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Research article

Oil productivity and adaptability of new sunflower open-pollinated cultivars

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Abstract

Sunflower (*Helianthus annuus* L.) is cultivated for oil production and as an ornamental crop. As an oil-producing crop, the yield is low due to variations in the geographical characteristics of cultivation regions as well as cultivation practices. Increased productivity of sunflower could be achieved from a cultivar that has high yield and wide adaptability. This study investigated the oil yield, stability and adaptability of five open-pollinated sunflower cultivars across different environments. The cultivars were planted in three locations in 2016 and 2017. The experiment was conducted in a randomized complete block design with five replications. The observed data were subjected to combined analysis of variance and stability analysis. The results showed that the Ha. 1, Ha. 3 and Ha. 15 cultivars had higher oil yields than the other cultivars. Ha. 1 produced the highest mean (± SD) oil yield of 374.7 ± 58.40 kg/ha but had narrow adaptability. Ha. 3 yielded 317.8 ± 48.85 kg/ha oil and had wide adaptability. Ha. 15 had 337.14 ± 46.83 kg/ha oil yield and narrow adaptability. Ha. 1 and Ha. 15 are suggested to be used as specific adaptation cultivars and Ha. 3 is suggested to be used as a broad adaptation cultivar. This information could be used in providing recommendations for sunflower varieties suitable to target cultivation regions.

Introduction

Sunflower (*Helianthus annuus* L.) is an annual plant that belongs to the family Asteraceae and is widely used as an ornamental and seed-producing crop that can be integrated in a cropping system as it can be grown biannually and has a stable economic value (Khan and Akmal, 2014). Sunflower is grown for its seeds and oil (Olowe et al., 2013). Sunflower seed contains 40–53% oil that has no cholesterol and has 85–91% unsaturated fatty acids (Ibrahim, 2012). The high content of unsaturated fatty acids makes sunflower oil suitable for cooking oil, margarine, cosmetics and as a raw material for medicines (Rosa et al., 2009). The sunflower seed is used as confectionary and bird feed and the kernel has high contents of protein and fat (Alizadah, 2009; Oshundiya et al., 2014).

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Sunflower is cultivated in arid regions with diverse soil and climatic types, using different genetic material. Some researchers (Khan and Akmal, 2014; Gul and Kara, 2015; Ernest, 2016) have reported a major effect of climate variation on the seed productivity and oil content of sunflower and seed variety can also affect the oil yield (Arash, 2013; Kandil et al., 2017). In addition, an experimental result showed the interaction between season, location and genetics affected the oil content and seed productivity of sunflower (Mrdja et al., 2012). The diversity of cultivation regions and lack of superior varieties has often resulted in low seed and oil yields. Thus, there is a need to increase seed productivity and oil content to support the success of the sunflower crop development.

Increases in the sunflower oil seed yield in diverse cultivation regions could be achieved by using superior varieties that have wide adaptability (Marjanović-Jeromela et al., 2011). However, the present genotype-environment interaction effect on the seed and oil yield of sunflower makes it difficult to identify truly superior genotype across diverse environments. Multi-environment testing could be used to identify cultivars with specific adaptation as well as those with broad adaptation (Kang, 2002). In Indonesia, the sunflower development program for oil yield is still in its early stage and a specific variety is not available yet. There is a need to conduct multi-environment testing that could identify a variety with broad and specific adaptation. These findings can then provide information to meet the demands of farmers and industry in selecting varieties that are suitable for the target cultivation area. Therefore, this study aimed to evaluate the stability and adaptability of five new open-pollinated cultivars of sunflower for oil yield based on multi-environment testing.

Materials and Methods

Plant materials and cultural practices

The genetic materials used in this study were five open-pollinated cultivars of sunflower selected for their high seed and oil productivity, namely, Ha. 1, Ha. 3, Ha. 15, Ha. 17 and Ha. 52. The research was conducted over 2 yr (2016 and 2017), at three different environments (Bojonegoro, Lumajang, and Situbondo districts, Indonesia). The characteristics of the environments are summarized in Tables 1 and 2. The planting date and harvest time at each location for each year are shown in Table 3.

The treatments in each location and year were arranged in a randomized complete block design with five replications. Every sunflower genotype was planted in a 4 m × 8 m plot with row × plant spacing of 40 cm × 8 cm and the spacing between replications was 100 cm. Three to four seeds were planted in one hole and then were covered with soil. Insecticides and fungicides were applied before planting to prevent attacks by pests and diseases. At 7 d after planting (DAP), one plant per hole was selected and the others were removed. Fertilizer was applied as follows: 75 kg N + 30 kg P_2O_5 + 30 kg K_2O per hectare. One-third of the N and the full amounts of P and K were applied at 7 DAP and the rest at 30 DAP. Weeds were controlled manually.

Data collection

The parameters observed were: flowering time, plant height, head diameter, oil content, seed yield and oil yield. The observations of plant height, flowering time and flower width were conducted on 10 plant samples for each genotype in each replication. Plant height and flowering time were measured when the plant was at the flowering stage, while the head diameter was measured when the plant was approaching its harvest time. The seed yield was obtained by weighing all harvested dry seeds from each plot. The moisture content in the seed was 7%. The oil content was measured using the Soxhlet method (Sudarmadji et al., 2007). Seed samples for oil content were obtained from harvested seeds from each genotype for each replication.

Table 1 Environment characterization

Parameter	Testing location		
	Bojonegoro	Lumajang	Situbondo
Soil type	Vertisol/Grumosol	Entisol/Regosol	Entisol/Regosol
Land type	Rainfed	Rainfed	Rainfed
Altitude (m)	20	110	10
Climate type (Oldeman)	D	C	E
Latitude	07°18’ S 112°21’ E	08°21’ S 113°08’ E	07°39’ S 114°12’ E

D = 3–4 wet monthsin a row; C = 5–6 wet months in a row; E = less than 3 wet months in a row

Table 2 Rainfall and temperature during 2016–2017 at three experimental locations

Month	Bojonegoro			Lumajang			Situbondo		
	Rainfall (mm)	Days of rain	T (°C)	Rainfall (mm)	Days of rain	T (°C)	Rainfall (mm)	Days of rain	T (°C)
2016:									
January	298	13	26.68	71	14	29.84	76.8	9	28.7
February	272	18	25.89	441	17	28.69	229.6	15	27.4
March	78	9	25.74	277	14	30.11	50.0	6	28.2
April	197	12	26.73	198	19	29.35	112.0	10	29.0
May	160	10	27.77	241	16	29.29	83.1	3	28.0
June	124	9	26.24	393	16	27.45	51.0	5	28.2
July	24	2	26.45	236	15	27.40	83.3	5	27.5
August	32	4	26.63	175	15	27.35	0.0	0	27.2
September	39	4	27.01	200	13	28.18	15.3	3	28.5
October	129	9	26.55	415	22	29.65	55.1	5	29.0
November	308	11	26.54	626	23	31.57	59.7	8	29.1
December	184	10	25.84	185	17	28.87	121.9	17	27.5
2017:									
January	505	21	25.88	323	20	27.16	184.7	15	27.4
February	248	20	25.45	217	19	27.57	138.1	9	28.1
March	209	16	25.72	193	13	28.19	56.3	6	28.0
April	170	12	26.68	219	14	28.45	120.0	8	28.6
May	137	5	26.06	116	11	27.50	34.4	6	28.2
June	67	4	25.46	29	6	26.25	36.4	4	26.9
July	72	2	24.87	23	8	25.15	2.2	1	26.1
August	4	2	25.08	20	6	25.52	0.0	0	26.1
September	91	4	26.52	86	4	26.22	0.0	0	27.1
October	127	10	27.51	67	13	28.40	0.0	0	28.3
November	271	18	27.09	341	20	28.00	105.6	11	27.9
December	251	13	25.96	235	20	27.81	61.3	12	27.7

T = temperature

Table 3 Planting date and harvest time

Location	Year 2016		Year 2017	
	Planting date	Harvest time	Planting date	Harvest time
Bojonegoro	29 April	2 August	1 May	5 August
Lumajang	27 January	3 May	7 February	2 August
Situbondo	22 February	5 May	15 February	10 May

Data analysis

Data on recorded parameters were subjected to combined analysis of variance between years, locations and cultivars. Duncan multiple range test at a significance level of 5% was used to compare the means of cultivars. The stability of the yield was analyzed using Equation 1 (Eberhart and Russel, 1966):

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij} \quad (1)$$

where Y_{ij} is the yield rate of genotype i at location j, μ_i is the average of the i^{th} genotype at all locations, β_i is the regression coefficient of the i^{th} genotype to the environmental index (x), I_j is the environmental index (the average deviation of all genotypes from an environment based on the general mean $I_j = (\sum j\ Yij/v) - (\sum i \sum jYij\ /vn)$ and δ_{ij} is the deviation from the regression of the i^{th} genotype in location j^{th}, Stability parameters for the regression coefficient (β_i) and the regression deviation ($\delta^2\ d_{ij}$) were calculated using Equations 2 and 3, respectively:

$$b_i = (\sum jYij\ Ij)/(\sum jI^2j) \quad (2)$$

$$S^2d_i = \sum j\hat{S}_{ij}(n\text{-}2) - S^2 e/r \quad (3)$$

where $S^2 e/r = n$ is estimated from the combined experimental error (variance of genotype mean in location j and

$$\sum j\hat{S}^2ij = (\sum Y^2 ij - Y^2 j/n) - (\sum ijYij\ Ij/\sum jI)^2/\sum j\ I^2j. \quad (4)$$

A genotype/variety was classified as stable if that genotype/variety had a regression coefficient not different from 1 (b_i =1) and the deviation of the regression was not different from 0 (S^2d_i = 0). The regression coefficient comparison test was done using a t test at a significant level of 5%. Deviation of the regression comparison test was done using an F test at $p < 0.05$.

Results

Growth and yield parameters

Combined analysis of variance of growth parameters (plant height, flowering time and head diameter) and yield parameters (seed yield, oil content and oil yield) were affected by the interactions between years, locations and sunflower cultivars (Table 4). The results implied that every cultivar responded to different locations and years with differences in plant height, flowering time, head diameter, seed yield, oil content and oil yield.

The growth parameters of the sunflower cultivars from every location and year are shown in Tables 5, 6, and 7. The plant height of sunflower cultivars was in the range 153.40– 261.64 cm with a mean value of 213.9 cm (Table 5). Ha. 1 and Ha. 3 had relatively similar plant heights (above 210 cm) that were higher than for Ha. 15, Ha. 17 and Ha. 52 across environments (year and location). The flowering time of sunflower cultivars was in the range 50.00–87.84 DAP with a mean value of 73.80 DAP (Table 6). Ha. 17 had the earliest flowering time among the other cultivars across environments (year and location). In 2016, Ha. 3 had the latest flowering time at Bojonegoro and Situbondo, while Ha. 15 had the latest flowering time at Lumajang. In 2017, Ha. 1 and Ha. 3 had the latest flowering time across the test sites. It was inferred that cultivars that had high plant height needed longer days to begin flowering. The head diameter of sunflower cultivars was in the range 12.36–26.22 cm with a mean value of 18.83 cm (Table 7). Ha. 17 and Ha. 52 had the biggest head diameters across locations and years. However, in 2017, the other two cultivars also produced heads that were not significantly different in diameter to Ha. 17 and Ha. 52 at Bojonegoro and Situbondo. From the recorded data, it could be seen that the head diameters of all cultivars planted in 2016 were smaller than all cultivars planted in 2017 at all locations.

The yield parameters of sunflower cultivars from every location and year are shown in Tables 8, 9, and 10. The seed yield was in the range 0.80–1.55 t/ha with a mean value of 1.13 t/ha (Table 8). Ha. 1 produced the highest seed yield across locations and years except in 2017 at Situbondo. In addition, the seed yield from Ha. 1 at Bojonegoro was not significantly different from Ha. 3 and Ha. 15 at the same location.

Table 4 Mean squares of combined analysis of variance for plant height, flowering time, flower width, seed yield, oil content, and oil yield of five sunflower cultivars evaluated at three locations during two years

Source of variation	Degrees of freedom	Mean square					
		Plant height	Flowering time	Head diameter	Seed yield	Oil content	Oil yield
Year	1	527.531**	2465.967**	1007.770**	0.909**	116.230**	22242.142**
Location	2	653.366**	478.115**	249.855**	0.007ns	19.340**	1270.590ns
Year×Location	2	8542.646**	210.166**	90.020**	0.024*	7.838**	2245.800*
Replication (Year×Location)	24	547.957**	13.046**	5.440**	0.154**	22.068**	22823.021**
Genotype	4	21460.423**	2934.421**	162.815**	0.487**	224.569**	105460.643**
Year×Genotype	4	2846.202**	695.597**	27.130**	0.099**	172.078**	45052.838**
Location×Genotype	8	1774.716**	171.698**	19.606**	0.062**	21.583**	3788.224**
Year×location×Genotype	8	1434.200**	63.108**	11.588**	0.035**	9.501**	5948.628**
Error	96	51.474	1.077	0.703	0.006	0.780	466.985

ns = not significant; * = significant at $p < 0.05$; ** = significant at $p < 0.01$

Table 5 Plant height (cm) ± SD of five sunflower cultivars evaluated at three locations during 2016 and 2017

Cultivar	2016			2017		
	Bojonegoro	Lumajang	Situbondo	Bojonegoro	Lumajang	Situbondo
Ha. 1	238.34 ± 19.67^{bcdef}	210.30 ± 12.08^{hij}	241.76 ± 9.61^{bcdef}	252.80 ± 8.76^{ab}	261.64 ± 2.19^{a}	250.60 ± 13.01^{abc}
Ha. 3	248.10 ± 7.69^{abcd}	228.38 ± 11.92^{efgh}	233.64 ± 30.54^{cdefg}	247.20 ± 12.56^{abcd}	250.34 ± 2.61^{abc}	227.50 ± 13.63^{fgh}
Ha. 15	179.28 ± 8.28^{mno}	171.40 ± 6.34^{nop}	189.46 ± 26.88^{klmn}	178.20 ±6.76^{mno}	202.86 ± 6.10^{ijkl}	153.40 ± 3.21^{p}
Ha. 17	191.34 ± 11.73^{klm}	163.14 ± 10.82^{op}	230.04 ± 10.27^{defg}	182.80 ± 3.11^{mn}	245.66 ± 11.03^{abcde}	205.84 ± 8.55^{ijk}
Ha. 52	237.08 ± 6.66^{bcdef}	192.84 ± 9.99^{jklm}	224.92 ± 8.89^{fgh}	186.20 ± 14.41^{ln}	174.84 ± 7.17^{mno}	216.40 ± 13.83^{ghi}

Mean values superscripted with different lowercase letters are significant different ($p < 0.05$).

Table 6 Flowering time (days after planting) ± SD of five sunflower cultivars evaluated at three locations in 2016 and 2017

Cultivar	2016			2017		
	Bojonegoro	Lumajang	Situbondo	Bojonegoro	Lumajang	Situbondo
Ha. 1	85.90 ± 0.28^{bc}	80.90 ± 4.59^{f}	86.46 ± 0.51^{b}	80.98 ± 0.19^{f}	79.26 ± 1.32^{g}	82.48 ± 0.95^{e}
Ha. 3	87.84 ± 1.03^{a}	70.24 ± 3.06^{k}	87.39 ± 0.53^{a}	79.80 ± 0.43^{fg}	77.08 ± 0.24^{gh}	79.38 ± 1.71^{g}
Ha. 15	83.60 ± 1.06^{de}	87.18 ± 3.15^{ab}	83.48 ± 0.96^{de}	76.00 ± 0.00^{h}	74.26 ± 0.41^{i}	72.08 ± 2.85^{l}
Ha. 17	60.86 ± 1.60^{mn}	58.04 ± 1.72^{o}	61.20 ± 1.30^{mn}	57.36 ± 1.61^{o}	62.16 ± 2.2^{lm}	61.90 ± 1.75^{m}
Ha. 52	86.58 ± 1.27^{ab}	63.34 ± 2.38^{l}	84.80 ± 3.17^{cd}	59.84 ± 2.36^{n}	50.00 ± 0.69^{q}	53.60 ± 2.19^{p}

Mean values superscripted with different lowercase letters are significant different ($p < 0.05$).

Table 7 Head diameter (cm) ± SD of five sunflower cultivars evaluated at three locations in 2016 and 2017

Culitivar	2016			2017		
	Bojonegoro	Lumajang	Situbondo	Bojonegoro	Lumajang	Situbondo
Ha. 1	18.32 ± 1.12^{def}	15.40 ± 1.01^{gh}	14.04 ± 0.88^{hi}	25.64 ± 1.34^{ab}	19.05 ± 0.52^{de}	26.22 ± 1.48^{a}
Ha. 3	17.88 ± 0.68^{def}	12.36 ± 0.47^{i}	13.62 ± 0.81^{hi}	23.96 ± 1.04^{b}	15.45 ± 0.90^{gh}	24.38 ± 0.81^{ab}
Ha. 15	12.40 ± 0.35^{i}	13.84 ± 2.09^{hi}	12.84 ± 0.61^{i}	17.96 ± 0.75^{def}	15.33 ± 1.52^{gh}	18.62 ± 0.51^{def}
Ha. 17	21.20 ± 1.01^{c}	16.81 ± 0.88^{fg}	19.36 ± 2.08^{cd}	23.80 ± 0.37^{b}	19.23 ± 0.87^{cd}	24.02 ± 0.18^{b}
Ha. 52	16.97 ± 0.60^{efg}	17.35 ± 0.66^{defg}	21.24 ± 2.09^{c}	24.86 ± 2.59^{ab}	17.79 ± 0.44^{def}	25.08 ± 3.35^{ab}

Mean values superscripted with different lowercase letters are significant different ($p < 0.05$).

Table 8 Seed yield (t/ha) ± SD of five sunflower cultivars evaluated at three locations in 2016 and 2017

Cultivar	Year 2016			Year 2017		
	Bojonegoro	Lumajang	Situbondo	Bojonegoro	Lumajang	Situbondo
Ha. 1	1.442 ± 0.182^{abc}	1.550 ± 0.097^{a}	1.448 ± 0.070^{ab}	1.322 ± 0.141^{bcd}	1.204 ± 0.388^{defgh}	0.992 ± 0.179^{ijkl}
Ha. 3	1.290 ± 0.081^{bcd}	1.206 ± 0.172^{defg}	1.228 ± 0.097^{def}	1.152 ± 0.096^{defghij}	1.040 ± 0.413^{fghijk}	1.000 ± 0.178^{ijk}
Ha. 15	1.299 ± 0.218^{bcd}	1.182 ± 0.144^{defghi}	1.251 ± 0.140^{cde}	1.072 ± 0.074^{efghijk}	0.994 ± 0.317^{ijkl}	1.068 ± 0.199^{efghijk}
Ha. 17	1.010 ± 0.087^{hijk}	1.035 ± 0.049^{fghijk}	1.047 ± 0.063^{fghijk}	0.800 ± 0.111^{l}	1.024 ± 0.187^{ghijk}	0.99 4± 0.239^{ijkl}
Ha. 52	0.944 ± 0.195^{kl}	1.163 ± 0.155^{defghij}	1.030 ± 0.127^{ghijk}	0.968 ± 0.112^{jkl}	1.024 ± 0.322^{ghijk}	1.136 ± 0.083^{defghijk}

Mean values superscripted with different lowercase letters are significant different ($p < 0.05$).

Table 9 Oil content (%) ± SD of five sunflower cultivars evaluated at three locations in 2016 dan 2017

Cultivar	2016			2017		
	Bojonegoro	Lumajang	Situbondo	Bojonegoro	Lumajang	Situbondo
Ha. 1	27.14 ± 0.65^{defgh}	26.85 ± 1.14^{defgh}	30.99 ± 1.27^{a}	27.59 ± 1.48^{def}	27.23 ± 3.95^{defg}	28.52 ± 1.86^{bcd}
Ha. 3	27.96 ± 1.21^{de}	30.69 ± 1.62^{ab}	28.24 ± 1.21^{cd}	25.49 ± 0.75^{fghi}	25.75 ± 3.02^{efghi}	25.21 ± 2.67^{ghi}
Ha. 15	30.67 ± 1.13^{ab}	27.53 ± 0.49^{def}	30.23 ± 1.15^{abc}	31.88 ± 2.02^{a}	27.46 ± 4.57^{def}	26.77 ± 3.09^{defgh}
Ha. 17	24.39 ± 2.05^{ij}	20.47 ± 2.99^{kl}	22.30 ± 0.94^{jk}	30.24 ± 1.82^{abc}	27.20 ± 3.50^{defgh}	27.32 ± 1.98^{defg}
Ha. 52	18.42 ± 0.78^{lm}	20.19 ± 2.61^{kl}	16.21 ± 1.92^{m}	26.73 ± 0.86^{defgh}	24.98 ± 3.26^{hi}	26.32 ± 3.27^{defghi}

Mean values superscripted with different lowercase letters are significant different ($p < 0.05$).

The oil contents in the sunflower cultivars varied in the range 16.21–31.88% with a mean value of 26.36% (Table 9). Ha. 1, Ha. 3, Ha. 15 and Ha. 17 had high oil contents (above 30%). However, Ha. 1, Ha. 3 and Ha. 17 only produced high oil contents in a certain environment. The high oil content for Ha. 1 was at Situbondo in 2016, whereas Ha. 3 produced high oil content at Lumajang in 2016 and Ha. 17 at Bojonegoro in 2017. In contrast, Ha 15 produced an oil content above 30% when it was planted in three different environments (at Bojonegoro and Situbondo in 2016 and at Bojonegoro in 2017). Consequently, the genotypic ranking at every location and for each year was different.

The oil yield of the sunflower cultivars was in the range 168.01–449.33 kg/ha with a mean value of 302.54 kg/ha (Table 10). Ha. 1, Ha. 3 and Ha. 15 had higher seed yields than Ha. 17 and Ha. 52, especially in 2016 at all locations. Interestingly, Ha. 52 at Situbondo in 2016 produced 168.01 kg/ha oil, whereas in 2017 it produced almost double that amount (300.99 kg/ha oil). Overall, the average seed yield and oil content of Ha. 1 were highest and the mean seed yields and oil contents of all sunflower cultivars planted in 2016 were higher than in 2017.

Yield stability and adaptability

In the current study, the yield parameters were affected by the interaction between genotype and environment (location and year), thus meeting the criteria for yield stability testing. The stability testing of sunflower cultivars for the seed yield parameter showed that Ha. 1 and Ha. 52 had different regression coefficient values from one, but they did not have different regression deviation values from zero (Table 11). These results indicated that those cultivars were classified as nonstable. On the other hand, the other three cultivars had regression coefficient values that were not different from one and the regression deviations were not different from zero, so those cultivars were classified as stable. Ha. 1 had the highest seed production and it was classified as a nonstable genotype. This result indicated that Ha. 1 could produce a high yield only under certain environmental conditions. This cultivar had narrow adaptability. Ha. 3 and Ha. 15 produced high seed yields and were stable genotypes and were classified as cultivars with wide adaptability.

Ha. 1 and Ha. 3 produced high oil contents and they were classified as stable. These results indicated that these cultivars had wide adaptability. A different result was found for Ha. 15 that produced the highest oil content but was nonstable, so Ha. 15 was classified as a cultivar that had narrow adaptability (location specific). Based on the stability analysis of the oil content parameter, Ha. 1, Ha. 3 and Ha. 17 had regression coefficients that were not different from one and regression deviations that were not different from zero (Table 12), indicating these cultivars were stable. Ha. 15 and Ha. 52 had regression coefficients that were not different from one and regression deviations that were different from zero; therefore, these cultivars were classified as nonstable.

Table 10 Oil yield (kg/ha) ± SD of five sunflower cultivars evaluated at three locations in 2016 and 2017

Cultivar	2016			2017		
	Bojonegoro	Lumajang	Situbondo	Bojonegoro	Lumajang	Situbondo
Ha. 1	392.15 ± 57.02^{bcd}	417.11 ± 43.51^{ab}	449.33 ± 40.13^{a}	365.94 ± 54.19^{bcde}	337.89 ± 141.78^{defgh}	285.54 ± 69.88^{hijklm}
Ha. 3	361.38 ± 37.01^{ce}	372.27 ± 71.69$^{bc\text{-}e}$	347.64 ± 41.27^{cdef}	294.27 ± 33.48^{fghijk}	275.59 ± 132.76^{ijklm}	255.83 ± 69.50^{jklmn}
Ha. 15	400.39 ± 80.54^{abc}	325.93 ± 45.24^{efghi}	379.37 ± 56.86^{bcde}	342.89 ± 45.01^{defg}	283.84 ± 129.28^{hijklm}	290.44 ± 85.31^{ghijkl}
Ha. 17	247.58 ± 41.25^{jklmn}	213.03 ± 40.51^{no}	233.92 ± 23.08^{mn}	243.43 ± 47.77^{klmn}	282.82 ± 83.07^{ijklm}	275.13 ± 86.21^{ijklm}
Ha. 52	174.94 ± 43.53^{o}	237.74 ± 63.10^{lmn}	168.01 ± 34.95^{o}	259.31 ± 37.04^{jklmn}	261.58 ± 107.34^{jklmn}	300.99 ± 58.43^{fghij}

Mean values superscripted with different lowercase letters are significant different ($p < 0.05$).

Table 11 Mean of **s**eed yield ± SD (from all environments), regression coefficient (b*i*), regression deviation (S^2_{di}) and yield stability of five sunflower cultivars

Cultivar	Seed yield (t/ha)	b*i*	S^2_{di}	Yield stability
Ha. 1	1.326 ± 0.203^{a}	2.097**	0.009^{ns}	Non stable
Ha. 3	1.153 ± 0.113^{b}	1.128^{ns}	0.003^{ns}	Stable
Ha. 15	1.144 ± 0.119^{b}	1.193^{ns}	0.003^{ns}	Stable
Ha. 17	0.985 ± 0.093^{d}	0.529^{ns}	0.007^{ns}	Stable
Ha. 52	1.044 ± 0.088^{c}	0.053*	0.009^{ns}	Non stable
General mean	1.131 ± 0.031			

Based on a t test for b*i*=1 and F test for S^2_{di} = 0, ns = not significant; * = significant at $p < 0.05$; ** = significant at $p < 0.01$.

Table 12 Mean of oil content ± SD (from all environments), regression coefficient (b*i*), regression deviation (S^2_{di}) and stability of oil content of five sunflower cultivars

Cultivar	Oil content (%)	b*i*	S^2_{di}	Stability
Ha. 1	28.05 ± 1.5^{b}	-0.156^{ns}	2.81^{ns}	Stable
Ha. 3	27.22 ± 2.23^{c}	-1.486^{ns}	1.77^{ns}	Stable
Ha. 15	29.09 ± 2.10^{a}	0.630^{ns}	4.69*	Non stable
Ha. 17	25.32 ± 3.61^{d}	2.931^{ns}	1.49^{ns}	Stable
Ha. 52	22.14 ± 4.46^{e}	3.080^{ns}	8.51**	Non stable
General mean	26.37 ± 0.68			

Based on a t test for b*i*=1 and F test for S^2_{di} = 0, ns = not significant; * = significant at $p < 0.05$; ** = significant at $p < 0.01$

The stability test based on oil yield showed that Ha. 1, Ha. 15 and Ha. 52 had regression coefficients that were not different from one and deviation regressions that were different from zero (Table 13), implying that these cultivars were nonstable. On the other hand, Ha. 3 and Ha. 17 had regression coefficients that were not different from one and regression deviations not different from zero; these cultivars were classified as stable. Ha. 1 and Ha. 15 had high oil yields and were nonstable, implying that they had narrow adaptability (location-specific). Ha. 3 had a high oil yield and was stable and had wide adaptability.

Discussion

Growth and productivity

The results of the current study indicated a genotype and environment interaction effect on sunflower growth and productivity traits based on multi-environment testing. The plant height and flower width of sunflower genotypes were affected by the interaction between genotype and the environment (location and year). The same results were reported by other researchers (Ieremenko and Kalitka, 2016; Demir, 2019), with plant photosynthesis being affected by genetic and environmental factors (soil and climate). Photosynthesis products may be used to maintain respiration and the by-product used for plant-growing processes,

Table 13 Oil productivity ± SD, regression coefficient (b*i*), regression deviation (S^2_{di}) and stability of sunflower cultivars

Line	Oil productivity (kg/ha)	b*i*	S^2_{di}	Stability
Ha. 1	374.66 ± 58.40^{a}	3.718^{ns}	331.50*	Non stable
Ha. 3	317.83 ± 48.85^{c}	3.170^{ns}	81.53^{ns}	Stable
Ha. 15	337.14 ± 46.83^{b}	2.720^{ns}	562.02**	Non stable
Ha. 17	249.32 ± 26.00^{d}	-1.485^{ns}	83.21^{ns}	Stable
Ha. 52	233.76 ± 51.34^{d}	-3.124^{ns}	613.47**	Non stable
General mean	302.54 ± 12.70			

Based on a t test for b*i*=1 and F test for S^2_{di} = 0, ns = not significant; * = significant at $p < 0.05$; ** = significant at $p < 0.01$

usually known as carbohydrate availability for growth. The carbohydrates available for plant growth may be partitioned into stem, leaf, flower and root growth and are influenced by genetic and environmental factors. For example, the accumulation of carbohydrates in the stem during the process of stem growth will determine the stem diameter and plant height, which are determined by the interaction between genetic and environmental factors (Baghdadi et al. 2014),.

The flowering time characteristic of the five sunflower cultivars used in the current study was also influenced by genotype and environment interaction. Sunflower is considered a day-neutral plant; its phenology (including flowering time) is determined in terms of growth degree days (GDD), where GDD is calculated from the daily temperature minus the base temperature, where the base temperature used is 7.2°C (Iqrasan et al., 2017). Each sunflower genotype needs a different GDD factor (Oshundiya et al., 2014; Panhwar et al., 2017). Each location in every year has a different daily temperature, so that it requires a different number of days to meet a certain value of GDD. The influence of the interaction between genotypes and environment on sunflower flowering time has also been reported by Ibrahim (2012) and Canavar et al. (2010).

Seed number and seed yield are the main components of the sunflower yield trait. Increasing the number of seeds per flower head and seed weight will result in a high yield. The number of seeds per head is positively correlated with the flower head width (Balalic et al., 2016). Seed weight is determined by the carbohydrate available for seed growth during seed filling, where the available carbohydrate and the duration of seed filling are affected by the genotype-environment interaction (Demir, 2016). In the current study, the seed yield was also affected by the interaction between genotype and environment (location and year). A similar result was reported also for sunflower by Ibrahim (2012). The complexity of the growth and yield components in influencing the seed yield resulted in a combined effect of the plant growth component (plant height, flowering time and flower width) on seed yield of only 46.8%, (plant height by 15.52%, head diameter by 66.0% and flowering time by 21.62%).

The oil content of sunflower seeds is the result of the accumulation of carbohydrates available for seed growth during the seed filling phase (Demir and Basalma, 2018). Carbohydrate partition for seed growth and the duration of seed filling is affected by the interaction between genotype and environment (Demir and Kamil, 2018); this may result in the sunflower oil content being affected by the genotype and environment interaction (Kaleem et al., 2016; Dutta, 2011). The seed-filling phase made a bigger contribution to determining the oil content than the growth phase. This caused the combination of growth components (plant height, flower width and flowering time) to only affect the oil content by 17.6% (plant height by 4.30%, head diameter by 3.82% and flowering time by 9.48%).

The seed yield and oil content are the main components that determine the sunflower oil yield (Ozturk et al., 2017). The combined effect of the seed yield and oil content on oil yield in the current study was 99.6% with the seed yield effect being 52.95% and oil content effect being 46.65%. The seed yield and oil content, in addition to the oil yield, were affected by the genotype and environment interaction. Other studies reported the effect of the genotype and environment interaction on oil yield (Dauguet et al., 2015; Anjum et al., 2012).

Yield stability and adaptability

Stability testing was used to classify the five sunflower cultivars into specific adapted and broadly adapted cultivars regarding seed and oil yield. Ha. 15 and Ha. 52 responded to the change in environmental conditions by changing the production of oilseeds and those genotypes had narrow adaptability, in contrast with the three other genotypes that had wide adaptability. Ha. 52 was a non-stable genotype based on both seed yield and oil content so that overall, Ha. 52 was a non-stable genotype for producing oil. Ha. 1 was not stable for producing seed but stable for producing oil, so this genotype was not stable for producing oil. In contrast, Ha. 15 was stable for producing seed and not stable for producing oil and so was considered a non-stable genotype for producing oil. Ha. 3 and Ha. 17 were stable for producing seed and oil; therefore, they were stable for producing oil.

Each sunflower genotype had a different response to changes in growing environmental conditions (Anjum et al., 2012; Ibrahim, 2012). Some genotypes respond by increasing or decreasing their seed yield, but other genotypes have a slight response regarding their yield (Iqrasan et al., 2017). A genotype that responds to changes in the environmental conditions by increasing or decreasing its yield is considered a genotype that has narrow adaptability. In contrast, a genotype that is nonresponsive to change in environmental conditions is considered a genotype with wide adaptability (Marjanović-Jeromela et al., 2011). In conclusion, Ha. 1, Ha. 3 and Ha. 15

had higher oil yields than the other tested genotypes. Ha. 1 had the highest oil yield (374.7 kg/ha) but was not stable and so was considered as a genotype with narrow adaptability. Ha. 3 had a high oil yield (317.8 kg/ha) and was stable and so was categorized as a genotype with wide adaptability. Ha. 15 produced 337.14 kg/ha of seed but the oil yield was not stable and so this genotype was categorized as having narrow adaptability. Thus, Ha. 1 and Ha. 15 could be used as specific adaptation cultivars and Ha. 3 could be used as a broad adaptation cultivar. This information could be used in providing recommendations for sunflower varieties suitable to target cultivation regions

Conflict of Interest

The authors declare that there are no conflicts of interest.

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