release spineless cultivars had no success (Knowles, 1989). However, in India, spineless varieties with improved traits such as oil content, seed yield, TSW and early maturity were developed. The performance of this material was so close to that of spiny varieties (Sawant and Deshpande, 1993). The observed correlation between TSW and oil content was negative and low. A similar result was found by Alizadeh and Carapetian (2006). This negative association could be due to the indirect effect of hull content rather than to direct effect of seed size (Rao *et al.*, 1977).

The evaluated safflower collection exhibited a large variation for economically important traits such as seed yield, oil content, leaf rust resistance, spinelessness and earliness. This variation is potentially useful for safflower breeding program in Morocco. On the basis of the examined traits, we have constituted 5 different pools. Each pool was formed by homogeneous and performant accessions with regard to a specific trait. Thus, we have pool 1 with high seed yield per plant (> 55 g), pool 2 with high seed oil content (> 35%), pool 3

of rust resistant accessions (score < 2), pool 4 with spineless material (score = 1) and pool 5 of early flowering accessions (days from sowing to flowering < 160). The nature and the composition of these pools will be confirmed after assessing the present collection for one more year at the same locations. From each pool, stable genotypes will be selected to constitute elite parents in our future crossing programme. The crosses should be achieved between genitors belonging to different pools in order to develop germplasm combining some of the traits mentioned above.

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