IMAM KHOMEINI INTERNATIONAL UNIVERSITY

IJGPB
Iranian Journal of Genetics and Plant Breeding
Print ISSN : 2251-9610
Online ISSN : 2676-346X

Impact of agronomic traits variability on grain yield of mid-oleic and standard sunflower hybrids vs. open-pollinated populations in Iran

Mehdi Ghaffari[1*], Fathollah Nadali[2], Farnaz Shariati[1], Morad Cheshmeh Nour[3], Hamid Jabbari[1]

[1]Oil Crops Research Department, Seed and Plant Improvement Institute, Agricultural Research Education and Extension Organization (AREEO), Karaj, Iran.
[2]Crop and Horticultural Science Research Department, Semnan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Shahroud, Iran.
[3]Crop and Horticultural Science Research Department, Lorestan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Khoramabad, Iran.
**Corresponding author, 0000-0003-2240-296X. Email: ghaffari@areeo.ac.ir.*

ABSTRACT INFO

Research Paper

Received: 22 Dec 2024

Accepted: 17 Mar 2025

ABSTRACT

This study compares three types of sunflower genotypes (standard hybrids, mid-oleic hybrids, and open-pollinated populations) regarding agronomic characteristics, using 16 standard hybrids, 9 mid-oleic hybrids, and 11 open-pollinated populations. The genotypes were evaluated in 6×6 simple lattice experiments conducted in Karaj and Shahrood, Iran, during the 2020-2021 growing season. The highest grain yield (3468 kg ha^{-1}) and oil yield (1462 kg ha^{-1}) were observed in standard hybrids, while the lowest values occurred in mid-oleic hybrids. Standard hybrids also exhibited the earliest maturity (96 days) and the shortest plant height (124 cm). In contrast, mid-oleic hybrids were characterized by lower grain yield (2513 kg ha^{-1}) and oil yield (1108 kg ha^{-1}) compared to the other genotypes. Open-pollinated populations showed similarities to standard hybrids in terms of grain and oil yield; however, the highest yields were consistently recorded among standard hybrids. These results indicate that not all crosses yield high-yielding hybrids with enhanced oil content. While the uniformity of hybrid cultivars facilitates agricultural operations, the higher yield observed in some open-pollinated populations justifies their cultivation in variable and unstable climatic conditions, particularly in marginal areas. Given the significant yield reduction in mid-oleic hybrids in Iran, their commercial production will depend on market demand and achieving a balance between yield and oleic acid content.

Key words: Hybrid, Open-pollinated, Mid-oleic, Single cross.

How to cite this article:
Ghaffari M., Nadali F., Shariati F., Cheshmeh Nour M., and Jabbari H. (2024). Impact of agronomic traits variability on grain yield of mid-oleic and standard sunflower hybrids vs. open-pollinated populations in Iran. *Iranian Journal of Genetics and Plant Breeding,* 13(2): 29-39.
DOI: 10.30479/ijgpb.2025.21359.1387

INTRODUCTION

Sunflower cultivars in Iran are available as both open-pollinated and hybrid varieties. The cultivation of oil-type sunflowers began in 1965 and expanded to over 100,000 hectares by the early 1990s (Ghaffari *et al*., 2020). Open-pollinated varieties possess unique morphological and physiological traits (Kaya *et al*., 2012). Before the commercialization of sunflower hybrids in the 1970s, open-pollinated cultivars were the sole source for sunflower production. The first open-pollinated cultivars were introduced in the early 20th century in the USSR (Seiler and Jan, 2010). The work of Pustovoit at VNIIMK in Russia, which led to the development of high-yielding open-pollinated varieties with oil content up to 50% in 1958, laid the groundwork for modern sunflower breeding (Rauf, 2019). From 1920 to 1970, open-pollinated sunflower cultivars were improved in Russia, Argentina, France, Canada, and Romania, forming the main genetic resources for cultivated sunflowers until the mid-1970s (Vear, 2010).

The first sunflower hybrids for commercial production were introduced in Canada in 1946 under a natural crossing system (Skoric *et al*., 2012). However, due to self- and sib-pollination, hybridization rates were often below 50%, limiting the full yield potential of these hybrids (Seiler and Jan, 2010). The development of hybrid varieties, such as Airelle, using marker genes for anthocyanin production to identify male-fertile parents, was pioneered by INRA between 1969 and 1980. The exploitation of cytoplasmic male sterility and pollen fertility-restoration genes facilitated the improvement of sunflower hybrids. The first hybrids using this system (Fransol and Relax) were registered in France in 1974, and cytoplasmic hybrids have been widely cultivated worldwide since 1978 (Vear, 2010). These hybrids were highly successful, with varieties from Hungary, Romania, Serbia, and Bulgaria dominating European production from 1980 to 2000. In the United States, the first hybrids were introduced in 1972, covering approximately 90% of the production area within five years. In Turkey, the proportion of hybrid cultivars increased from 32% in 1986 to 90% within a decade (Kaya, 2004). Similarly, nearly all oil-type sunflower cultivars in China have been converted to hybrid varieties. In contrast, Russia, the birthplace of open-pollinated cultivars, experienced a slower transition, with open-pollinated varieties still accounting for 60% of sunflower cultivation in 2007 (Vick and Hu, 2010). In Iran, approximately 50% of the sunflower seed demand reported by the Ministry of Agricultural Jihad comes from open-pollinated varieties, which are primarily cultivated in the Golestan and Semnan provinces.

Early studies on hybrid vigor in sunflowers during the late 1940s reported a 60% increase in yield compared to open-pollinated varieties (Unrau and White, 1944). F1 hybrids based on the PET1 system in the 1970s exhibited a 25% yield advantage over open-pollinated varieties, along with greater disease resistance and morphological uniformity (Seiler and Jan, 2010). Pereira *et al*. (1999) reported that hybrids are 23% and 36% superior to open-pollinated cultivars in grain and oil yield, respectively. Commercial hybrids in Argentina demonstrated a 30% to 50% yield advantage over open-pollinated varieties. While the first hybrids had lower oil content than the open-pollinated variety Peredovik, significant improvements were achieved in the 1980s, resulting in a 148% increase in oil yield from 1970 to 2000 (Vear, 2016).

The primary advantage of hybrids over open-pollinated cultivars is heterosis, which enhances grain yield (Meena and Sujatha, 2022). Additional benefits include uniformity of plants and seeds, simplifying field management, higher self-fertility, and easier implementation of disease and broomrape resistance (Skoric *et al*., 2012; Gunduz and Goksoy, 2016). In contrast to open-pollinated varieties, which rely solely on additive gene action for plant traits, the productivity of hybrids depends on both additive and non-additive gene actions (Rauf, 2019). However, farmers must purchase new hybrid seeds each year because the yield of seeds saved from the previous season decreases by 20% to 45%. Additionally, hybrids may be unstable and yield less than open-pollinated varieties in poor environmental and management conditions. The limitations of open-pollinated varieties include restricted yields and the potential loss of genetic purity. While certified seeds of open-pollinated varieties can be relatively easy to generate, they must be produced every three to five years to maintain genetic purity (Davey *et al*., 2010). Pourdad and Beg (2008) reported that, under dryland conditions, some open-pollinated varieties were as productive as hybrids.

The use of sunflower oil is primarily influenced by its fatty acid composition (Piva *et al*., 2000). Conventional sunflower seeds contain oil composed of four major fatty acids: palmitic acid (6%), stearic acid (5%), oleic acid (16-19%), and linoleic acid (68-72%) (Skoric *et al*., 2012). Based on fatty acid composition, sunflower cultivars are categorized into three types: standard or high-linoleic (48–74% C18:2), high-oleic (75–91% C18:1), and mid-oleic (43–72% C18:1) (Skoric *et al*., 2012). The unsaturated fatty acids predominantly found in sunflower oil include oleic and linoleic acids (Zhou *et al*., 2024). Oils rich in oleic acid are preferred due to their hypocholesterolemic effects (Mensink and Katan, 1989) and greater oxidative stability compared to linoleic acid (Pei *et al*., 2022). This stability makes high-oleic sunflower oil suitable for frying (Premnath *et al*., 2014), leading to the emergence of high-oleic and mid-oleic sunflower cultivars (Pacureanu-Joita *et al*., 2005).

To the best of our knowledge, information comparing these three types of sunflower genotypes is limited. Fernandez-Martine *et al*. (1993) reported that the high-oleic OL allele appears to have a positive effect on grain yield and oil content but a negative effect on the self-compatibility of sunflowers; they emphasized that this effect depends somewhat on the genetic background of the studied genotypes. They concluded that the higher productivity of high-oleic hybrids seems to stem from their increased above-ground biomass production. Conversely, studies by Kleingartner (2004) indicated that the grain yield of high-oleic sunflower hybrids is 10-13% lower than that of standard hybrids. The relationship between the high-oleic trait and agronomic traits has been studied in some oil crops. Due to the varying expression of traits in open-pollinated, mid-oleic, and hybrid cultivars that impact grain and oil yields, this study was conducted to provide reliable information for comparing these three types of sunflower genotypes.

High and mid-oleic acid sunflower cultivars are not widely recognized in Iran, and there has been no comparative evaluation of these cultivars against other hybrid and open-pollinated varieties. Therefore, examining and comparing the agronomic characteristics of these hybrids with standard and open-pollinated cultivars is essential. Such an analysis can provide valuable insights into determining optimal cultivation locations and making informed decisions regarding the justification of producing each type of cultivar in Iran.

MATERIALS AND METHODS

The study involved 36 sunflower genotypes, including 16 hybrids with standard oil content, 9 mid-oleic hybrids, and 11 open-pollinated populations (Table 1). The classification of hybrids was based on oleic acid content, with the range of the four main fatty acids detailed in Table 2. All genotypes were sourced from the Seed and Plant Improvement Institute (SPII) in Karaj, Iran. The experiments were designed as a 6×6

Table 1. The list of genetic materials.

No.	Hybrid	Pedigree	Type
1	SUN99-H1	RGK15×AGK32	SH
2	SUN99-H2	RGK15×AGK2	SH
3	SUN99-H3	RGK15×AGK222	SH
4	SUN99-H4	RGK24×AGK58	SH
5	SUN99-H5	RGK3×AGK110	SH
6	SUN99-H6	RF81-65×AGK38	SH
7	SUN99-H7	RF81-65×AGK110	SH
8	SUN99-H8	RF81-65×AGK222	SH
9	SUN99-H9	RF81-65×AGK370	SH
10	SUN99-H10	RGK60×AGK358	SH
11	SUN99-H11	RGK131×AGK370	SH
12	SUN99-H12	RN1-73×AGK110	SH
13	SUN99-H13	RN1-73×AF81-222	SH
14	SUN99-H14	RGK24×AGK2	SH
15	SUN99-H15	R60×AF196	SH
16	SUN99-H16	RO54×AO67	MO
17	SUN99-H17	RO54×AO60	MO
18	SUN99-H18	RO53×AO67	MO
19	SUN99-H19	RO53×AO35	MO
20	SUN99-H20	RO53×AO36	MO
21	SUN99-H21	RO53×AO42	MO
22	SUN99-H22	RGK15×AO67	MO
23	SUN99-H23	RN1-73×AO42	MO
24	SUN99-H24	RO54×AO36	MO
25	Chek1	Golsa	SH
26	SUN99-OP1	Karaj 1	OP
27	SUN99-OP2	Karaj 2	OP
28	SUN99-OP3	Gabor	OP
29	SUN99-OP4	Karaj 3	OP
30	SUN99-OP5	Armavirski	OP
31	SUN99-OP6	Karaj 4	OP
32	SUN99-OP7	Zabol	OP
33	SUN99-OP8	Karaj 5	OP
34	SUN99-OP9	Gonbad1	OP
35	Chek2	Progress	OP
36	Chek3	Lakumka	OP

SH: Standard oil hybrid, MO: High oleic acid hybrid, OP: Open pollinated.

Table 2. The range of major fatty acids in three groups of sunflower genotypes.

Hybrid type	Palmitic acid (C16:0) (%)	Stearic acid (C18:0) (%)	Oleic acid (C18:1) (%)	Linoleic acid (C18:2) (%)
Standard hybrid	5-7	4-6	15-24	62-72
Mid-oleic hybrid	4-7	1-6	40-70	20-50
Open pollinated	4-6	5-7	18-23	65-75

simple lattice with two replications at two locations: Karaj (35.84°N, 50.93°E; altitude of 1321 m above sea level) and Shahrood (36.25°N, 54.57°E; altitude of 1349 m above sea level) during the 2020-2021 growing season. Planting took place in mid-April at both sites.

To prepare the seedbed, plowing was conducted in the autumn, followed by supplementary tillage before planting in early May. Fertilizers (N, P, and K) were applied before planting according to soil tests conducted in each region. All phosphate and potassium fertilizers, along with one third of the nitrogen fertilizer, were distributed before planting, while the remaining nitrogen fertilizer was applied in two splits up to the 8-10 leaf stage. Each plot consisted of four rows, each 4 meters in length, with a 60 cm spacing between rows and 25 cm spacing within rows. Trifluralin herbicide (2 L ha^{-1}) was used for weed control.

Plant characteristics, including phenological and agronomic traits, were measured during the growing season. Grain yield and yield components were assessed after harvest. Days to maturity were recorded according to the method described by Schneiter and Miller (1981). Plant height, head diameter, and stem diameter were measured for six plants in each plot at physiological maturity.

The 1000-grain weight was determined based on three random samples from each plot. The grain number per head was calculated using the mean head yield and 1000-grain weight. Oil content was analyzed using a Soxhlet extractor with a 10 g ground seed sample from each plot. Grain yield was determined by harvesting three meters from the two central rows of each plot, excluding 0.5 m of the margins. Oil yield was calculated by multiplying grain yield by oil content.

A combined analysis of variance was performed based on a randomized complete block design. Following the combined analysis, the means of the genotypes for each trait were compared using the LSD test. The statistical analysis was conducted with SPSS Version 24.

RESULTS AND DISCUSSION

Analysis of variance

The results of the combined analysis of variance revealed significant differences between locations for days to maturity, head diameter, and 1000 achene weight (Table 3). While considerable differences were observed among locations for traits such as grain and oil yield, significant differences for most traits were not expressed due to lower degrees of freedom for the

Table 3. Combined analysis of variance for agronomic traits of sunflower genotypes.

Sources of variations	df	Days to maturity	Plant height	Head diameter	Stem diameter	1000-grain weight	Achene No./Head	Oil content	Grain yield	Oil yield
Location	1	4635.3**	7876.6^{ns}	835.7*	250.3	11019.8*	1004839.2^{ns}	62.2^{ns}	2428662.5^{ns}	833245.9^{ns}
Replication/location	2	40.3	2555.3	15.5	33.3	451.7	65710.3	29.2	330814.5	56382.3
Genotypes	35	15.2**	1611.2**	6.7**	12.9**	155.3**	50178.6**	5.4**	334050.8**	74929.5**
Location×genotypes	35	6.1**	246.5*	3.9**	5.0*	141.1**	68130.8**	1.8^{ns}	262565.2**	58206.7**
Error	70	2.0	141.3	1.7	2.7	33.4	15009.7	1.8	66469.4	12452.7
Coefficient of variation (%)		1.4	6.9	7.8	7.7	10.5		15.0	3.0	9.1

ns, * and ** are non-significant and significant in probability of 5 and 1% respectively.

related mean squares of experimental errors used in the F-tests. Significant differences among the genotypes were found for all traits, indicating considerable genetic variability within the genotypes. The simultaneous evaluation of three types of sunflowers in this study contributed significantly to this genetic variability. The significant interaction between genotypes and locations for all traits, except for oil content, indicated different responses of the genotypes to variable environmental conditions at each location.

Agronomic features of the three types of sunflower genotypes

Days to maturity

The growing duration of the three types of genotypes under investigation ranged from 99 to 102 days (Figure 1). Among them, SUN99-H7 was the earliest maturing genotype, requiring only 96 days, while SUN99-OP8 took the longest, maturing at 105 days (Table 4). Notably, the open-pollinated populations required a longer duration to reach physiological maturity, maturing three days later than the other types. Both the standard and mid-oleic hybrids exhibited similar growth durations of 99 days. Amir and Khalifa (1991) similarly reported shorter growth durations for hybrids compared to open-pollinated cultivars. The observed early maturity of hybrids may be attributed to the higher heritability of this trait, which facilitated selection for early maturity during inbreeding. Additionally, Fernandez-Martinez *et al.* (1993) indicated that low oleic hybrids tend to exhibit early maturity and suggested that alleles associated with higher oleic acid content might influence early maturity in sunflowers. In contrast, the delayed maturity of open-pollinated populations could be due to the uneven phenological stages present within these populations.

Plant features

Open-pollinated genotypes exhibited the highest average plant height at 195 cm, while standard hybrids were the shortest, averaging 160 cm. This height difference is largely attributed to strong selection pressure for shorter plant heights in the parent inbred lines used to produce standard hybrids. In contrast,

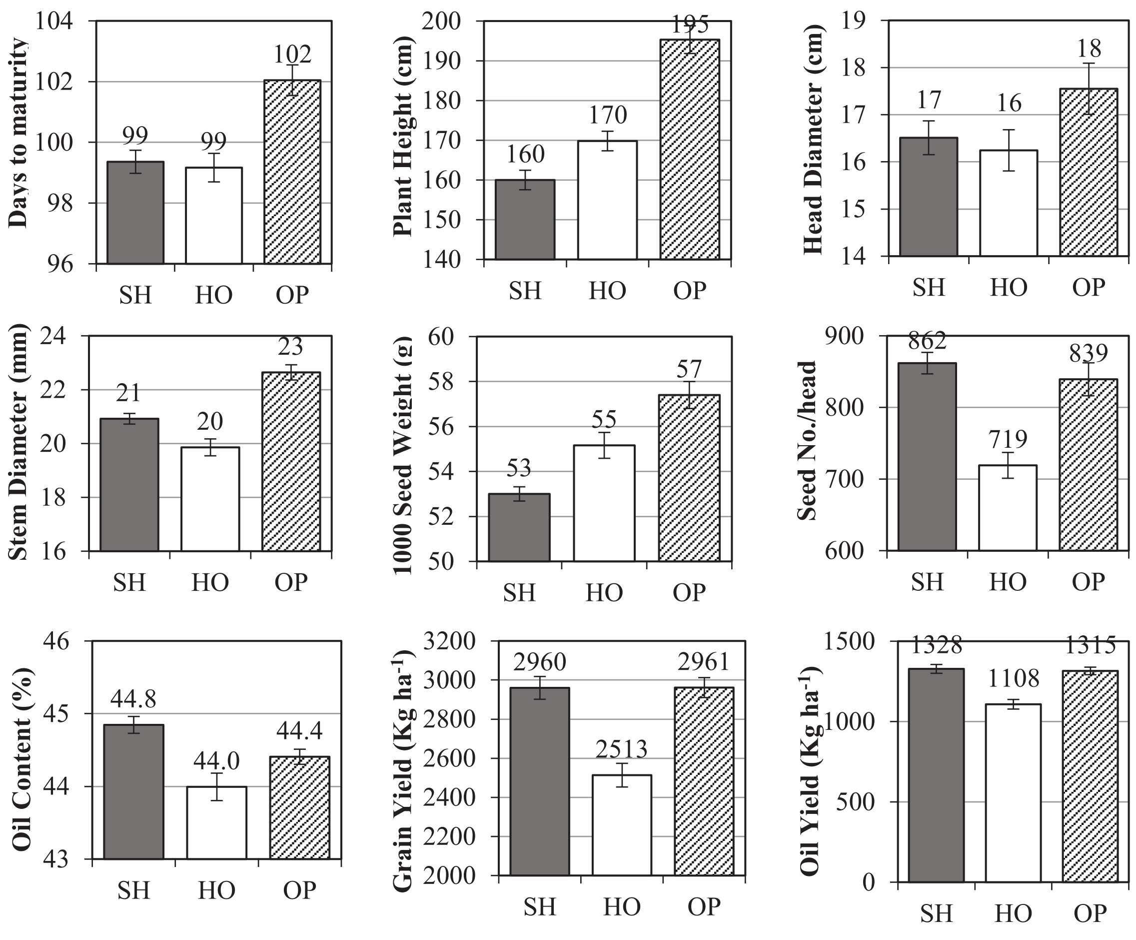

Figure 1. Comparison of agronomic traits in three types of sunflower genotypes.
SH: Standard hybrid, HO: High oleic type, OP: Open pollinated population. Bars represent the standard error of the mean.

Table 4. Mean values for agronomic traits of sunflower genotypes in Karaj and Shahrood.

No.	Days to maturity	Plant height (cm)	Head diameter (mm)	Stem diameter (mm)	1000-grains weight (g)	Achene No./head	Oil content (%)	Grain yield (kg ha^{-1})	Oil yield (kg ha^{-1})
SUN99-H1	99	150	18	20	50	879	46.45	2944	1378
SUN99-H2	101	152	15	21	46	959	43.87	2891	1269
SUN99-H3	100	163	16	20	49	1003	43.01	3214	1381
SUN99-H4	100	177	17	21	50	893	43.80	2971	1302
SUN99-H5	100	146	17	21	62	702	44.26	2819	1247
SUN99-H6	98	175	18	21	67	858	44.37	3298	1462
SUN99-H7	96	124	15	19	52	712	46.46	2480	1159
SUN99-H8	97	162	16	20	55	831	44.01	3012	1328
SUN99-H9	98	143	16	21	56	782	44.82	2941	1315
SUN99-H10	100	192	17	24	53	818	43.80	2867	1257
SUN99-H11	100	150	16	18	48	984	44.06	3150	1388
SUN99-H12	101	153	18	20	51	843	47.14	2792	1317
SUN99-H13	100	163	17	22	51	1020	45.92	3468	1594
SUN99-H14	101	171	17	23	49	990	45.36	3108	1410
SUN99-H15	101	174	16	21	54	722	45.90	2609	1198
SUN99-H16	101	173	18	22	55	703	44.80	2482	1117
SUN99-H17	101	178	15	19	65	711	44.15	2785	1227
SUN99-H18	99	168	17	18	52	695	44.02	2412	1062
SUN99-H19	97	161	16	22	57	662	43.98	2377	1050
SUN99-H20	97	169	16	19	60	658	43.81	2538	1113
SUN99-H21	99	170	16	19	49	699	44.06	2290	1016
SUN99-H22	101	177	15	21	43	921	44.31	2591	1148
SUN99-H23	100	168	17	20	52	746	45.34	2555	1163
SUN99-H24	99	166	16	18	63	678	41.48	2591	1072
CHK1	101	168	15	23	53	796	44.32	2798	1241
SUN99-OP1	102	211	18	24	69	660	43.50	2845	1237
SUN99-OP2	104	198	19	25	53	909	44.03	3075	1352
SUN99-OP3	102	205	16	22	55	830	43.77	2977	1303
SUN99-OP4	101	192	19	23	59	916	44.88	3211	1440
SUN99-OP5	100	193	17	23	51	875	45.58	2839	1293
SUN99-OP6	101	176	21	24	66	801	46.39	3121	1446
SUN99-OP7	101	171	15	20	51	744	42.31	2458	1035
SUN99-OP8	105	201	17	23	56	884	43.88	3086	1353
SUN99-OP9	104	203	16	22	54	951	44.68	3194	1427
CHK2	103	207	16	21	51	945	44.94	2853	1282
CHK3	102	192	18	22	66	718	44.54	2918	1299
LSD 5%	1.0	8.4	0.9	1.2	4.1	86.4	0.9	181.8	78.7
LSD 1%	1.3	11.1	1.2	1.5	5.4	114.7	1.3	241.4	104.5

the selection process for open-pollinated populations did not exert the same level of pressure to reduce plant height. Notably, among the genotypes, SUN99-OP1 achieved the tallest height at 211 cm, while SUN99-H11 was the shortest at 150 cm.

In terms of stem diameter, open-pollinated genotypes also outperformed standard hybrids and mid-oleic hybrids, with diameters of 23 cm compared to 21 cm and 20 cm, respectively. The largest stem diameter observed was in SUN99-OP2, measuring 25 cm. Additionally, open-pollinated genotypes had the largest head diameter (18 cm), whereas mid-oleic hybrids exhibited the smallest head diameter (16 cm) (Figure 1). The largest head diameter was recorded for SUN99-OP6 at 21 cm.

Yield components

Open-pollinated populations and mid-oleic hybrids exhibited higher grain weights, averaging 57 g and 55 g, respectively, compared to standard hybrids, which averaged 53 g. Among these, SUN99-OP1 recorded the highest grain weight at 69 g. Nisar *et al*. (2011) similarly reported that open-pollinated sunflower cultivars had greater grain weights than hybrids.

Significant differences in achene numbers were observed among the three genotype types (Figure 1), likely due to variations in seed set. Some varieties are capable of self-fertilization, producing seeds independently of pollinators (Mota *et al*., 2024). Overall, a balance between seed number and seed weight was evident. Standard hybrids had the highest average number of achenes per head (862), followed by open-pollinated genotypes (839) and mid-oleic hybrids (719). The highest achene count was observed in the standard hybrid SUN99-H13 (1020), while the lowest count was recorded for the mid-oleic hybrid SUN99-H20 (658). Pereira *et al*. (1999) indicated that yield response plateaus at 7500 grains per m², suggesting that further increases in grain number may not enhance yield potential. Therefore, improving both seed components, particularly in mid-oleic hybrids, could contribute to higher yields. Mid-oleic hybrids typically produce significantly fewer seeds per head, which is a critical determinant of both grain and oil yield (Shankar *et al*., 2006; Ghaffari *et al*., 2019, Ghaffari *et al*., 2023). Gholizadeh *et al*. (2023) proposed that simultaneous genetic improvements in traits such as plant height, 1000-seed weight, seed number per head, and early maturity are achievable in sunflowers.

The highest oil content was found in the standard oil-type hybrid SUN99-H12, which had an oil percentage of 47.14%. Additionally, SUN99-H23, a mid-oleic hybrid, exhibited an oil content of 45.34%, while SUN99-OP6, an open-pollinated population, recorded an oil content of 46.39%. Although the average oil content among the three groups did not show significant differences (Figure 1), standard hybrids (44.85%) and open-pollinated populations (44.41%) had slightly higher oil content than mid-oleic hybrids (43.99%).

Amir and Khalifa (1991) observed that open-pollinated populations yielded lower oil content than hybrids under both irrigated and rain-fed conditions, a pattern resulting from selection efforts aimed at increasing oil content in hybrids. The oil content among the genotypes ranged from 43.01% to 47.14% for standard hybrids, 41.48% to 45.34% for mid-oleic hybrids, and 42.31% to 46.39% for open-pollinated populations.

Morrison *et al*. (1981) reported greater variation in oil percentage among hybrid cultivars (42.7% to 48.0%) compared to open-pollinated cultivars, such as Peredovik and Spotnik (47.6% to 48.9%). This suggests similar genetic diversity concerning oil percentage within each of the three studied genotypes, justifying the application of selection to enhance oil content among these genetic materials. The findings regarding achene number and weight align with Pereira *et al*. (1999), which stated that hybrids typically exhibit more grains with lower grain weights compared to open-pollinated cultivars. However, contrary to their findings, the oil percentage among hybrids did not significantly differ from that of open-pollinated populations and mid-oleic hybrids. The negative relationship between achene number and weight is a common response to variable resource supply (Villalobos *et al*., 1994).

Grain and oil yields

The comparison of means for grain yield identified the standard oil-type hybrids SUN99-H13, SUN99-H6, and SUN99-H3 as the highest yielding, with yields of 3468, 3298, and 3214 kg ha^{-1}, respectively (Table 4). The most productive standard hybrid, SUN99-H13, outperformed the best open-pollinated genotype, SUN99-OP4, by 8% and the leading mid-oleic hybrid, SUN99-H17, by 24%. Although average grain yields for standard hybrids and open-pollinated genotypes were nearly identical at 2960 kg ha^{-1}, the highest yielding genotypes were predominantly standard hybrids, suggesting a greater expression of heterosis in these hybrids.

Pourdad and Beg (2008) reported similar average yields for open-pollinated varieties and hybrids, while Vear (2010) and Yadava *et al*. (2012) indicated a yield superiority of 20-30% for hybrids over open-pollinated cultivars. Pereira *et al*. (1999) documented a 23% yield advantage for hybrids compared to open-pollinated cultivars, highlighting a significant 36% superiority in oil yield. The comparable yields of hybrids and open-pollinated varieties in this study may stem from deliberate selection for early maturity. Standard hybrids and open-pollinated populations exhibited approximately 17% higher grain yields than mid-oleic hybrids, which had an average yield of 2513 kg ha^{-1}. Kleingartner (2004) noted a 10-13% yield advantage for standard hybrids over high oleic hybrids. However, Premnath *et al*. (2014) found no correlation between oleic acid content and yield or other agronomic traits in sunflowers. Fernandez-Martinez *et al*. (1993) suggested that the high oleic OL allele positively influences grain yield and oil content, although its impact is contingent upon the genetic background of the materials used.

Oil yield is derived from the product of grain yield and oil content. Typically, the correlation between oil yield and grain yield is stronger than that with oil percentage. Sunflowers may compensate for pre- and post-emergence losses by increasing head size and grain number per head (Lamichhane *et al*., 2022). The highest oil yields were recorded in the standard and mid-oleic hybrids SUN99-H13 and SUN99-H16, at 1594 kg ha^{-1} and 1227 kg ha^{-1}, respectively. Among open-pollinated varieties, SUN99-OP6 had the highest oil yield, attributed to its high oil percentage of 46.4%. The standard hybrid with the highest oil yield surpassed the best open-pollinated genotype by 10.2% and the most productive mid-oleic hybrid by 29.9%.

The reduction in both grain yield and oil percentage contributed to lower oil yield in the mid-oleic hybrids. The overall averages for oil yield in standard hybrids (1328 kg ha^{-1}) and open-pollinated populations (1315 kg ha^{-1}) exceeded that of mid-oleic hybrids (1108 kg ha^{-1}) by approximately 200 kg, which is statistically significant. This negative correlation, coupled with the inverse relationship between grain weight and oil percentage, justifies the higher grain and oil yields of standard hybrids compared to the other two genotype types. These results emphasize the necessity for balanced selection between components to maximize both grain and oil yields in sunflower cultivation.

Variability among the genotypes

The results demonstrated greater variability for agronomic traits among open-pollinated genotypes compared to both standard and mid-oleic hybrids. Individual plants within open-pollinated populations exhibited considerable heterogeneity, whereas hybrid cultivars showed more uniform characteristics. This uniformity among hybrids was evident in this study and aligns with Aksyonov's (2024) assertion that higher genetic purity is essential for successful heterotic breeding in sunflowers.

To illustrate the dispersion of data related to measured characteristics within each group, box plots were utilized (Figure 2). These visual representations aid in selecting genotypes based on desired traits within the studied groups. For days to maturity, open-pollinated populations had a wider range of variation than standard and mid-oleic hybrids, although median values indicated that the latter two groups were more inclined toward early maturity. In terms of plant height, most standard hybrids were shorter compared to the other two groups.

The variation in stem diameter was greater in open-pollinated populations, while standard hybrids exhibited less variability. Nevertheless, the largest head and stem diameters were recorded in open-pollinated populations. For critical components of grain yield, such as 1000-grain weight and the number of achenes per head, open-pollinated populations also displayed more variation than hybrids. This indicates that open-pollinated varieties are a valuable source of genetic diversity, offering opportunities for selecting traits that could enhance grain yield.

Conversely, regarding oil content and grain yield, the results revealed contradictory findings, with hybrids exhibiting a greater range of variation than open-pollinated populations. This variability underscores the necessity for extensive screening of hybrids concerning oil content and grain yield. The findings suggest that not all crossings yield high-performance hybrids with elevated oil content. Consequently, alongside hybrid breeding aimed at improving the principal sunflower fatty acids (Ghaffari and Shariati, 2023), selection remains a critical process in any sunflower hybrid breeding program.

CONCLUSION

While the comparison between open-pollinated and hybrid cultivars has a long-standing history, our study uniquely evaluates three types of sunflower genotypes (standard hybrids, mid-oleic hybrids, and open-pollinated populations) within a singular framework. The results indicate that mid-oleic hybrids generally exhibited lower grain and oil yields compared to both open-pollinated populations and standard hybrids. The reduction in yield associated with oleic hybrids can only be justified by the increase in oleic fatty acid content. Consequently, the economic price of oleic oils must rise to offset this reduced yield. In contrast, open-pollinated populations showed results similar to standard hybrids regarding grain and oil yield, achene number per head, and oil content, with standard hybrids achieving the highest levels in these traits.

Within each group, standard hybrids demonstrated superior performance, yielding the highest grain and oil yields and the most grains per head, while mid-oleic hybrids had the lowest values for these traits, including 1000-seed weight. Open-pollinated populations exhibited longer growth durations and greater plant heights, whereas standard hybrids were characterized by earlier maturity and shorter plant heights.

Our findings highlighted that open-pollinated genotypes displayed greater variability compared to both standard and mid-oleic hybrids. As sunflower is a non-native plant in Iran, open-pollinated cultivars serve as the exclusive source of genetic diversity. The development of hybrid cultivars has reduced this genetic diversity, underscoring the critical importance of preserving open-pollinated cultivars. This preservation is vital for maintaining the genetic variability necessary for inbred line extraction in sunflower breeding programs. Moreover, the sustainability of hybrid

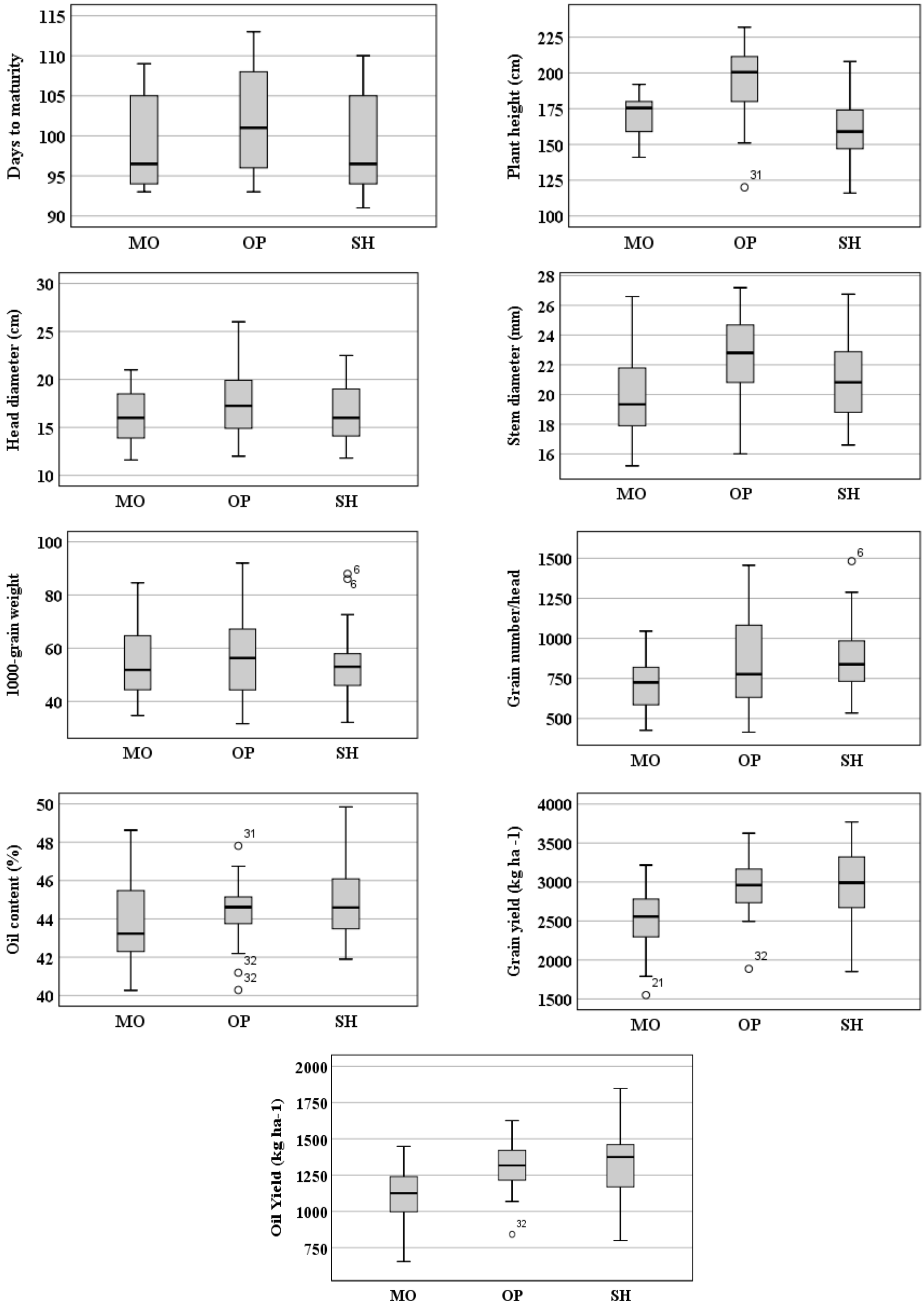

Figure 2. Variability of agronomic characters among the three types of sunflower genotypes. The horizontal axis represents the types of sunflower genotypes: SH: Standard oil hybrid, MO: High oleic acid hybrid, and OP: Open Pollinated. The bars/ points depict the variability in agronomic traits measured in each genotype.

cultivar production relies significantly on the diversity present in these open-pollinated cultivars.

While the variability of open-pollinated populations offers advantages for genetic improvement, the uniformity of hybrids can simplify agricultural management. However, this uniformity may become a disadvantage under unfavorable environmental conditions, such as high temperatures or frost during flowering, which can adversely affect insect pollination and seed set. With their longer flowering duration, open-pollinated cultivars may better withstand these extremes, which could explain the higher average yields observed in this study. The greater variability in grain weight and the number of seeds per head among open-pollinated populations further reinforces their value as a genetic resource for yield enhancement.

These results broadly illustrate how selection impacts the enhancement of traits such as early maturity, reduced plant height, increased oil content, and improved grain and oil yields in standard hybrids. Conversely, improving these characteristics in mid-oleic hybrids is challenging without addressing the negative genetic correlations between these traits and oleic acid content. The higher variability observed in oil content and grain yield among standard and mid-oleic hybrids indicates that not all crossings result in high-yielding hybrids with elevated oil content. This emphasizes the central role of selection in any sunflower breeding program. The commercial viability of mid-oleic hybrids remains contingent upon market demand and the necessity to balance yield with oleic acid percentages, particularly given the significant yield reductions associated with these hybrids.

ACKNOWLEDGMENTS

We express our gratitude to the Seed and Plant Improvement Institute (SPII), Karaj, Iran, for their support through grants and provision of genetic materials.

REFERENCES

Aksyonov I. (2024). Evaluation of genetic purity of parental lines and hybrids of sunflower. *Bulgarian Journal of Crop Science*, 61(5): 44-53.

Amir H. A., and Khalifa, F. M. (1991). Performance and yield of sunflower (*Helianthus annuus*) cultivars under rainfed and irrigated conditions in Sudan. *The Journal of Agricultural Science*, 116(2): 245-251.

Davey M. R., and Jan M. (2010). Sunflower (*Helianthus annuus* L.): genetic improvement using conventional and in vitro technologies. *Journal of Crop Improvement*, 24(4): 349-391.

Fernández-Martínez J., Muñoz J., and Gómez-Arnau J. (1993). Performance of near-isogenic high and low oleic acid hybrids of sunflower. *Crop Science*, 33(6): 1158-1163.

Ghaffari M., Davaji A. M. N. R., and Ghadimi F. N. (2019). Oil yield determinant of sunflower in climatically different regions of Iran. *Bulgarian Journal of Agricultural Science*, 25(1): 67-71.

Ghaffari M., Andarkhor S., Homayonifar M., Kalantar Ahmadi S., Shariati F., Jamali H., and Rahmanpour S. (2020). Agronomic attributes and stability of exotic sunflower hybrids in Iran. *Helia,* 43(72): 67-81.

Ghaffari M., Gholizadeh A., Rauf S., and Shariati F. (2023). Drought stress induced changes of fatty acid composition affecting sunflower grain yield and oil quality. *Food Science & Nutrition*, 11(12): 7718-7731.

Ghaffari M., and Shariati F. (2023). Genetic analysis of sunflower fatty acids under optimum and water stressed conditions. *Helia*, 46(78): 123-142.

Gholizadeh A., and Ghaffari M. (2023). Genotype by yield* trait (GYT) biplot analysis: A novel approach for phenotyping sunflower single cross hybrids based on multiple traits. *Food Science & Nutrition*, 11: 5928-5937.

Gunduz O., and Goksoy A. T. (2016). Determination of superior hybrid combinations in sunflower and testing of their resistance to broomrape (*Orobanche cumana* Wallr.) in infested areas. In: 19th International Sunflower Conference, Edirne, Turkey, 353-370.

Kaya Y., Jocic S., and Miladinovic D. (2012). Sunflower. Technological Innovations in Major World Oil Crops, Volume 1: Breeding, Springer, 85-129.

Kaya Y. (2004). Sunflower breeding, seed industry and future directions in Turkey. In: Proceedings of 16th International Sunflower Conference, Fargo, North Dakota, 465-472.

Kleingartner L. W. (2004). World outlook and future development of sunflower markets around the world. In: Proceedings of the 16th International Sunflower Conference, Paris, 69-77.

Lamichhane J. R., Wojciechowski A., Bourgeois C., and Debaeke P. (2022). Genetic variability for early growth traits in second season sunflower. *Frontiers in Agronomy*, 4: 822456.

Meena H. P., and Sujatha M. (2022). Sunflower breeding. In Book: Fundamentals of Field Crop Breeding (pp. 971-1008). Singapore: Springer Nature Singapore.

Mensink R. P., and Katan M. B. (1989). Effect of a diet enriched with monounsaturated or polyunsaturated fatty acids on levels of low-density and high-density lipoprotein cholesterol in healthy women and men. *New England Journal of Medicine*, 321(7): 436-441.

Morrison W. H., Akin D. E., and Robertson J. A. (1981). Open pollinated and hybrid sunflower seed structures that may affect processing for oil. *Journal of the American Oil Chemists Society*, 58: 969-972.

Mota L., Loureiro J., González J. A., Hevia V., et al.

(2024). Optimizing sunflower yield: Understanding pollinator contribution to inform agri-environmental strategies. *Field Crops Research*, 319: 109651.

Nisar M., Hussain S., Nausheen A., and Siddique F. (2011). Chemical composition of open pollinated and hybrid population of sunflower (*Helianthus annuus* L.). *Pakistan Journal of Botany*, 43(1): 157-163.

Pacureanu-Joita M., Stanciu D., Petcu E., Raranciuc S., and Sorega I. (2005). Sunflower genotypes with high oleic acid content. *Infection*, 40: 50.

Pei X.-C., Liu Y.-X., Liu H.-L., Li D.-Y., et al. (2022). Improving the oxidation stability of high-oleic sunflower oil with composite antioxidants. *Journal of Food Bioactives*, 18(18): 90-97.

Pereira M. L., Sadras V. O., and Trápani N. (1999). Genetic improvement of sunflower in Argentina between 1930 and 1995. I. Yield and its components. *Field Crops Research*, 62(2-3): 157-166.

Piva G., Bouniols A., and Mondies G. (2000). Effect of cultural conditions on yield, oil content and fatty acid composition of sunflower kernel. In: 15th International Sunflower Conference, Toulouse, France, 61-66.

Pourdad S. S., and Beg A. (2008). Sunflower production: hybrids versus open pollinated varieties on dry land. *Helia*, 31(48): 155-160.

Premnath A., Manivannan N., Chandirakala R., and Vanniarajan C. (2014). Association of oleic acid content with yield and its component traits in sunflower (*Helianthus annuus* L.). *Trends in Biosciences*, 7(16): 2245-2247.

Putt E. D. (1962). The value of hybrids and synthetics in sunflower seed production. *Canadian Journal of Plant Science*, 42(3): 488-500.

Rauf S. (2019). Breeding strategies for sunflower (*Helianthus annuus* L.) genetic improvement. *Advances in Plant Breeding Strategies: Industrial and Food Crops*, 6: 637-673.

Schneiter A. A., and Miller J. F. (1981). Description of sunflower growth stages 1. *Crop Science*, 21(6): 901-903.

Shankar V. G., Ganesh M., Ranganatha A. R. G., and Bhave M. H. V. (2006). A study on correlation and path analysis of seed yield and yield components in sunflower (Helianthus annuus L.). *Agricultural Science Digest*, 26(2): 87-90.

Seiler G., and Jan C. C. (2010). Basic information. In: Hu J., Seiler G., and Kole C. (Eds.), Genetics, genomics and breeding of sunflower (pp. 1-50). Science Publishers, Enfield, New Hampshire.

Skoric D., Seiler G. J., Liu Z., Jan C. C., Miller J. F., and Charlet L. D. (2012). Sunflower genetics and breeding. Serbian Academy of Sciences and Arts, Novi Sad, Serbia, 1-496.

Unrau J., and White W. J. (1944). The yield and other characteristics of inbred lines and single crosses of sunflower. *Scientific Agriculture*, 24: 516-525.

Villalobos F. J., and Ritchie J. T. (1992). The effect of temperature on leaf emergence rates of sunflower genotypes. *Field Crops Research*, 29(1): 37-46.

Vear F. (2010). Classic genetics and breeding. In: Hu J., Seiler G., and Kole C. (Eds.), Genetics, genomics and breeding of sunflower (pp. 51-78). Science Publishers, Enfield, New Hampshire.

Vear F. (2016). Changes in sunflower breeding over the last fifty years. *OCL-Oilseeds and fats, Crops and Lipids*, 23(2): D202.

Vick B. A., and Hu J. (2010). Future prospects. In: Hu J., Seiler G., and Kole C. (Eds.), Genetics, genomics and breeding of sunflower (pp. 313-326). Science Publishers, Enfield, New Hampshire.

Yadava D. K., Vasudev S., Singh N., Mohapatra T., and Prabhu K. V. (2012). Breeding major oil crops: Present status and future research needs. In Book: Technological Innovations in Major World Oil Crops, Volume 1 (pp. 17-51).

Zhou F., Liu Y., Xie P., Ma J., et al. (2024). Identification of candidate proteins related to oleic acid accumulation during sunflower (*Helianthus annuus* L.) seed development through comparative proteome analysis. *Acta Physiologiae Plantarum*, 46(11): 95.