# Performance, genetic variation and interrelationships in different traits of some safflower (*Carthamus tinctorius* L.) genotypes

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## ABSTRACT

The success of safflower improvement and production activities can be enhanced with scientific information generated from the study of genotypes, environments and genotype by environment interactions (GEI). In this study, 15 safflower genotypes were evaluated during two consecutive winter seasons (2013/14 and 2014/15) at three locations *viz* Gezira, El- Suki and Hudeiba Research Station farms of the Agricultural Research Corporation, Sudan. The objectives of this study were to evaluate seed yield potential, the extent of genetic variability and interrelationships in 15 safflower genotypes under different environments in Sudan. Data were collected on days to 50% flowering, days to maturity, plant height (cm), number of branches per plant, number of capitula per plant, number of seeds per capitula, 100 seed weight (g), seed yield (kg/ha), and oil content. A wide range of genetic variability was observed among the genotypes for most of the studied traits. The results also indicated that the tallest genotype (Saff 1) was the latest maturing, and the shortest genotype (Saff 13) was the earliest maturing. Simple linear correlation and path coefficient analyses indicated that days to 50% flowering, plant height, number of branches/plant and number of capitula per plant could be used as potential selection criteria in breeding programs for developing high yielding safflower genotypes. Genotypes Saff 1, Saff 12 and Saff 14 were high yielders (582.4, 507.9 and 572.8, kg/ha, respectively). Also, Saff 14 showed the highest oil content (37.5 %) followed by Saff 12 (31.0 %) and Saff 1 (29.1 %), therefore, they could be grown successfully under irrigated winter condition of central and northern Sudan.

# INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is cultivated mainly for its seed, which was used as edible oil and as birdseed (Istanbulluoglu, 2009). The largest producing countries of safflower for oil were India, USA, Mexico, Australia and Ethiopia accounting for about 85% of the world's safflower production. (FAO, 2002).

Safflower is not cultivated in Sudan, except in the Northern State along the Nile River, although cultivated safflower is believed to have originated in Northern Sudan (Knowles, *et al.* 1989). It had been grown, for a long time, in small areas in the Northern State for farmer's personal use. It has been mainly grown for seeds and not really for oil production. The seeds have been roasted with wheat to make what is known as *Galleya* and served to people on occasions; also, it is used for medicinal purposes. The plants are also used around cereal and vegetable farms to fence out animals (Khidir, 1997).

Safflower plant is native to the Middle East and have some agronomic advantages such as drought resistance and adaptation to arid and semi-arid climatic conditions and resistant to saline conditions. Therefore, it is suitable for growing in dry and marginal areas as a drought tolerant plant (Weiss, 2000).

Safflower oil has been produced commercially and for export for about 50 years, for the paint industry, for cooking, margarine and salad oil. The oil is rich in poly unsaturated fatty acids (linoleic acid, 78%), plays an important role in reducing blood cholesterol level and considered as a healthy cooking medium (Shivani *et al.*, 2009).

Progress in plant breeding depends on the extent of genetic variability present in a population that permits effective selection procedures. The success of safflower as a commercial oil seed crop in traditional areas and its expansion to new areas will largely depend on the extent of improvement made in both its yield and oil content.

Evaluating yield components and their interrelationships and detecting suitable selection indices is very important in safflower breeding programs, especially the direct components of yield that are related to the various morphological characters regarded as indirect components of yield.

Engels (1991) mentioned that Sudan has to be a worldwide partner in safflower research activity.

The objective of this study was to evaluate the performance for seed yield potential, the extent of genetic variability and interrelationships in 15 safflower genotypes under different environments in Sudan.

# MATERIALS AND METHODS

## Experimental sites

The experiments were conducted during two consecutive winter seasons (2013/14 and 2014/15), at three locations, *viz*. Gezira (GRS), El-Suki (SRS) and Hudeiba (HRS) Research Stations, of the Agricultural Research Corporation (ARC), Sudan. The Gezira Research Station farm is located in Wad Medani at latitude 14° 24′N, longitude 33° 29′ E. It is characterized by heavy cracking clays (58%), calcareous alkaline soil, with a pH of 8.3 and low organic matter content (0.02%). El-Suki Research Station farm is located in Sinnar State, latitude 13° 20′N, longitude 33° 50 E, is characterized by heavy clay soil, with a pH of 8.0. Hudeiba Research Station farm is located on high terrace soil near EL- Damer in River Nile State, latitude 17° 34′N, longitude 33° 56′ E. The high terrace soil is characterized by clay loam with high calcium carbonate content.

## Plant material and experimental design

Fifteen genotypes of safflower introduced from different countries were used in this study (Table 1). The experiments were arranged in a randomized complete block design with four replicates in all locations and seasons.

## Cultural practices

Across all growing seasons and locations, the land was plowed, harrowed, leveled and ridged. In the first season, sowing date was at the second week of December across different locations and at the second week of November for the second season. was 6.0 * 3.2 m, with four ridges. Inter and intra- row spacing was 0.8 and 0.2m, respectively. Three seeds per hill were sown and thinned to one plant per hill after three weeks. Weeding was done manually. The crop was irrigated every two weeks or whenever necessary and irrigation was held three weeks before harvest. No pest or diseases were observed during the growing seasons. The data were collected on days to 50% flowering, days to maturity, plant height (cm), number of branches per plant, number of capitula per plant, number of seeds per capitula, 100 seed weight (g), seed yield (kg/ha), and oil content.

## Statistical analysis

Analysis of variance procedure was used for each season to test the significant differences among the evaluated genotypes. Combined analysis of variance was carried out for testing the effect of environments, genotypes and their interactions. Mean for seasons was used to compute simple linear correlation coefficients between all possible combinations. The path coefficients analysis was done to partition the correlation coefficients between seed yield and its components into direct and indirect effects.

Table 1. Safflower genotypes grown at Gezira, El-Suki, and Hudeiba Research Station Farms in seasons 2013/ 14 and 2014 / 15.

| | Genotype | Pedigree | Origin | Description |
|---|---|---|---|---|
| | Saff 1 | Saff 89 | Pakistan | Non-spiny |
| | Saff 2 | Saff 151 | Iran | Spiny |
| | Saff 3 | Saff 171 | China | Spiny |
| | Saff 4 | Saff 150 | Uzbekistan | Spiny |
| | Saff 5 | Saff 69 | Morocco | Non-spiny |
| | Saff 6 | Saff 79 | Afghanistan | Spiny |
| | Saff 7 | Saff 78 | Afghanistan | Spiny |
| | Saff 8 | Saff 153 | Thailand | Spiny |
| | Saff 9 | Saff 155 | Libya | Non-spiny |
| | Saff 10 | Saff 75 | Iran | Non-spiny |
| | Saff 11 | Saff 152 | Syria | Spiny |
| | Saff 12 | Saff 146 | Ukraine | Spiny |
| | Saff 13 | Saff 135 | India | Spiny |
| | Saff 14 | Saff 156 | Bangladesh | Spiny |
| | Saff 15 | Saff 131 | Egypt | Spiny |

## RESULTS AND DISCUSSION

**Genotypic variation**

Significant differences were observed among the studied genotypes for most of the measured traits in both seasons and locations (Table 2). In season 2013/14, the variability among genotypes was highly significant for most of the studied traits with the exception of seed yield in Gezira and Hudeiba, number of seeds per capitulum in El-Suki and days to 50% flowering and number of capitula per plant in Hudeiba location. Days to maturity and number of branches per plant showed non-significant differences in all locations.

In season 2014/15, the variability between genotypes was significant for most of the studied traits with the exception of number of capitula per plant in all locations, plant height, and 100-seed weight in Gezira location, number of seeds per capitula in El-Suki location and number of branches per plant in Gezira and Hudeiba locations.

Variability among genotypes for most of the studied traits indicated that differences existed between the genotypes for yield and its components. These results were in agreement with those obtained by Ramazani *et al.*, (2006) in safflower. While it is in contrary with the findings of Ghamarnia and Sepehri (2010) who reported significant differences between cultivars for the number of capitula per plant, number of seeds per capitulum and 100-seed weight.

Table 2. Mean squares for 15 safflower genotypes, grown at Gezira (GRF), El- Suki (SRF) and Hudeiba (HRF) Research Station Farms during winter season (2013/14 and 2014/15).

| Trait | Gezira | El-Suki | Hudeiba |
|---|---|---|---|
| | | Season 2013/ 14 | |
| Days to 50% flowering | 19.64** | 31.85** | 2.42ns |
| Days to maturity | 10.08ns | 22.10ns | 7.71ns |
| Plant height (cm) | 327.23** | 225.24** | 75.27* |
| Number of branches/plant | 2.99ns | 6.14ns | 0.34ns |
| Numbers of capitula/plant | 26.59* | 61.96* | 10.64ns |
| Number of seeds/ capitulum | 77.40* | 136.53ns | 147.86* |
| 100- seed weight (g) | 0.21* | 0.15* | 3.76* |
| Seed yield ( kg/ha) | 9499.41ns | 11577.50* | 33599.42ns |
| | | Season 2014/15 | |
| Days to 50% flowering | 10.09** | 43.91** | 109.26** |
| Days to maturity | 7.86** | 14.24** | 27.09** |
| Plant height (cm) | 45.52ns | 85.07** | 93.33** |
| Number of branches/plant | 2.67ns | 10.88** | 1.36ns |
| Number of capitula/plant | 11.18ns | 62.01ns | 5.13ns |
| Number of seeds/ capitulum | 18.73* | 67.32ns | 17.04** |
| 100-seed weight (g) | 0.65ns | 1.00* | 0.81* |
| Seed yield ( kg/ha) | 40394.02** | 26582.86* | 7187.52* |

*, ** Significant at 0.05 and 0.01 probability levels, respectively; ns = not significant.

**Days to 50%flowering**

This trait is used as an earliness index. It showed significant differences among genotypes across seasons and locations (Table 3). From the combined analysis over all seasons and locations, it ranged between 76 to 84 days for Saff 13 and Saff 1, respectively, with an average mean of 79.91 days. This trait is usually used as an indicator to earliness to identify early and medium flowering genotypes to

suit short growing seasons. Hence, the early flowering genotypes were Saff 13 followed by Saff 14, while the latest one was Saff 1. These findings are in agreement with the results of Munaiza *et al*., (2015), who reported that among safflower genotypes, days to 75% flowering, plant height, number of secondary branches per plant, number of capsules per plant, number of seeds per capsule and seed yield per plant were significantly different.

**Days to maturity**

Significant differences were observed among the studied genotypes for days to maturity (Table 3). From the combined analysis over all seasons and locations, the mean days to maturity ranged from 109 days (Saff 15) to 114 days (Saff 1), with an average mean of 112 days. These findings are in agreement with those of Zabta *et al.,* (2014) who reported large variations for days to maturity in safflower genotypes.

Both early and late maturity are vital for breeding programs to identify early, medium and late maturing genotypes for choosing suitable genotype (s) for different environments. However, to avoid biotic and abiotic stresses, early maturing genotypes result in early harvest. Hence, the early maturing genotypes were Saff 15 followed by Saff 3 and Saff 13, indicating that these genotypes were suitable for short seasons, while the late maturing ones were Saff 1 followed by Saff 5 and Saff 4. These findings were consistent with those obtained for days to 50% flowering.

**Plant height (cm)**

Development of medium height genotypes is important for any plant breeding program, because these genotypes are suitable for mechanical harvesting and are resistant to lodging. Plant height showed significant differences among genotypes across seasons and locations. From the combined analysis over all seasons and locations, the mean plant height ranged from 63.77 to 84.7 cm for Saff 13 and Saff 1, respectively, with an average mean of 72.01 cm (Table 3). These results are in agreement with the findings of Koutroubas *et al.,* (2004) who reported that safflower genotypes differed in plant height. Thus, in this study, the tallest genotype was Saff 1, while the shortest genotype was Saff 13. Camas *et al.,* (2007) suggested that the variations observed between cultivars for plant height were related to genotypic variations. This study indicated that the tallest genotype (Saff 1) was the latest maturing, and the shortest genotype was the earliest maturing (Saff 13).

**Number of branches/plant**

This character showed non - significant differences among the genotypes across seasons and locations except for El Suki location in the 2$^{nd}$ season (Table 2). From the combined analysis over all seasons and locations, it ranged between 5.75 and 7.29 branches, with an average mean of 6.4 branches. The highest number of branches per plant was obtained by genotype Saff 8, while the lowest was recorded by genotypes Saff 4 followed by Saff 2, Saff 5 and Saff 12 (Table 3).

Safflower possesses remarkable genetic diversity across different regions of the world (Knowles *et al.,* 1989). Therefore, the variations obtained in this study were considered to be related to the genotypes used, environment and genotypes X environments interaction. Number of branches may

result in increasing number of capitula per plant which leads to an increase in seed yield. These results are in agreement with the findings of Camas *et al.*, (2007) who reported that safflower cultivars were significantly different for number of branches.

Table 3. Means of days to 50% flowering (D50%F), days to maturity (DM), Plant height (PHT) and number of branches/plant (NBR) combined over seasons (2013/14 and 2014/15) and locations (Gezira, Suki and Hudeiba).

| Genotype(Saff) | D 50%F | DM | PHT (cm) | NBP |
|---|---|---|---|---|
| 1 | 84.62a | 114.96a | 84.76a | 6.3ab |
| 2 | 80.46b | 111.88cd | 75.41b | 5.97b |
| 3 | 79.83bc | 110.25de | 72.73bcde | 7.26a |
| 4 | 84.29a | 113.29bc | 74.75bc | 5.75b |
| 5 | 79.21bc | 114.04ab | 72.81bcde | 5.92b |
| 6 | 79.96bc | 113.00bc | 73.19bcd | 6.10b |
| 7 | 80.25bc | 111.63cd | 68.69ef | 6.49ab |
| 8 | 78.83bc | 111.67cd | 68.22f | 7.29a |
| 9 | 80.46b | 113.00bc | 71.15cdef | 6.68ab |
| 10 | 78.46bc | 112.88bc | 71.08cdef | 6.63ab |
| 11 | 78.50bc | 112.00cd | 70.31def | 6.41ab |
| 12 | 80.25bc | 113.00bc | 74.40bcd | 5.95b |
| 13 | 76.04d | 110.71de | 63.77g | 6.40ab |
| 14 | 78.21c | 110.92de | 70.15def | 6.10b |
| 15 | 79.25bc | 109.29e | 68.74ef | 6.81ab |
| Mean | 79.91 | 112.17 | 72.01 | 6.4 |
| C.V (%) | 3.81 | 2.46 | 8.98 | 25.92 |
| SE± | 0.32 | 0.23 | 0.61 | 0.12 |

Means having the same letter (s) within each column are not significantly (P= 0.05) different according to Duncan's Multiple Range Test.

**Number of capitula per plant**

Number of capitula per plant is one of the most important traits that directly influence the yield. This trait showed highly significant differences among the studied genotypes across all seasons and locations (Tables 4). From the combined analysis of variance, ranged between 13.83 and 19.37 capitula, with an average mean of 16.41, the highest number of capitula/plant was obtained by genotypes Saff 15 followed by Saff 8 and Saff 3, whereas the lowest number was recorded by genotype Saff 4. These findings are in agreement with the results of Ghamarnia and Sepehri (2010) who reported significant differences among cultivars for the safflower number of capitula per plant,

number of seeds per capitulum and 100-seed weight. Omidi *et al.,* (2009) indicated that the number of capitula/plant was associated with the increase of seed yield/plant in safflower and concluded that selection for number of capitula/plant was effective to improve seed yield.

Although number of capitula per plant was greatly affected by environmental factors, it is considered as one of the important traits that mostly influences yield of safflower and for new cultivars of safflower, well-developed 12 to 14 capitula/ plant are sufficient (Weiss, 2000).

**Number of seeds per capitulum**

Highly significant differences in number of seeds per capitulum were observed among genotypes over all seasons and locations (Table 4). From the combined analysis of variance, it ranged from 19.50 to 30.93 seeds/ capitulum, with an average mean of 25.72. Genotype Saff 4 had the highest number of seeds per capitula followed by genotype Saff 1; in contrast, the lowest number of seeds per capitulum was genotype Saff 6 (Table 4).

Bagheri *et al.,* (2001) reported that the seed yield/plant had significant and positive correlation with number of seeds/ plant, number of capitula/plant and seed weight. Therefore, number of seed per capitulum is an important trait for safflower production. These results were in agreement with that of Ghamarnia and Sepehri (2010) who reported significant differences among cultivars for the number of capitula per plant, number of seeds per capitulum and 1000-seed weight. This variability can be used to develop varieties with desirable trait(s).

**One hundred seed weight (g)**

This trait showed highly significant differences among the studied genotypes across all seasons and locations (Tables 4). The combined analysis showed that the highest 100-seed weight was exhibited by the genotypes Saff 7 (4.7g) followed by genotype Saff 11, Saff 8 and Saff 9, while the lowest was shown by genotype Saff 1 (3.3 g).

Although 100-seed weight is considered as one of the major traits affecting seed yield, it is highly influenced by the genetic structure and the environment. The evaluation of 100-seed weight demonstrated that a wide range of variations existed between the genotypes. These variations were considered to be from the reactions of the different genotypes to different environmental conditions. These results were in agreement with those reported by Camas *et al.* (2007). However, Alizadeh and Carapetian (2006) stated that 100-seed weight of safflower is genotype dependent. Such genotypes (Saff 7, Saff 11, Saff 8 and Saff 9), which displayed the highest 100-seed weight, were also included in the groups with the highest and medium seed yield.

**Oil content and fatty acid composition**

Safflower genotypes showed differences in oil content; it ranged from 28.4% to 37. 5%. The highest oil content (37.5 %) was recorded for Saff 14, while the lowest was 28.40% which was recorded by Saff 10 (Table 4). These results were higher than those reported by Gama *et al.* (2005) who stated that the oil content of safflower cultivars varied between 24.5% to 27.2%. Our results

agree with those of Xuehai and Qingwei (1993) who reported that the oil content of safflower was 30% or more. Donglas *et al.* (2004) reported that 33% of the variation in seed oil content was a consequence of environmental and technical variation; thus 67% of the variation observed was due to genetic factors.

Table 4. Means of number of capitula /plant (NCP), number of seeds/ capitula (NSPC), 100-seed weight (100 SW) and percentage oil content combined over seasons (2013/14 and 2014/15) and locations (Gezira, Suki and Hudeiba).

| Genotype (Saff) | NCP | NSPC | 100-SW | POC |
|---|---|---|---|---|
| 1 | 16.06bcd | 29.85ab | 3.3d | 29.1 |
| 2 | 15.70bcd | 25.21cde | 4.1bc | 31.2 |
| 3 | 17.32abc | 25.54cde | 4.2bc | 30.3 |
| 4 | 13.83d | 30.93a | 4.0c | 28.6 |
| 5 | 15.85bcd | 28.31abcd | 4.3abc | 31.6 |
| 6 | 16.78abcd | 19.50f | 4.2abc | 31.7 |
| 7 | 16.37abcd | 24.51de | 4.7a | 31.9 |
| 8 | 18.98ab | 23.43e | 4.5abc | 31.9 |
| 9 | 17.06abcd | 24.13de | 4.5abc | 31.9 |
| 10 | 16.90abcd | 24.99cde | 4.4abc | 28.4 |
| 11 | 15.36cd | 28.94abc | 4.6ab | 32.2 |
| 12 | 15.24cd | 25.35cde | 4.2abc | 31.03 |
| 13 | 15.77bcd | 24.15de | 4.4abc | 34.7 |
| 14 | 15.60cd | 26.12bcde | 4.4abc | 37.5 |
| 15 | 19.37a | 24.78cde | 4.1bc | 31.9 |
| Mean | 16.41 | 25.72 | 4.26 | - |
| C.V (%) | 29.76 | 25.24 | 18.48 | - |
| SE± | 0.38 | 0.66 | 0.06 | - |

Means having the same letter (s) within each column are not significantly (P= 0.05) different according to Duncan's Multiple Range Test.

**Seed yield (kg/ha)**

Seed yield plays an important role in determining the economics of the safflower crop. Seed yield of the genotypes significantly varied depending on the genetic constitutions and their interactions with the environment. Highly significant differences were observed across all seasons and locations (Table 5). The highest general means of 830 and 932 kg/ha were obtained in El-Suki (2013/14) and Gezira (2014/15) locations, respectively, while the lowest general means of 603 and 311 kg/ha were obtained in Hudeiba location for season 2013/14 and 2014/15, respectively.

Across locations, in season 2013/14, it ranged between 473 to 1230 kg for Saff 8 and Saff 6, and from 237 to 620 kg for Saff 13 and Saff 7 in season 2014/15.

From the combined analysis over all seasons and locations, the mean seed yield ranged between 478.5 to 627.5 kg/ha, with an average mean of 561.51 kg/ha. Nine out of fifteen genotypes obtained higher seed yield than the grand mean; these were Saff 1, Saff 2, Saff 6, Saff 7, Saff 8, Saff 9, Saff 11, Saff 14 and Saff 15. The genotype Saff 6 outyielded all genotypes. The highest seed yield was exhibited by genotype Saff 6 (1230 kg/ha), while the lowest was obtained by genotypes Saff 13 followed by Saff 12 (478.5 and 507.9 kg/ha), respectively. These results suggest that genotype and environmental factors have a great influence on the variation between genotypes for seed yield. Generally, the findings obtained in this study are in agreement with the results reported by Camas *et al.* (2007) who showed significant differences in seed yield among safflower cultivars.

Table 5. Means of seed yield (kg/ha) for 15 Safflower genotypes grown at Gezira, El-Suki and Hudeiba
Research Station Farms, season 2013/20 14 and 2014/15 and their combined analysis.

| Genotype | Gezira | | El-Suki | | Hudeiba | | Combined |
|---|---|---|---|---|---|---|---|
| (Saff) | 2013/14 | 2014/15 | 2013/14 | 2014/15 | 2013/14 | 2014/15 | |
| 1 | 684ab | 536.98abcd | 780.obc | 462.5abcd | 682ab | 346.9abc | 582.4abc |
| 2 | 690ab | 542.18abcd | 870.b | 382.5bcd | 603ab | 318.18abcd | 567.7abc |
| 3 | 573b | 370.73de | 690.0bc | 532.5abcd | 569ab | 321.88abcd | 508.7bc |
| 4 | 664ab | 534.75abcd | 820.0bc | 350.0cd | 488b | 303.38abcd | 526.3abc |
| 5 | 670ab | 427.6bcd | 870.07b | 457.5abcd | 610ab | 263.83bcd | 554.7abc |
| 6 | 671ab | 526.43abcd | 1230.0a | 562.5ab | 526b | 252.35cd | 627.5a |
| 7 | 638ab | 441.8bcd | 0.70bc | 620.0a | 646ab | 382.08a | 571.3abc |
| 8 | 651ab | 482.28abcd | 910.1ab | 567.5ab | 473b | 284.90abcd | 561.9abc |
| 9 | 703ab | 565.78abc | 740.0bc | 520.0abcd | 814a | 371.10ab | 618.2ab |
| 10 | 729a | 586.05ab | 500.0c | 505.0abcd | 691ab | 359.13abc | 562.0abc |
| 11 | 645ab | 498.20abcd | 980.0ab | 505.0abcd | 684ab | 303.88abcd | 601.7ab |
| 12 | 580b | 384.88cde | 780.0bc | 472..5abcd | 547b | 286.48abcd | 507.9bc |
| 13 | 573b | 243.23e | 660.bc | 550.0abc | 610ab | 237.78d | 478.5c |
| 14 | 645ab | 489.73abcd | 870.0b | 500.0abcd | 606ab | 328.93abcd | 572.8abc |
| 15 | 697ab | 651.08a | 990.0ab | 332.5d | 501b | 314.83abcd | 581.0abc |
| Mean | 657 | 932.05 | 830.0 | 488.00 | 603 | 311.57 | 561.51 |
| C.V(%) | 13.04 | 23.56 | 26.12 | 25.38 | 24.90 | 20.51 | 28.8 |
| SE± | 12.46 | 46.15 | 36.3 | 17.648 | 21.350 | 9.78 | 12.29 |

**Simple linear correlation coefficients**

Correlation coefficients, as indicators of the degree of relationship between different attributes, are useful in determining those traits which are highly associated with seed yield and, consequently, can be used as indicators in selection for yield. Simple linear correlation coefficients among various pairs of eight traits of safflower genotypes are presented in Table 6. In the present study, all of the studied traits, except days to maturity and 100 seed weight, were positively and highly significantly correlated with seed yield and could play a significant role in assessment of seed yield (Table 6)

Also, the strong association of number of capitula per plant, number of branches per plant and 100 seed weight with seed yield was observed by Bidgoli *et al.*, (2006). Hence, selection for days to 50% flowering, plant height, number of branches per plant, number of capitula per plant and number of seeds per capitulum may indirectly help in selecting high yielding genotypes.

Seed yield was negatively and significantly correlated with days to maturity (-0.26***) and 100 seed weight (-0.23***). Such findings were consistent with those of Prasad and Agrawal (1994), but inconsistent with the results of Omidi (2000), for 100-seed weight.

From the obtained results, traits such as days to 50% flowering, plant height, number of branches/plant, number of capitula per plant and number of seeds per capitulum, which were strongly and positively correlated with seed yield can be considered among the most important traits in selection of high yield safflower genotypes.

**Path coefficient analysis**

Path coefficients analysis divided the correlation coefficient into direct and indirect effects of the studied traits on the seed yield and it had been used to assist in identifying the traits that could be useful as selection criteria to improve crop yield.

Path analysis showed that days to 50% flowering, plant height, number of branches/plant, number of capitula/plant and100-seed weight had strong positive direct effects to enhancement of seed yield, while days to maturity and number of seeds/capitulum had negative direct effects (Table 7). The correlation between days to maturity and seed yield were significantly negative due to their strong negative direct effects (-0.47). These results are in agreement with the findings of Ahmadzadeh *et al.*, (2012) who reported a positive direct effect of days to 50% flowering and negative direct effect of days to maturity on seed yield in safflower.

Yield components not only directly affect the yield, but also indirectly by affecting other yield components in positive or negative ways. Among the different studied traits for the direct as well as indirect contribution towards seed yield, the direct effect of days to 50% flowering was more pronounced followed by number of capitula/plant, number of branches/plant and plant height. This finding, for number of capitula per plant, was supported by the finding of Lahane *et al.*, (1999) who reported that, number of capitula per plant is an important trait to enhance seed yield in safflower. So, selection for any of these traits leads to improving the genotypes for seed yield. From these results, the traits of days to 50% flowering, plant height, number of branches/plant and number of capitula/plant appear to be principal traits affecting seed yield and any positive increase in these traits

will result on increasing seed yield, therefore, should be considered in any safflower improvement program.

Table 6. Simple linear correlation coefficients among various pairs of 9 traits of 15 safflower genotypes combined over two seasons (2013/ 14 and 2014/15) and three locations (Gezira , El-Suki ,and Hudeiba).

| | DF | DM | PH | NBr | Nca | NSCa | HSW | Sy |
|---|---|---|---|---|---|---|---|---|
| DF | - | | | | | | | |
| Dm | 0.09* | - | | | | | | |
| Ph | 0.08ns | 0.11 | - | | | | | |
| NBr | 0.06ns | -0.46*** | 0.09* | - | | | | |
| Nca | 0.16** | -0.41*** | 0.06ns | 0.63*** | - | | | |
| NSCa | 0.53*** | -0.10* | -0.05ns | 0.36*** | 0.40*** | - | | |
| HSW | -0.32*** | 0.38*** | 0.00 | -0.31*** | -0.35*** | 0.20*** | - | |
| Sy(ha) | 0.26*** | -0.26*** | 0.29*** | 0.39*** | 0.47*** | 0.42*** | -0.23*** | - |

*,**, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively, ns = not significant.

DF: days to 50% flowering, DM: Days to maturity, PH: Plant height, NBr: Number of branches/plant, Nca: Number of capitula /plant, NSCa: Number of seeds/ capitulum, HSW: Hundred seed weight, Sy: Seed yield (kg/ha).

Table 7. Path coefficient analysis of direct (in bold) and indirect effect of 7 traits on safflower seed yield of 15 genotypes grown in seasons 2013/14 and 2014/15 at Gezira, El-Suki, and Hudeiba Research station farms.

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | rij |
|---|---|---|---|---|---|---|---|---|
| X1 | **0.87** | -0.04 | 0.01 | 0.02 | 0.09 | -0.34 | -0.36 | 0.26 |
| X2 | 0.08 | **-0.47** | 0.02 | -0.15 | -0.23 | 0.07 | 0.42 | -0.26 |
| X3 | 0.07 | -0.05 | **0.18** | 0.03 | 0.04 | 0.03 | 0.00 | 0.29 |
| X4 | 0.06 | 0.22 | 0.02 | **0.32** | 0.37 | -0.23 | -0.34 | 0.39 |
| X5 | 0.14 | 0.19 | 0.01 | 0.20 | **0.58** | -0.26 | -0.39 | 0.47 |
| X6 | 0.46 | 0.05 | -0.01 | 0.11 | 0.23 | **-0.65** | 0.23 | -0.42 |
| X7 | 0.28 | -0.18 | 0.00 | -0.10 | -0.20 | -0.13 | **0.66** | -0.23 |

X1: Days to 50% flowering, X2: Days to maturity, X3: Plant height, X4 = number of branches / plant, X5: number of capitula/plant, X6: Number of seeds/capitula, 7: hundred seed weight (g).

rij= Simple linear correlation coefficient

## CONCLUSIONS

Based on the results of this study, it could be concluded that a wide range of genetic variability was observed among safflower genotypes for most of the studied traits. Genotypes Saff 1, Saff 12 and Saff 14 were high yielding, therefore, they could be suggested for growing successfully under irrigated winter conditions of the Sudan. Saff 14 (spiny) showed the highest oil content of the investigated genotypes (37.5%), followed by Saff 12 (spiny) at 31. 03 % and Saff 1 (non spiny) at 29.1%. Simple linear correlation and path coefficient analysis indicated that days to 50% flowering, plant height, number of branches/plant and number of capitula/plant could be used as potential selection criteria in breeding programs for developing high yielding safflower genotypes.

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# أداء الإنتاجية والاختلافات الوراثية والعلاقات المتداخلة بين الصفات المختلفة لبعض الطرز الوراثية من القرطم (*Carthamus tinctorius* L.).

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## الخلاصة

القرطم من المحاصيل الزيتية المهمة في العالم، وفي السودان يزرع المحصول فقط في الولاية الشمالية في المساحة الواقعة علي طول النيل. إن نجاح تحسينِ محصول القرطمِ ونشاطاتِ إنتاجِه يُمْكِنُ أَنْ يُحَسّنا بالمعلومات العلمية التي تنتج منْ دراسة التراكيب الوراثية. قُيّمَت في هذه الدراسةِ خمسة عشرَ تركيباً وراثياً من القرطمَ علي مدي فصلي شتاء متتاليينِ (15/2014-14/2013) في ثلاثة مواقع هي محطات بحوث الجزيرة و السوكي والحديبة التابعة لهيئة البحوث الزراعية بالسودان. هدفت الدراسةِ إلي تُقييم هذه التراكيب الوراثية من حيث الانتاجية ومكوّناتِها و دراسة العلاقات المترابطة بين الانتاجية والصفات المرتبطة بها بإستعمال الإرتباطَ الخطي البسيط و معامل تحليل المسار وتمييز التراكيب الأعلى إنتاجية. كانت الصفات المدروسة هي عدد الأيام حتي 50% إزهار و عدد الأيام حتي النضج و طول النبات و عدد الفروع بالنبات و عدد الكبسولات بالنبات و عدد البذور بالكبسولة و وزن المائة حبة بالجرام و الإنتاجية بالكيلوجرام للهكتار ونسبة الزيت بالبذور. أوضحت النتائج وجود مدي واسع من التباين الوراثي بين التراكيب الوراثية لمعظم الصفات المدروسة. أوضحت النَتائِج إلي أنّ التركيب الوراثي (Saff 1) هو الاطول من بين التراكيب الوراثية الاخري و متأخر النُضُج، بينما التركيب الوراثي (Saff 13) مبكر النُضُج وهوأقصرالتراكيب الوراثية. من ناحية أخري، باستخدام الارتباط الخطي البسيط ومعامل تحليل المسار، أوضحت الدراسة أن صفات عدد أيام 50% إزهار و طول النبات و عدد الفروع في النبات و عدد الرؤوس بالنبات يمكن استعمالهما كصفات إنتخاب غير مباشر في برامج التربية لاستنباط أصناف عالية الإنتاجية من القرطم. خلصت الدراسة إلي أن التراكيب الوراثية Saff 1 و Saff 12 و Saff 14 كانت عالية الإنتاجيةً ( 582.4 ، 507.9 و 572.8 :جم/ ه علي التوالي)، كما وأن التركيب الوراثي Saff 14 له أعلي محتوي من نسبة الزيت (37.5 %) يعقبه في ذلك Saff 12 (31.0 %) و Saff 1 (29.1 %) لذلك يمكن زراعتها بنجاح تحت ظروف الري الشتوي بأواسط وشمال بالسودان.