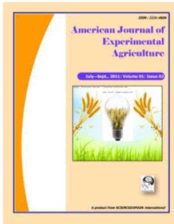

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Modeling the Influence of Nitrogen Rate and Plant Density on Seed Yield, Yield Components and Seed Quality of Safflower

Ashraf A. Abd El- Mohsen[1*] and Gamalat O. Mahmoud[1]

[1]Department of Agronomy, Faculty of Agriculture, Cairo University, El-Gamaa Street, P.O. Box12613 Giza, Egypt.

Authors' contributions

This work was carried out in collaboration between authors. Author AAAE designed the study, supervised the experiment and revised both the protocol and manuscript. Also, author AAAE performed the experiment and statistical analysis, wrote the protocol and manuscript, and revised the manuscript. Author GOM helped to manage the analyses of the study and helped in relevant literature search. Authors read and approved the final manuscript.

Research Article

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ABSTRACT

To study the effect of nitrogen rate and plant density at different levels on yield, yield components and quality traits of safflower (cv. Giza 1) an experiment was conducted as split plot design in randomized complete block design arrangement with three replications, during the successive seasons 2010/11 and 2011/12. The factors consisted of four levels of nitrogen (0, 40, 80 and 120 kg N ha^{-1}) and four different densities (80,000, 100,000, 133,000 and 200,000 plants ha^{-1}). Different statistical analyses such as ANOVA, polynomial regression, correlation, and stepwise multiple linear regression were used. The multiple statistical procedures showed that the main effects of nitrogen rate and plant density levels were significant (*P* = 0.01) for yield and yield components studied. A rise in nitrogen rate and plant density increased seed and oil yield, whereas plant height, number of branches plant^{-1}, number of heads plant^{-1}, seed yield plant^{-1} and 1000-seed weight decreased as plant density increased. In general, the highest plant density (200,000 plants ha^{-1}) and the nitrogen level (80 kg ha^{-1}) was the best treatment in this research to attain high safflower seed yield under environmental conditions of Giza Governorate, Egypt. Polynomial models of seed, oil yield and yield components based on the ANOVA were fitted. Polynomial regression analysis indicated that the relationship

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**Corresponding author: Email: dr_ashraf200625@yahoo.com, ashraf_stat91@yahoo.com;*

between the nitrogen amount applied and safflower seed, oil yield and yield components could be defined by using a quadratic function. Also, the results revealed that, yield and yield components were significantly affected by plant density in linear responses. Correlation analysis showed a positive and significant correlation between seed yield ha^{-1} and each of number of heads $plant^{-1}$, seed yield $plant^{-1}$, number of branches $plant^{-1}$ and 1000-seed weight. Stepwise regression analysis showed that number of heads $plant^{-1}$ explained 45.57% and along with seed yield $plant^{-1}$, number of branches $plant^{-1}$ and 1000-seed weight explained 81.63% of total variations for seed yield (kg ha^{-1}).

Keywords: Safflower; nitrogen fertilizer; plant density; statistical models; polynomial regression; correlation; stepwise regression.

1. INTRODUCTION

Safflower (*Carthamus tinctorious* L.) is an important oilseed crop that has long been cultivated for different purposes, such as oil, fabric dyes, food coloring, medicinal and industrial needs [1]. Safflower produces oil rich in polyunsaturated fatty acids which play an important role in reducing blood cholesterol level and is considered as a healthy cooking medium. The importance of vegetable oil crops has increased over the years following a higher consumer demand for healthier edible oils [2]. World production is around 600,000 tons, produced in more than sixty countries worldwide (mainly in India, USA and Mexico) from about 850,000 ha [3]. Today, Egypt imports more than 90% of vegetable oil consumed. Therefore, an improvement of the productivity of this crop is needed to meet the shortage of vegetable oils.

Safflower growth as well as composition and quality of seeds are influenced by many factors like genotype, environment and agronomic practices [4]. The yield of safflower is a function of many factors, among them the nitrogen fertilization and plant densities being the most important ones. The choice of the optimum plant density and nitrogen rate are two of the key points in crop management to obtain high quality and quantity yield, so suggestion of most appropriate nitrogen rate and plant density to farmers increase their yield and profit and therefore their tendency for cultivation of a specific crop such as safflower.

It is necessary to apply sufficient amount of nitrogen to achieve optimum yield and high-quality product. Fertilizing with nitrogen is one of the most important factors effects determining yield due to its multi-dimensional effects on the growth and development of safflower [5]. However, over-fertilization and insufficient fertilization lead to economic losses and discharge an excessive amount of nitrogen in the nitrate form through washing [6]. Therefore suggestions for fertilizers with nitrogen should be made so as to ensure a high-quality product, optimum yield, high profit and less environmental pollution risks [7].

Another important factor controlling yield is planting density. Appropriate plant density is a key for gainful production of safflower. Plant spacing is an important factor in determining the microenvironment in the safflower field. Plant spacing is among the factors affecting safflower yield and seed oil percentage. The optimization of this factor can lead to a higher yield in the crop by favorably affecting the absorption of nutrients and exposure of the plant to the light. In safflower the advantages for higher plant density generally are: increased yield, reduced erosion, increased harvesting efficiency and early crop canopy closure to help control weeds [8]. Bilgili et al. [9] reported lower seed yield in lower plant densities. Besides, they indicated more efficiently control of weeds in higher plant densities.

Using statistical models to predict safflower yield under different nitrogen rate and plant density conditions could be helpful in the management of safflower. In this study, several statistical models made to describe the effect of nitrogen rate and plant density on seed yield, yield components and quality traits by using polynomial regression analysis. The goal of polynomial regression analysis is to model the expected value of a dependent variable y in terms of the value of an independent variable x. Also, the study of correlation between seed yield and yield components is very important to select desirable genotype. The success of selection depends on the choice of selection criteria for improvement of seed yield [10]. Correlation coefficient analysis could distinguish significant relationship between evaluated traits. Stepwise regression could reduce the effect of non-important traits in regression model; in this way, traits accounted for considerable variations of dependent variable could be determined [11].

The aim of this study was to evaluate the effect of different levels of nitrogen application and plant density on yield, yield components and quality traits of safflower in order to achieve the optimum use of resources and to develop statistical models to describe the sequence of tests used to model curves of such variables, using polynomial regression. Also, to estimate the best selection criteria for yield improvement in safflower breeding program using correlation and stepwise regression analysis.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

Two Field experiments were carried out at the Agricultural Research and Experimental Center, Faculty of Agriculture, Cairo University, Giza, Egypt (30º 02' N latitude and 31º 13' E longitude with an altitude of 22.50 meters above sea level), during the two growing seasons 2010/11 and 2011/12 using the commercial cultivar of safflower Giza 1. Soil samples (0-30 cm) were taken at sowing and analyzed for some parameters. The soil was a clay loam with 0.82% organic matter content, an electrical conductivity (EC) of 0.25 ds m^{-1} and a pH of 7.50. Total N content was 0.38%, available P was 4.19 mg kg^{-1}, available K was 78.00 mg kg^{-1}, S04-N was 2.56 mg kg^{-1} and no salinity problems were observed (Table 1). The meteorological data during the study are shown in Table 2.

Table 1. Soil properties of the experimental site at 0-30 cm depth

Properties	Value
Soil texture	Clay-loam
Organic matter, %	0.82
CaCO3, %	33.00
Total N, %	0.38
Available phosphorus, mg kg^{-1}	4.19
Available potassium, mg kg^{-1}	78.00
Sulfate-S, mg kg^{-1}	2.56
pH	7.50
Electrical conductivity, dS m^{-1}	0.25

Table 2. Meteorological data for the study period in 2010/11 and 2011/12 at Giza governorate

Month	Mean monthly temperature (ºC)		Mean relative humidity (%)		Precipitation (mm)	
	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12
November	18.60	16.85	55.50	65.16	0.00	0.00
December	15.25	13.50	55.00	69.65	0.00	0.00
January	15.55	12.70	55.00	60.00	0.00	0.00
February	15.95	14.30	54.36	60.13	0.00	0.00
March	18.00	16.85	56.00	54.00	0.00	0.00
April	20.40	19.30	56.10	55.00	0.00	0.00

2.2 Experimental Layout and Crop Management

Every experiment included 16 treatments which were the combination of four levels of nitrogen fertilization and four plant densities. The experiment was laid out in a split plot design in a randomized complete block design arrangement with three replications. Four nitrogen levels as no-nitrogen fertilization (N_1), net nitrogen of 40 (N_2), 80 (N_3) and 120 (N_4) kg N ha^{-1} were applied to main plots, as the Urea form with 46% nitrogen and four plant densities of 20, 13.3, 10 and 8 plant m^{-2} (200,000 (P_1), 133,000 (P_2), 100,000 (P_3) and (P_4) 80,000 plant ha^{-1}) corresponding to intra-row spacing of (10, 15, 20 and 25 cm), respectively were applied to sub-plots. Each sub plot (experimental unit) had five ridges, each of 0.5 m in width and 4.0 m in length, occupying an area of 10.0 m^2. The commercial cultivar Giza 1, was used in the study. Sowing date was 15th and 18th of November in the first and second season, respectively. The preceding crop was sesame in both seasons. Seedlings were thinned 15 days after sowing to secure one plant hill^{-1}. Phosphorus fertilizer was added before seeding during land preparation as calcium super phosphate (15.5 % P_2O_5) at the rate of 200 kg ha^{-1}. One third of each nitrogen level was applied as the starter before sowing, while the second and third parts were dressed at seedling and early flowering stages, respectively. Irrigation method was as furrowing and crop was kept free from weeds by hand hoeing before stem elongation. Six irrigations were added during growth by flooding system. All agronomic practices were keeping normal and uniform for all the treatments.

2.3 Data Collection and Sampling

2.3.1 Measurements of yield and yield components

Data on different agronomic traits were collected both on plant and plot basis. Data on yield per plant and yield components and other agronomic traits were recorded on ten plants randomly selected from the two middle rows in each sub-plot. The following data were measured; plant height (cm), number of branches plant^{-1}, number of heads plant^{-1}, 1000-seed weight (g). Seed yield (kg ha^{-1}) was calculated from central ridges of each experimental unit and then transformed to kg ha^{-1}. The harvesting areas (3 m^2) determined after deletion of the plot sides, were from the two middle rows. After recording the seed yield of net plot area, seed yield ha^{-1} was worked out and expressed in kg ha^{-1}. The final seed yield (kg ha^{-1}) and oil yield (kg ha^{-1}) was estimated as following equations:

$$Seed\ yield\ in\ kg\ ha^{-1} = \frac{Seed\ weight\ (kg)\ x\ 10000}{Harvested\ plot\ area\ (m^2)}$$

$$Oil\ yield\ in\ kg\ ha^{-1} = \frac{Seed\ oil\ content\ (\%)\ x\ Seed\ yield\ in\ kg\ ha^{-1}}{100}$$

2.3.2 Quality parameters

Thirty grams of dried seeds of safflower drawn from the net plot of each treatment were used for estimation of oil and protein content (%). Oil percentage of seeds was determined by Soxhlet extraction according to the method used by the Association of Official Agricultural Chemists [12]. Total nitrogen of seeds was determined using Kjeldahl method of the A.O.A.C. [12] and then protein percentage of seeds was calculated by multiplying the total nitrogen by 6.25.

2.4 Statistical Analyses and Interpretation of Data

Keeping in view the objectives set out for the study, following statistical tools and methods have been deployed. In this research several statistical analyses were used in order to achieve the goals of the research. The normality test of data, analysis of variance (ANOVA) for evaluated traits, mean comparisons, polynomial regression analysis, correlation and stepwise multiple linear regression analysis and diagrams drawing were conducted by using the Statistical Package for the Social Sciences, (SPSS) version 17.0 software (SPSS Inc., Chicago, USA, 2008), MSTAT-C computer programmed (Michigan State University, 1992) and Microsoft Excel, 2003 software packages.

2.4.1 Analysis of variance and mean comparisons

Individual analysis of variance was performed for all traits of each year according to the procedure described by Gomez and Gomez [13] for the split plot design. Error mean squares were tested for variance heterogeneity using Bartlett's [14] method and combined analysis of variance was done, for all traits, following the method described by Steel et al. [15], based on a split plot design to determine the main and interaction effects of different nitrogen rates and plant densities on yield, yield components and quality traits. Duncan's multiple range test (DMRT), Duncan [16] at 5% level of probability was used to conduct mean comparison of treatments and find significant differences among means.

2.4.2 Polynomial and nonlinear models

Polynomial regression analysis was used to study the relationships between different nitrogen rate, plant density levels and studied traits as well as to interpret the relation nature between them. Linear, quadratic and cubic orthogonal polynomials were tested using appropriate regression models to examine the nature of the response of safflower plants to increasing nitrogen and plant density levels. The least squares procedure was applied to develop linear, quadratic and cubic models according to Snedecor and Cochran [17]. The fundamental goal is to find the best model that best fits the data. If the trend is statistically significant at $P = .05$, then the best model chosen from models including a linear, quadratic and cubic trend factor.

2.4.3 Correlation and stepwise multiple linear regression analysis

The relationships among dependent and independent variables through calculation of simple correlation coefficient were estimated by means between each of the dependent and independent variables according to Snedecor and Cochran [17]. Stepwise multiple linear regression analysis was performed according to _ [18] for determination of the best model, which accounted for most of the variation, existed in seed yield as dependent variable.

3. RESULTS AND DISCUSSION

3.1 Combined Analysis of Variance

Firstly, the results of the combined analysis of variance for all investigated traits, after homogeneity test for error variances, are summarized in Tables 3 and 4.

Combined analysis of variance across two years and results of mean squares for different sources of variation revealed that year's effect was non-significant (P > .05) for all the studied traits. By looking at the different factors tested, it is clear that there were highly significant (P = .01) influences of nitrogen rate and plant density on all traits under study. Data presented in Tables 3 and 4 indicated that the interaction effect between nitrogen rate and plant density levels exhibited non-significant variations for most studied yield, yield components and quality parameters indicating that the two factors are independent from each other. In contrast, there was a highly significant (P =.01) interaction between nitrogen application rates and plant density levels for seed yield ha^{-1} (Table 3), indicating that response to plant density depended upon nitrogen application. Analysis of variance also indicated significant year x nitrogen rate x plant density interaction (P = .05) for seed yield ha^{-1}.

According to analysis of variance (Tables 3 and 4), the statistical analysis revealed that the effect of nitrogen rate x year, plant density x year and nitrogen rate x plant density x year interactions were not significant (P > .05) for all studied traits except seed yield ha^{-1}. The lack of a year x nitrogen rate and year x plant density interactions indicated that nitrogen rate and plant density had a similar effect in each year and revealing that the effect of nitrogen rate and plant density treatments was stable from one year to another (Tables 3 and 4). These results are in agreement with those obtained by [19,20,21,22,23,24,25,26].

Table 3. Combined analysis of variance results and significance for different traits of safflower evaluated across two years under different nitrogen rates and plant densities

Source of variation	Df	Mean squares				
		Days to 50% flowering	Seed oil content (%)	Seed protein content (%)	Seed yield kg ha^{-1}	Oil yield kg ha^{-1}
Years (Y)	1	16.17^{ns}	5.31^{ns}	1.34^{ns}	3966555.78^{ns}	353017.08^{ns}
Replicates/Years	6	22.27	9.98	3.45	4988706.62	88971.14
Nitrogen rates (N)	3	8164.63*	55.83**	7.95**	64365948.16**	6581541.72**
Y x N	3	151.90^{ns}	9.66^{ns}	1.18^{ns}	152211.30^{ns}	57119.34^{ns}
Pooled Error (a)	12	1424.59	3.80	2.85	299315.75	36601.11
Plant densities (P)	3	6680.47*	14.79*	8.73*	2755723.93**	372883.67**
Y x P	3	119.80^{ns}	2.52^{ns}	5.12^{ns}	8020.36^{ns}	398.40^{ns}
N x P	9	184.73^{ns}	3.47^{ns}	3.50^{ns}	29998.47**	2522.12^{ns}
Y x N x P	9	144.41^{ns}	4.04^{ns}	2.09^{ns}	88099.98*	6487.99^{ns}
Pooled Error (b)	48	1129.11	1.88	2.37	29200.14	8389.04
Coefficient of Variation (%)		13.24	8.71	7.14	20.4	18.32

*ns, * and ** show non-significance and significance at 5 and 1% probability level, respectively.*

Table 4. Combined analysis of variance results and significance for different traits of safflower evaluated across two years under different nitrogen rates and plant densities

Source of variation	Df	Mean squares				
		Plant height (cm)	No. of branches $plant^{-1}$	Thousand seed weight (g)	No. of heads $plant^{-1}$	Seed yield $plant^{-1}$(g)
Years (Y)	1	100.99^{ns}	933.54^{ns}	724.10^{ns}	221.88^{ns}	11.79^{ns}
Replicates/Years	6	589.91	577.88	499.81	401.77	7.79
Nitrogen rates (N)	3	15503.23**	507.11**	1395.88**	598.38**	1548.51**
Y x N	3	1199.44^{ns}	99.77^{ns}	222.20^{ns}	100.06^{ns}	19.90^{ns}
Pooled Error (a)	12	1884.64	113.30	97.79	136.88	413.55
Plant densities (P)	3	10940.60**	299.68**	1008.68**	881.2**	1647.68**
Y x P	3	1289.4^{ns}	88.87^{ns}	111.23^{ns}	88.87^{ns}	40.99^{ns}
N x P	9	1175.46^{ns}	659.71^{ns}	477.47^{ns}	154.56^{ns}	45.81^{ns}
Y x N x P	9	1499.30^{ns}	147.17^{ns}	100.02^{ns}	99.90^{ns}	65.11^{ns}
Pooled Error (b)	48	1699.87	99.55	88.84	59.61	197.88
Coefficient of Variation (%)		15.78	13.63	8.91	10.59	16.37

*ns, * and ** show non-significance and significance at 5 and 1% probability level, respectively.*

3.2 Effect of Nitrogen Rate and Plant Density on Yield, Quality Traits, Agronomic Traits and Yield Components of Safflower

3.2.1 Yield performance of safflower

3.2.1.1 Seed yield (kg ha^{-1})

The results of combined analysis of variance revealed that the main effect of nitrogen rate and plant density on seed yield (kg ha^{-1}) at P = .01 and the interaction effect of them on this trait at P = .05 were significant (Table 3).

Effect of nitrogen: Nitrogen is a component of protoplasm, proteins, nucleic acids and chlorophyll and plays a vital role both in vegetative and reproductive phase of crop growth. It is necessary to give a sufficient amount of nitrogen to a plant for optimum yield and high quality production. Mean of seed yield per hectare obtained from the experiment are presented in Table 5. The difference between maximum and minimum of seed yield obtained at different nitrogen levels was statistically significant (Table 5).

There was an increase in seed yield with increasing nitrogen rates from 0 to 80 kg N ha^{-1}, but application of 120 kg N ha^{-1} showed a decline in seed yield. This is due to the excessive vegetative growth of plants due to high rate of nitrogen. In our study seed yield ranged from 1058.7 to 1610.2 kg ha^{-1} (Table 5). The highest seed yield (1610.2 kg ha^{-1}) was obtained by applying 80 kg N ha^{-1} and the lowest seed yield (1058.7 kg ha^{-1}) was obtained by applying 0 kg N ha^{-1} (Table 5). This result clearly indicated the importance of nitrogen for higher seed production in safflower. Application of 80 kg N ha^{-1} resulted in maximum seed yield ha^{-1} due to proper vegetative and reproductive growth. With regard to comparison of mean for seed yield at different N levels showed 1.62, 9.13 and 34.25% higher seed yield at N level of 80 kg ha^{-1} than that at N levels of 120, 40 and 0 kg ha^{-1}, respectively (Table 5). Maximum seed yield at 80 kg N ha^{-1} was attributed to improvement in yield attributes, such as number of branches plant^{-1}, number of heads plant^{-1}, 1000-seed weight and seed yield plant^{-1} (Table 5). Generally, in most previous studies seed yield was increased by N fertilization at different rates depending on the experiment. One possible reason which can explain the difference between our data and those reported by other authors is the use of different cultivars that respond to high rates of N and can increase seed yield.

The importance of nitrogen fertilization for safflower grown in the field Zaman and Das [27], and its physiological response Dordas and Sioulas [28], has been investigated in only a limited manner. These studies showed that elevated nitrogen levels to 200 kg N ha^{-1}, in the form of $(NH4)_2$ SO_4, increased leaf nitrogen concentration and chlorophyll content leading to an increase in photosynthetic rate and stomatal conductance. Such increased photosynthetic rate and stomatal conductance resulted in enhanced water use efficiency and net increased seed yield.

Table 5. Means comparison for the main effects of nitrogen rate and plant density levels on quality parameters, seed and oil yield of safflower based on Duncan's multiple range test (DMRT) at 5% probability level

Treatment	Mean comparisons of seed, oil yield and quality parameters			
	Oil content (%)	**Protein content (%)**	**Seed yield kg ha^{-1}**	**Oil yield kg ha^{-1}**
Nitrogen rate (kg ha^{-1})				
N_1 = (0 kg N ha^{-1})	30.20 c	18.02 d	1058.7 d	329.96 d
N_2 = (40 kg N ha^{-1})	31.65 b	19.54 c	1463.2 c	533.11 c
N_3 = (80 kg N ha^{-1})	33.90 a	21.67 b	1610.2 a	594.69 a
N_4 = (120 kg N ha^{-1})	31.31 b	22.89 a	1584.1 b	585.38 b
Regression model				
Linear	**	**	**	**
Quadratic	**	**	**	**
Cubic	ns	ns	ns	ns
Plant density				
P_1= (200,000 plant ha^{-1})	30.51 d	19.45 d	1613.8 a	545.39 a
P_2= (133,000 plant ha^{-1})	32.36 c	20.15 c	1461.8 b	525.88 b
P_3= (100,000 plant ha^{-1})	33.13 b	21.34 b	1359.5 c	498.74 c
P_4= (80,000 plant ha^{-1})	34.47 a	22.75 a	1281.1 d	473.13 d
Regression model				
Linear	**	**	**	**
Quadratic	ns	ns	ns	ns
Cubic	ns	ns	ns	ns

Means followed by similar letters in each column for each main nitrogen rate or plant distance are not significantly different at the 5 % probability level.
*** Significant at 1% probability level and ns: not significant.*

In general, in most previous studies seed yield was increased by increasing nitrogen fertilization rates depending on the experiment. Sary et al. [29] reported application of nitrogen significantly increased yield and yield component characters of safflower. Beech and Norman [30] reported higher seed yield by applying 80 kg N ha^{-1} than 0 kg N ha^{-1}. Dordas and Sioulas [28] reported that nitrogen fertilization increased seed yield by an average of 19%. Zareie et al. [24] found that nitrogen had an important effect on seed yield, and that increasing nitrogen rates from 50 to 100 kg ha^{-1}, increased seed yield from 5.48 to 9.08 ton ha^{-1}, respectively.

The statistical model which defines this relation between using N and yield of safflower was obtained using the quadratic function (Table 5). Also, there was a positive and significant correlation between seed yield and rate of nitrogen, so that increasing of nitrogen application increased seed yield. According to the regression analysis results, nitrogen level used to obtain the highest total production is shown in Fig. 1.

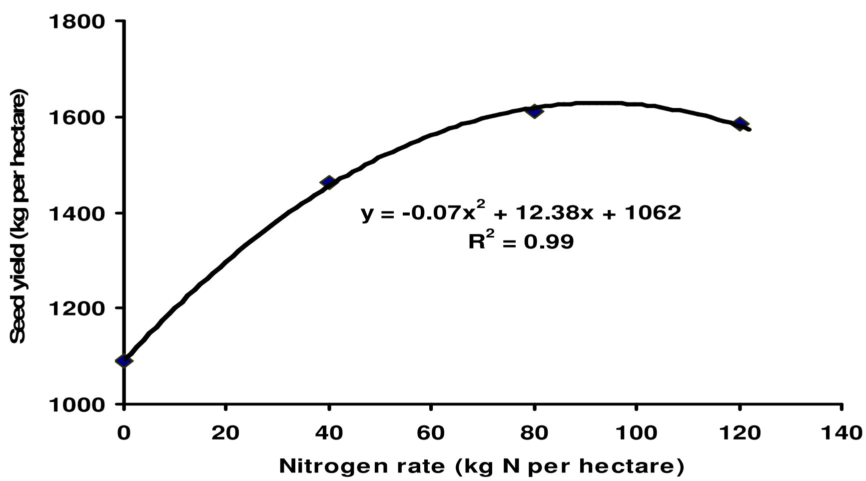

Fig. 1. Measured and predicted seed yield (kg ha^{-1}) values versus nitrogen rate

The response of nitrogen application to seed yield was quadratic in nature. The quadratic response of seed yield to nitrogen application (Fig. 1) showed the importance of this element in the production system. High R^2 (0.99) indicates a close relationship between seed yield and nitrogen rates. This result is in conformity with the findings of Kulekci et al. [5] who reported that the relationship between the nitrogen amount applied and safflower yield was defined by using a quadratic function.

The measured and predicted values versus net nitrogen were shown in Fig. 1. The obtained model is formulated as: $y = - 0.07 x^2 + 12.38 x – 1062$, R^2=0.99
where Y is seed yield in kg ha^{-1} and x is applied net nitrogen applied in kg ha^{-1}.

Effect of plant density: Determination of optimal population density is an essential step in the production of safflower. It is a fact that spacing between the plants has direct effect on the seed yield. Therefore, the study of the effect of different levels of plant density is of utmost importance. With respect to the effect of plant population density on safflower crop, plant densities of planting had significant effect on the seed yield ha^{-1} of safflower (Table 5).

Average seed yield ranged from 1613.8 kg ha^{-1} (200,000 plants ha^{-1}) to 1281.1 kg ha^{-1} (80,000 plants ha^{-1}). In general, the yield increments of the highest density (i.e., 200,000 plants ha^{-1}) over those of 133,000, 100,000 and 80,000 plants ha^{-1} were 9.41%, 15.76% and 20.62%, respectively. This increase of seed yield with the highest plant density was mainly attributed to the higher number of plants and heads per unit area at harvest. However, yield attributes like number of branches $plant^{-1}$, number of heads $plant^{-1}$, 1000-seed weight and seed yield $plant^{-1}$, were significantly higher at 80,000 plants ha^{-1} (Table 5). These results are similar to the findings of Leilah et al. [19] who observed significant increase in yield at higher plant density. Ahadi et al. [31] reported that increasing the plant population from 20 to 40 plants m^{-2} resulted in an increase of 30% in seed yield. Pourhadian and Khajehpour [32] concluded with increasing planting density number of branches/plant, seeds $head^{-1}$, heads $plant^{-1}$ and seed yield $plant^{-1}$ significantly decreased.

It may be concluded that 200,000 plants ha^{-1} gave substantially higher seed yield because such an optimum plant density facilitated maximum utilization of nutrients and increased dry matter production which ultimately resulted in higher seed yield ha^{-1}. These results are in harmony with those reported by Azari and Khajehpour [33] who reported that as the plant density was increased; the plant size and yield components were decreased, but the increase in the number of plants per unit area usually compensates the decrease in total yield. Similar results have been reported in safflower [24,34].

Relatively high seed yields were obtained for a wide range of plant density from 30 to 50 plants per m^2 independence on site conditions. This finding may indicate large yield compensating ability of safflower. Singh and Singh [35] reported an optimum density of 89,000 plants ha^{-1} to achieve the highest yield of safflower seed in the soil and climatic conditions of Punjab in India. Mane et al. [36] obtained the highest yields of safflower seed for the plant density of 225,000 individuals per hectare. Salera [37] reported high yields of safflower seed for the plant density of 40 individuals per m^2 under Italian conditions (when the densities of 20, 30, 40 plants per m^2 were investigated).

The relationship between seed yield and plant density represented a linear character and followed the equation $y=1081+0.003\ x$, which means a raising trend of seed yield by increasing plant density (Fig. 2). According to the above equation, the highest seed yield was obtained in the highest plant population (200,000 plants ha^{-1}). Also, there was a positive and significant correlation between seed yield and plant density, so that increasing of plant density increased seed yield. The linear response of seed yield to plant density (Fig. 2) showed the importance of this factor in the production system. These results are consistent with findings of Sharifmoghaddasi and Omidi [38].

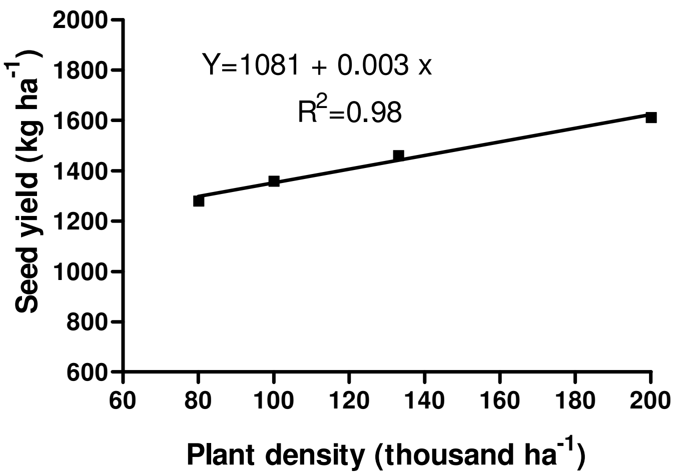

Fig. 2. Linear regression of seed yield on plant density (Average of two seasons)

3.2.1.2 Oil yield (Kg ha^{-1})

Effect of nitrogen: Oil yield, is the major economical product of safflower. Significant variations on oil yield were seen among four nitrogen rates adopted across the plant density levels. Oil yield was increased with N application which is mainly attributed to the fact that the seed yield was increased by N fertilization. As a result, increasing nitrogen application will raise oil yield in addition to seed yield. Gawand et al. [39] in safflower and Abbadi et al. [21] in safflower and sunflower reported similar results with increasing nitrogen application.

The results revealed that maximum seed oil yield (594.69 kg ha^{-1}) was obtained by applying 80 kg N ha^{-1} and minimum seed oil yield (329.96 kg ha^{-1}) by applying 0 kg N ha^{-1} (Table 5). These results agree with the findings of Weiss [40] who mentioned that oil content or seed composition generally have little direct response to applied N fertilizer, however, by increasing seed yield, the fertilizer increases total oil yield. On the contrary, Elfadl et al. [41] found that the effect of N rates on safflower oil content and oil yield is not significant.

Effect of plant density: In this study, oil yield in various plant density treatments was measured. The results indicated that significant effect of plant densities on safflower oil yield. Maximum oil yield (545.39 kg ha^{-1}) was obtained at a narrow plant spacing of 10 cm (200,000 plants ha^{-1}), against the minimum (473.13 kg ha^{-1}) at 25 cm plant spacing (80,000 plants ha^{-1}). Increase in oil yield ha^{-1} at higher plant density (200,000 plants ha^{-1}) was attributed to more seed yield ha^{-1} (Table 5) than the lowest plant density (80,000 plant ha^{-1}). Since the highest seed yield was obtained from the density of 200,000 plants ha^{-1}, it seems that seed yield per hectare was the reason for the increase in oil yield per hectare at this density. This is indicative of the fact that oil yield is more affected by seed yield than seed oil content. Similar results were reported by Sharif and Omidi [42] and Amoghein et al. [25].

As it can be observed in Fig. 3, oil yield kg ha^{-1} has high correlation with seed yield kg ha^{-1}; it means that if seed yield increases the oil yield will increase linearly.

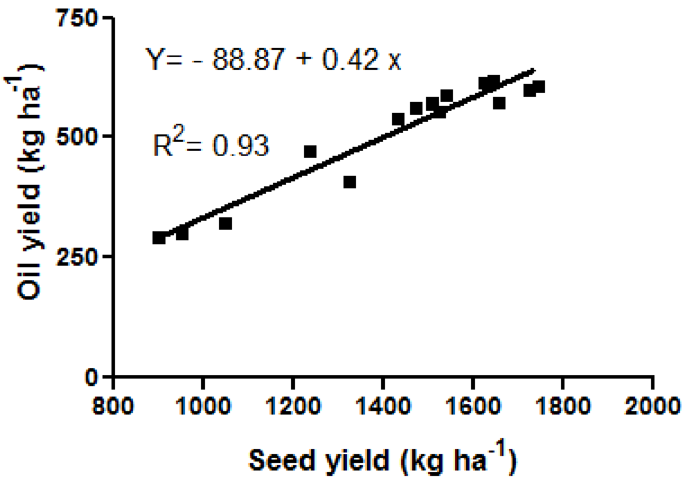

Fig. 3. Relationship between seed and oil yield in safflower

3.2.2 Performance of quality traits

3.2.2.1 Oil content of seeds

It is necessary to give a sufficient amount of nitrogen to a plant for optimum yield and high-quality production. Oil content is one of the important components, which play a crucial role in the safflower seed quality. The data showed that a slight increase was observed by increasing N rate in oil content up to 80 kg N ha^{-1}, but by applying the highest level of N (120 kg N ha^{-1}) the oil content decreased again which agrees with Bassil et al. [43] who found that at high N levels there was a significant decrease in oil content. Dordas and Sioulas [28] did not find any relationship between rates of N and oil content. In our study maximum seed oil content (33.90%) was obtained by applying 80 kg N ha^{-1} and minimum seed oil content (30.20%) was obtained by applying 0 kg N ha^{-1} (Table 5).

The data showed that seed oil content increased by 12.25% with increasing N application from 0 to 80 kg N ha^{-1} and then it decreased significantly. However, there was no significant difference between 40 and 120 kg N ha^{-1} on seed oil content (Table 5). These results are in harmony with those reported by Bitarafan et al. [22] who reported that a slight increase was observed by increasing N rate in oil content up to 100 kg N ha^{-1}, but by applying the highest level of N (150 kg N ha^{-1}) the oil content decreased again. Golzarfar et al. [23] found that increasing N rates from 0 to 150 kg N ha^{-1} increased all traits means, except seed oil content which had a slight decrease in highest level of N. In the present study the effect of nitrogen application on seed oil content (%) was quadratic in nature (Fig. 4). Also, there was a positive and significant correlation coefficient between seed oil content and nitrogen fertilization rate (r= 0.88), so that increasing nitrogen application up to 80 kg N ha^{-1}, increased seed oil content.

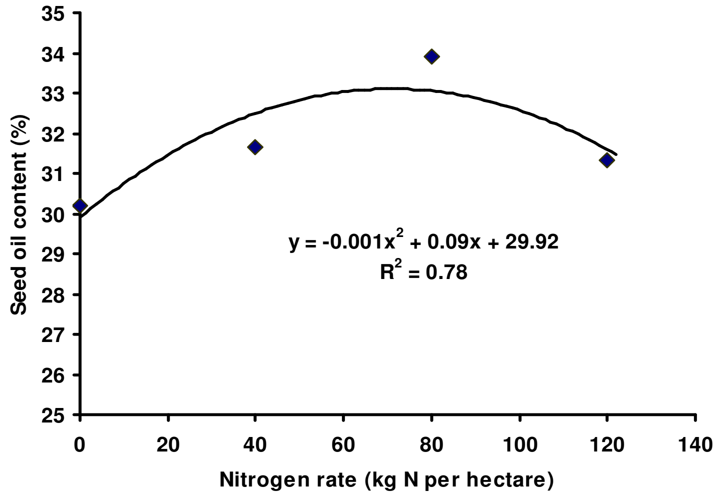

Fig. 4. Measured and predicted oil content % values versus nitrogen rate

Statistical analysis showed that there was a significant increase in seed oil percentage by decreasing plant density up to 80,000 plants ha^{-1}. Data presented in Table 5 indicated that seed oil content (%) of safflower was inversely related to increasing plant density. May be the lack of the number of plants per unit area helps the growth of remaining in a better way due to better plants availability of fertilizer nutrients, water and air, and thereby increases the accumulation of food ingredients in seeds as part of the economic yield and oil content of seeds.

3.2.2.2 Protein content of seeds

The results showed that the effect of nitrogen rate and plant density on seed protein content was significant (P = .05). As shown in Table 5, there were statistical differences between nitrogen rates for protein content (%). Using Duncan's multiple range test, results showed that higher and lower protein contents of (20.61%) and (19.90%) were recorded at N_4 (120 kg N ha^{-1}) and N_1 (0 kg N ha^{-1}), respectively. The higher crude protein at higher nitrogen levels was mainly due to structural role of nitrogen in building up amino acids. For each successive increase of N rate, there was a significant increase in protein content but it negatively affected the oil contents by applying the highest level of N (120 kg N ha^{-1}). As it can be observed in Fig. 5, protein content (%) has high correlation with applying nitrogen rate levels; it means that if nitrogen rate increases the protein content (%) will increase linearly. As seen in Fig. 5, seed protein content (%) had a significant and positive correlation coefficient with nitrogen fertilization rate (r= 0.99). High R^2 in N rates (R^2 = 0.99) indicates a close relationship between protein content and N rates.

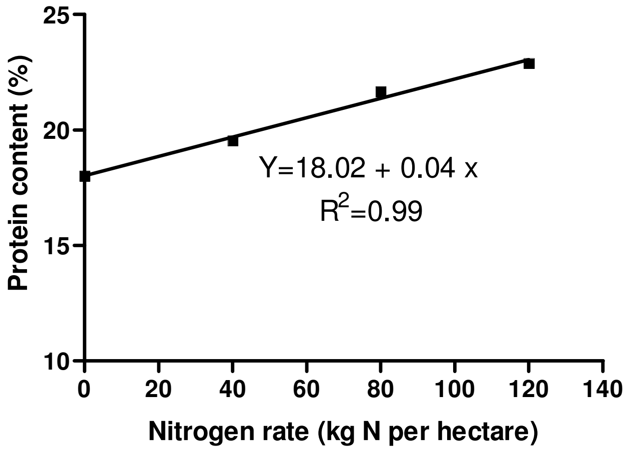

Fig 5. Measured and predicted protein content % values versus nitrogen rate

The results revealed that, safflower crop sown at different plant densities significantly affected protein content (%). According to the two-year averages, the maximum protein contents (22.75%) was recorded where the crop was sown at plant density of 80,000 plants ha^{-1} against the minimum protein contents (19.45%) recorded under plant density of 200,000 plants ha^{-1}. At higher plant populations, competition for photo-assimilates due to deficiency of nitrogen caused reduction in protein content. Statistically significant effect of plant density levels on protein content (%) was observed which agrees with studies of Bitarafan et al. [22]. Data reported in Table 5, shows the effect of plant density on seed oil and protein content (%). It could be concluded that, by increasing plant density, seed oil and protein content (%) decreased significantly (Table 5). Sharikian and Babayian [44] observed the decrease in oil percentage and increase in protein percentage of the seeds.

Interactive effects of different nitrogen and plant density levels on seed yield were significant. According to the results in Table 6, seed yield values ranged from 902.3 to 1744.3 kg ha^{-1} across 2 years for all treatment combinations. Maximum seed yield (1744.3 kg ha^{-1}) was recorded when nitrogen was applied at 80 kg N ha^{-1} and crop was sown at plant density of 200,000 plants ha^{-1}. These results showed that use of high densities will just be useful when enough quantity of nitrogen fertilizer is used. The minimum seed yield (902.3 kg ha^{-1}) was recorded when the nitrogen was applied at 0 N ha^{-1} and the crop was sown at plant density of 80,000 plants ha^{-1}. Therefore, it is suggested that among different plant densities (200,000, 133,000, 100,000 and 80,000 plant ha^{-1}) and different nitrogen levels (0, 40, 80 and 120 kg ha^{-1}), plant density of 200,000 plant ha^{-1} with 80 kg of nitrogen per hectare are optimum for safflower crop under agro-ecological conditions of Giza, Egypt.

Table 6. Effect of nitrogen and plant density levels on seed safflower yield (kg ha^{-1})

Nitrogen rate (kg ha^{-1})	Plant density			
	80,000 plant ha^{-1}	100,000 plant ha^{-1}	133,000 plant ha^{-1}	200,000 plant ha^{-1}
N_1 (0 kg N ha^{-1})	902.3 ij	954.3 i	1051.3 h	1326.7 f
N_2 (40 kg N ha^{-1})	1238.3 g	1432.0 e	1524.3 c	1658.0 b
N_3 (80 kg N ha^{-1})	1508.3 cd	1543.3 c	1644.7 b	1744.3 a
N_4 (120 kg N ha^{-1})	1475.3 de	1508.3 cd	1626.7 b	1726.0 a

Any two means not sharing a letter in common differ significantly at 5% probability level- using Duncan's multiple range test.

3.2.3 Performance of agronomic traits and yield components of safflower

The results of combined analysis of variance revealed that the main effect of nitrogen on yield components at (P = .01) and the main effect of plant density on these traits at (P = .05) were significant but the interaction effect of them on these traits was not significant (Table 3). The mean performances across the two years for yield parameters are presented in Table 7. Based on polynomial regression analysis, the relationship between yield parameters and applied nitrogen was described by the quadratic model, but there was a linear response as the plant density increased (Table 7).

Effect of nitrogen: Results markedly indicated that yield components were increased by N fertilization. Number of heads plant^{-1}, 1000-seed weight and seed yield plant^{-1} increased by increasing N rates from 0 to 80 kg N ha^{-1} , but application of 120 kg ha^{-1} nitrogen showed a decline in these traits (Table 7).

Data regarding days to 50% flowering in safflower crop as influenced by different nitrogen levels are presented in Table 7. Significant differences at 1% probability level were found among the different nitrogen levels for number of days to 50%. Data presented in Table 7 show that on average, maximum number of days to 50% flowering (135.22) were recorded by safflower crop when the fertilizer was applied at 120 kg N ha^{-1} that was statistically at par with the treatments when nitrogen was applied at 80 kg N ha^{-1}. The number of heads plant^{-1} is one of the most important yield components that can have much influence on the yield. It is directly related to the final yield. Maximum number of heads plant^{-1} (29.45) was produced at the nitrogen level of 80 kg ha^{-1}, followed by 120 kg N ha^{-1} which produced (26.14) heads plant^{-1}. Minimum number of heads plant^{-1} (10.11) was recorded in control treatment. It can be attributed to the more availability of nitrogen resulting in enhanced vegetative growth, and leading to improved fruiting. Maximum seed yield plant^{-1} (28.45) was produced when nitrogen was applied at the rate of 80 kg ha^{-1}. While minimum seed yield plant^{-1} (10.25) was produced by N_1 (control) treatment. Increase in seed yield plant^{-1} by N_3 (80 kg N ha^{-1}) treatment might be attributed to better growth of the plant which ultimately increased seed yield plant^{-1} as compared to control.

These results can be related to some earlier studies by El-Nakhlawy [45] who reported that the highest seed yield, 100-seed weight, number of heads plant^{-1} and seeds weight head^{-1}, resulted from using 92 kg N ha^{-1} as compared to 46 and 138 kg N ha^{-1}. Leilah et al. [19] indicated that increasing nitrogen levels significantly increased plant height and number of heads plant^{-1}. Bansal and Katara [46] investigated the effect of different levels of nitrogen, i.e., 0, 30, 60 and 90 kg N ha^{-1} on safflower yield. They found that 1000-seed weight and seed yield reached to maximum values by fertilizing safflower plants with 90 kg N ha^{-1}. Das and Ghosh [47] examined the effects of four different doses of nitrogen on safflower in India, and found that fertilizer doses significantly affected yield and yield components and recommended the 60 kg N ha^{-1} dose as an optimum dose. Dordas and Sioulas [28] found that nitrogen fertilization increased seed yield by an average of 19%, the seed weight per plant by 60%, the seed weight per head by 18%, the number of heads per plant by 32% and the number of seeds per plant by 41% as compared with the control.

Nitrogen levels have been shown to affect safflower crop component and growth performance. Siddique and Oad [20] considered 120 kg N ha^{-1} as the optimum level for production of maximum seed yield by significantly producing greater branches, heavier seed weight and more seeds per plant. While more heads per plant and taller plants were recorded in plots treated with 180 kg N ha^{-1}, these did not produce any further significant increases in yield. Strasil and Vorlicek [7] found that neither the one thousand seed weight nor number of capitula per plant and consequent, seed yield in three varieties of safflower (Gila, cw-74 and Sironaria) at two sites under three rates of nitrogen (0, 40 and 80 kg N ha^{-1}) were significantly affected by nitrogen fertilizer.

Effect of plant density: Several reports indicate that yield components of safflower change under the effect of the different densities of planting [19,24,25,48]. Therefore, identifying the suitable planting density is the first and the most essential strategies considered for achieving high yield in a region.

It is clear form Table 7 that, plant density negatively affected all yield components. It was observed that the plant height, number of branches $plant^{-1}$, number of heads $plant^{-1}$, seed yield $plant^{-1}$ and 1000 seed weight significantly decreased as plant density increased. The reduction in these traits as plant population density increased might be attributed to the possible competition for soil moisture and nutrients. Environmental conditions such as interplant competition can adversely influenced seed development by inhibiting photosynthesis and other metabolites required during the seed filling stage [24]. Oad et al. [49] who observed that plant height, number of branches, number of heads per plant, seed yield and oil content varied significantly under different plant densities and reported that highest plant densities gave higher seed yield (kg ha^{-1}). Otherwise, number of days to 50% flowering increased as plant density increased. Samadi and Zafarali [50] concluded flowering time in plant densities (100,000, 125,000, 200,000 plants ha^{-1}) is different on safflower. 100,000 plants ha^{-1} flowered earlier than the others. Similar results were reported by Zareie et al. [24]. Majd et al. [51] stated that seed yield per unit area and per plant, yield components, the number of seeds per plant and kernel percentage were influenced by plant density.

3.3 Correlation and Stepwise Regression Analysis

3.3.1 Correlation analysis

Evaluating yield components and their interrelationships as well as detecting suitable selection indices are very important in safflower breeding program. The simple correlation coefficient is one of the important indicators to study the nature of the correlations between traits for use in crop improvement following appropriate method of selection**.** Table 8 shows the matrix of correlation coefficient describing the relationships between yield component characters and seed yield of safflower. The combined data across the two years in Table 8 showed that seed yield $plant^{-1}$, number of heads $plant^{-1}$, number of branches $plant^{-1}$ and 1000-seed weight have positive and highly significant relationships with seed yield per hectare; the Pearson's coefficients were (0.812**), (0.933**), (0.796**) and (0.715**), respectively (Table 8). These results imply that most of these traits contribute to increase in seed yield. Thus, they also form critical traits for safflower improvement. These relationships need to be considered by the safflower breeder, when making selections for the isolation of superior genotypes with desirable characters. Further, days to 50% flowering, oil content % and protein content % showed a negative relation with seed yield ha^{-1}; the Pearson's coefficients were (- 0.558*), (- 0.384) and (0.486*), respectively (Table 8). Little association between plant height and seed yield ha^{-1} was observed. Therefore, plant height cannot be used as a criterion of seed yield improvement in safflower.

Several researchers have reported their findings regarding the correlation studies in safflower. Our results confirm the findings of Tuncturk and Ciftci [52] and Alizadeh and Carapetian [53]. Camas et al. [54] reported significant associations between seed yield and number of heads $plant^{-1}$, number of seeds $head^{-1}$ and 1000-seed weight. Hajghani et al. [55] showed that significant correlation exists between seed yield and number of heads per plant (r = 0.933**) and number of secondary branches (r = 0.912**). Safavi et al. [10] reported that seed yield was positively correlated with number of heads $plant^{-1}$, seed yield $plant^{-1}$ and 1000-seed weight except days to 50% maturity.

3.3.2 Modeling of total seed yield based on stepwise multiple linear regression

In order to gain a predictor model of seed yield variation and study the traits effective on yield, regression modeling was conducted based on stepwise regression. The results of stepwise regression analysis in safflower under nitrogen and plant density conditions was calculated by considering the seed yield as the dependent variable and other characters as the independent variables.

The regression analysis of seed yield (kg ha^{-1}) as dependant variable (Table 9) according to stepwise method demonstrated that traits such as total number of heads $plant^{-1}$, seed yield $plant^{-1}$, number of branches $plant^{-1}$ and 1000-seed weight entered to regression model and totally justified 81.63% of the variation that existed in seed yield. These results are in agreement with those of correlation, so that the number of heads $plant^{-1}$ character which was first entered into the regression model, had the most correlation with the seed yield kg ha^{-1} and seed yield $plant^{-1}$ and the number of branches $plant^{-1}$ had a very high correlation with the seed yield kg ha^{-1}. Therefore, these traits were considered as the main seed yield components. The unexplained variation (18.37% of the total) may be due to variation in other components. These results corroborate with the path analysis and stepwise regression reported earlier for yield parameters of safflower [56,57].

Table 7. Means comparison for the main effects of nitrogen rate and plant density levels on growth and yield parameters of safflower based on Duncan's multiple range test (DMRT) at 5% probability level

Treatment	**Mean comparisons of yield parameters**					
Nitrogen rate (kg ha^{-1})	**Days to 50% flowering**	**Plant height (cm)**	**Number of branches plant^{-1}**	**Thousand seed weight (g)**	**Number of heads plant^{-1}**	**Seed yield plant^{-1} (g)**
N_1 = (0 kg N ha^{-1})	113.22 d	104.36 d	5.32 d	40.22 d	10.11 d	10.25 d
N_2 = (40 kg N ha^{-1})	120.57 c	113.66 c	6.57 b	52.14 c	17.54 c	17.26 c
N_3 = (80 kg N ha^{-1})	130.33 ab	121.55 b	6.95 a	59.77 a	29.45 a	28.45 a
N_4 = (120 kg N ha^{-1})	135.22 a	124.85 a	7.02 a	57.27 ab	26.14 ab	25.43 ab
Regression model						
Linear	**	**	**	**	**	**
Quadratic	**	**	**	**	**	**
Cubic	ns	ns	ns	ns	ns	ns
Plant density						
P_1= (200,000 plant ha^{-1})	137.57 a	109.53 d	4.74 d	37.15 d	18.45 d	7.79 d
P_2= (133,000 plant ha^{-1})	128.36 b	113.79 c	5.83 c	45.76 c	25.78 c	10.36 bc
P_3= (100,000 plant ha^{-1})	122.74 c	119.07 b	7.23 b	55.46 b	28.44 ab	12.66 b
P_4= (80,000 plant ha^{-1})	120.38 c	122.04 a	7.45 a	60.24 a	31.28 a	15.99 a
Regression model						
Linear	**	**	**	**	**	**
Quadratic	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns

Means followed by similar letters in each column for each main nitrogen rate or plant density are not significant different at the 5 % probability level.
*** Significant at 1% probability level and ns: not significant.*

Table 8. Matrix of correlation coefficients showing the relationships between seed yield and yield components of safflower under different nitrogen fertilizer and plant density levels (Data are combined across treatments and seasons)

Trait	1	2	3	4	5	6	7	8	9
1- Seed yield (kg ha^{-1})	1								
2- Plant height	0.427^{ns}	1							
3- Days to 50% flowering	-0.558*	-0.564*	1						
4- No. of branches $plant^{-1}$	0.796**	0.657**	-0.297^{ns}	1					
5- No. of heads $plant^{-1}$	0.933**	0.816**	-0.332^{ns}	0.943**	1				
6- 1000-seed weight (g)	0.715**	0.601**	-0.347^{ns}	0.459^{ns}	0.586*	1			
7- Seed yield $plant^{-1}$ (g)	0.812**	0.584*	-0.265^{ns}	0.768**	0.884**	0.821**	1		
8- Oil content %	-0.384^{ns}	-0.277^{ns}	-0.542*	0.256^{ns}	0.110^{ns}	0.291^{ns}	0.672**	1	
9- Protein content %	-0.486*	0.375^{ns}	-0.267^{ns}	-0.341^{ns}	0.660**	0.359^{ns}	0.574*	-0.443^{ns}	1

*ns, * and **, not significant and significant at 5 and 1% level of probability, respectively.*

Table 9. Final model and contributions of different yield components to seed yield ha^{-1} determined by stepwise regression

Variable	Regression coefficient	T Statistic	Probability value	Model R^2 (%)
No. of heads $plant^{-1}$	0.091	10.239**	0.010	45.57
Seed yield $plant^{-1}$ (g)	0.077	5.273**	0.000	61.29
No. of branches $plant^{-1}$	0.090	6.856 **	0.001	74.34
1000-seed weight (g)	0.026	3.442*	0.036	81.63
$Y = 1285.52 + 0.091\ x_1 + 0.077\ x_2 + 0.090\ x_3 + 0.026\ x_4$				

R- squared = 81.63 percent and R-squared (adjusted for d.f.) = 79.59 percent.
** and **, significant at 5 and 1% levels of probability, respectively.*

Similar results were reported by Nassiri et al. [58] who found that heads per plant described 73% of variation in seed yield. Safavi et al. [10] reported that diameter of primary head explained 46.4% and along with heads per plant, 1000-seed weight and seeds per head explained 74.3% of total variations for seed yield. Golkar et al. [59] used stepwise multiple linear regression analysis to study the relationships between seed yield and yield components and found that 86% of the total variation in seed yield could be explained by variation in seeds per head, heads per plant and 1000-seed weight. Golparvar [60] reported that 1000-seed weight, seed yield $plant^{-1}$ and No. of seeds $head^{-1}$ are the best selection criteria for genetic improvement of seed yield.

At last, the following regression model was obtained for indicating the relationship between the seed yield and yield traits as independent variables:

$$Y = 1285.52 + 0.091\ x_1 + 0.077\ x_2 + 0.090\ x_3 + 0.026\ x_4$$

In this equation Y is the seed yield; x_1, x_2, x_3 and x_4 are number of heads $plant^{-1}$, seed yield $plant^{-1}$, number of branches $plant^{-1}$ and 1000-seed weight, respectively (Table 9). A positive regression coefficient of the four variables implies that defining a logical index selection with these variables, considering their correlation coefficients with seed yield, might be a good strategy for increasing seed yield in safflower.

4. CONCLUSION

Nitrogen and plant density are considered some of the most important factors affecting yield and yield components. This study provides new information about the effect of N rates and plant densities on seed yield and some yield component traits. The results demonstrated that, the effect of nitrogen and plant density was significant on seed yield and yield components. Nitrogen application had positive influence on all the yield components. However, the response with nitrogen application of 80 and 120 kg ha^{-1} was statistically similar. Therefore, to achieve the optimum values of yield components, application of nitrogen with rate of 80 kg ha^{-1} is recommended for Giza cultivar under similar climate and cultivation conditions. The highest seed and oil yields were obtained at the highest plant density (200,000 plants ha^{-1}). Developed statistical models may be applied to predict seed yield, oil yield, seed oil and protein content (%) as a function of nitrogen application and plant density under Giza governorate conditions and need to be confirmed further for wider viability. Effective selection for superior genotypes is possible considering number of heads $plant^{-1}$, seed yield plant^{-1}, number of branches plant^{-1} and 1000-seed weight and could be used as target traits to improve safflower seed yield.

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RECOMMENDATION

The results of this research could be implemented for improving productivity of safflower crop. Finally the present investigation provided considerable information that could be useful for safflower breeders, statisticians and agronomists to determine the optimum nitrogen fertilizer dose and plant density for introduce to farmers and understand the nature of the relationship between the most important factors affecting the yield of safflower, and developing statistical models to describe these relations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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