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*Full Length Research Paper*

# Analysing and modeling the relationship between yield and yield components in sunflower under different planting dates

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**The relationships between planting dates and yield and it's components in sunflower was evaluated through orthogonal polynomial regression analysis. Five field experiments were conducted during the summer season of 2011 to study the effect of five planting dates and three oilseed sunflower genotypes and their interactions on yield and yield components of sunflower. The highest seed yield, oil yield, plant height, head diameter, 1000-seed weight, seed yield plant$^{-1}$ and oil content were obtained at the earliest planting date (1st May). The evaluated genotypes differed significantly for all the studied traits. Sakha 53 cultivar was the best cultivar in seed yield, oil yield, plant height, head diameter, thousand seed weight and seed yield plant plant$^{-1}$ followed by Giza 102 and Pioneer hybrid 63M02, respectively. Orthogonal polynomial regression analysis revealed that, yield and yield components were significantly affected by planting date in linear responses. Multiple linear regression analysis indicated that seed yield plant$^{-1}$, head diameter and thousand seed weight were the most important variables contributing toward higher seed yield (kg ha$^{-1}$). Finally, it can be concluded that planting sunflower cultivar Sakha 53 on 1st May was recommended for maximizing seed and oil yields per unit area under the environmental conditions of this study.**

**Key words:** Sunflower, planting date, genotype, regression analysis, yield, yield components.

## INTRODUCTION

Sunflower (*Helianthus annuus* L.) occupies the fourth most important oil seed crop in the world. It is grown as a source of vegetable oil and protein. In Egypt, it is grown on 15 611 000 ha with an average seed yield of 2.52 ton ha$^{-1}$ and total production of 39 274 000 tons (FAO, 2010). Egypt's oil consumption has increased considerably over recent years. The acute shortage of edible oil in the country is increasing every year with increasing population growth. The local production of vegetable oils is still, therefore, below current needs, since it covers less than 10% of the consumption. Sunflower is considered one of the most important oil crops in Egypt and has a great potential in bridging the gap between demand and supply of edible oil to a significant extent in the years to come. Therefore, an improvement of the sunflower productivity of this crop is needed to meet the shortage of vegetable oils. The main objective in crop production is to obtain high yield and high quality. Achievement of this goal requires the use of appropriate cultivars for any region, accompanied with high quality seed and application of proper management practices. Appropriate planting time of various field crops results in higher economic yield without involving extra cost as it helps varieties to express their full growth potential. Planting date is a critical component of successful sunflower production. Therefore, determining the optimum planting date and suitable genotypes becomes very necessary for high seed yield under the Egyptian conditions.

Numerous studies have shown that yield and yield components of sunflower are reduced when normal sowing dates are delayed. Miller and Obunger (1981) reported that planting of sunflower after mid May reduced seed yield, oil content and head diameter significantly at Wisconsin, USA. Owen (1983) concluded from the studies conducted at Lubbock, Texas, USA found that late May and mid to late June planting gave higher yield than planting in July. Khan et al. (1985) obtained the maximum yield when sunflower was planted from April to May in North West Frontier Province of Pakistan. De-shen and Renzha (1985) conducted a study at Shenyang, China and found that early planting in April and May is better than planting in July. Ahmad et al. (2001) reported that the best time of sowing for sunflower is February in spring season and from mid August to mid September in kharif. De La Vega and Hall (2002) found that seed and oil yields are greatly reduced when normal sowing dates are delayed. Ali et al. (2004) found significantly higher yield in the sunflower crops sown earlier on August 10 and lower yield in late sowing crops on August 30. Yousaf et al. (2007) reported that seed yield significantly decreased when sunflower was planted on January 15 (1264 kg $ha^{-1}$), March 1 (1382 kg $ha^{-1}$) and March 15 (927 kg $ha^{-1}$) at Islamabad, Pakistan. Abdou et al. (2011) conducted a study at Tameia, Fayoum, Egypt and found that the sowing on June 1 gave the highest averages of yield and yield components, whereas, the lowest ones were obtained from sowing on July 1.

Lawal et al. (2011) conducted a study at Ibadan, Oyo State, Nigeria and found that planting date significantly affected all the growth and yield parameters including oil yield. Similar results were reported by Allam et al. (2003) in a two-year study at Assiut, Egypt. To study traits relations under different planting dates, multiple linear regression analysis was applied. Many researchers examined the relationships among yield components generally using correlation and regression analysis and concluded that selection for seed yield in sunflower should largely be dependent on thousand seed weight, head diameter, oil content (%) and seed yield $plant^{-1}$ (Farhatullah et al., 2006; Arshad et al., 2007; Behradfar et al., 2009; Anandhan et al., 2010; Yasin and Singh, 2010). A suitable combination of genotype and planting date is the most important factor in acquiring economic yield.

In view of the importance of planting date and genotype, the present investigation was designed to study the effects of planting dates, genotypes, and their interactions on yield and yield components of sunflower and to find out a suitable time of planting for better sunflower yield. Also, to fit the models for yield and its components as a function of planting dates through polynomial and multiple linear regression.

## MATERIALS AND METHODS

### Experimental details and layout

Five field experiments were conducted based on a split-plot design arranged in a basic randomized complete block plan with four replicates in the Agricultural Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt (30° 02' N latitude and 31° 13' E longitudes, altitude 22.50 m), during the summer season of 2011. The experiment was laid out under irrigated conditions on a clay loam soil. The main plots had five different planting dates [1st May ($D_1$), 15th May ($D_2$), 1st June ($D_3$), 15th June ($D_4$) and 1st July ($D_5$)], and sub plots comprised three oilseed sunflower genotypes (including two open pollinated cultivars Sakha 53, Giza 102 and one hybrid Pioneer 63M02 introduced from USA). Each sub plot (experimental unit) had eight ridges, each of 60 cm in width and 4.0 m in length and 30 cm hill spacing, occupying an area of 19.2 $m^2$.

### Cultural practices

The sunflower seeds were sown by putting three seeds in each hill which were thinned to one plant per hill 15 days after sowing. Calcium super phosphate (15.5% $P_2O_5$) at the rate of 100 kg $ha^{-1}$ was added during field preparation. Nitrogen fertilization (ammonium nitrate 33.5% N) at the rate of 80 kg N $ha^{-1}$ was added in two equal doses (at 1st and 2nd irrigations). Cultural practices, control of insects and weeds and furrow irrigation were given as needed during the growing season according to the local recommendations. The heads of the four central rows of each plot, which were kept for final harvest, were covered with newspaper completely right after pollination to prevent birds attack. All other production practices were as per recommended standards. All measurements relating to yield and quality data were uniform in the 5 planting dates.

### Collection of data

At harvest, when sunflower leaves and stems turned a straw color, backs of the heads were yellow and seeds became hard, the four middle rows were harvested and the border rows were discarded. Ten guarded plants were randomly selected from each experimental unit, harvested, tied and left to head dry, thereafter the following characters were estimated: plant height in cm, head diameter in cm, 1000-seed weight in gram and seed yield $plant^{-1}$ in gram. Seed oil content was determined on dry weight basis according to the method used by the Association of Official Agricultural Chemists (A.O.A.C.) (1990) using soxhelt apparatus and petroleum ether as an organic solvent. Plants in the four central ridges in each subplot were harvested for seed and biological yield per square meter and converted to record seed yield and biological yield in kg $ha^{-1}$.

Oil yield in kg $ha^{-1}$ was calculated by multiplying seed yield (kg $ha^{-1}$) by seed oil %. Harvest index was computed as the ratio of the seed yield to biological yield.

### Statistical analyses

For statistical analyses, collected data of each planting date were statistically analyzed using analysis of variance technique appropriate of the split-plot design according to Gomez and Gomez (1984). When analysis of variance showed significant treatment effect, the least significant difference (LSD) test was applied to make comparisons among the means at the 0.05 level of significance (Steel et al., 1997). To describe the impact of planting date on seed yield and yield components, regression analysis for determination of linear, quadratic, cubic and quartic relationships were done. Linear, quadratic and cubic components of each regression equation were successively tested for significance and included in the equation if they significantly reduced the residual sum of squares ($P < 0.05$). The model with the highest R and $R^2$ indicates the best possible fit. To analyze the relationships between seed yield and yield components accurately, multiple regression analysis as given by Snedecor and Cochran (1989) was performed.

Regression analyses were conducted on data points that were means of four replications. Testing the goodness of fit of the regression equation to the observed data was done by computing

**Table 1.** Mean squares from the analysis of variance of seed, oil and biological yield and harvest index as affected by planting dates and the genotypes of sunflower on the basis of a split plot design.

| Source of variation | df | Mean squares | | | |
|---|---|---|---|---|---|
| | | Seed yield (kg $ha^{-1}$) | Oil yield (kg $ha^{-1}$) | Biological yield (kg $ha^{-1}$) | Harvest index (%) |
| Replications | 3 | 13880** | 2183** | 53779.7$^{ns}$ | 0.00032$^{ns}$ |
| Planting dates (D) | 4 | 1062911.5** | 186297** | 6312001.44** | 0.005** |
| Linear regression | 1 | 1052768.37** | 185191.06** | 25157758.72** | 0.0197** |
| Quadratic regression | 1 | 9084.01$^{ns}$ | 921.21$^{ns}$ | 45804.02$^{ns}$ | 0.0005$^{ns}$ |
| Cubic regression | 1 | 553.07$^{ns}$ | 53.78$^{ns}$ | 43761.92$^{ns}$ | 0.00005$^{ns}$ |
| Quartic regression | 1 | 506.05$^{ns}$ | 134.73$^{ns}$ | 681.12$^{ns}$ | 0.00005$^{ns}$ |
| Error a | 12 | 1894 | 265 | 28996 | 0.00025 |
| Genotypes (G) | 2 | 1179916** | 143113** | 3395723** | 0.01199** |
| D × G | 8 | 7291* | 1696** | 212961** | 0.00141** |
| Error b | 30 | 2420 | 349 | 30497.5 | 0.00022 |

*, **, Significant at 0.05 and 0.01 probability levels, respectively. Ns = non significant at 0.05 probability level.

**Table 2.** Mean squares from the analysis of variance of yield components as affected by planting dates and sunflower genotypes on the basis of a split plot design.

| Source of variation | df | Mean squares | | | | |
|---|---|---|---|---|---|---|
| | | Plant height (cm) | Head diameter (cm) | 1000-seed weight (g) | Seed yield $plant^{-1}$ (g) | Oil content (%) |
| Replications | 3 | 350.20$^{ns}$ | 0.923$^{ns}$ | 8.63** | 32.43** | 0.0724$^{ns}$ |
| Planting dates (D) | 4 | 3037.96** | 59.27** | 444.29** | 2406.65** | 7.8495** |
| Linear regression | 1 | 2743.15** | 58.12** | 441.06** | 2365.45** | 7.78** |
| Quadratic regression | 1 | 210.78$^{ns}$ | 0.032$^{ns}$ | 1.46$^{ns}$ | 38.15$^{ns}$ | 0.004$^{ns}$ |
| Cubic regression | 1 | 13.95$^{ns}$ | 0.092$^{ns}$ | 1.49$^{ns}$ | 1.58$^{ns}$ | 0.026$^{ns}$ |
| Quartic regression | 1 | 8.14$^{ns}$ | 0.028$^{ns}$ | 0.05$^{ns}$ | 1.22$^{ns}$ | 0.028$^{ns}$ |
| Error a | 12 | 315.75 | 0.474 | 0.82 | 6.79 | 0.0533 |
| Genotypes (G) | 2 | 7062.76** | 43.91** | 1013.61** | 1207.38** | 24.2429** |
| D x G | 8 | 343.69$^{ns}$ | 1.04** | 9.45** | 63.95** | 0.5678** |
| Error b | 30 | 374.99 | 0.17 | 2.48 | 7.53 | 0.0820 |

** and ns, are significantly different at the 0.01 level of probability, insignificant, respectively.

the multiple correlation coefficients and adjusted R-square. All statistical analyses were performed with the program MSTATC 2.10 (1994) and SPSS 17.0 (2008) statistical software packages.

## RESULTS AND DISCUSSION

Planting dates is one of the very important factors which can significantly affect the crop growth and yield. Determination of the optimum planting date for sunflower is very critical for better crop yields. So, a correct decision on the planting date should be based in a through understanding of the environmental factors influencing sunflower growth, development, yield and quality.

### Analysis of variance

The variance analysis results showed that all the studied characters exhibited significant differences with regard to planting dates and genotypes. The main effects associated with date of planting and genotypes were highly significant (p<0.01) for all of the investigated characteristics. However, the interaction term (planting dates × genotypes) was highly significant (p<0.01) for seed, oil, biological yield and harvest index (Table 1). Insignificant differences for replications revealed reliability of the result due to negligible influence of environments. The planting dates × genotypes interactions were found statistically significant at 1% level of probability for seed, oil, biological yield and harvest index. These interactions indicated that genotypes responded differently at different planting dates (Table 1). The main factors had dependent (inconstant) effects for these characteristics measured which is an indication that the two sets of treatment were dependent in their effects on sunflower. These interactions were also pronounced on head diameter, 1000-seed weight, seed yield $plant^{-1}$ and oil content percent except plant height (Table 2). De La Vega and Hall (2002) found that the interaction between planting date and genotype significantly affected seed and oil yields. This findings support those reported by Khajehpour and Seyedi (2000), De La Vega and Hall (2002) and Ahmad et al. (2005).

Partitioning planting date mean squares (Tables 1 and 2) showed that linear effects were detected at 0.01 level of probability, while quadratic, cubic and quartic effects for planting date were not significant (Tables 1 and 2). These results are confirmed with the results of Ahmad et al. (2005).

## Yield performance of sunflower

### *Seed yield (kg ha$^{-1}$)*

Yield is the major goal toward which all efforts are directed. Seed yield is the combined function of different components and it is a complex character depending on it's optimization of a large number of environmental, morphological and physiological balances; as can be seen on the basis of designed analysis of variance. In the present study, all sources of variation were highly significant. This indicated variations among sunflower genotypes for seed yield and variations in planting date and genotype × planting date effects. Differences in sunflower parameters among planting dates and genotypes are presented in Table 3. The effect of planting date on seed yield was statistically significant (P<0.01). It was noticed that, 1st May ($D_1$) sowing date produced the highest seed yield followed by 15th November ($D_2$), 1st June ($D_3$), 15th June ($D_4$) and 1st July ($D_5$). As the planting date was delayed, seed yield was reduced. Reduction of seed yield at second, third, forth and fifth planting dates compared to the first sowing date was 6, 15, 25 and 36%, respectively. $D_4$ and $D_5$ experienced shorter growing period and steep rise in temperature at the later stages of growth. Late planting of sunflower adversely affected in reduced yields due to low temperature that the crop encounters during its reproductive growth stage (Ahmad et al., 2005). Sunflower grain and oil yields are greatly reduced when normal sowing dates are delayed (Vega et al., 2002a).

Generally, delay in planting reduced seed yield. Similar results were reported in sunflower by Allam et al. (2003) and Ahmad et al. (2005). The seed yield varied between 2056.3 and 1315.6 kg ha$^{-1}$. The seed yield in early planting (1st May) was found higher by 740.7 kg ha$^{-1}$ than late sowing (1st July). Late sown crop produced smaller plants, smaller heads, less seed yield plant$^{-1}$, lighter thousand seed weight that was ultimately translated into less seed yield per unit area compared to early plantings. De La Vega and Hall (2002) concluded that late planting dates affect negatively sunflower yield through reduction in all components. Significantly, linear relationship between sowing dates and seed yield gave a clue that seed yield is dependent more on dates that is, length of crop life cycle than any other factor. Similar results have been reported by Ahmad et al. (2005) and Hassan et al. (2005). Flagella et al. (2002) and Abdou et al. (2011) reported that a delay of the sowing date significantly reduced grain yield of sunflower due to a decrease in the number of seeds per head and in seed weight. Seed yield is a function of integrated effects of various yield components like number of plants per unit area, head size, number of seeds per head and 1000-seed weight developed under a particular set of environmental conditions. The delay in sunflower cultivation decreases the length of vegetative phase (Anderade, 1995) and it also decreases the time needed for the seeds to be filled (Ferreia and Abreu, 2001) and a decrease in the numbers of days and cumulated GDD (Goyne et al., 1989). The reason for these decreases is the increase of temperature on late planting dates. Because of this increase, phonological phases of plant pass rapidly (Goyne et al., 1990; Ferreia and Abreu, 2001; Flagella et al., 2002). Statistical analysis of the data also revealed that sunflower genotypes had significantly ($p < 0.05$) affected seed yield. These results are in accordance with finding of Lawal et al. (2011) who reported that both sowing date and varieties significantly influenced seed yield. Highest seed yield of 1990.7 kg ha$^{-1}$ was observed in the commercial cultivar Sakha 53 followed by cultivar Giza 102 having seed yield of 1633 kg ha$^{-1}$. It is also clear from the mean value of the data that the lowest seed yield was recorded for Pioneer hybrid 63M02 with an average production of 1527.1 kg ha$^{-1}$. The difference in productivity might be due to difference of genetic makeup (Miralles et al., 1997; Razi and Assad, 1999). These finding are supported by Dash et al. (1996) who reported significant differences for seed yield plant$^{-1}$ among 18 hybrids. These results are also in confirmatory with that of Austin (1993) who reported significant differences in seed yield of different genotypes.

Significant interaction was seen between planting dates and genotypes for seed yield (p<0.01). Seed yield decreased gradually and reached to a minimum value at fifth planting date (1st July). Delaying planting until July resulted in a significant reduction in seed yield of the three sunflower genotypes (Figure 1). Delaying from first to third planting date resulted in decreasing seed yield in Sakha 53, Giza 102 and Pioneer hybrid 63M02, but more delaying from 3rd to 5th planting date caused severe reduction of seed yield (Table 3). Generally, the first planting date produced the highest grain yield (Figure 1). Among sunflower genotypes, Sakha 53 cultivar and Pioneer hybrid 63M02 had the highest and the lowest seed yield respectively (Table 3).

### *Oil yield (kg ha$^{-1}$)*

Oil yield per unit area is the ultimate target in growing

**Table 3.** Effect of planting date, genotype and interaction of planting date × genotype on seed, oil, biological yield and harvest index of sunflower during summer 2011 season.

| Planting date | Genotype | | | Mean |
|---|---|---|---|---|
| | Sakha 53 | Giza 102 | Pioneer 63M02 | |
| | | **Seed yield (kg ha$^{-1}$)** | | |
| 1st May | 2324.7$^{a}$ | 1958.9$^{d}$ | 1885.4$^{e}$ | 2056.3$^{A}$ |
| 15th May | 2199.9$^{b}$ | 1804.7$^{f}$ | 1796.7$^{f}$ | 1933.7$^{B}$ |
| 1st June | 2049.1$^{c}$ | 1686.6$^{g}$ | 1475.4$^{i}$ | 1737.0$^{C}$ |
| 15th June | 1796.4$^{f}$ | 1486.3$^{i}$ | 1343.1$^{j}$ | 1542.0$^{D}$ |
| 1st July | 1583.1$^{h}$ | 1228.5$^{k}$ | 1135.2$^{l}$ | 1315.6$^{E}$ |
| Mean | 1990.7$^{A}$ | 1633.0$^{B}$ | 1527.1$^{C}$ | 1716.92 |
| $LSD_{0.05}$ | Genotype (G): 31.77 | Planting date (D): 38.70 | G × D: 67.98 | |
| | | **Oil yield (kg ha$^{-1}$)** | | |
| 1st May | 880.62$^{a}$ | 729.77$^{d}$ | 760.37$^{c}$ | 790.25$^{A}$ |
| 15th May | 824.67$^{b}$ | 669.99$^{e}$ | 706.61$^{d}$ | 733.75$^{B}$ |
| 1st June | 762.65$^{c}$ | 618.79$^{f}$ | 566.11$^{g}$ | 649.18$^{C}$ |
| 15th June | 665.65$^{e}$ | 536.18$^{h}$ | 511.96$^{h}$ | 571.26$^{D}$ |
| 1st July | 577.74$^{g}$ | 435.43$^{i}$ | 422.80$^{i}$ | 478.66$^{E}$ |
| Mean | 742.26$^{A}$ | 598.03$^{B}$ | 593.57$^{B}$ | 644.62 |
| $LSD_{0.05}$ | Genotype (G): 12.06 | Planting date (D): 14.48 | G × D: 25.72 | |

Means followed by the same letter within columns and rows are not significantly different at p = 0.05 according to least significant difference test.

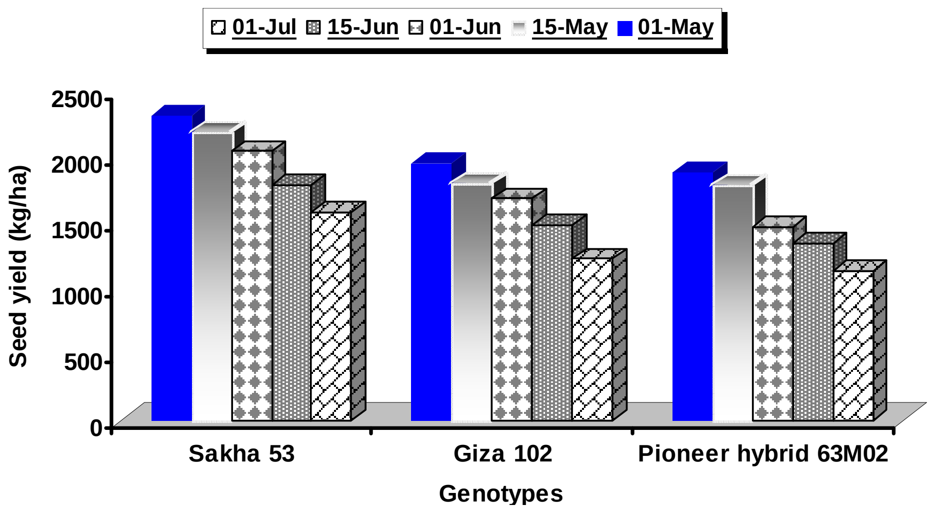


**Figure 1.** Response of sunflower seed yield to differences in genotypes and planting dates during the summer season of 2011.

high-oil sunflower genotypes and it is in direct dependence on seed yield and oil concentration. It is a complex character determined by genetic and environmental factors, as well as by their interaction (Fick and Miller, 1997). Concerning mean values for oil yield, significant differences were found between genotypes, planting dates and interactions (Table 1). In the present study, oil yield was significantly affected by planting dates. The maximum oil yield was achieved in the first and second planting dates (1st May and 15th May, respectively). After that, the oil yield decreased, reaching the lowest value in last planting date (1st July). Balalic et al. (2007) found a significant effect of planting date on oil yield in a two-year experiment. Our results are in agreement with the findings of De la Vega and Hall (2002) who claimed that planting date was the main source of variation for oil yield. In their experiment oil yield varied from 817 (sowing in December) to 2300 kg ha$^{-1}$ (sowing in October)

**Table 4.** Effect of planting date, genotype and interaction of planting date (D) × genotype (G) on seed yield components of sunflower during summer 2011 season.

| Parameter | Plant height (cm) | Head diameter (cm) | Thousand seed weight (g) | Seed yield plant$^{-1}$ (g) | Oil content (%) |
|---|---|---|---|---|---|
| **Planting date** | | | | | |
| 1st May (D1) | 148.35$^{a}$ | 18.26$^{a}$ | 62.87$^{a}$ | 102.34$^{a}$ | 38.49$^{a}$ |
| 15th May (D2) | 143.79$^{a}$ | 16.80$^{b}$ | 58.99$^{b}$ | 96.63$^{b}$ | 37.98$^{b}$ |
| 1st June (D3) | 135.86$^{ab}$ | 15.57$^{c}$ | 55.65$^{c}$ | 89.00$^{c}$ | 37.43$^{c}$ |
| 15th June (D4) | 127.39$^{b}$ | 13.92$^{d}$ | 52.22$^{d}$ | 77.95$^{d}$ | 37.08$^{d}$ |
| 1st July (D5) | 108.07$^{c}$ | 12.67$^{e}$ | 47.08$^{e}$ | 67.28$^{e}$ | 36.39$^{e}$ |
| $LSD_{0.05}$ | 15.80 | 0.61 | 0.80 | 2.31 | 0.20 |
| **Genotype** | | | | | |
| Sakha 53 | 151.62$^{a}$ | 16.92$^{a}$ | 63.26$^{a}$ | 95.56$^{a}$ | 37.22$^{b}$ |
| Giza 102 | 132.42$^{b}$ | 15.45$^{b}$ | 53.38$^{b}$ | 82.96$^{b}$ | 36.52$^{c}$ |
| Pioneer 63M02 | 114.04$^{c}$ | 13.96$^{c}$ | 49.44$^{c}$ | 81.38$^{b}$ | 38.68$^{a}$ |
| $LSD_{0.05}$ | 12.50 | 0.26 | 1.01 | 1.77 | 0.18 |
| **D × G** | ns | ** | ** | ** | ** |

** and ns, significantly different at the 0.01 level of probability, and ns is not significant, respectively. For each main effect, values within columns followed by the same letter are not significantly different at *P* = 0.05 according to LSD test.

on average for two years in the conditions of Argentina. Ekin et al. (2005) found that, on average over several years, oil yield ranged from 0.66 to 1.58 t/ha in Van region, Turkey.

Analysis of variance regarding oil yield, indicated that genotypes were significantly different among themselves for oil yield. Highest mean oil yield of 742.26 kg ha$^{-1}$ was recorded by Sakha 53 followed by Giza 102 (598.03 kg ha$^{-1}$) and Pioneer hybrid 63M02 (593.57 kg ha$^{-1}$), respectively. There was significant interaction between planting date and genotype on oil yield ($p<0.01$), so that Sakha 53 cultivar at first planting date had the highest oil yield and Pioneer hybrid 63M02 at fifth planting date had the lowest oil yield (Table 3). At 1st planting date, Sakha 53 and Giza 102 cultivars had the highest oil yield. At fifth planting date, Sakha 53 cultivar produced the highest oil yield and there was significant difference between Giza 102 and Pioneer hybrid 63M02 genotypes (Table 3). Generally, the first planting date produced the highest oil yield and the fifth planting date had the lowest oil yield and significant differences were seen among first, second, third, forth and fifth planting date.

Sakha 53 cultivar and Pioneer hybrid 63M02 produce the highest and the lowest oil yield respectively (Table 3).

## Yield components of sunflower

Plant height and other yield components such as head diameter, 1000-seed weight and seed yield plant$^{-1}$ played an important role in determining seed yield in sunflower. In this study, according to the results of variance analysis shown in Table 2, statistical differences were found for the response of plant height, head diameter, 1000-seed weight, seed yield plant$^{-1}$, and oil content to planting dates and genotypes at 0.01 level probability. Similar results have been reported by Sharief (1998), Vega et al. (2002b), Allam et al. (2003), Ahmad et al. (2005), Hassan et al. (2005) and Abdou et al. (2011). The data on the effect of planting date and genotype and their interaction have been presented in Table 4. All measured yield components were significantly reduced by delaying planting from 1st May to 1st July (Table 4). Plant height, head diameter, thousand seed weight, seed yield plant$^{-1}$ and percentage of oil content of the crop were reduced by 27, 31, 25, 34 and 5%, respectively (Table 4). Reduction in these traits was considered to be related to the coincidence of vegetative and reproductive growth stages with higher temperatures prevailing at later plantings. On the other hand, the genotypes varied significantly in their yield components. Such results are in accordance with the finding of Ahmad et al. (2005) who reported that both planting dates and genotypes significantly influenced seed yield, plant height, head diameter, thousand seed weight and oil content.

The cultivar Sakha 53 surpassed the other genotypes in plant height, head diameter, thousand seed weight, seed yield plant$^{-1}$ (Table 4), which reflected the higher seed yield per unit area compared to Giza 102 cultivar and Pioneer hybrid 63M02.

**Table 5.** Summary of simple linear regression analysis of important relationships of planting dates and seed, oil, biological yield and harvest index.

| Independent variable (x) | Regression equation | Coefficient of correlation (R) | Coefficient of determination ($R^2$) |
|---|---|---|---|
| Seed yield (kg $ha^{-1}$) | Y = 2279 – 187 x | 0.99** | 0.99 |
| Oil yield (kg $ha^{-1}$) | Y = 880.3 – 78.57 x | 0.99** | 0.99 |
| Biological yield (kg $ha^{-1}$) | Y = 7872.82 – 915.74 x | 0.99** | 0.99 |
| Harvest index | Y = 0.26 + 0.03 x | 0.97** | 0.96 |

**; means that r is significant at p< 0.01 level of probability.

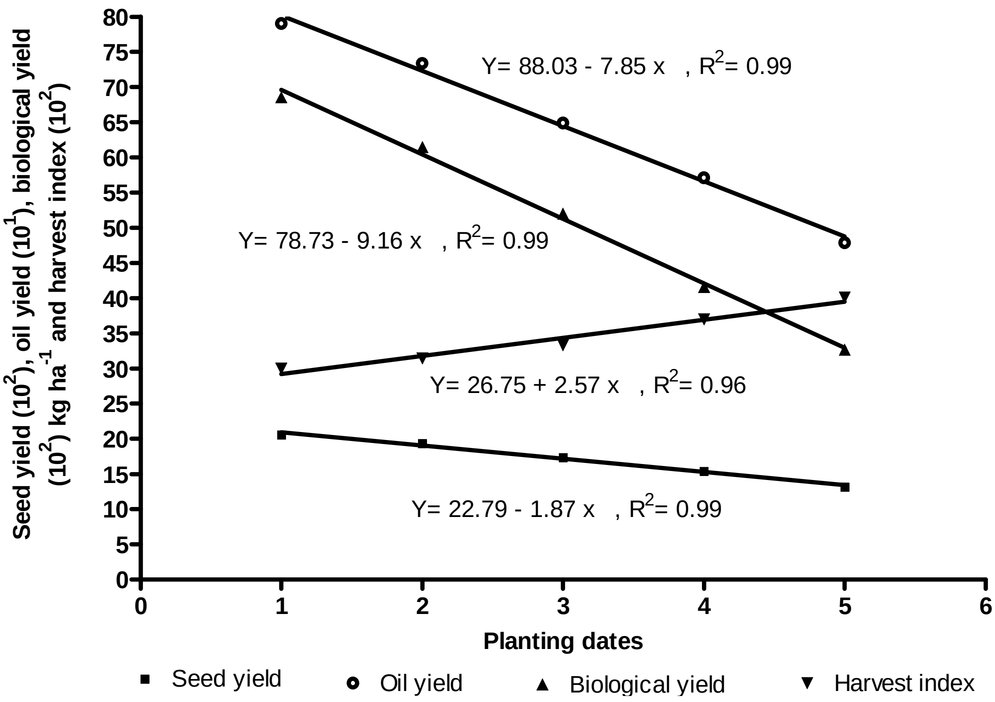


**Figure 2.** Relationship among planting dates, seed, oil and biological yield and harvest index.

## Polynomial regression analysis

### *Relationships between planting dates and sunflower seed, oil, biological yield and harvest index*

The relationship between planting date (x) and the different sunflower factors (y) was significant at the 0.01 level of significance in all cases. Although, considerable planting date variations can be expected, the high correlation coefficients indicated that the effects of planting dates on sunflower factors can be predicted quite accurately. Although, the relationships were calculated using simple linear, quadratic, cubic and quartic regression analysis, only linear relationships are shown (Table 5) because, in each case, linear effects were highly significant and the coefficient of determination was higher for the linear than the other polynomial regression relationships. Linear relationships were observed between planting dates and seed, oil, biological yield and harvest index in the research (Figure 2). The model with the highest R and $R^2$ indicates the best possible fit. Regression analysis to reveal the relations between the two variables, that is, planting date (x) and seed yield (y) indicated a linear relation as well as a highly significant ($P \leq 0.01$) correlation coefficient (r = 0.99). Besides, $R^2$ (coefficient of determination), revealed that it was possible to account up to 99% of the variability in seed yield (y), to planting date.

Yield decreased in a linear fashion in oilseed sunflower (Figure 2). High $R^2$ (0.99) indicates a close relationship between seed yield and planting dates. The relationship between planting dates and seed yield was negative and followed the linear equation of:

Y = 2279 – 187 x

Representing a high negative value of (b), which means yield decrease against late planting dates (Figure 2).

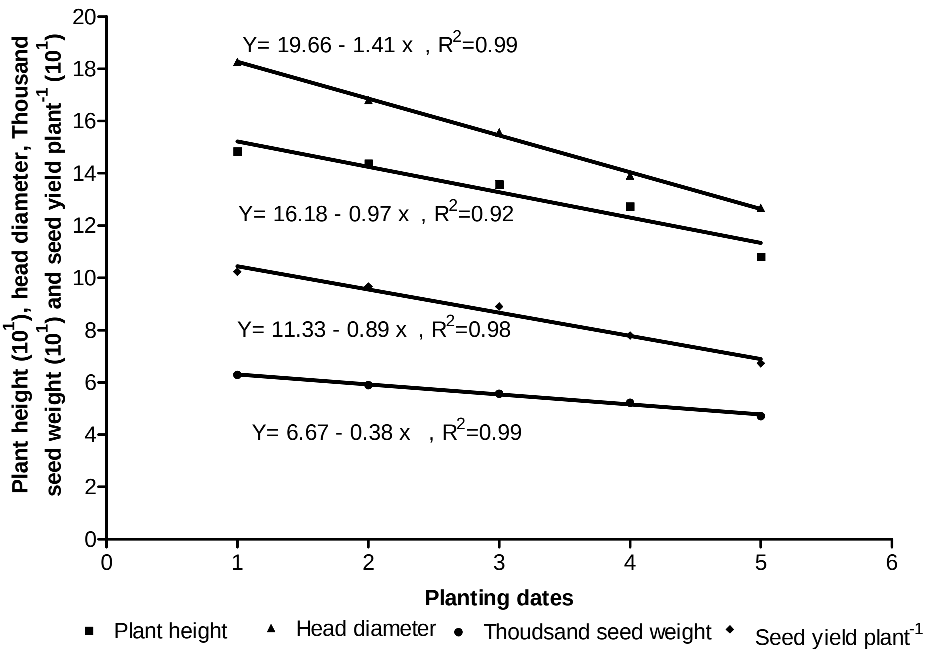


**Figure 3.** Relationship among planting dates, plant height, head diameter, thousand seed weight and seed yield per plant.

Linear regression equation for planting date suggested that increase in one unit (15 days delaying) of planting date lead to decreased seed yield by 187 kg $ha^{-1}$. Linear relationships were observed between planting dates and oil yield in the research (Figure 2). Planting date affected oil yield negatively and played an important role in determining oil yield in sunflower. Plotting planting dates against mean oil yield (kg $ha^{-1}$) gave a linear relationship:

$$Y = 880.3 – 78.57 x, R^2 = 0.99$$

The aforementioned linear relationship explaining coefficient for equation ($R^2$ = 0.99) indicate justification of the variation of dependent variable (oil yield) due to independent variable. Significant linear relationship (Figure 2) between planting dates and oil yield favors the view point of Lawal et al. (2011) who reported that planting date significantly affected all the growth and yield parameters including oil yield. Oil yield decreased in a linear fashion in oilseed sunflower (Figure 2). Also, regression analysis of the data revealed that linear relationships were observed between planting dates and biological yield in the research (Figure 2). Planting date affected biological yield negatively and played an important role in determining oil yield in sunflower. Biological yield of oilseed sunflower is a function of planting date. Plotting planting dates against mean biological yield (kg $ha^{-1}$) gave a linear relationship:

$$Y = 7872.82 – 915.74 x, R^2 = 0.99$$

The regressive relation of planting date and harvest index showed a linear equation of:

$$Y = 0.26 + 0.03 x$$

On the bases of this equation, harvest index increase against delaying in planting date (Figure 2). Similar results have been reported by Ahmad et al. (2005) and Hassan et al. (2005) who reported that harvest index increase against delaying in planting date.

## Relationships between planting dates and sunflower yield components

Significant linear relationship (Figure 3) between planting dates and each plant height, head diameter, thousand seed weight, seed yield $plant^{-1}$ and oil content percent provides the clue that these traits are dependent upon planting dates. The relationship between planting dates and plant height, head diameter, thousand seed weight, seed yield $plant^{-1}$ and oil content (%) represented a linear relationship and followed the equation: Y = 161.24 – 9.56 x, Y = 19.62 – 1.39 x, Y = 66.86 – 3.83 x, Y = 113.28 – 8.88 x and Y = 38.99 – 0.51 x respectively, which means a falling trend of yield components against planting date. According to the aforementioned equations, the highest yield components were obtained at the first planting date (1st May).

The linear regression equations between planting date and yield components (Table 6 and Figure 3) showed

**Table 6.** Summary of simple linear regression analysis of important relationships of planting dates and plant height, head diameter, thousand seed weight, seed yield plant$^{-1}$ and oil content.

| Independent variable (x) | Regression equation | Coefficient of correlation (R) | Coefficient of determination ($R^2$) |
|---|---|---|---|
| Plant height (cm) | Y = 161.24 – 9.56 x | 0.95** | 0.92 |
| Head diameter (cm) | Y = 19.62 – 1.39 x | 0.99** | 0.99 |
| Thousand seed weight (g) | Y = 66.86 – 3.83 x | 0.99** | 0.99 |
| Seed yield plant$^{-1}$ (g) | Y = 113.28 – 8.88 x | 0.99** | 0.99 |
| Oil content (%) | Y = 38.99 – 0.51 x | 0.99** | 0.99 |

**; means that r is significant at p< 0.01 level of probability.

**Table 7.** The contribution of five characteristics in predicting seed yield ha$^{-1}$ of sunflower under different planting dates by using multiple linear regression analysis.

| Independent variable (x) | Standard partial regression | | | | |
|---|---|---|---|---|---|
| | Planting dates | | | | |
| | 1st May ($D_1$) | 15th May ($D_2$) | 1st June ($D_3$) | 15th June ($D_4$) | 1st July ($D_5$) |
| Plant height (cm) | -1.68 | 10.25 | 9.87 | 1.89 | 1.29 |
| Head diameter (cm) | 19.16** | 49.27** | 36.30** | 21.61** | 89.67** |
| Thousand seed weight (g) | 27.92** | 25.34** | 12.29** | 17.58** | 10.25** |
| Seed yield plant$^{-1}$ (g) | 6.01* | 18.028* | 14.10** | 2.57* | 9.34** |
| Oil content (%) | 16.98 | - 153.43 | -235.41 | -20.84 | 17.92 |
| F value | 38.62** | 39.88** | 45.31** | 28.38** | 12.88** |
| Coefficient of determination ($R^2$) | 0.96 | 0.97 | 0.97 | 0.95 | 0.88 |
| Adjusted R-square | 0.94 | 0.94 | 0.95 | 0.92 | 0.81 |

Significance at 5 and 1% probability level is shown by * and ** , respectively.

that a unit increase (15 days delaying) of planting date led to decrease in plant height (cm), head diameter (cm), thousand seed weight (g), seed yield plant$^{-1}$ (g) and oil content (%) by 9.56, 1.39, 3.83, 8.88 and 0.51, respectively.

## Multiple linear regression analysis

Plant breeders need production measurement of given traits to improve plant characteristics. Understanding of the relationship between the traits, for the selection of the important traits, is of utmost importance. Plant height and other yield components such as head diameter, 1000-seed weight, seed yield plant$^{-1}$ and oil content (%) played an important role in determining seed yield in sunflower. To formulate the relationship between the five independent variables measured in our experiment, with a dependent variable, multiple regression analysis was carried out for the plant height, head diameter, 1000-seed weight, seed yield plant$^{-1}$ and oil content (%) as independent variables and seed yield as a dependent variable. Multiple regression analysis in the present sunflower experiments under different planting dates was calculated by considering the seed yield as the dependent variable and other characters as the independent variables. Data in Table 7 showed the contribution for yield components in predicting seed yield ha$^{-1}$, standard partial regression coefficients under different planting dates. The significance of partial regression coefficients was tested using F value (Table 7).

Regarding dependent variable of seed yield, the rate of measured traits participation as independent variable on this trait was computed by multiple regression analysis. Related coefficients to each of the introduced trait are presented in the model of Table 7. Surely, the high $R^2$ do not necessarily implicates a good regression model; because adding a variable to the model always increases the amount of $R^2$ regardless of the variable participated in the model or not. Therefore, statisticians prefer to use adjusted $R^2$ statistics. By examining Table 7, it can be noted that, at the first planting date ($D_1$), adjusted squared R ($R^2$ = 94%) of the total variation in seed yield ha$^{-1}$ could be linearly related to variations in all variables and 6% could be due to residual. Variability in seed yield (kg ha$^{-1}$) accounted by the five characteristics was from 81 to 95% as indicated by the highly significant adj-$R^2$ values. It is clear from the standard partial regression coefficients that head diameter, thousand seed weight and seed yield plant$^{-1}$ influenced significantly for the determination of seed yield ha$^{-1}$, thus reflecting the importance of these variables in seed yield evaluation, while the other two traits did not contribute significantly towards yield (Table 7). These results suggested that improvement of seed yield in sunflower is linked with these traits and selection of these characters might have good impact on seed yield.

The research results proved that these yield components were playing an important role in determining seed yield in sunflower like other studies reported by Farhatullah et al. (2006), Arshad et al. (2007), Behradfar et al. (2009) and Anandhan et al. (2010). Yasin and Singh (2010) used stepwise multiple linear regression analysis to study the relationships between seed yield and yield components and found that five traits including number of filled seed in head, 1000-seed weight, head diameter, seed yield plant$^{-1}$ and oil percentage were the most important variables contributing toward higher seed yield. Khajehpour and Seyedi (2000) reported that number of seeds head$^{-1}$ was the most contributing trait to the increase in seed yield.

## Conclusion

Determination of the optimum planting date for sunflower is very crucial for better crop yield. The study revealed that both planting date and genotype had significant effects on seed yield and yield components of sunflower. The fact that the effects of the planting date are significant for all the features studied suggests that the planting date has a pronounced effect on all the features studied, so that delay in planting often result in a decrease in yield and yield components. On the basis of this study, it can be concluded that oilseed sunflower genotypes should be sown in middle Egypt in the first week of May to obtain maximum yield and yield components.

In our study, the highest seed yield (2324.7 kg ha$^{-1}$) was that of the commercial Egyptian cultivar Sakha 53 planted at the first planting date, and the lowest seed yield (1135.2 kg ha$^{-1}$) was that of the Pioneer hybrid 63M02 planted at the last planting date. Regression modeling of the data indicated that sunflower breeding studies should focus on head diameter, thousand seed weight and seed yield plant$^{-1}$ for improvement studies of high seed yielding genotypes. Linear regression equation for planting date suggested that increase in one unit (15 days delaying) of planting date lead to decreased seed yield by 187 kg ha$^{-1}$. Significant linear relationship between planting dates and each of plant height, head diameter, thousand seed weight, seed yield plant$^{-1}$ and oil content percent provides the clue that these traits are dependent upon planting dates.

The data obtained from this study could be useful for sunflower breeders, agronomists and seed producers in order to increase seed yield under different planting dates.

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