

Investigation of morphoagronomic performance and selection indices in the international safflower panel for breeding perspectives

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Abstract: Developing high yielding safflower cultivars with good adaptation to diverse environmental conditions can improve production in terms of seed yield and reduce the deficiency in edible oil. The genetic variability that exists among and within populations for desirable agronomic traits can be used to develop elite cultivars. A total of 94 safflower accessions from 26 different countries were used in this study to evaluate morphoagronomic performance, determine the pattern of similarity centers, and identify the best performing accessions by conducting 2 field experiments in Pakistan and Turkey using augmented design. Genetic diversity for important yield and yield traits was described including capitulum diameter (17.30 to 28.30 mm), branches per plant (5.10 to 17.30), capitula per plant (8.70 to 80.40), and seed yield per plant (4.86 to 51.02 g). These analyses showed a good level of variation in the current study. Using principal component analysis, it was observed that days to flower initiation, days to 50% flowering, days to flower completion, seed yield per plant, capitula per plant, branches per plant, seeds per capitulum, and capitulum diameter were the major contributors to the observed genetic variability in the evaluated safflower panel. Seed yield per plant reflected a significant and positive correlation with capitula per plant, branches per plant, and capitulum diameter, and these traits can be suggested as a selection criterion in safflower breeding programs. The hierarchical clustering was in agreement with the patterns of 7 similarity centers based on seed yield per plant, capitula per plant, capitulum diameter, and branches per plant. During this study, a few promising safflower accessions were selected for future breeding programs.

Key words: Agronomic traits, germplasm characterization, multivariate analyses, safflower, selection criteria, similarity center

1. Introduction

Agronomic crops are grown on a large scale for consumption purposes because they provide food, feed grain, oil, and fiber. They also serve as a source of income to farmers and as an important source of raw materials for industries (Sahin et al., 2002; Serce et al., 2010; Cesur et al., 2018; Galiana-Belaguer et al., 2018).

About 75% of the global vegetable oil trade is derived from 4 main crops: soybeans, oil palm, rapeseed, and sunflowers. Such a large percentage has led some to consider other oilseed crops as underutilized or neglected (Murphy, 1999). However, these underutilized oilseed crops represent a good source of genetic diversity and adaptation to diverse agroecological zones (Padulosi et al., 1999; Thies, 2000; Ozdemir et al., 2018).

Safflower (*Carthamus tinctorius* L.) is an underutilized oilseed crop and belongs to the family *Asteraceae* (Knowles, 1989; Ali et al., 2019). It is known as one of the oldest crop plants grown under dry and hot climatic conditions of the Middle East, which is its origin and diversity center (Knowles and Ashri, 1995). Safflower was first domesticated and grown because of its flowers for dyes, food coloring, and various medicinal uses, but it is also grown as an oilseed crop. Safflower is preferred over other oilseed crops due to its agronomic advantages such as drought resistance and adaptation to the arid and semiarid conditions that represent important scenarios of climate change (Weiss, 2000).

Safflower accessions belonging to specific geographical locations present similarities on the basis of their

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morphoagronomic traits, and these geographical locations for safflower are known as its similarity centers. Various studies have been conducted to explore safflower similarity centers and different similarity centers have been proposed. Knowles (1969) proposed 7 similarity centers (1: the Far East, 2: India and Pakistan, 3: the Middle East, 4: Egypt, 5: Sudan, 6: Ethiopia, and 7: Europe) for safflower while Ashri (1975) identified 10 similarity centers (1: the Near East, 2: Iran and Afghanistan, 3: Turkey, 4: Egypt, 5: Ethiopia, 6: Sudan, 7: the Far East, 8: India and Pakistan, 9: Europe, and 10: Kenya). Similarly, Chapman et al. (2010) proposed 5 similarity centers for safflower (1: the Near East, 2: Iran, Afghanistan, and Turkey, 3: Egypt, Ethiopia, and Sudan, 4: the Far East, India, Pakistan, and Sudan, 5: Europe).

It has been estimated that safflower is cultivated in nearly 20 different countries of the world on a total of 1,140,002 ha and with a production of 948,516 t (FAOSTAT, 2015). Russia, Kazakhstan, Mexico, USA, Turkey, and India are the largest producers, accounting for approximately 71% of total world production (FAOSTAT, 2015). Safflower oil is rich in polyunsaturated fatty acids and resistant to dry climates, but it shows some unfavorable characteristics, including low seed yield, low oil content, biotic stresses susceptibility, and spininess (Nimbkar, 2008). Cultivated safflower varieties and available breeding lines reflect a low level of genetic diversity, which limit their utilization in safflower breeding programs. Therefore, it is necessary to devise an extensive genetic and phenotypic characterization of the global safflower germplasm for the development of crop improvement strategies to enhance safflower productivity (Kumar et al., 2015) and contribute to meeting the world's oil demand. Characterization of crop genetic resources provides an opportunity to find novel variations which can be helpful for breeding activities (Baloch et al., 2017; Nadeem et al., 2018; Yaldiz et al., 2018). Fast phenotyping using easy-to-measure traits is particularly helpful for the preliminary evaluation of breeding nurseries (Asare et al., 2011). Several studies have been conducted on safflower germplasm characterization using morphoagronomic traits. Dwivedi et al. (2005) tested 570 safflower accessions in a core collection in search for plant characteristics to enhance traits including morphoagronomic and quality traits and resistance to stresses. Jaradat and Shahid (2006) investigated 631 accessions of safflower from 11 countries using various morphoagronomic traits that revealed a good level of genetic variation. Kumar et al. (2016) evaluated 531 safflower accessions for 12 morphoagronomic traits revealing significant variation; 85% of these accessions had a plant height less than 155 cm and were more suitable for mechanical harvesting. Shivani et al. (2010) characterized 75 safflower accessions using morphoagronomic traits and recommended 4 best performing accessions for different

breeding objectives. They found maximum variability for seed yield and clustered all of the accessions into 8 groups. It has been suggested that phenotypic diversity in any crop plant is best estimated if morphoagronomic trait evaluation is used along with proper multivariate analysis (Mohammadi and Prasanna, 2003; Vollmann et al., 2005). Correlation analysis can be helpful to investigate the level of association between various traits, and evaluated information can be effectively utilized as selection criteria for the improvement of crops (Iqbal et al., 2006; Özer et al., 2010; Baloch et al., 2014).

This study aims to evaluate the morphoagronomic performance in an international panel of 94 safflower accessions across 2 diverse locations (Pakistan and Turkey), observe similarity centers patterns, and assess some promising accessions for future safflower breeding.

2. Materials and methods

2.1. Plant material and phenotypic evaluation

Ninety-four safflower accessions, including one check cultivar named Thori-78 from 26 different geographical countries provided by the United States Department of Agriculture, were used in the experiments (Table 1). Safflower field experiments were conducted at the National Agricultural Research Center in Pakistan (2016–2017) and at the Research Farm of Bolu Abant İzzet Baysal University in Turkey (2018), respectively. The experiments were arranged in augmented design at both locations with a single row having a length of 3 m for each safflower accession. Row to row and block to block distances of 50 cm and 1 m were maintained, respectively. The check cultivar Thori-78 used as control in this study is most commonly used in Pakistan due to its higher oil contents and resistance to various stresses, and this was repeated after every 16 accessions in both experiments. Ten plants for each accession were maintained and used for data recording. Diammonium phosphate and ammonium sulfate were used as sources of fertilizer. All accessions were managed with the same agronomic practices and weeding was manually controlled.

Data were recorded on important qualitative and quantitative traits using International Board of Plant Genetic Resources descriptors for safflower. Qualitative traits include; early vigor: poor, intermediate, strong; growth habit: erect, bushy; leaf shape: ovate, lanceolate, oblong; leaf margins: entire, serrate, parted; leaf hairiness: nonhairy, intermediate, many hairs; leaf spininess: no spines, few spines, intermediate, many spines; branching pattern: basal, medium, upper; angle of branches: appressed (15° – 20°), intermediated (20° – 60°), spreading (60° – 90°); flower color: white, pale-yellow, yellow, yellow-orange, orange, orange-red, red; head shape: conical, oval, flattened; and seed shape: oval, conical, crescent.

Table 1. List of 94 international safflower accessions panel evaluated during the current study using 13 morphoagronomic traits across 2 locations (Pakistan and Turkey).

S.No.	Genotype name	Accession no.	Donor organization	Country origin	Plant ID	Continent
1	Afghanistan-1	30614	USDA	Afghanistan	P1-253764	Asia
2	Afghanistan-2	30653	USDA	Afghanistan	P1-304592	Asia
3	Afghanistan-3	33541	USDA	Afghanistan	PI 220647	Asia
4	Argentina-1	30695	USDA	Argentina	P1-367833	America
5	Australia-1	33542	USDA	Australia	PI 235660	Oceania
6	Austria-1	33568	USDA	Austria	PI 253519	Europe
7	Austria-2	33670	USDA	Austria	BVAL-901352	Europe
8	Bangladesh-1	31509	USDA	Bangladesh	PI-401472	Asia
9	Bangladesh-2	31510	USDA	Bangladesh	PI-401478	Asia
10	Bangladesh-3	31511	USDA	Bangladesh	PI-401480	Asia
11	Bangladesh-4	33609	USDA	Bangladesh	PI 401470	Asia
12	China-1	30624	USDA	China	P1-262452	Asia
13	China-2	30625	USDA	China	P1-262453	Asia
14	China-3	33638	USDA	China	PI 543979	Asia
15	China-4	33639	USDA	China	PI 543982	Asia
16	China-5	33642	USDA	China	PI 544001	Asia
17	China-6	33651	USDA	China	PI 568809	Asia
18	China-7	33661	USDA	China	PI 568874	Asia
19	Egypt-1	30563	USDA	Egypt	P1-250082	Africa
20	Egypt-2	30574	USDA	Egypt	P1-250528	Africa
21	Egypt-3	30577	USDA	Egypt	P1-250532	Africa
22	Egypt-4	30578	USDA	Egypt	P1-250540	Africa
23	Egypt-5	30580	USDA	Egypt	P1-250605	Africa
24	Egypt-6	30581	USDA	Egypt	P1-250608	Africa
25	France-1	33662	USDA	France	PI 576985	Europe
26	Hungary-1	33575	USDA	Hungary	PI 288983	Europe
27	India-1	30579	USDA	India	P1-250601	Asia
28	India-2	30662	USDA	India	P1-305195	Asia
29	India-3	30673	USDA	India	P1-306926	Asia
30	India-4	30674	USDA	India	P1-306941	Asia
31	India-5	30677	USDA	India	P1-306976	Asia
32	India-6	33538	USDA	India	PI 199878	Asia
33	Iran-1	30588	USDA	Iran	P1-250720	Asia
34	Iran-2	30631	USDA	Iran	P1-304444	Asia
35	Iran-3	30633	USDA	Iran	P1-304448	Asia
36	Iran-4	30713	USDA	Iran	P1-405958	Asia
37	Iran-5	30718	USDA	Iran	P1-405967	Asia
38	Iran-6	33556	USDA	Iran	PI 250840	Asia
39	Iran-7	33621	USDA	Iran	PI 406010	Asia
40	Israel-1	30548	USDA	Israel	P1-198990	Asia
41	Israel-2	30594	USDA	Israel	P1-253386	Asia

Table 1. (Continued).

42	Israel-3	3015	USDA	Israel	P1-253892	Asia
43	Israel-4	33564	USDA	Israel	PI 251290	Asia
44	Iraq-1	30612	USDA	Iraq	P1-253761	Asia
45	Iraq-2	30613	USDA	Iraq	P1-253762	Asia
46	Jordan-1	30589	USDA	Jordan	P1-251284	Asia
47	Jordan-2	30590	USDA	Jordan	P1-251285	Asia
48	Jordan-3	33559	USDA	Jordan	PI 251265	Asia
49	Jordan-4	33560	USDA	Jordan	PI 251267	Asia
50	Jordan-5	33561	USDA	Jordan	PI 251268	Asia
51	Kazakhstan-1	30681	USDA	Kazakhstan	P1-314650	Asia
52	Libya-1	33608	USDA	Libya	PI 393499	Africa
53	Morocco-1	30552	USDA	Morocco	P1-239042	Africa
54	Morocco-2	30606	USDA	Morocco	P1-253560	Africa
55	Pakistan-1	30564	USDA	Pakistan	P1-250194	Asia
56	Pakistan-2	30565	USDA	Pakistan	P1-250201	Asia
57	Pakistan-3	30567	USDA	Pakistan	P1-250345	Asia
58	Pakistan-4	30568	USDA	Pakistan	P1-250346	Asia
59	Pakistan-5	30569	USDA	Pakistan	P1-250351	Asia
60	Pakistan-6	30570	USDA	Pakistan	P1-250353	Asia
61	Pakistan-7	30573	USDA	Pakistan	P1-250481	Asia
62	Pakistan-8	33547	USDA	Pakistan	PI 250474	Asia
63	Pakistan-9	33548	USDA	Pakistan	PI 250478	Asia
64	Pakistan-10	33635	USDA	Pakistan	PI 426521	Asia
65	Pakistan-11	Check	PGRI-Pakistan	Pakistan	Thori-78	Asia
66	Portugal-1	30604	USDA	Portugal	P1-253553	Europe
67	Portugal-2	30605	USDA	Portugal	P1-253556	Europe
68	Portugal-3	30608	USDA	Portugal	P1-253564	Europe
69	Portugal-4	30610	USDA	Portugal	P1-253569	Europe
70	Portugal-5	30611	USDA	Portugal	P1-253571	Europe
71	Portugal-6	30620	USDA	Portugal	P1-258412	Europe
72	Romania-1	30549	USDA	Romania	P1-209287	Europe
73	Russia-1	30663	USDA	Russia	P1-305535	Asia
74	Spain-1	30595	USDA	Spain	P1-253388	Europe
75	Spain-2	30596	USDA	Spain	P1-253391	Europe
76	Spain-3	30597	USDA	Spain	P1-253394	Europe
77	Spain-4	30598	USDA	Spain	P1-253395	Europe
78	Syria-1	30616	USDA	Syria	P1-253898	Asia
79	Syria-2	30617	USDA	Syria	P1-253900	Asia
80	Syria-3	30700	USDA	Syria	P1-386174	Asia
81	Thailand-1	30701	USDA	Thailand	P1-387821	Asia
82	Turkey-1	30646	USDA	Turkey	P1-304498	Asia

Table 1. (Continued).

83	Turkey-2	30648	USDA	Turkey	P1-304502	Asia
84	Turkey-3	30650	USDA	Turkey	P1-304504	Asia
85	Turkey-4	30651	USDA	Turkey	P1-304505	Asia
86	Turkey-5	30688	USDA	Turkey	P1-340086	Asia
87	Turkey-6	33543	USDA	Turkey	PI 237538	Asia
88	Turkey-7	33565	USDA	Turkey	PI 251978	Asia
89	Turkey-8	33567	USDA	Turkey	PI 251984	Asia
90	Turkey-9	33627	USDA	Turkey	PI 406701	Asia
91	Turkey-10	33628	USDA	Turkey	PI 406702	Asia
92	Uzbekistan-1	30623	USDA	Uzbekistan	P1-262435	Asia
93	Uzbekistan-2	30696	USDA	Uzbekistan	P1-369846	Asia
94	Uzbekistan-3	30697	USDA	Uzbekistan	P1-369853	Asia

USDA: United States Department of Agriculture; PGRI: Plant Genetic Resources Institute.

Similarly, important quantitative traits were leaf length, leaf width, days to flower initiation, days to 50% flowering, days to flower completion, days to maturity, plant height, branches per plant, capitula per plant, seeds per capitulum, capitulum diameter, 100-seed weight, and seed yield per plant.

2.2. Statistical tools

Augmented block design (Federer, 1956) with one standard check variety named Thori-78 was used for this study and mean was evaluated using the online software for augmented block design developed by Rathore et al. (2004). Analysis of variance was computed for all the studied traits using the SAS statistical program (version 9.1.3, Cary, USA). Quantitative data traits from both locations were averaged to calculate different parameters such as mean, minimum, maximum, standard deviation correlations, principal component analysis (PCA), and multivariate analysis using the statistical software XLSTAT (www.xlstat.com).

3. Results

3.1. Morphoagronomic performance of safflower accessions

The studied plant traits revealed a wide range of variation in the evaluated safflower materials. Analysis of variance (ANOVA) was performed on 13 morphoagronomic traits recorded across 2 different environments (Pakistan and Turkey) to understand the effects of accessions and locations (Table 2). Days to maturity, leaf length, capitulum per plant, seeds per capitulum, seed yield, and 100 seeds weight had no effects on accession. Mean data across the 2 locations is presented in Table 3. The studied traits reflected great variations for various traits in both

places; however, all traits reflected greater performance in Pakistan except leaf length, seeds per capitulum, and 100-seed weight, which were more superior in Turkey. Overall mean across the 2 locations, minimum, maximum, and standard deviation are presented in Table 4. Days to flower initiation ranged from 113.5 to 131.5 with a mean of 120.95 days. Minimum days to flower initiation were recorded for accession India5, while the maximum was recorded in the accession Afghanistan2. Days to 50% flowering ranged from 117.5 to 137.5 with a mean of 126.48 days. Safflower accession India5 revealed minimum days to 50% flowering, while maximum days to 50% flowering were observed for accession Afghanistan2. Days to flower completion ranged from 121.5 to 143.5 with a mean of 133.09 days. Minimum and maximum days to flower completion were recorded for accessions India5 and Afghanistan2, respectively. Days to maturity ranged from 139.5 to 157.5 with a mean of 148.50 days. Minimum days to maturity were recorded for accession India5, while highest number of days to maturity was recorded with Syria2 accession. Seed yield per plant ranged from 4.86 to 51.02 with a mean of 15.95 g. Minimum seed yield per plant was obtained with accession France1, while maximum seed yield per plant was exhibited for accession China3. In addition, 100-seed weight ranged from 2.17 to 5.32 g with a mean of 3.33 g and minimum and maximum 100-seed weight was revealed for accessions Afghanistan1 and Egypt5, respectively.

Morphoagronomic variations were also investigated at the country level (Table 5), and Afghanistan revealed maximum days to flower initiation and days to 50% flowering, while Iraq exhibited maximum days to flower completion and days to maturity. Portugal showed maximum plant height and capitulum diameter. Hungary showed maximum leaf length, leaf width, capitulum per

Table 2. Analysis of variance for different traits of 94 safflower accessions across 2 locations.

Traits	Source of variation	Mean squares
Days to Flower Initiation	Accessions	18.9516***
	Location	198803.4141***
Days to 50% flowering	Accessions	34.9301***
	Location	189596.6111***
Days to flower completion	Accessions	38.8753***
	Location	171896.7475***
Days to maturity	Accessions	30.2526
	Location	156410.2273***
Leaf length	Accessions	9.2772996
	Location	94.0884854***
Leaf width	Accessions	0.90938296*
	Location	10.18640455***
Plant height	Accessions	212.16869***
	Location	65837.64985***
Branches per plant	Accessions	9.3901519*
	Location	15.5232000
Capitula per plant	Accessions	238.09251
	Location	12625.16336***
Seeds per capitulum	Accessions	54.357623
	Location	576.682667***
Capitulum diameter	Accessions	11.320729***
	Location	165.477879***
Seed yield per plant	Accessions	180.18912
	Location	9472.65167***
100-seed weight	Accessions	0.71088189***
	Location	1.07804091

*Statistically significant; * ($P \leq 0.05$); ** ($P \leq 0.01$); *** ($P \leq 0.001$).

plant, and seed yield per plant, while maximum branches per plant, seeds per capitulum, and 100-seed weight were shown in Australia, Kazakhstan, and China, respectively.

To investigate genetic diversity more comprehensively in an international safflower panel of 94 accessions, various qualitative traits were recorded at the proper time. Leaf color was observed as light green (25.53% of total accessions) and dark green (74.47% of total accessions). Most of the safflower accessions (84.04% of total accessions) showed strong early vigor, while intermediate early vigor (15.96% of total accessions) was also observed. Growth habit was revealed as erect (75.53% of total accessions) and bushy (24.47% of total accessions) type. Leaf shape was classified as ovate (84.04% of total accessions), lanceolate (2.13% of total accessions), and oblong (13.83% of total

accessions). Leaf margins revealed 3 categories; entire (9.57% of total accessions), serrate or dentate (78.72% of total accessions), and parted (11.70% of total accessions). All of the safflower accessions (100%) showed nonhairy leaf traits. In terms of leaf spininess, 31.91% of total accessions contained no spines, few spines in 23.40% of total accessions, intermediate spines in 22.34% of total accessions, and many spines in 22.34% of total accessions. Branching pattern was observed as basal (3.19% of total accessions), medium (84.04% of total accessions), and upper (12.77% of total accessions). The angle of branches was classified as appressed with angle of $15^\circ - 20^\circ$ (7.45% of total accessions), intermediate with angle of $20^\circ - 60^\circ$ (86.17% of total accessions), and spreading type with angle of $60^\circ - 90^\circ$ (6.38% of total accessions). Flower color,

Table 3. Mean data across 2 locations (Pakistan and Turkey) of the 94 international safflower accessions panel.

Accessions	DFI	DFH	DFC	DM	LL	LW	PH	BPP	CPP	SPC	CD	SYP	100-SW
ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL
Alghazian-1	161	92	165	100	169	108	143	126	166	106	146	816 ± 1.56	241
Alghazian-2	163	100	169	116	174	113	188	125	147 ± 0.37	9.68 ± 0.69	24.48 ± 1.73	20.41 ± 1.58	277
Alghazian-3	158	90	161	96	165	103	179	113	9.7 ± 1.20	13.26 ± 1.69	4.2 ± 0.31	6.93 ± 2.28	314
Argentina-1	163	83	150	86	152	92	166	113	14 ± 1.40	13.48 ± 0.76	4.7 ± 0.41	25.43 ± 0.67	309
Australia-1	156	88	160	95	164	103	178	113	19.85 ± 0.95	12.56 ± 0.57	6.3 ± 0.62	11.36 ± 2.07	336
Australia-2	154	88	159	93	164	106	178	125	15.25 ± 1.33	15.44 ± 1.72	4.3 ± 0.69	9.26 ± 2.15	291
Australia-3	151	94	158	100	162	105	176	125	14.4 ± 1.73	12.42 ± 0.73	3.2 ± 0.58	10.13 ± 2.41	307
Bangladesh-1	153	90	159	92	165	100	179	125	12.05 ± 0.93	13.02 ± 1.06	4.25 ± 0.62	14.65 ± 2.35	271
Bangladesh-2	154	87	159	96	165	103	179	113	17 ± 0.70	12.94 ± 0.76	4.9 ± 0.42	18.96 ± 2.43	299
Bangladesh-3	154	90	159	97	165	103	179	118	16.08 ± 0.96	16.08 ± 1.61	4.4 ± 0.36	15.45 ± 0.84	279
Bangladesh-4	141	87	151	92	153	100	167	124	10.002 ± 1.13	12.62 ± 0.82	2.5 ± 0.18	6.01 ± 2.05	351
China-1	155	88	162	94	166	100	180	125	14.15 ± 0.78	16.14 ± 0.47	4.5 ± 0.26	17.73 ± 3.12	235
China-2	158	94	160	108	168	106	182	118	19.75 ± 1.06	11.92 ± 0.25	3.15 ± 0.37	15.52 ± 0.96	313
China-3	151	83	158	88	164	99	178	113	8 ± 1.13	13.88 ± 0.88	5.2 ± 0.56	6.59 ± 1.71	275
China-4	151	89	157	97	172	105	186	115	17.2 ± 1.82	16.6 ± 1.05	4.8 ± 0.80	5.94 ± 0.63	329
China-5	152	87	157	98	162	109	176	125	12.9 ± 1.57	24.9 ± 1.37	4.2 ± 0.61	14.65 ± 0.84	279
China-6	155	97	160	107	168	115	182	125	22.4 ± 1.86	14.94 ± 0.90	8 ± 1.01	15.65 ± 1.98	329
China-7	158	93	162	105	166	115	180	125	11 ± 1.08	19.64 ± 1.48	2.6 ± 0.56	6.01 ± 2.05	351
Egypt-1	152	91	157	100	162	103	176	114	16.6 ± 1.13	14.96 ± 0.73	11.0 ± 0.60	17.73 ± 3.12	235
Egypt-2	161	91	166	100	170	106	184	117	20.276 ± 0.76	14.62 ± 0.27	5.826 ± 0.23	6.08 ± 1.51	428
Egypt-3	154	91	166	100	170	106	184	117	20.276 ± 0.76	14.62 ± 0.27	5.826 ± 0.23	6.08 ± 1.51	428
Egypt-4	153	90	159	93	167	100	181	125	20.732 ± 1.47	15.78 ± 1.40	5.7 ± 0.52	17.73 ± 3.12	235
Egypt-5	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-6	150	90	155	96	160	104	174	117	13.032 ± 0.79	14.46 ± 1.20	4.064 ± 0.33	6.08 ± 1.51	428
Egypt-7	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-8	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-9	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-10	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-11	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-12	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-13	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-14	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-15	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-16	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-17	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-18	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-19	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-20	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-21	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-22	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-23	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-24	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-25	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-26	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-27	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-28	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-29	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-30	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-31	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-32	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-33	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-34	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-35	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-36	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-37	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-38	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-39	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-40	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-41	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-42	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-43	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-44	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-45	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-46	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-47	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-48	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-49	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-50	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-51	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-52	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-53	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-54	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-55	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-56	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-57	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-58	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-59	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-60	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-61	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-62	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-63	150	89	155	93	160	101	174	115	22.132 ± 1.57	18.14 ± 0.89	6.764 ± 1.01	15.45 ± 0.84	279
Egypt-64													

Table 3. (Continued).

Monocco-1	146	87	151	94	157	102	171	115	133.08 ± 1.00	16.16 ± 0.90	3.432 ± 0.25	4.98 ± 0.35	122 ± 8.00	79.4 ± 3.08	14.60 ± 2.2	7.00 ± 1.52	34.20 ± 3.07	31.60 ± 8.7	26.8 ± 3.19	24.6 ± 5.58	21.38 ± 1.55	25.28 ± 3.46	10.14 ± 1.42	11.35 ± 5.99	2.55	3.41
Monocco-2	153	91	157	99	163	103	177	124	12.3 ± 0.78	15.14 ± 1.01	4 ± 0.32	5.04 ± 0.34	114 ± 4.00	88 ± 3.24	11.80 ± 2.42	14.00 ± 0.77	52.00 ± 15.21	34.60 ± 10.06	23.4 ± 3.06	27 ± 6.04	21.98 ± 1.69	16.73 ± 0.74	16.52 ± 5.46	4.35 ± 1.14	2.91	1.81
Pakistan-1	148	88	153	92	157	105	171	124	17.5 ± 0.85	16.56 ± 1.37	5.564 ± 0.36	4.99 ± 0.16	120 ± 6.00	78.6 ± 2.68	12.00 ± 1.84	10.90 ± 1.84	32.60 ± 5.3	26.80 ± 8.1	25.9 ± 5.12	23 ± 5.14	27.2 ± 1.4	20.4 ± 1.59	27 ± 2.55	67.21 ± 1.07	3.55	3.37
Pakistan-2	147	85	151	89	155	93	169	118	17.832 ± 1.46	16.42 ± 1.37	5.884 ± 0.31	4.68 ± 0.57	89 ± 3.00	80 ± 1.70	10.60 ± 0.87	12.00 ± 1.62	33.20 ± 4.95	25.20 ± 5.38	41.2 ± 3.97	22.38 ± 1.57	24.18 ± 1.27	19.29 ± 1.94	17.96 ± 2.07	7.16 ± 2.32	3.73	3.68
Pakistan-3	147	85	150	86	155	92	169	118	14.264 ± 0.84	13.28 ± 0.57	4.8 ± 0.34	4.32 ± 0.33	82 ± 3.00	56.4 ± 1.21	10.20 ± 1.59	11.00 ± 0.89	30.20 ± 5.87	28.00 ± 2.83	24.3 ± 1.9	23.4 ± 5.35	17.94 ± 2.09	19.84 ± 0.94	17.96 ± 2.07	7.16 ± 2.32	3.73	3.68
Pakistan-4	150	84	151	87	156	92	170	118	12.8 ± 1.23	12.02 ± 0.29	3.932 ± 0.18	4.2 ± 0.23	76 ± 1.00	41.2 ± 1.88	9.00 ± 0.71	9.00 ± 0.32	17.20 ± 3.25	23.40 ± 1.5	27 ± 2.13	42.4 ± 5.48	20.64 ± 1.85	21.46 ± 1.41	9.87 ± 1.55	5.57 ± 1.14	2.39	2.63
Pakistan-5	146	86	152	91	157	99	171	118	12.8 ± 0.53	12.14 ± 0.83	4.3 ± 0.25	3.72 ± 0.21	111 ± 2.00	71 ± 3.81	6.20 ± 0.37	10.60 ± 1.12	18.60 ± 2.4	25.60 ± 4.27	30.4 ± 8.6	29 ± 5.23	20.52 ± 1.55	16.97 ± 1.16	5.39 ± 1.07	8.59 ± 2.22	2.39	2.33
Pakistan-6	153	94	163	106	177	124	14.664 ± 1.16	13.68 ± 0.45	4.832 ± 0.16	4.56 ± 0.16	108 ± 2.00	67.8 ± 1.96	9.00 ± 0.63	9.00 ± 0.63	9.00 ± 0.63	10.20 ± 0.86	36.00 ± 1	30.40 ± 5.09	23.4 ± 5.38	38.4 ± 5.2	26.75 ± 1.38	20.86 ± 1.84	19.71 ± 2.48	15.76 ± 5.79	2.3	2.34
Pakistan-7	152	88	155	93	160	102	174	125	18.032 ± 1.54	16.48 ± 0.86	5.3 ± 0.24	4.98 ± 0.39	103 ± 5.00	73 ± 3.78	10.00 ± 1.52	8.40 ± 0.98	52.60 ± 8.52	27.20 ± 4.73	28.8 ± 1.71	28.9 ± 1.98	24.2 ± 6.41	19.49 ± 0.57	66.55 ± 4.47	20.08 ± 4.23	3.23	3.33
Pakistan-8	153	90	157	96	160	107	174	118	17.2 ± 1.20	12.72 ± 0.68	6.35 ± 0.64	4.1 ± 0.24	96 ± 4.00	58 ± 3.99	13.00 ± 2.76	10.80 ± 1.07	28.80 ± 1.71	28.80 ± 1.71	28.9 ± 1.98	24.2 ± 6.41	24.00 ± 1.26	19.49 ± 0.57	60.51 ± 7.08	2.82	2.92	
Pakistan-9	153	90	157	96	160	107	174	118	16.95 ± 1.27	13.82 ± 1.17	5.29 ± 0.59	4.5 ± 0.50	99 ± 4.00	64 ± 4.79	13.00 ± 2.37	10.80 ± 1.07	71.60 ± 18.32	27.60 ± 4.81	31.8 ± 3.35	23.3 ± 1.31	21.64 ± 0.39	44.39 ± 4.73	7.99 ± 2.52	3.21	2.54	
Pakistan-10	152	89	158	97	171	108	185	125	15.6 ± 1.69	14.72 ± 0.39	4.5 ± 0.65	4.68 ± 0.18	113 ± 3.00	75 ± 6.14	8.60 ± 0.93	9.80 ± 0.37	33.80 ± 3.99	16.80 ± 3.54	24 ± 1.68	32.4 ± 5.39	27.42 ± 1.3	25.5 ± 0.9	18.09 ± 3.51	12.75 ± 2.35	3.55	4.5
Pakistan-11 (Chari-28)	150	87	155	91	161	100	175	115	15.38 ± 1.15	8.72 ± 0.61	4.7 ± 0.22	3.28 ± 0.26	112 ± 4.00	66.4 ± 3.75	6.27 ± 0.36	7.23 ± 0.43	41.20 ± 9.1	16.65 ± 1.84	35.8 ± 0.58	15.38 ± 2.55	24.21 ± 0.6	19.83 ± 0.73	11.78 ± 2.69	4.14 ± 0.74	3.52	3.66
Portugal-1	152	87	160	93	170	104	184	125	13.964 ± 0.68	18.3 ± 0.80	4.264 ± 0.20	5.22 ± 0.26	121 ± 4.00	89.6 ± 2.29	8.60 ± 1.12	12.60 ± 0.93	21.20 ± 9.1	29.00 ± 4	39.5 ± 2.39	31.8 ± 7.87	27.85 ± 1.31	24.9 ± 1.08	18.61 ± 2.4	13.56 ± 2.13	3.79	3.94
Portugal-2	152	96	159	104	168	107	182	125	14.964 ± 0.47	15.92 ± 0.66	4.8 ± 0.26	4.08 ± 0.06	124 ± 2.00	87.6 ± 2.16	8.00 ± 1.14	8.40 ± 0.81	41.00 ± 2.7	22.00 ± 4.4	27.9 ± 5.34	38.2 ± 14.72	24.6 ± 1.31	22.24 ± 0.63	32.39 ± 2.91	6.94 ± 1.54	3.81	2.99
Portugal-3	152	90	159	97	166	106	180	125	16.332 ± 0.64	13.3 ± 0.85	4.4 ± 0.39	4.4 ± 0.55	146 ± 3.00	81.6 ± 3.03	6.20 ± 0.49	9.00 ± 0.55	21.60 ± 3.5	26.00 ± 4.37	29 ± 3.54	29.79 ± 1.31	24.12 ± 1.25	24.84 ± 3.9	9.17 ± 2.57	3.93	4.16	
Portugal-4	151	92	155	100	160	107	174	125	18.932 ± 1.25	14.12 ± 0.29	7.032 ± 0.34	4.56 ± 0.27	126 ± 8.00	72.6 ± 6.60	9.00 ± 1.14	12.00 ± 1.22	33.00 ± 4.74	9.00 ± 1.64	27.8 ± 2.34	28.54 ± 1.67	24.26 ± 1.45	16.03 ± 1.81	9.65 ± 2.3	3.28	3.12	
Portugal-6	157	96	166	103	171	112	185	125	17.3 ± 0.70	13.38 ± 2.31	5.09 ± 0.63	4.7 ± 0.48	120 ± 5.00	81.4 ± 3.26	13.20 ± 2.13	6.40 ± 0.75	44.80 ± 9.76	15.20 ± 4.97	27.7 ± 0.94	31.6 ± 6.45	27.65 ± 1.51	25.53 ± 2.03	23.57 ± 2.78	6.19 ± 1.83	4.06	3.55
Romania-1	153	92	155	101	159	107	173	124	15.36 ± 1.99	15.24 ± 1.22	4.48 ± 0.61	4.74 ± 0.22	123 ± 4.00	80.2 ± 3.58	6.80 ± 0.97	8.00 ± 1.14	34.00 ± 10.59	25.60 ± 5.54	21.7 ± 3.37	25 ± 3.02	17.01 ± 1.52	21.34 ± 0.8	10.39 ± 1.3	15.15 ± 4.52	1.88	4.09
Russia-1	150	90	155	100	159	112	173	125	14.5 ± 0.72	13.44 ± 1.28	4.95 ± 0.43	3.94 ± 0.56	131 ± 3.00	74.8 ± 5.51	7.20 ± 1.02	13.40 ± 1.44	11.80 ± 2.63	28.40 ± 8.7	28.7 ± 3.71	26.8 ± 4.5	21.19 ± 1.85	21.59 ± 1	4.92 ± 0.8	8.82 ± 3.1	3.07	3.45
Spain-1	151	88	159	100	174	109	188	127	14.264 ± 0.77	15.66 ± 0.85	4.4 ± 0.33	4.7 ± 0.20	111 ± 6.00	71.2 ± 2.73	7.60 ± 1.21	7.80 ± 0.8	23.80 ± 6.24	23.60 ± 2.66	30.7 ± 3.84	31.4 ± 7.01	26.37 ± 1.51	23.47 ± 1.33	25.81 ± 3.86	14.26 ± 1.11	4.74	2.79
Spain-2	154	88	158	92	162	100	176	125	12.032 ± 0.56	15.44 ± 0.95	4.864 ± 0.29	4.98 ± 0.41	118 ± 3.00	85.4 ± 1.66	5.40 ± 0.51	10.20 ± 0.49	18.60 ± 1.33	27.80 ± 1.36	23.7 ± 2.37	20.8 ± 1.32	22.22 ± 1.31	22.58 ± 0.99	10.64 ± 1.74	10.23 ± 1.48	3.81	3.1
Spain-3	151	89	159	95	160	106	174	125	15.732 ± 0.69	15.1 ± 0.43	5.3 ± 0.31	5.06 ± 0.25	113 ± 5.00	89.6 ± 1.21	6.00 ± 0.84	12.00 ± 1.31	23.00 ± 3.83	16.6 ± 4.11	32.2 ± 6.79	28.17 ± 1.31	25.01 ± 1.3	14.73 ± 1.99	13.34 ± 5.9	3.17	2.81	
Spain-4	155	88	161	93	164	100	178	115	14.532 ± 1.18	13.2 ± 0.74	5.8 ± 0.46	5.34 ± 0.54	108 ± 3.00	83.8 ± 3.38	9.00 ± 1.38	12.00 ± 1.1	43.40 ± 9.64	23.80 ± 5.09	15.7 ± 2.81	15.6 ± 4.96	23.4 ± 1.85	21.59 ± 0.99	15.73 ± 4.12	1.78 ± 0.51	3.06	1.99
Syria-1	154	89	160	96	164	103	178	125	15.792 ± 1.24	15.9 ± 0.94	4.05 ± 0.35	5.84 ± 0.94	119 ± 4.00	83.6 ± 4.71	8.20 ± 1.83	10.40 ± 0.75	35.80 ± 6.83	23.00 ± 3.32	12.5 ± 2.25	30.4 ± 3.23	23.6 ± 1.66	25.99 ± 0.42	6.22 ± 1	14.28 ± 3.01	3.33	4.48
Syria-2	157	93	169	100	174	109	188	127	15.35 ± 0.82	15.56 ± 0.85	4.4 ± 0.33	4.7 ± 0.20	112 ± 4.00	82.8 ± 4.18	5.40 ± 0.4	9.40 ± 0.75	12.60 ± 2.66	17.80 ± 3.15	14.2 ± 1.27	27.6 ± 5.42	25.98 ± 1.8	24.19 ± 0.6	1.72 ± 0.37	10.43 ± 1.93	2.71	3.65
Syria-3	151	89	155	96	160	104	174	118	10.9 ± 0.84	14.56 ± 0.68	4.6 ± 0.59	4.76 ± 0.36	95 ± 2.00	82.2 ± 3.04	8.80 ± 1.46	9.60 ± 1.67	23.40 ± 5.77	20.80 ± 5.36	19.6 ± 1.37	31 ± 4.3	23.17 ± 1.93	24.22 ± 1.3	7.2 ± 2.3	12.52 ± 2.88	2.37	3.67
Thailand-1	150	90	152	100	154	109	168	125	17.4 ± 1.65	13.76 ± 0.34	5.1 ± 0.48	4.38 ± 0.16	102 ± 4.00	80.2 ± 2.91	7.60 ± 1.17	8.80 ± 1.83	21.50 ± 5.38	18.40 ± 3.84	34.2 ± 2.56	24 ± 1.66	25.72 ± 0.7	7.32 ± 1.79	8.19 ± 2.19	2.77	4.12	
Turkey-1	150	86	154	90	160	99	174	125	13.8 ± 0.91	14.16 ± 0.80	4.55 ± 0.40	4.62 ± 0.44	118 ± 6.00	83.2 ± 5.07	12.40 ± 1.63	8.80 ± 1.02	45.00 ± 8.99	16.60 ± 4.11	22.4 ± 3.85	30.8 ± 5.58	28.69 ± 1.46	23.11 ± 1.53	26.14 ± 3.04	10.58 ± 5.06	3.33	3.86
Turkey-2	149	86	151	88	157	100	171	113	14.65 ± 0.79	13.76 ± 0.83	5.15 ± 0.47	5.04 ± 0.28	88 ± 3.00	71.4 ± 1.78	9.00 ± 1	10.20 ± 1.11	33.00 ± 3.39	19.20 ± 3.25	11.3 ± 1.6	20.8 ± 5.59	25.27 ± 1.5	22.95 ± 0.74	23.07 ± 3.09	8.35 ± 1.48	4.22	4.26
Turkey-3	155	83	159	90	164	102	178	118	13.7 ± 0.79	11.98 ± 0.99	3.95 ± 0.37	3.72 ± 0.39	99 ± 5.00	59.8 ± 3.67	12.00 ± 0.95	8.80 ± 1.16	54.60 ± 1.16	18.60 ± 4.18	22.8 ± 2.92	27.8 ± 9.6	22.88 ± 1.97	21.99 ± 1.67	27.35 ± 3.74	5.99 ± 3.9	3.35	3.1
Turkey-4	151	89	154	93	159	101	173	118	14.75 ± 0.61	15.28 ± 0.55	5 ± 0.42	4.5 ± 0.30	97 ± 1.00	77 ± 3.39	12.80 ± 2.06	7.20 ± 0.8	46.40 ± 8.86	13.60 ± 1.21	24.8 ± 3.86	32 ± 5.81	27.24 ± 1.73	23.5 ± 1.27	50.47 ± 4.72	10.45 ± 1.86	4.27	4.33
Turkey-5	150	87	152	91	154	108	168	125	13.5 ± 1.03	11.94 ± 0.74	4.6 ± 0.43	3.92 ± 0.44	136 ± 2.00	73.2 ± 2.87	5.60 ± 0.81	11.00 ± 1.25	31.60 ± 19.97	31.80 ± 4.5	20 ± 3.08	33 ± 6.27	20.46 ± 1.57	23.85 ± 1.67	6.41 ± 1.51	16.92 ± 3.23	2.41	3.88
Turkey-6	162	89	167	100	172	104	186	113	13.84 ± 0.53	13.84 ± 0.53	6.5 ± 0.73	4.48 ± 0.17	129 ± 3.00	76.6 ± 1.29	11.00 ± 0.84	9.40 ± 0.68	59.00 ± 8.01	17.40 ± 4.35	31 ± 4.87	23 ± 4.52	28.04 ± 1.38	22.62 ± 0.86	14.97 ± 2.19	7.16 ± 3.73	2.72	3.04
Turkey-7	154	89	159	94	169	108	183	124	14.55 ± 1.84	12.94 ± 0.96	5.35 ± 0.62	4.66 ± 0.45	137 ± 4.00	85 ± 2.14	12.20 ± 2.26	10.00 ± 1.14	74.00 ± 22.69	23.80 ± 3.65	13.8 ± 1.08	27.8 ± 2.69	24.58 ± 1.28	24.68 ± 1.41	24.29 ± 3.19	10.68 ± 3.29	3.02	3.35
Turkey-8	159	89	168	99	173	109	187	124	16.05 ± 0.92	13.5 ± 1.02	5.9 ± 0.59	4.48 ± 0.29	129 ± 7.00	74.6 ± 6.56	8.40 ± 2.14	9.40 ± 1.5	29.20 ± 3.14	19.00 ± 2.3	26.9 ± 2.07	23.6 ± 4.58	29.16 ± 1.4	21.78 ± 1.25	12.08 ± 2.64	17.47 ± 1.55	3.88	3.79
Turkey-9	152	90	157	99	162	106	176	125	13.7 ± 1.77	12.92 ± 0.71	4.2 ± 0.71	4.52 ± 0.20	122 ± 2.00	79.2 ± 2.42	8.00 ± 0.32	9.20 ± 1.16	46.20 ± 10.92	17.80 ± 4.21								

Table 4. Mean, minimum, maximum, and standard deviation (StD) of the 13 morphoagronomic traits in the 94 international safflower accessions panel.

Variable	Minimum	Maximum	Mean	Std. deviation
Days to flower initiation	113.5	131.5	120.946	3.033
Days to 50% flowering	117.5	137.5	126.478	4.1006
Days to flower completion	121.5	143.5	133.098	4.3712
Days to maturity	139.5	157.5	148.498	3.8143
Leaf length	9.66	20.235	14.9549	2.0515
Leaf width	2.975	6.615	4.7399	0.6531
Plant height	60.08	121.476	92.6249	10.3238
Branches per plant	5.1	17.3	9.8569	2.0503
Capitula per plant	8.7	80.4	28.9419	10.7033
Seeds per capitulum	15	42.05	25.2935	5.1874
Capitulum diameter	17.301	28.302	23.4978	2.3556
Seed yield per plant	4.855	51.021	15.9477	9.3188
100-seed weight	2.165	5.3195	3.3287	0.5933

an important trait for the genetic diversity classification in safflower, were categorized as pale-yellow (1.06% of total accession), yellow (38.30 of total accessions), yellow-orange (55.32% of total accessions), orange (2.13% of total accessions), orange-red (1.06% of total accession), and red (2.13% of total accessions). Head and capitulum shape was recorded as conical (95.75% of total accessions), oval (1.06% of total accession), and flattened (3.19% of total accessions). Seed shapes were observed as oval (24.47% of total accessions), conical (71.28% of total accessions), and crescent (4.26% of total accessions).

3.2. Correlation, principal component analysis, hierarchical clustering, and multivariate analysis

The correlation coefficients among the 94 international safflower accessions panel are presented in Table 6. Days to flower initiation, days to 50% flowering, days to flower completion, and days to maturity were significantly correlated (+ve) with leaf length, plant height, and capitulum diameter. Days to flower initiation and days to 50% flowering revealed significant correlation (–ve) with the trait 100-seed-weight. Plant height showed significant relationship (+ve) with leaf length, leaf width, and capitulum diameter. Capitula per plant exhibited significant correlation (+ve) with leaf length, leaf width, branches per plant, and seed yield per plant. There was significant correlation (+ve) between seeds per capitulum and capitulum diameter. Capitulum diameter revealed significant correlation (+ve) with seed yield per plant. Seed yield per plant was significantly correlated (+ve) with leaf length, leaf width, branches per plant, capitulum diameter, and 100-seed weight. 100-seed weight showed

significant relationship (+ve) with leaf length, leaf width, and capitulum diameter.

When applying principal component analysis on 13 morphoagronomic traits together, the first 4 principal components were selected, which accounted for 75.16% of the total variation (Table 7). The first principal component (PC1) represented a total of 32.83% of the variation, showing the highest contribution from days to flower completion (0.44). PC2 represented 20.71% of the variation with the highest contribution from seed yield per plant (0.48). In the same way, PC3 and PC4 resulted in a total of 12.71% and 8.91% variation having the highest contribution from branches per plant (0.61) and seeds per capitulum (0.86), respectively.

Hierarchical clustering implemented in XLSTAT software divided the evaluated safflower accessions into 3 main groups: 26 accessions (27.66%) in group A (blue), 31 accessions (32.98%) in group B (green), and 37 accessions (39.36%) in group C (red), (Figure 1). Multivariate analysis was performed which also revealed 3 groups and supported the hierarchical clustering of 94 safflower accessions (Figure 2).

4. Discussion

ANOVA was performed and revealed significant variations due to accessions as well as locations. Accessions were found highly significant for days to flower initiation, days to 50% flowering, days to flower completion, leaf width, plant height, branches per plant, capitulum diameter, and 100-seed weight among safflower accessions, while location revealed significant differences for all the studied

Table 5. Country-specific means of the 94 international safflower accessions panel across 2 locations (Pakistan and Turkey).

Country	DFI	DFF	DFC	DM	LL	LW	PH	BPP	CPP	SPC	CD	SYP	100-SW
Afghanistan	127.3333 ± 3.8188	132.8333 ± 4.5092	138.6667 ± 4.7522	152.3333 ± 5.5752	13.4267 ± 1.8964	4.5117 ± 0.5019	98.0153 ± 9.0492	11.7000 ± 4.8539	29.3000 ± 16.2945	24.3500 ± 1.9975	22.1893 ± 1.9975	9.0757 ± 6.2434	2.4813 ± 0.3022
Argentina	123 ± 56.569	118 ± 45.255	122 ± 42.426	139.5 ± 37.477	13.74 ± 0.368	4.49 ± 0.297	79.336 ± 19.991	8.6 ± 0.566	22.1 ± 4.667	31.95 ± 15.910	24.719 ± 1.000	13.406 ± 2.891	3.526 ± 0.617
Australia	122 ± 48.083	127.5 ± 45.962	133.5 ± 43.134	145.5 ± 45.962	16.205 ± 5.155	5.06 ± 1.754	86.202 ± 31.116	13.4 ± 2.546	42 ± 27.436	26 ± 3.677	22.676 ± 2.537	14.112 ± 6.856	2.7875 ± 0.173
Austria	121.75 ± 1.061	127.5 ± 2.121	134.25 ± 1.061	151 ± 0.707	14.3775 ± 1.368	4.01 ± 0.580	88.339 ± 6.170	10.55 ± 3.323	28.8 ± 1.838	23.95 ± 3.182	20.7085 ± 0.643	16.0765 ± 5.215	3.09275 ± 0.439
Bangladesh	119.5000 ± 3.7193	125.6250 ± 2.9545	131.7500 ± 3.5707	148.0000 ± 2.9721	13.7203 ± 2.1809	4.2463 ± 0.5489	85.5420 ± 14.2754	8.7000 ± 0.3916	22.2250 ± 4.4124	20.7750 ± 4.6284	22.0538 ± 2.1717	12.6713 ± 1.5157	3.0986 ± 0.3127
China	122.2143 ± 3.6384	129.2143 ± 3.9249	136.7857 ± 3.7177	150.7143 ± 2.6435	15.9586 ± 2.6821	4.6079 ± 0.9053	91.9471 ± 6.7309	8.7714 ± 1.8136	25.3143 ± 7.8001	26.2786 ± 5.4436	24.7860 ± 1.3364	25.7379 ± 15.4375	3.8914 ± 0.4751
Egypt	121.8333 ± 2.3166	127.5000 ± 3.1623	133.7500 ± 2.7704	148.6667 ± 3.3566	16.6530 ± 2.4067	5.1692 ± 0.7657	95.3200 ± 6.2144	10.9833 ± 1.5766	25.7000 ± 6.4498	21.6917 ± 2.1488	24.2827 ± 3.2002	19.3258 ± 12.1672	3.6563 ± 0.9449
France	125.5 ± 40.305	132 ± 38.184	136.5 ± 37.477	151 ± 36.770	13.86 ± 1.216	3.47 ± 0.665	82.052 ± 19.307	7.9 ± 2.404	11.9 ± 0.707	23.45 ± 2.899	21.035 ± 1.990	4.855 ± 1.520	2.7235 ± 0.037
Hungary	120.5 ± 44.548	126.5 ± 43.134	133.5 ± 40.305	150 ± 36.770	18.99 ± 6.237	5.46 ± 1.754	93.346 ± 43.481	13.1 ± 4.384	44.8 ± 32.527	21.3 ± 2.121	24.08 ± 1.884	31.556 ± 25.348	3.469 ± 0.946
India	118.4167 ± 2.8181	123.0000 ± 3.3166	129.2500 ± 4.0589	145.8333 ± 3.9581	12.8542 ± 2.2756	4.4967 ± 1.2475	82.5727 ± 5.3888	9.5833 ± 1.7360	24.1333 ± 6.8850	18.8500 ± 3.5940	21.4418 ± 1.9915	8.6467 ± 3.0159	3.6653 ± 0.4277
Iran	121.8571 ± 1.4058	128.5000 ± 2.7538	135.1429 ± 2.3401	149.5714 ± 1.5119	16.0974 ± 1.2182	5.0296 ± 0.4253	99.9254 ± 11.7864	11.6000 ± 1.4989	34.5714 ± 5.3646	31.6214 ± 6.1721	25.7359 ± 1.6408	15.1129 ± 7.9995	3.0302 ± 0.5767
Iraq	126.250 ± 2.475	132 ± 2.828	139.25 ± 1.061	152.75 ± 0.354	15.5875 ± 0.788	4.7425 ± 0.541	101.195 ± 7.265	11.975 ± 3.217	26.6375 ± 2.316	25.725 ± 2.298	25.2215 ± 0.265	12.0865 ± 3.559	2.90725 ± 0.503
Israel	120.0000 ± 1.9579	125.0000 ± 1.5811	131.2500 ± 1.4434	148.0000 ± 1.2247	15.8490 ± 2.7027	4.6178 ± 0.6327	95.1240 ± 5.6605	8.3000 ± 1.7493	23.0750 ± 10.0523	22.3750 ± 2.6085	22.6163 ± 2.7343	14.2218 ± 6.6882	3.6674 ± 0.3669
Jordan	119.4000 ± 1.7103	124.2000 ± 1.2042	131.4000 ± 1.5166	145.6000 ± 1.3416	16.4452 ± 2.6769	5.2286 ± 0.3924	89.1496 ± 5.1069	10.3600 ± 1.4276	44.5400 ± 7.1542	24.4500 ± 4.1997	24.2656 ± 1.0984	28.5120 ± 7.3616	3.8223 ± 0.2706
Kazakhstan	117.5 ± 45.962	120.5 ± 44.548	125.5 ± 40.305	140.5 ± 38.891	14.095 ± 0.205	4.765 ± 0.728	87.664 ± 31.203	7.7 ± 0.424	15.4 ± 0.283	35.75 ± 10.960	22.185 ± 0.830	6.208 ± 4.480	2.5785 ± 0.026
Libya	122 ± 46.669	129 ± 43.841	136 ± 41.012	151.5 ± 38.891	12.73 ± 1.739	4.62 ± 0.170	94.984 ± 28.544	7.2 ± 1.697	26 ± 5.374	24.3 ± 2.970	22.32 ± 0.744	7.019 ± 1.868	2.735 ± 0.262
Morocco	119.25 ± 3.889	125.25 ± 3.889	131.25 ± 2.475	146.75 ± 5.303	14.177 ± 0.646	4.363 ± 0.222	101.032 ± 0.167	11.85 ± 1.485	38.1 ± 7.354	25.45 ± 0.354	21.8435 ± 2.101	10.5895 ± 0.218	2.6705 ± 0.438
Pakistan	118.6752 ± 3.9999	122.9959 ± 3.1385	129.9298 ± 4.9368	146.8025 ± 3.5794	14.7083 ± 1.9229	4.6978 ± 0.5031	83.2040 ± 11.8735	10.1136 ± 1.9771	34.4447 ± 17.6172	28.9716 ± 3.9375	22.3514 ± 2.0421	18.6848 ± 11.4550	3.1641 ± 0.6106
Portugal	122.3333 ± 2.5033	129.4167 ± 3.0069	136.5000 ± 2.9833	152.5000 ± 2.3022	16.0470 ± 1.1432	4.9055 ± 0.5209	102.7510 ± 6.4244	9.2167 ± 1.2592	26.6833 ± 7.2082	28.4333 ± 4.6474	25.9208 ± 1.3106	16.8807 ± 2.9735	3.6668 ± 0.3126
Romania	122.5 ± 43.134	128 ± 38.184	133 ± 36.770	148.5 ± 34.648	15.3 ± 0.085	4.61 ± 0.184	101.822 ± 30.578	7.4 ± 0.849	29.8 ± 5.940	23.35 ± 2.333	19.175 ± 3.059	12.769 ± 3.364	2.987 ± 1.566
Russia	120 ± 42.426	127.5 ± 38.891	135.5 ± 33.234	149 ± 33.941	13.97 ± 0.750	4.445 ± 0.714	102.724 ± 39.490	10.3 ± 4.384	20.1 ± 11.738	27.4 ± 0.849	21.39 ± 0.280	6.871 ± 2.759	3.261 ± 0.270
Spain	120.5000 ± 0.9129	125.7500 ± 1.5000	131.5000 ± 1.2910	148.8750 ± 1.7017	14.4950 ± 0.8242	5.2245 ± 0.4041	97.1075 ± 5.1466	8.5250 ± 1.3276	25.5000 ± 5.4375	23.3375 ± 6.3480	23.8528 ± 1.6448	14.4913 ± 4.0196	3.1834 ± 0.5416
Syria	122.1667 ± 2.5658	129.3333 ± 4.6458	135.6667 ± 5.1072	151.6667 ± 5.7518	14.6770 ± 1.6974	4.7250 ± 0.2013	97.4047 ± 7.5836	8.6667 ± 1.1015	22.2333 ± 7.1009	22.5500 ± 2.3974	24.1883 ± 0.7643	8.7280 ± 2.3059	3.3670 ± 0.4711
Thailand	120 ± 42.426	126 ± 36.770	131.5 ± 31.820	146.5 ± 30.406	15.58 ± 2.574	4.74 ± 0.509	90.888 ± 15.115	8.2 ± 0.849	19.95 ± 2.192	23.35 ± 15.344	24.863 ± 1.215	7.753 ± 0.612	3.446 ± 0.956
Turkey	120.9500 ± 2.8718	126.1500 ± 4.8594	133.7000 ± 4.2308	148.6500 ± 3.9655	14.0405 ± 0.9294	4.7380 ± 0.4992	96.9880 ± 10.9116	9.2800 ± 1.7261	30.7100 ± 10.4041	25.9100 ± 4.6883	24.8124 ± 1.5173	16.4338 ± 6.4915	3.3955 ± 0.5853
Uzbekistan	119.0000 ± 1.5000	124.5000 ± 4.9244	130.0000 ± 4.7697	143.6667 ± 3.8837	13.4317 ± 2.0579	4.5017 ± 1.1678	83.7967 ± 6.3533	11.2167 ± 1.6766	25.5417 ± 3.9856	21.5500 ± 3.0278	19.5803 ± 2.5315	10.1930 ± 1.4139	2.8163 ± 0.4255

Table 6. Correlation coefficients among 13 morphoagronomic traits in 94 international safflower accessions panel.

Variables	DFI	DFF	DFC	DM	LL	LW	PH	BPP	CPP	SPC	CD	SYP	100-SW
Dfi	1												
DFtF	0.8862*	1											
DFC	0.7913*	0.9157*	1										
Mt	0.6263*	0.7330*	0.8301*	1									
LL	0.2220*	0.2464*	0.2673*	0.2125*	1								
Lw	0.1408	0.1375	0.1449	0.0666	0.7138*	1							
PH	0.4728*	0.5128*	0.5930*	0.5354*	0.3200*	0.2753*	1						
B	-0.0050	0.0064	-0.0108	-0.0917	0.1196	0.1209	-0.0600	1					
CPP	-0.0258	-0.0334	0.0027	-0.0595	0.2191*	0.2839*	-0.0022	0.6219*	1				
SPC	0.1024	0.0274	0.0160	0.0671	0.1179	0.0650	0.0960	-0.0600	0.0772	1			
CDm	0.2945*	0.3231*	0.3839*	0.3233*	0.4165*	0.4229*	0.4284*	-0.0411	0.0689	0.3853*	1		
SY	-0.1499	-0.1411	-0.0274	-0.0229	0.3372*	0.2517*	-0.0304	0.3071*	0.4985*	0.1585	0.3918*	1	
100-SW	-0.2856*	-0.2397*	-0.1017	-0.0482	0.3024*	0.2313*	-0.0581	-0.1415	-0.0426	-0.1522	0.3513*	0.4784*	1

*Statistically significant at $P \leq 0.05$, DFI: days to flower initiation; DFF: days to 50% flowering; DFC: days to flower completion; DM: days to maturity; LL: leaf length; LW: leaf width; PH: plant height; BPP: branches per plant; CPP: capitula per plant; SPC: seeds per capitulum; CD: capitulum diameter; SYP: seed yield per plant; 100-SW: 100-seed weight.

Table 7. Eigen values of the first 4 principal component axes (PC) in the 94 international safflower accessions panel.

Traits	PC1	PC2	PC3	PC4
Days to flower initiation	0.4027	-0.1782	0.1300	0.0159
Days to 50% flowering	0.4308	-0.1793	0.1157	-0.0760
Days to flower completion	0.4430	-0.1257	0.0582	-0.1123
Days to maturity	0.3920	-0.1335	-0.0218	-0.0652
Leaf length	0.2382	0.3666	-0.1110	-0.1523
Leaf width	0.1859	0.3765	-0.0804	-0.1461
Plant height	0.3491	-0.0132	-0.0763	0.0066
Branches per plant	0.0018	0.2426	0.6136	-0.0847
Capitula per plant	0.0309	0.3606	0.5255	0.0294
Seeds per capitulum	0.0856	0.1048	-0.0564	0.8644
Capitulum diameter	0.2815	0.2769	-0.2750	0.2763
Seed yield per plant	0.0309	0.4840	0.0353	0.0548
100-seed weight	-0.0271	0.3397	-0.4567	-0.3131
Eigen value	4.2675	2.6925	1.6520	1.1582
Variability (%)	32.8269	20.7116	12.7076	8.9090
Cumulative %	32.8269	53.5385	66.2461	75.1552

traits except branches per plant and 100-seed weight (Table 2). The presence of significant variation in the studied safflower accessions, the environmental factors strongly affecting the various attributes of safflower, and

the results of this study are supported by Ashri et al. (1975). Table 3 reflected the performance of safflower accessions for various traits at both locations, and it is clear that the overall performance of safflower was found to be

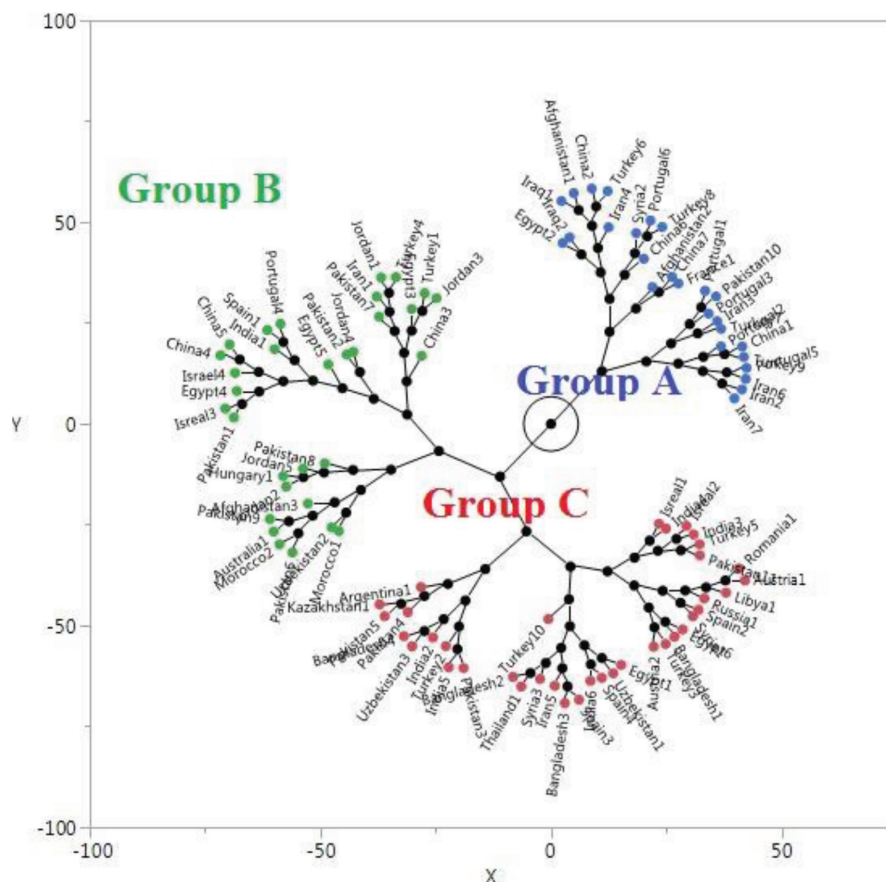


Figure 1. Hierarchical clustering analysis divided the evaluated 94 international safflower accessions panel into 3 groups.

superior in Pakistan as compared to Turkey. However, a few traits like leaf length, seeds per capitulum, and 100-seed weight showed better performance in the Turkey, as well. These differences may be due to environmental conditions and the soil properties of location. Variations in the locations are also confirmed by ANOVA. The presence of morphoagronomic variability in the current safflower accessions reflected their long-term response to selective pressure (both spatial and temporal) and to the deliberate selection of the farmers for preferred phenotypes, which ultimately lead to their morphoagronomic changes (Abebe and Bjornstad, 1996; Vom Brocke et al., 2003). Breeding methods based on different morphoagronomic traits have a significant role in the development high-yielding genotypes. Morphological markers are visually characterized phenotypic traits such as flower color and leaf spininess in safflower and serve the purposes of plant breeders well (Golkar et al., 2010). The present study revealed sufficient variability for qualitative traits, especially flower color and leaf spininess. In general, the safflower is a spiny crop plant with most of its genotypes containing many sharp spines on its leaves and bracts (Bradley et al.,

1999). Therefore, one of the major goals during safflower breeding programs is to develop cultivars that are spineless and exhibit high yield (Golkar et al., 2010). In addition, safflower spininess and flower color are expected to be used more as valuable morphological markers in marker-assisted selection during breeding programs (Golkar et al., 2010). Safflower leaf spininess is considered as a handicap in the areas where this crop is manually harvested (Chaudhry, 1986; Li and Mundel, 1996). A good range of variations for studied traits was observed among the 94 safflower accessions collected from the 26 countries (Table 4). Ramachandran (1985) reported the existence of a great level of variations for seed yield in this crop and revealed its great potential as a major oilseed crop. Early and late plant maturing are important characteristics in safflower breeding programs as they enable to develop cultivars for various agroecological zones with different photoperiod and thermosensitivity (Suddhiyam et al., 1992; Rehman et al., 2009). Early maturing safflower cultivars can be used an alternative strategy to avoid damage from insects and disease (Golkar, 2011). Early maturing safflower accessions can compete with crops like wheat and can

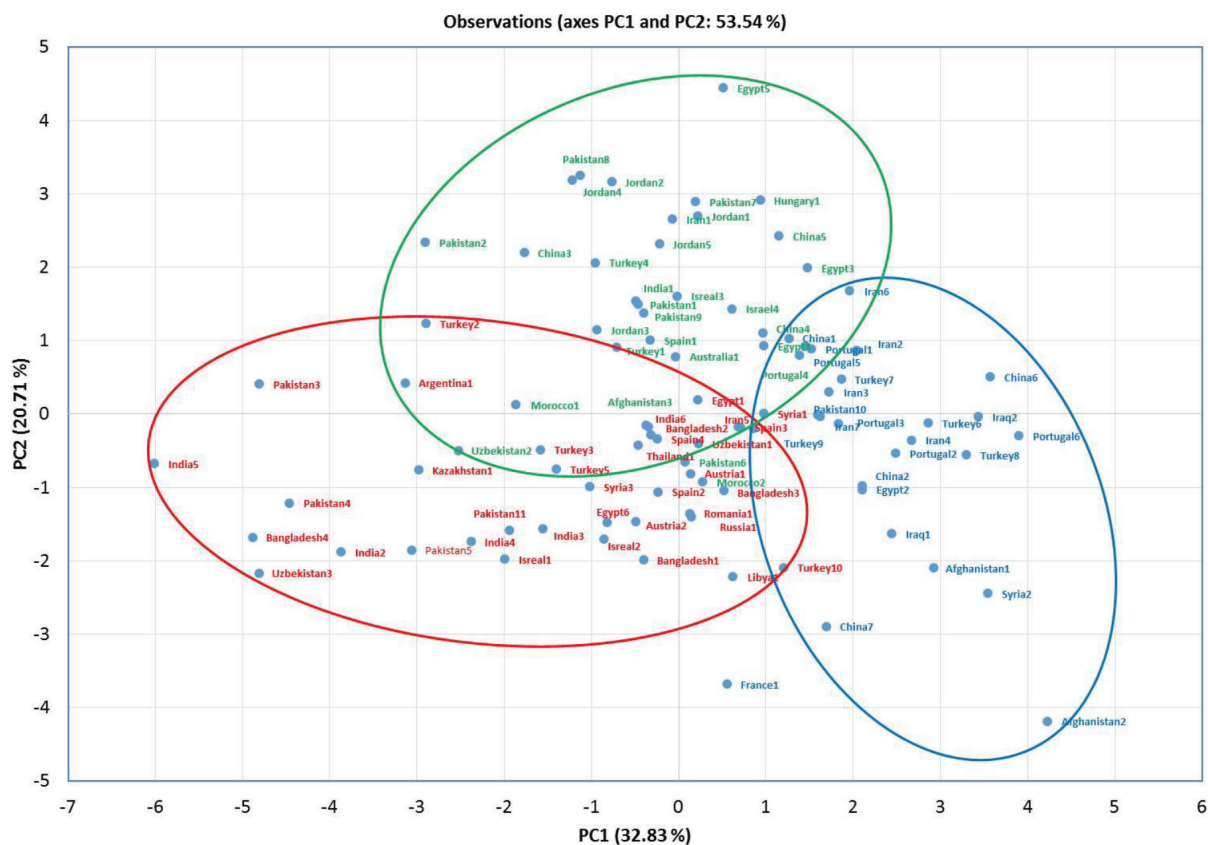


Figure 2. Multivariate analysis revealed 3 groups in the 94 international safflower accessions panel.

be encouraged for cultivation on marginal lands. Instead of direct selection for seed yield, it would be better to focus on various yield-contributing traits for the efficient improvement of safflower yield due to pleiotropic effects. The plant height variability obtained in this study was supported by the findings of Esendal (1990) and Sergek (2001); short-statured safflower accessions are better suited for mechanical harvesting (Weiss, 2000). Shinwari et al. (2014) obtained capitulum diameter and seed yield per plant in the range of 15.5 to 30.4 cm and 3.0 to 38.1 g, which was in line with our results. Branches per plant measurements were observed as one of the important yield traits showing a strong relationship with yield in the safflower (Golkar et al., 2012). Golkar et al. (2011) found branches per plant with a mean of 8.5, which was within the same range as our results. Either accessions kinship or similar environmental conditions can explain the similarity of these findings. Zheng et al. (1993) emphasized the indirect selection of higher capitula per plant and 1000-seed weight with a lower number of branches per plant for the improvement of the safflower. In addition, capitula per plant and capitulum weight were suggested as important traits for the improvement of safflower yield (Corleto et al., 1997; Rao and Ramachandram,

1997; Mozaffari and Asadi, 2006). Capitula per plant is an important seed yield determinant and revealed the highest relationship (+ve) with seed yield (Bagawan and Ravikumar, 2001). Yield attributes revealed the presence of a good level of variability during this study and indicated that an efficient selection could be employed on these yield components for the improvement of safflower crops. Yield attributes such as branches per plant, capitula per plant, and capitulum diameter were found to be more diverse and had significant correlation (+ve) with seed yield per plant and could be used as selection criteria for breeding purposes.

Correlation analysis is mainly applied to understand the association among the various traits, and the evaluated information can be best used for crop improvement by indirect selection of the components effecting crop yield (Sharaan and Ghallab, 1997; Karakoy et al., 2014). Crop improvement depends on the success of the selection criteria. The importance of the traits can be judged from their direct or indirect effects upon yield components, especially seed yield. It is therefore very important to know about the relative effects of the traits influencing the economic traits in a desirable manner and whether these traits should be selected or not in crop improvement

programs (Singh et al., 2004). Traits such as plant height, branches per plant, capitula per plant, seeds per capitulum, capitulum diameter, and 1000-seed weight are the most important traits in safflower improvement for increasing seed yield (Hamadi et al., 2001; Rudra Naik et al., 2001) as they have revealed either direct or indirect correlation with seed yield (Camas and Esendal, 2006; Mahasi et al., 2006). Days to flower initiation, days to 50% flowering, days to flower completion, and days to maturity were significantly correlated (+ve) with plant height. Zheng et al. (1993) stated that the taller safflower accessions have longer flowering times, which was in line with our current study. Bidgoli et al. (2006) studied correlation in various safflower accessions and exhibited significant correlation (-ve) of days to flower initiation and days to 50% flowering with 1000-seed weight. They obtained significant correlation (+ve) between seeds per capitulum and capitulum diameter. Similarly, 1000-seed weight showed a significant relationship (+ve) with capitulum diameter. Arslan (2007) found significant correlation (+ve) between plant height and capitulum diameter, and this also supported our results. Significant correlation (+ve) between capitula per plant and branches per plant were also reported by Mahasi et al. (2006) and strengthen our results. Our current results confirmed the findings of Omid (2000) and Bagheri et al. (2001) as they reported significant correlation (+ve) of capitulum diameter with seed yield per plant. Our results on significant correlation (+ve) of seed yield per plant with branches per plant and 100-seed weight were strongly supported by Tuncturk and Ciftci (2004) as they reported the same findings while studying safflowers under different fertilizer and row spacing levels. This clearly suggests that an increase in any of the traits having positive correlation with seed yield per plant will ultimately boost safflower yield.

PCA helps to recognize important plant traits that are used to characterize the variations among experimental materials (Chakravorty et al., 2013). Principal component analysis precisely classified 13 morphoagronomic traits into 13 principal components, among which the first 4 principal components, namely PC1, PC2, PC3, and PC4, were selected based on the magnitude of respective Eigen values. These 4 components explained nearly 75.16% of the total genetic variation (Table 7). PC1 contributed about 32.83% of the variation, showing the highest contributions from days to flower completion (0.44), followed by days to 50% flowering (0.43) and days to flower initiation (0.40). Owing to the high amount of maturity traits contribution, PC1 was considered a maturity component. PC2 explained 20.71% of the variation with the highest contributions from seed yield per plant (0.48), followed by leaf length (0.37) and capitula per plant (0.36). PC3 revealed 12.71% variation, with the highest contributions from branches

per plant (0.61), followed by capitula per plant (0.53) and days to flower initiation (0.13). PC4 revealed 8.91% variation, with the highest contributions from seeds per capitulum (0.86), followed by capitulum diameter (0.28) and seed yield per plant (0.05).

The results suggested the following traits: days to flower initiation, days to 50% flowering, days to flower completion, seed yield per plant, capitula per plant, branches per plant, seeds per capitulum, and capitulum diameter were responsible for the genetic variation in the current international safflower panel. It can be interpreted from the above that the traits consistently contributing to variation in each PC may be governed by genes that can be useful during selection to develop desirable cultivars in safflower breeding programs. These morphoagronomic traits are the drivers of the observed genetic variability and should be considered in the process of genetic combinations during crossing and screening elite safflower accessions. It can be concluded that principal component analysis is very helpful in identifying relationships between different traits and, in this study, it was found that maximum variations are due to seed yield per plant and that this can be used to predict the best selection indices for the yield improvement in various safflower breeding programs.

The international safflower panel comprised of 94 accessions was clustered into 3 groups (A, B, and C) on the basis of important yield traits such as seed yield per plant, capitula per plant, capitulum diameter, and branches per plant. Knowles (1969) proposed 7 similarity centers (1: the Far East, 2: India and Pakistan, 3: the Middle East, 4: Egypt, 5: Sudan, 6: Ethiopia, and 7: Europe) for safflower using various plant traits as standard characteristics (Table 8). Our current hierarchical cluster analysis revealed that safflower accessions from Iran, Syria, Turkey, Afghanistan, and Iraq were clustered in group A (blue), showing the Middle East similarity center. Group A was also comprised of safflower accessions from Portugal and France, which made up the Europe similarity center. Group B (green) was comprised of the Middle East, India and Pakistan, Europe, and Egypt similarity centers as this group exhibited safflower accessions from Jordan, Turkey, Iran, Israel, and Afghanistan (the Middle East center), India and Pakistan (India and Pakistan center), Spain, Hungary, Portugal, Australia, and Morocco (Europe center) and Egypt (Egypt center). In a very similar way, group C was comprised of safflower accessions belonging to 3 different similarity centers; the Middle East (Syria, Iran, Israel, and Turkey), India and Pakistan (India, Pakistan, and Bangladesh), Europe (Argentina, Spain, Austria, and Romania). Overall, our current hierarchical cluster analysis exhibited 4 safflower similarity centers (the Middle East, India and Pakistan, Europe, and Egypt) based on yield traits (seed

Table 8. List of the 7 safflower similarity centers based on various morphoagronomic traits during evaluation.

Center	Height	Branching	Spines	Head size	Flower color
Far East	Tall	Intermediate	Spines, spineless	Intermediate	Orange
India-Pakistan	Short	Many	Spines	Small, intermediate	Orange, white, red
Middle East	Tall	Few	Spineless	Intermediate, large	Red, orange, yellow, white
Egypt	Intermediate	Few	Spines, spineless	Large, intermediate	Orange, yellow, white, red
Sudan	Short, Intermediate	Intermediate	Spines	Small, intermediate	Yellow, orange
Ethiopia	Tall	Many	Spines	Small	Red
Europe	Intermediate	Intermediate	Spines, spineless	Intermediate	Orange, red, yellow, white

Table 9. List of promising safflower accessions evaluated at the 2 diverse environments of Pakistan and Turkey during 2016–2018.

Genotypes	DFI	DFF	DFC	DM	LL	LW	PH	BPP	CPP	SPC	CD	SY	100-SW
Pakistan-7	120	124	131	149.5	17.256	5.14	88.062	9.2	39.9	33.25	25.199	43.313	3.261
Egypt-3	122.5	128	136	148.5	14.552	5.042	97.93	10.5	36.4	22.1	28.302	35.859	3.7875
Egypt-5	119.5	124	130.5	144.5	20.136	6.112	104.592	11	26	19.6	26.652	32.82	5.3195
Iran-1	119.5	124.5	131	150	16.672	5.042	84.454	13	36.1	30.25	25.611	29.457	3.8585
Jordan-1	121.5	124.5	131.5	145.5	16.62	5.322	95.796	9.7	38.9	30.3	25.4	31.516	4.0205
Jordan-2	119	122.5	130.5	146.5	17.016	5.226	90.696	12.3	46.1	18.5	24.02	39.187	3.4405
Portugal-4	121.5	128.5	133.5	150	16.526	5.796	96.646	8.6	14.7	25.95	26.616	20.814	3.688
China-1	121.5	128	133	152.5	15.145	5.15	98.318	9.2	36.2	32.4	24.643	24.476	3.5155
Turkey-4	120	123.5	130	145.5	15.015	4.75	87.204	10	30	28.4	25.372	30.462	4.301
Pakistan-8	121	125.5	129.5	145.5	14.96	5.225	76.752	13.9	80.4	26.55	21.767	33.576	2.868
Pakistan-9	121.5	126.5	133.5	146	15.385	4.895	81.276	11.9	49.6	27.8	22.482	26.19	2.874
Jordan-3	119	125	132	145.5	12.825	4.695	90.502	9.5	37.6	24.85	25.387	23.253	3.994
Jordan-4	117	123.5	129.5	143.5	20.235	5.785	82.1	8.9	44.5	24.9	22.944	20.385	4.026
Jordan-5	120.5	125.5	133.5	147	15.53	5.115	86.654	11.4	55.6	23.7	23.577	28.219	3.6305
Israel-4	122.5	127	133	146.5	18.54	5.33	98.368	8.1	32	20.2	22.493	22.681	4.1455
Hungary-1	120.5	126.5	133.5	150	18.99	5.46	93.346	13.1	44.8	21.3	24.08	31.556	3.469
Turkey-9	121	128	134	150.5	13.31	4.36	100.392	8.6	32	31	25.993	21.545	3.0485
China-3	117	123	131.5	145.5	10.94	3.65	85.252	10.8	21.4	35.1	27.052	51.021	4.5325
China-4	120	127	138.5	150.5	16.9	4.67	95.122	10.4	24.4	22	23.623	33.114	3.7275
China-5	119.5	127.5	135.5	150.5	18.9	4.76	95.652	9.5	26.2	24.35	25.427	35.896	4.5225

DFI: days to flower initiation; DFF: days to 50% flowering; DFC: days to flower completion; DM: days to maturity; LL: leaf length; LW: leaf width; PH: plant height; BPP: branches per plant; CPP: capitula per plant; SPC: seeds per capitulum; CD: capitulum diameter; SY: seed yield per plant; 100-SW: 100-seed weight.

yield per plant, capitula per plant, branches per plant, and capitulum diameter) other than the standard traits proposed by Knowles (1969). Therefore, further testing is needed and, after confirmation, these yield traits should also be used along with other standard traits to more comprehensively consolidate the number of safflower similarity centers. Multivariate analysis clustered 94 safflower accessions into 3 different groups in the same

pattern as revealed from hierarchical cluster analysis (Figure 2). The basic grouping factors were seed yield per plant, capitula per plant, branches per plant, and capitulum diameter.

4.1. Selection of best performing accessions

Various statistical analysis methods such as correlation, principal component analysis, hierarchical clustering, and multivariate studies have been previously used to

explore morphoagronomic traits and to select the best performing accessions (Kotecha, 1979; Pascual-Villalobos and Alburquerque, 1996). Yield traits such as capitula per plant, seeds per capitulum, seed weight, and capitulum diameter are known as important yield determinants (Chaudhary, 1990; Pascual-Villalobos and Alburquerque, 1996; Omid, 2000). Golkar et al. (2011) suggested seeds per capitulum and capitula per plant as part of an important selection criteria for the improvement of safflower seed yield. Similarly, Chaudhary (1990) pointed out that safflower agronomic traits like plant height, leaf number, primary branches per plant, seeds per capitulum, and 1000-seed weight had positive effects on seed yield. Furthermore, he suggested a selection criteria combining seeds per capitulum, capitula per plant, and 1000-seed weight to be efficiently used in selecting high yielding genotypes during the selection process. Therefore, this study also aimed to investigate accessions that could be superior in terms of various traits in both locations. On the basis of principal component analysis, it was observed that days to flower initiation, days to 50% flowering, days to flower completion, seed yield per plant, capitula per plant, branches per plant, seeds per capitulum, and capitulum diameter were the major variability contributing components. However, as revealed from the correlation analysis, it was suggested that seed yield per plant had a significant (+ve) relationship with capitula per plant, branches per plant, and capitulum diameter. Therefore,

the above-mentioned 4 traits (seed yield per plant, capitula per plant, branches per plant, and capitulum diameter) can be used to select the best performing accessions. After applying a 20% selection response to yield traits, 20 safflower accessions were separated and recommended for future safflower breeding programs for various important morphoagronomic traits to improve production (Table 9).

4.2. Conclusion

The data obtained from this study could be useful for safflower breeders and seed producers concerned with increasing seed yield. The main traits determined in this study affecting seed yield in safflower were capitula per plant, branches per plant, and capitulum diameter, and this can be used as a selection criteria during safflower breeding programs. Hierarchical clustering of safflower accessions follows the patterns of 7 similarity centers based on seed yield per plant, capitula per plant, capitulum diameter, and branches per plant. However, there is still a need to test further and, after validation, these yield traits should also be used to consolidate the safflower similarity centers.

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