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Evaluation of the Germ Plasm Collection of Safflower *Carthamus tinctorius* L. VI. Length of Planting to Flowering Period and Plant Height in Israel, Utah and Washington

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Summary. Germ plasm collections of safflower, *Carthamus tinctorius* L. were evaluated for variability and divergence in two traits which are strongly influenced by the environment, viz. length of the growing period from planting to flowering (GPPF) and plant height. The test locations were: Bet-Dagan, Israel, 1969, about 2000 lines; Logan, Utah, USA, 1964, about 1000 lines; Washington, USA, 1959, 339 lines. Natural selection produced a wide range of variation for length of the GPPF: there were considerable differences between introductions from the same countries. Divergence between lines within countries for GPPF length was so extensive that there was little evident divergence between regions. Generally lines from the Indian subcontinent, Egypt, Morocco, Spain, Portugal and France were earlier, while those from Turkey and Ethiopia were later. Some significant but inconsistent correlations were obtained between the length of the GPPF and other traits measured in Utah. It was not significantly correlated with yield and yield components or with oil content. Therefore, selection can be applied for a shorter GPPF without effecting yield or oil content.

Plant height variations between lines from the same countries were very high in all test locations, still divergence between regions was apparent. The means of the lines from the Indian subcontinent were the lowest while those of the lines from Iran, Afghanistan, Turkey and Ethiopia were the highest in all the locations tested. Plant height was not correlated significantly with yield/plant and yield components in the Indian and Egyptian lines, and with yield and some components in the Iranian lines. Therefore, it appears possible to breed shorter, high yielding varieties.

The correlations of GPPF and of plant height between test locations though low, were highly significant. Generally, the lines maintained their developmental pattern (early vs. late, short vs. tall) in the different nurseries, but there were position changes within the groups.

Introduction

The collection of germ plasm resources of crop plants, their maintenance and their study and utilization in breeding and evolution research have been receiving increased attention in recent years (Creech and Reitz, 1971; Frankel, 1970; Frankel and Bennett, 1970; Krull and Borlaug, 1970). The safflower (*Carthamus tinctorius* L.) germ plasm collection has yielded various beneficial results in breeding programs (Ashri, 1973; Knowles, 1969). It also has many advantages for research on crop evolution. Safflower is a crop of antiquity. It was usually grown in small populations in plots or as borders, for the dye extracted from the dried florets and also as a minor oil plant (Hanelt, 1961; Knowles, 1955; Weiss, 1971), it has related wild species with which it is cross-fertile (Ashri and Knowles, 1960; Hanelt, 1963; Knowles, 1969) and its collection and sampling in the major areas of old culture is fairly adequate (Knowles, 1969).

A study of the safflower germ plasm collection in Israel was augmented by data from the USA and thus it was possible to study regional divergence (Ashri, 1973), reaction to pests (Ashri, 1971a, 1971b, and 1973) and the effects of human and natural selection on yield (Ashri et al. 1974), oil content (Ashri et al. in press) and morphological traits (Ashri, 1973; Ashri, in press). The present study deals with two interconnected characters which are strongly influenced by the environment, hence were probably affected primarily by natural selection. The traits are the length of the growing period from planting to flowering (GPPF) and plant height.

Characteristically, safflower plants stay in the rosette stage until the weather warms, when they rapidly develop tall main stalks which carry leaves, secondary branches and flowering heads. The length of the rosette stage, the GPPF and plant height are greatly affected by sowing date, photoperiod, temperature, soil moisture and soil fertility (Beech, 1969; Knowles, 1955; Weiss, 1971; Zimmerman, 1973). The first study of a safflower collection was made by Kupsow (1932) who divided the lines into three ecotypic classes: late and tall, intermediate in both growing season and height, early and short. Knowles (1955) and Weiss (1971) also reported that late plants tend to be taller. Kupsow (1932) found that many areas contained more than one ecotype.

Table 1. Mean length of period from planting to flowering of lines from different origins in three nurseries together with standard errors (S.E.) and ranges*

Country of origin	Washington				Utah				Israel 1969			
	No. of lines	No. of days			No. of lines	No. of days			No. of lines	No. of days		
		$\bar{x}$	S.E.	Range		$\bar{x}$	S.E.	Range		$\bar{x}$	S.E.	Range
Afghanistan	2	82.5	2.5	80- 85	13	117.4	1.3	110-123	33	70.0	1.8	50-68
Bangladesh	34	74.3	0.5	70- 80	8	101.2	0.3	101-103	49	63.0	0.8	50-86
Egypt	34	82.9	0.4	80- 85	58	107.3	0.3	102-112	375	63.0	0.2	50-77
Ethiopia	-	-	-	-	20	116.1	1.4	101-123	25	68.0	0.7	62-74
India	123	79.3	0.2	75- 85	432	105.1	0.1	101-120	958	63.0	0.1	34-86
Iran	31	83.7	0.9	80- 90	79	110.9	0.5	101-120	119	68.0	0.6	50-86
Iraq	3	85.0	0.0	-	8	111.0	1.9	108-113	11	68.0	0.8	65-74
Israel	4	76.3	1.3	75- 80	14	108.2	3.6	101-117	21	64.0	0.9	59-71
Japan	-	-	-	-	9	104.0	0.7	101-107	9	68.0	2.1	62-77
Jordan	14	97.9	3.6	80-110	9	109.2	1.7	105-122	15	65.0	1.0	56-71
Kenya	-	-	-	-	12	111.9	1.9	105-123	9	64.0	2.0	59-74
Kuwait	-	-	-	-	1	118.0	-	-	19	63.0	1.1	59-74
Morocco	3	78.3	1.7	75- 80	11	103.7	0.7	101-110	14	63.0	0.8	59-68
Pakistan	21	77.4	1.1	70- 85	78	102.2	0.3	101-122	24	65.0	1.8	50-86
Portugal	33	81.8	0.4	80- 85	56	105.6	0.4	101-113	65	64.0	0.4	50-74
Romania	-	-	-	-	5	105.6	1.8	102-110	2	66.0	4.5	62-71
Spain	12	77.1	0.7	75- 80	17	106.1	1.6	102-110	25	65.0	0.4	62-68
Sudan	-	-	-	-	4	105.5	1.4	103-108	32	62.0	0.5	59-68
Syria	6	79.2	0.8	75- 80	12	107.8	1.0	103-113	9	60.0	2.6	50-71
Turkey	16	99.1	5.2	80-140	45	114.5	0.8	101-123	85	66.0	0.5	50-77
U.S.S.R.	-	-	-	-	1	105.0	-	-	6	62.0	1.3	59-68

* In Washington and Israel to first bloom, in Utah to 10% bloom

Knowles (1969) reported that the lines of the Indian and European centers were early while those of Ethiopia were late. Zimmerman (1973) has shown that there are different genotypes affecting the length of the rosette stage in *C.tinctorius* and *C.flavescens* Spreng. (which is closely related to the first). Recently, Obeso (1975) discovered an extremely early safflower genotype which has no rosette stage and which appears to differ from the original accession by one or two genes (personal communication).

Materials and Methods

The studies were conducted independently in three locations over a span of ten years. The germ plasm collections for the tests were assembled by P.F. Knowles. Over the years the number of lines increased through additional introduction and selection in mixed accessions, while some lines were lost. The nurseries and procedures were:

Bet-Dagan, Israel (longitude 35E, latitude 32N). The germ plasm collection with early 2000 lines (Table 1) was grown in 1968 and 1969. Since the collections were evaluated also for resistance to insects (Ashri, 1971b) they were planted much later than the accepted commercial practice. Since the 1968 season was unusually hot and dry, only the 1969 data will be discussed here (see Ashri, 1973 for 1968 data). In the 1969 nursery each collection was planted in one 5 m row on May 2, with rows 1 m apart. It was sprinkler irrigated as needed. The date of the first flower -- when three plants started blooming -- was recorded for each row. Plant height was measured at the end of the season.

Logan, Utah (longitude 110W, latitude 41N). Nearly 1000 lines were planted on April 13, 1964, in rows as above. The date in which 10% of the plants in the row flowered was recorded. Plant height was measured as above.

Wawawai, near Pullman, Washington (longitude 117W, latitude 46N). The nursery with about 340 lines was planted on April 15, 1959 and was sprinkler-irrigated. First flower and plant height were recorded as described for Bet Dagan.

Association of characters was tested by calculating correlation coefficients for the measurement data and by contingency tables in all other instances, using the BMD programs (Anon., 1967). Since regional germ plasm pools with opposing trends may balance each other, the correlation and χ^2 contingency values were calculated for the whole collection and separately for the lines from India, Iran and Egypt. These sources were chosen because they were heavily represented in the collection, have an old history of safflower culture (Hanelt, 1961; Knowles, 1969; Weiss, 1971) and represented different gene pools (Knowles, 1969).

The Student-Newman-Keuls simultaneous range test procedure for the mean scores of the regions of origin was performed by the Gabriel method as described by Sokal and Rohlf (1969). The countries were grouped into regions following the "Centers of Cultivation" of Knowles (1969) with some modifications. Sokal and Rohlf (1969) emphasize that *a posteriori* tests are not very sensitive to differences of individual means or differences within small subsets. This is especially true with an increasing number of means (regions) and with unequal numbers of observations (lines per region). Analyses within locations were conducted on all the lines for which there were data. Analyses between locations were conducted on common lines.

Results and Discussion

It is readily seen from the findings presented in Table 1 that the length of the GPPF was greatly affected by the

Table 2. Simultaneous range test for significance of the differences in mean number of days from planting to flowering of lines from the major safflower regions *

Region No.	Countries	Washington No. of lines	Washington Mean	Utah No. of lines	Utah Mean	Israel 1969 No. of lines	Israel 1969 Mean
1	India, Bangladesh, Pakistan	178	76.1 a	510	104.1 a	993	62.6 a
2	Iran, Afghanistan	33	81.8 a	92	111.8 ab	141	68.4 b
3	Israel, Jordan, Syria	24	87.0 ab	34	108.7 a	42	63.3 a
4	Turkey	16	96.9 b	44	114.8 b	82	65.6 ab
5	Egypt	34	80.6 a	58	107.3 a	358	62.3 a
6	Ethiopia	-	-	19	117.1 b	25	66.4 ab
7	Kenya	-	-	12	112.2 ab	9	63.0 a
8	Portugal, Spain, France, Morocco	48	78.3 a	90	105.7 a	107	63.2 a

* Values having different letters differ significantly at the 5% level.

Table 3. Correlation values (r) of the number of days to 10% bloom and of plant height in Utah with other traits measured in Utah, calculated for the collection as a whole and separately for the lines from India, Iran, and Egypt +

Traits	Days to 10% bloom: Whole Collection	Lines from India	Lines from Iran	Lines from Egypt	Plant height: Whole Collection	Lines from India	Lines from Iran	Lines from Egypt
OIB ‡, width	.104***	.237***	.225	.234	.299***	.193***	.262	-.080
" , length	-.167***	.269***	-.380***	-.045	-.150**	.135**	-.357**	.096
Primary head diameter	.372***	.277***	-.093	.274*	.280***	.426***	-.034	-.210
Plant height	.726***	.324***	.590***	-.182	--	--	--	--
Days to 10% bloom	--	--	--	--	.726***	.324***	.590***	-.182
Heads/plant, $\bar{X}$ No.	-.011	.068	-.080	.075	-.095	-.041	-.058	-.040
Seeds/head, $\bar{X}$ No.	.137***	.053	-.055	.050	.141**	.096	-.133*	-.022
Seed weight	-.238***	.120*	-.111	.025	-.200***	-.018	-.297*	-.064
Yield/plant	-.021	.055	-.076	.211	-.088	.017	.017	-.140
Oil content	-.144***	.166**	-.040	-.252	-.078	.126*	.278*	-.009
No. of lines	1002	432	79	58	1002	432	79	58

+ Significance levels: * = 5%, ** = 1%, *** = 0.1%

‡ OIB = Outer Involucral Bracts.

test location and the very late sowing in Israel. There are also clear differences between the source countries in their mean GPPF. Generally though, most of the lines flowered within a short period: in Washington 80% of the lines flowered within 75-85 days after planting, in Utah most lines flowered 101-110 days after planting and in Israel most flowered 59-68 days after planting (flowering was hastened by the very late planting) (Ashri, 1973). It is interesting to note the extent of variability within sources: e.g. in Utah, Turkish and Ethiopian introductions were among the earliest and the latest; in Israel, this was the case with the lines from India, Bangladesh, Iran, and Pakistan. It appears that in these large countries with varied climatic and

Table 4. Mean height of plants of lines from different origins in three nurseries, together with standard errors (S.E.) and ranges

Country of origin	Washington				Utah				Israel 1969			
	No. of lines	Height, cm			No. of lines	Height, cm			No. of lines	Height, cm		
		$\bar{X}$	S.E.	Range		$\bar{X}$	S.E.	Range		$\bar{X}$	S.E.	Range
Afghanistan	13	96.9	2.8	75-120	13	117.6	1.2	104-119	33	79.0	5.1	25-121
Bangladesh	35	54.6	1.4	40- 70	8	68.4	5.0	53- 92	49	59.0	1.7	25- 89
Egypt	36	87.4	0.9	75-100	58	86.2	1.2	68-104	375	64.0	0.6	25- 97
Ethiopia	-	-	-	-	20	104.7	3.5	53-119	25	80.0	1.6	65- 97
India	131	66.9	0.7	40- 80	432	74.5	0.5	53-119	958	53.0	0.3	25- 97
Iran	54	95.6	1.8	40-120	79	103.6	1.3	71-119	119	86.0	1.8	25-121
Iraq	5	94.0	1.9	90-100	8	104.0	3.4	92-119	11	93.0	5.0	65-121
Israel	4	71.3	1.3	70- 75	14	93.7	4.1	71-116	21	75.0	3.4	57- 89
Japan	-	-	-	-	9	87.0	1.8	80- 95	9	71.0	4.0	57- 89
Jordan	14	78.9	2.2	60- 90	9	87.3	2.9	74-104	15	77.0	2.7	65-105
Kenya	-	-	-	-	12	96.7	4.1	74-119	9	59.0	4.6	25- 37
Kuwait	-	-	-	-	1	119.0	-	-	19	71.0	2.7	57- 89
Morocco	3	80.0	2.9	75- 85	11	84.1	2.3	68- 92	14	66.0	3.0	49- 89
Pakistan	22	64.5	2.6	45-100	78	67.6	1.5	53-119	24	63.0	3.7	25- 97
Portugal	37	72.2	1.5	45-100	56	88.2	1.4	62-116	65	68.0	1.4	25-121
Romania	1	75.0	-	-	5	81.8	4.6	68- 92	2	57.0	0.0	-
Spain	12	78.3	1.3	75- 90	17	87.2	2.1	71-101	25	66.0	0.9	57- 73
Sudan	-	-	-	-	4	98.0	0.0	-	32	70.0	1.5	57- 89
Syria	6	82.5	2.1	75- 90	12	92.0	3.1	71-107	9	53.0	8.9	25- 81
Turkey	17	86.8	1.7	75-100	45	102.5	2.2	53-119	85	80.0	1.8	25-105
U.S.S.R.	1	60.0	-	-	1	80.0	-	-	6	66.0	3.2	57- 89

agricultural conditions different ecotypes were established, due primarily to natural selection but aided perhaps by human selection. For example, in Iran two types are known: a winter type which withstands cold better and a spring type that must be planted later to avoid the cold winter.

There was little evident divergence between the regions when the means are compared (Table 2). This probably resulted from the high degree of variability within the regions and the source countries and because most of the lines flowered within a short period of time in all test locations. Generally, lines from the Indian subcontinent, Egypt, Portugal, Spain, France and Morocco were early in the three nurseries while those from Turkey and Ethiopia were late in the three tests.

The correlations between the GPPF in the different locations were low but highly significant: Israel-Utah $r = 0.35^{***}$, Israel-Washington $r = 0.15^{**}$, Utah-Washington $r = 0.50^{***}$. Although many lines changed their relative position within the early, medium or late groups, lines that were early in one test location tended to be early in the other locations. This can be important in planning tests for earliness in new locations where a more limited, yet more promising groups of lines, could be tested initially.

Significant correlations were obtained between the GPPF in Utah and several other traits (Table 3). However, the pattern varied with the germ plasm pools and was inconsistent. It is important to note that the GPPF was not significantly correlated with yield per plant and the yield components except for the low $r = 0.12^{*}$ with seed weight in the Indian varieties, which is a component of minor impact (Ashri et al., 1974). Similarly, yield was not correlated with the length of the season to flowering also in a study in India (Chavan, 1961). Thus, it is concluded that artificial selection could be applied for a shorter growing period and for higher yields, simultaneously.

Plant height is determined to a large extent by conditions during the flowering period and by the onset of flowering. This is shown by the correlations of the length of the GPPF and plant height shown in Table 3. The low negative r value in the Egyptian lines would indicate that in this genetic reservoir the relationship between the two traits is not as complete.

Plant height varied between test locations and sources with an extremely wide range for some of the latter (Table 4). Generally, there was a good agreement in plant height between the test nurseries despite the different conditions: Israel-Utah $r = 0.64^{***}$, Israel-Washington $r = 0.59^{***}$ and Utah-Washington $r = 0.70^{***}$ (Ashri, 1973). It would appear that, as for the GPPF, a thorough screening of the collection in one location can help preselect lines of the desired height for testing in other locations.

Because of the wide range observed in height, it was possible to identify more divergence between sources

Table 5. Simultaneous range test for significance of the differences in mean height of plants of lines from the major safflower regions *

Region No.	Countries	Washington No. of lines	Washington Mean	Utah No. of lines	Utah Mean	Israel 1969 No. of lines	Israel 1969 Mean
1	India, Bangladesh, Pakistan	188	62.0 a	513	72.1 a	990	50.6 a
2	Iran, Afghanistan	67	93.5 d	88	104.9 c	141	84.9 cd
3	Israel, Jordan, Syria	24	76.0 c	35	90.3 b	41	71.0 bc
4	Turkey	17	83.7 c	43	103.1 c	81	79.4 c
5	Egypt	36	84.6 c	58	85.2 b	335	63.4 b
6	Ethiopia	-	-	19	106.3 c	25	76.6 c
7	Kenya	-	-	12	96.3 bc	8	60.0 b
8	Portugal, Spain, France, Morocco	52	71.4 b	91	86.4 b	107	64.6 b

* Values having different letters differ significantly at the 5% level

(Tables 4, 5). The correlations between plant height and various other traits (Table 3) are usually low and not significant. Yield per plant and the yield components were not significantly correlated to plant height except for two components in the Iranian germ plasm (Table 3) which have only a minor contribution to yield (Ashri et al., 1974). Thus, it should be possible to breed shorter, high yielding varieties. The lower plant stature would have various benefits in dryland and irrigated conditions. Oil content and height were significantly correlated in the Indian and Iranian lines, but the values were very low. They were not correlated in the lines from Egypt. It appears that selection for lower plants and higher oil content can be practiced.

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