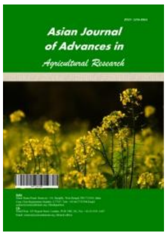

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Straw, Seed Yield and Quality of Three *Linum usitatissimum* L. Cultivars in Relation to Nitrogen Fertilizer Rate and Plant Density

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Authors' contributions

This work was carried out in collaboration among all authors. Author EMME designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors GYMH, SAHA, SHAM and KSSE supervised the study and managed the literature searches. Also, all Authors managed the experimental process and performed data analyses. All authors read and approved the final manuscript.

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ABSTRACT

Methodology: Two field experiments were conducted on the Experimental Farm at El-Gemmeiza Research Station, Gharbia Governorate, Agricultural Research Center, Egypt, during two successive winter seasons of 2018-19 and 2019-20.
Aims: To investigate the effect of three nitrogen fertilizer rates, *i.e.* 30, 50 and 70 kg N feddan^{-1} [one feddan (fed) = 4200 m^2] and three plant densities, *i.e.* 1500, 2000 and 2500 seeds m^{-2} on flax (*Linum usitatissimum* L.) yield and its quality of three cultivars of flax, *i.e.* Sakha 3, Giza 11 and Giza 12.
Results: Results in combined analysis of the two seasons showed that Sakha 3 cultivar significantly produced the maximum total plant height, technical stem length, upper branching zone

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length, No. of seeds capsule^{-1}, total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1}, fiber length and fiber fineness. Meanwhile, the highest No. of basal branches plant^{-1}, straw yield plant^{-1}, straw yield fed^{-1} and seed oil content were recorded with Giza 12 cultivar. While, Giza 11 cultivar gave the maximum stem diameter, No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed index, seed yield plant^{-1}, seed yield fed^{-1}, harvest index, oil yield plant^{-1} and oil yield fed^{-1}. Increasing nitrogen fertilizer rates from 30 up to 70 kg N fed^{-1} caused significant increases in almost straw, fiber, seed and oil yields and its related traits of flax, on the other hand, fiber fineness which significantly decreased with increasing nitrogen rates. Flax plants growing at 1500 seeds m^{-2} markedly gave the greatest No. of basal branches plant^{-1}, stem diameter, straw yield plant^{-1}, upper branching zone length, No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed yield plant^{-1}, harvest index, oil yield plant^{-1} and fiber yield plant^{-1}. Meanwhile, the maximum total plant height, technical stem length, straw yield fed^{-1}, seed yield fed^{-1}, oil yield fed^{-1}, total fiber percentage, fiber yield fed^{-1}, fiber length and fiber fineness were obtained from flax planting at 2500 seeds m^{-2}. The maximum fiber yield were recorded from the interactions among treatments Sakha 3 X 70 kg N fed^{-1}, Sakha 3 X 2500 seeds m^{-2}, 70 kg N fed^{-1} X 2500 seeds m^{-2} and Sakha 3 X 70 kg N fed^{-1} X 2500 seeds m^{-2}. Meanwhile, the maximum seed and oil yields fed^{-1} were recorded from the interactions between treatments Giza 11 X 70 kg N fed^{-1}, Giza 11 X 2500 seeds m^{-2}, 70 kg N fed^{-1} X 2500 seeds m^{-2} and Giza 11 X 70 kg N fed^{-1} X 2500 seeds m^{-2}.

Generally, it could be concluded that Sakha 3 cultivar under soil fertilized by 70 kg N fed^{-1} with plant density of 2500 seeds m^{-2} to maximizing fiber yield fed^{-1}, while Giza 11 cultivar with the same rates of nitrogen and plant density to maximizing seed and oil yields fed^{-1}.

Keywords: Flax cultivars; nitrogen fertilizer; plant density; straw; seed; oil and fiber yield.

1. INTRODUCTION

In Egypt, Flax (*Linum usitatissimum* L.) ranked second after cotton as a fiber crop regarding the cultivated area and industry importance [1]. The fibers, which extracted from flax stem by retting process is a good row material for textile in addition to the oil obtained from seeds. Therefore, many industries had been established on flax fiber and seeds. Fresh linseed oil is used as human food and after boiling and treated chemically used as painting ink and varnish industries [2,3]. Moreover, linseed cake is a valuable protein source to poultry and ruminants [4,5]. Recently, the cultivated area by flax in Egypt tended to decrease in the valley lands due to great competition with other major winter crops [6,7]. Flax yield potential could be sustained through the use of high yielding varieties with application of the best agronomic practices such as nitrogen rates and plant densities.

Differences among the flax cultivars have been reported by many researchers they found that significant differences between the flax cultivars in straw yield as well as its related traits [8,9,10,11], seed yield as well as its related traits [12,13,14,15], oil yield as well as its related traits [16,17,18] and fiber yield as well as its related traits [19, 20].

Determination of the required rate of nitrogen fertilizer of flax plants is the main practice for the highest production and better quality, as well as nitrogen is a key element for flax plants [21,22]. Several investigations reported that increasing nitrogen fertilizer rates caused significant increase in all straw [8,10,21], seed [13,22], oil [13,23] and fiber [19,20,24] traits of flax, except fiber fineness was significantly decreased [10,21].

The effect of plant density on straw, seed, oil and fiber yield as well as their quality were studied by many investigators as [10,16,25,26] who found significant increment in total plant height, technical stem length, straw yield fed^{-1}, seed yield fed^{-1}, oil yield fed^{-1}, total fiber percentage, fiber yield fed^{-1}, fiber length and fiber fineness, but significant decreased in No. of basal branches plant^{-1}, stem diameter and straw yield plant^{-1}, upper branching zone length, No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds capsules^{-1}, No. of seeds plant^{-1}, seed index, seed yield plant^{-1}, harvest index, seed oil content, oil yield plant^{-1} and fiber yield plant^{-1} with increasing plant density.

The main objective of this investigation was designed to study the effect of nitrogen fertilizer rates and plant densities on straw and seed yield of flax cultivars, in addition to their quality in farm at El-Gemmeiza Research Station, Gharbia Governorate, Egypt

2. MATERIALS AND METHODS

Two field experiments were conducted at the Experimental Farm at Gemmeiza Agriculture Research Station, Agricultural Research Center, Egypt, during two successive winter seasons of 2018-19 and 2019-20 to study the response of three flax cultivars, *i.e*. Sakha 3, Giza 11 and Giza 12, three nitrogen fertilizer rates (30, 50 and 70 kg N fed^{-1}) and three plant densities; 1500, 2000 and 2500 seeds m^{-2} and their effect on yield and yield components.

2.1 Soil Analysis

Soil texture of the experimental site was silty clay loam and pH of 8.0. Soil samples were taken before sowing of crop to depth of 0-30 cm for chemical and physical properties analysis of the experimental soil were determined according to the standard procedures described by [27] and represented in Table 1.

2.2 Treatment Details and Experimental Design

Each experiment included twenty seven treatments, which were the combination of three flax cultivars, three nitrogen fertilizer rates and three plant densities.

a) **Flax cultivars**
1) Sakha 3.
2) Giza 11.
3) Giza 12.

The cultivars seeds were obtained from Fiber Crops Research Section, Field Crops Research Institute, Agricultural Research Center, Egypt and its pedigree was shown in Table 2.

b) **Nitrogen fertilizer rates**
1) 30 kg N fed^{-1}.
2) 50 kg N fed^{-1}.
3) 70 kg N fed^{-1}.

Nitrogen fertilizer was applied in form of urea (46% N), and divided into two equal parts and applied before the first and second irrigations in both seasons.

c) **Plant densities**
1) 1500 seeds m^{-2}.
2) 2000 seeds m^{-2}.
3) 2500 seeds m^{-2}.

The seeding rates (kg fed^{-1}) from plant densities (No. of seeds m^{-2}) for the three studied cultivars of flax as shown in Table 3.

The preceding summer crop in two seasons was rice (*Oryza sativa* L.). The experimental design was laid out using split-split plot design in four replications. Each of the three flax cultivars were distributed in the main plots, whereas the three nitrogen fertilizer rates were arranged at random in sub-plots and the three plant densities were assigned at random in sub-sub plots. The sub-sub area was 9 m^2 with 3 m long and 3 m width, forming 20 rows of 15 cm between rows. Flax seeds were sown on November 1st and 11th in 2018-19 and 2019-20 seasons, respectively. Phosphorous fertilizer was applied in form of calcium super phosphate (12.5% P_2O_5) at a level of 100 kg fed^{-1} during soil preparation in each season. The other recommended agronomic practices of growing flax were applied in the manner prevailing in the region were practiced.

Table 1. Chemical and physical properties of the experimental soil units before flax planting (Average the 2018-19 and 2019-20 seasons

Chemical analysis									
E.C. (ds m^{-1})	**pH (1 :2.5)**	**$CaCo_3$ (%)**	**O.M (%)**	**Total (%)**			**Available (mg kg^{-1})**		
				N	**P**	**K**	**N**	**P**	**K**
3.41	7.94	2.05	1.99	0.121	0.089	0.111	26.99	9.73	122.25

Physical analysis (Particle size distribution)				
Course sand (%)	**Find sand (%)**	**Silt (%)**	**Clay (%)**	**Texture grade**
4.89	10.11	46.69	38.32	Silty Clay Loam

Table 2. Type and pedigree of studied flax cultivars

Flax cultivar	Type	Pedigree
Sakha 3	Fiber	I.2596 x Belinka
Giza 11	dual purpose	Giza 8 x S.2419
Giza 12	dual purpose	S.2419 x S.148/6/1

Table 3. Planting density of flax cultivars (seeds m^{-2}) and their corresponding number of seeds per 3 m long of row and seeding rates (kg fed^{-1})

Flax cultivar	Plant density (No. of seeds m^{-2})	No. of seeds per 3 m long of row	Seeding rates (kg fed^{-1})
Sakha 3	1500	675	33.08
	2000	900	44.10
	2500	1125	55.13
Giza 11	1500	675	48.83
	2000	900	65.10
	2500	1125	81.38
Giza 12	1500	675	46.31
	2000	900	61.74
	2500	1125	77.18

2.3 Sampling and Data Collecting

At maturity, about 150 days from sowing date, ten guarded plants were taken randomly from each sub-sub plot for recording the straw and seed plant traits. Biological, straw, fiber and seed yields fed^{-1} (kg) were estimated according to yield from three meter square of each sub-sub plot. After harvesting and removing the capsules from plants in one meter square of each sub-sub plot, retting process took place at Fiber Crops Research Section, Gemmeiza Agriculture Research Station, Gharbia Governorate, Agricultural Research Center, Egypt. Straw from plants in one meter square of each sub-sub plot was arranged in bundles and put in retting basins and soaked in water for about 12 hours. After soaking, the water was changed to leach out all the soluble materials. Retting interval was about one week in summer season. The degree of water temperature during retting process ranged from 28 to 32°C and the pH was 6-7. The retted straw was washed with water and finally dried in open air. Thus, the fibers were easily extracted from the woody part of the stem. The following traits studied were:

2.3.1 Straw yield and its related traits

Total plant height (cm), technical stem length of the main stem (cm), number of basal branches plant^{-1}, stem diameter (mm), straw yield plant^{-1}(g), and straw yield fed^{-1} (kg).

2.3.2 Seed yield and its related traits

Upper branching zone length (cm), number of upper branches plant^{-1}, number of capsules plant^{-1}, number of seeds capsule^{-1}, number of seeds plant^{-1}, seed index [1000-seed weight] (g), seed yield plant^{-1} (g), seed yield fed^{-1} (kg), harvest index (%) it was calculated from dividing (seed yield/biological yield) X 100, oil seed content (%) it was determined as described by [28] methods, using petroleum ether (40-60°C) in Soxhlet apparatus, oil yield plant^{-1} (g) it was calculated by multiplying seed yield plant^{-1} (g) X oil %, and oil yield fed^{-1} (kg) it was calculated by multiplying seed yield fed^{-1} (kg) X oil %.

2.3.3 Fiber yield and its related traits

Total fiber percentage (%), fiber yield plant^{-1} (g), fiber yield fed^{-1} (kg), fiber length (cm) of the main stem, fiber fineness (Nm) determined using [29] methods according to the following equation: Nm = (N X L)/W. Where, Nm = Metrical number, N = number of fibers (20 fibers and the length for each one equal 10 cm), L = Length of fibers in mm (2000 mm) and W = Weight of fibers in mg.

2.3.4 Statistical analysis

Analysis of variance was performed using MSTATC statistical software package according to method described by [30]. Before conducting a combined analysis over years, error variances were tested for homogeneity by using Bartlett test and mean combined comparisons were performed using the least significant differences (L.S.D.) test with a significance level of 5% was calculated according to the method given by [31].

3. RESULTS AND DISCUSSION

3.1 Straw Yield and its Related Traits

3.1.1 Effect of flax cultivars

Results presented in Table 4 showed that straw yield and its related traits under study were different significantly between the three flax cultivars, but the differences between Giza 11 and Giza 12 cultivars did found non-significant in total plant height, technical stem length, straw yield plant^{-1} and straw yield fed^{-1} in the combined analysis of 2018-19 and 2019-20 seasons. The maximum total plant height and technical stem length were obtained from Sakha 3 cultivar. Sakha 3 cultivar increased total plant height by 10.62 and 13.17% and technical stem length by 6.51 and 7.68%, over total plant height and technical stem length of Giza 12 and Giza 11 flax cultivars, respectively. Results may reveal the superiority of Giza 12 flax cultivar in No. of basal branches plant^{-1}, straw yield plant^{-1} and straw yield fed^{-1}. Meanwhile, Giza 11 cultivar gave the thickness stem diameter. The superiority ratios between Giza 11 and Giza 12 cultivars over Sakha 3 were 38.24 and 80.43% for No. of basal branches plant^{-1}; 47.18 and 34.40% for stem diameter; 11.96 and 16.79% for straw yield plant^{-1} in addition to 11.86 and 15.58% for straw yield fed^{-1}, respectively. These differences in straw yield and its related traits of flax cultivars may be due to the genetic differences between Sakha 3 cultivar (fiber flax type) and Giza 11 and Giza 12 cultivars (dual purpose type). As well as, It could be concluded that Giza 12 surpassed the other two flax cultivars to increase straw yield fed^{-1} may be due to more likely attributed to the increase in straw yield plant^{-1} and No. of basal branches plant^{-1}. These results in good accordance with those reported by [8,9,10,11] showed that cultivars markedly varied for straw yield and its related traits of flax plants.

3.1.2 Effect of nitrogen fertilizer rates

Results in Table 5 revealed that increasing nitrogen fertilizer rates from 30 and 50 to 70 kg N fed^{-1} caused significant increments in straw yield and its related traits, but the differences between nitrogen fertilizer rates of 50 and 70 kg N fed^{-1} on technical stem length and stem diameter were not significant. While, No. of basal branches plant^{-1} of flax was not significantly affected by nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons. Flax plants which fertilized with the highest nitrogen fertilizer rate (70 kg N fed^{-1}) produced significantly the maximum straw yield and its related traits under study. On the other hand, the lowest straw yield and its related traits were obtained from flax planting when received the lowest nitrogen fertilizer rate (30 kg N fed^{-1}). The superiority ratios between the highest nitrogen rate (70 kg N fed^{-1}) and each of 50 and 30 kg N fed^{-1} were 4.03 and 9.64% for total plant height; 3.53 and 9.24% for technical stem length; 2.70 and 7.17% for stem diameter; 10.18 and 31.20% for straw yield plant^{-1} in addition to 10.10 and 32.55% for straw yield fed^{-1}, respectively. The increase in growth for traits (total plant height, technical stem length and stem diameter) associated with increasing nitrogen fertilization rates may be attributed to the role of nitrogen in enhancement meristematic activity and cell division, which caused increases in number and size of cells in flax stem. Also, the increase in straw yield plant^{-1} and straw yield fed^{-1} with increase in nitrogen fertilizer rates may be attributed to the increase in total plant height, technical stem length and stem diameter of flax plant. Many investigators came out with similar results as [8,10,21].

Table 4. Mean values of straw yield and its related traits of flax cultivars in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Total plant height (cm)	Technical stem length (cm)	No. of basal branches plant^{-1}	Stem diameter (mm)	Straw yield plant^{-1} (g)	Straw yield fed^{-1} (kg)
Sakha 3	98.83	73.63	1.441	1.276	1.882	3466.69
Giza 11	87.33	68.38	1.992	1.878	2.107	3877.89
Giza 12	89.34	69.13	2.600	1.715	2.198	4006.92
L.S.D. at 5%	3.32	2.49	0.072	0.071	0.095	299.51

Table 5. Mean values of straw yield and its related traits of flax as affected by nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons

Nitrogen rate (kg N fed^{-1})	Total plant height (cm)	Technical stem length (cm)	No. of basal branches plant^{-1}	Stem diameter (mm)	Straw yield plant^{-1} (g)	Straw yield fed^{-1} (kg)
30	87.45	67.08	1.919	1.563	1.766	3216.38
50	92.17	70.78	2.013	1.631	2.103	3871.96
70	95.88	73.28	2.102	1.675	2.317	4263.17
L.S.D. at 5%	2.63	2.51	N.S.	0.067	0.087	267.36

3.1.3 Effect of plant densities

Results presented in Table 6 revealed that the differences between the three plant densities of flax were significant on straw yield and its related traits in the combined analysis of 2018-19 and 2019-20 seasons. Flax planting at highest plant density (2500 seeds m^{-2}) markedly gave the maximum total plant height, technical stem length and straw yield fed^{-1}. On the other hand, the lowest total plant height, technical stem length and straw yield fed^{-1} were recorded from flax planting under the lowest plant density (1500 seeds m^{-2}). The superiority ratios between sowing flax at 2500 seeds m^{-2} and each of 2000 and 1500 seeds m^{-2} were 8.30 and 14.02% for total plant height; 14.85 and 27.02% for technical stem length in addition to 9.16 and 28.52% for straw yield fed^{-1}, respectively. The increase in total plant height and technical stem length might be due to the increased intra-specific competition among flax plants for light and decrease in light penetration, interception and photosynthetic efficiency at higher densities as well as higher dense of plants excessive shade exist which help to produce more content of gibberellin in tissues and consequently higher plants formed. Such increase in straw yield could be due to the increase in total plant height and technical stem length as well as No. of flax plants m^{-2} due to increasing plant densities. These results are in harmony with those reported by [10,25]. The greatest No. of basal branches plant^{-1}, stem diameter and straw yield plant^{-1} were obtained from flax planting with 1500 seeds m^{-2}. On the other hand, sowing flax at plant density of 2500 seeds m^{-2} markedly recorded the lowest No. of basal branches plant^{-1}, stem diameter and straw yield plant^{-1}. The increase ratios with flax planting at plant density of 1500 seeds m^{-2} over each of 2000 and 2500 seeds m^{-2} were 16.31 and 53.64% for No. of basal branches plant^{-1}; 10.30 and 22.55% for stem diameter in addition to 13.60 and 29.21% for straw yield plant^{-1}, respectively. This trend could be explained on the fact that in case of low plant density produced resulted in low competition between plants for nutrient elements, soil moisture and sun light, plants would have better opportunity to produce more metabolite contents and positive effect on plant growth, especially No. of basal branches plant^{-1}, stem diameter, straw yield plant^{-1}. As well as, such increase in straw yield plant^{-1} at flax plant density of 1500 seeds m^{-2} could be due to the increase in stem diameter and No. of basal branches plant^{-1} of flax. Such results agree with those reported by [8,10,25].

3.1.4Effect of interaction between flax cultivars and nitrogen fertilizer rates

Straw yield and its related traits of flax were significantly affected by interaction between flax cultivars and nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 7. Sakha 3 cultivar when received 70 kg N fed^{-1} produced significantly the maximum total plant height (103.07 cm) and technical stem length (76.68 cm). While, the lowest total plant height (83.07 cm) and technical stem length (65.26 cm) were obtained from Giza 11 cultivar fertilized with30 kg N fed^{-1}. Giza 12 cultivar under soil fertilized by 70 kg N fed^{-1} recorded the highest No. of

Table 6. Mean values of straw yield and its related traits of flax as affected by plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Plant density (seeds m^{-2})	Total plant height (cm)	Technical stem length (cm)	No. of basal branches plant^{-1}	Stem diameter (mm)	Straw yield plant^{-1} (g)	Straw yield fed^{-1} (kg)
1500	86.28	62.54	2.403	1.788	2.331	3272.90
2000	90.84	69.17	2.066	1.621	2.052	3862.43
2500	98.38	79.44	1.564	1.459	1.804	4216.17
L.S.D. at 5%	2.07	1.94	0.061	0.059	0.082	259.89

basal branches plant^{-1} (2.722), straw yield plant^{-1} (2.476 g) and straw yield fed^{-1} (4513.54 kg). Meanwhile, Sakha 3 cultivar applied with 30 kg N fed^{-1} gave the lowest No. of basal branches plant^{-1} (1.377), straw yield plant^{-1} (1.612 g) and straw yield fed^{-1} (2903.50 kg). It is clear that Giza 11 cultivar when received 70 kg N fed^{-1} gave thickness stem diameter by 1.935 mm. Whereas thinnest stem diameter was 1.223 mm which obtained from Sakha 3 cultivar fertilized with 30 kg N fed^{-1}. These results agree with those reported by [8,10] found that straw yield and its related traits were significantly affected by interaction between flax cultivars and nitrogen fertilizer rates.

3.1.5 Effect of interaction between flax cultivars and plant densities

Results in Table 8 indicated that the interaction between flax cultivars and plant densities had significant effect on straw yield and its related traits of flax in the combined analysis of 2018-19 and 2019-20 seasons. Sakha 3 cultivar with 2500 seeds m^{-2} recorded the maximum total plant height (106.04 cm) and technical stem length (82.71 cm). On the other hand, the lowest total plant height (81.46 cm) and technical stem length (60.38 cm) were recorded from Giza 11 cultivar at 1500 seeds m^{-2}. The greatest No. of basal branches plant^{-1} (3.103) and straw yield plant^{-1} (2.504 g) were obtained from Giza 12 cultivar at the lowest plant density (1500 seeds m^{-2}) as well as, planting the same flax cultivar with 2500 seeds m^{-2} significantly recorded the maximum straw yield fed^{-1} (4397.21 kg). Meanwhile, Sakha 3 cultivar gave the lowest No. of basal branches plant^{-1} (1.080) and straw yield plant^{-1} (1.714 g) under plant density of 2500 seeds m^{-2} as well as lowest straw yield fed^{-1} (2920.88 kg) at plant density of 1500 seeds m^{-2}. The thickness stem diameter (2.060 mm) was obtained by Giza 11 cultivar with 1500 seeds m^{-2}. Whereas, the thinnest stem diameter (1.121 mm) was obtained from Sakha 3 cultivar at plant density of 2500 seeds m^{-2}. The results agree with those reported by [8,10] which reported that there was significantly difference among interaction between flax cultivars and plant densities of straw yield and its related traits.

3.1.6 Effect of interaction between nitrogen fertilizer rates and plant densities

Results in Table 9 showed that the interaction effect among nitrogen fertilizer rates and plant densities induced significant differences on almost straw yields and its related traits except, stem diameter in the combined analysis of 2018-19 and 2019-20 seasons. The highest total plant height (102.63 cm), technical stem length (82.57 cm) and straw yield fed^{-1} (4763.79 kg) were recorded from growing flax when received the highest nitrogen rate (70 kg N fed^{-1}) at the highest plant density (2500 seeds m^{-2}), as well as sowing flax with the same nitrogen fertilizer rate under the lowest plant density (1500 seeds m^{-2}) gave the maximum No. of basal branches plant^{-1} (2.530) and straw yield plant^{-1} (2.605 g). On the other hand, flax planting under soil fertilized by the lowest nitrogen rate (30 kg N fed^{-1}) with 1500 seeds m^{-2} gave the lowest total plant height (81.49 cm), technical stem length (58.71 cm) and straw yield fed^{-1} (2826.25 kg), as well as planting the flax with the same nitrogen fertilizer rate at 2500 seeds m^{-2} recorded the lowest No. of basal branches plant^{-1} (1.505) and straw yield plant^{-1} (1.534 g). The results reported here are in harmony with those obtained by [8,10].

Table 7. Mean values of straw yield and its related traits of flax as affected by interaction among flax cultivars and nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Nitrogen rate (kg N fed^{-1})	Total plant height (cm)	Technical stem length (cm)	No. of basal branches plant^{-1}	Stem diameter (mm)	Straw yield plant^{-1} (g)	Straw yield fed^{-1} (kg)
Sakha 3	30	94.41	70.33	1.377	1.223	1.612	2903.50
	50	99.00	73.88	1.443	1.280	1.913	3553.75
	70	103.07	76.68	1.503	1.325	2.122	3942.83
Giza 11	30	83.07	65.26	1.898	1.807	1.811	3331.25
	50	87.65	68.67	1.998	1.891	2.155	3969.29
	70	91.29	71.22	2.080	1.935	2.355	4333.13
Giza 12	30	84.86	65.66	2.482	1.658	1.877	3414.38
	50	89.86	69.80	2.597	1.722	2.242	4092.83
	70	93.29	71.95	2.722	1.766	2.476	4513.54
L.S.D. at 5%		4.56	4.35	0.121	0.116	0.151	463.08

Table 8. Mean values of straw yield and its related traits of flax as affected by interaction among flax cultivars and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Plant density (seeds m^{-2})	Total plant height (cm)	Technical stem length (cm)	No. of basal branches $plant^{-1}$	Stem diameter (mm)	Straw yield $plant^{-1}$ (g)	Straw yield fed^{-1}(kg)
Sakha 3	1500	92.98	65.90	1.732	1.424	2.085	2920.88
	2000	97.46	72.28	1.512	1.282	1.848	3506.17
	2500	106.04	82.71	1.080	1.121	1.714	3973.04
Giza 11	1500	81.46	60.38	2.373	2.060	2.403	3392.46
	2000	86.54	67.26	2.035	1.867	2.103	3962.96
	2500	94.01	77.51	1.568	1.707	1.814	4278.25
Giza 12	1500	84.41	61.36	3.103	1.881	2.504	3505.38
	2000	88.51	67.97	2.652	1.714	2.206	4118.17
	2500	95.09	78.08	2.045	1.550	1.885	4397.21
L.S.D. at 5%		3.59	3.36	0.106	0.102	0.142	450.14

Table 9. Mean values of straw yield and its related traits of flax as affected by interaction among nitrogen fertilizer rates and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Nitrogen rate (kg N fed^{-1})	Plant density (seeds m^{-2})	Total plant height (cm)	Technical stem length (cm)	No. of basal branches $plant^{-1}$	Stem diameter (mm)	Straw yield $plant^{-1}$ (g)	Straw yield fed^{-1} (kg)
30	1500	81.49	58.71	2.270	1.727	2.016	2826.25
	2000	87.08	66.53	1.982	1.562	1.750	3261.29
	2500	93.77	76.01	1.505	1.399	1.534	3561.58
50	1500	87.01	63.36	2.408	1.796	2.371	3328.25
	2000	90.76	69.26	2.062	1.629	2.090	3964.50
	2500	98.74	79.73	1.568	1.467	1.849	4323.13
70	1500	90.33	65.56	2.530	1.842	2.605	3664.21
	2000	94.68	71.72	2.155	1.672	2.318	4361.50
	2500	102.63	82.57	1.620	1.512	2.029	4763.79
L.S.D. at 5%		3.59	3.36	0.106	N.S.	0.142	450.14

3.1.7 Effect of interaction between flax cultivars, nitrogen fertilizer rates and plant densities

Results in Table 10 showed significant interaction effect among flax cultivars, nitrogen fertilizer rates and plant densities in relation to total plant height, technical stem length, straw yield $plant^{-1}$ and straw yield fed^{-1} of flax. While, No. of basal branches $plant^{-1}$ and stem diameter were not significantly affected by interaction in the combined analysis over 2018-19 and 2019-20 seasons. The maximum total plant height (111.00 cm) and technical stem length (86.69 cm) were obtained by Sakha 3 cultivar under soil fertilized by 70 kg N fed^{-1} with plant density of 2500 seeds m^{-2}. On the other hand, Giza 11 cultivar when received 30 kg N fed^{-1} at plant density of 1500 seeds m^{-2} gave the lowest total plant height (76.90 cm) and technical stem length (56.66 cm). The heaviest straw yield $plant^{-1}$ was 2.814 g which obtained from Giza 12 cultivar fertilized with 70 kg N fed^{-1} at plant density of 1500 seeds m^{-2}. On the other hand, Sakha 3 cultivar when received 30 kg N fed^{-1} with plant density of 2500 seeds m^{-2} gave the lightest value of straw yield $plant^{-1}$ (1.469 g). Giza 12 cultivar when received 70 kg N fed^{-1} by plant density of 2500 seeds m^{-2} gave the maximum straw yield fed^{-1} (4950.25 kg). On the other hand, the minimum value of straw yield fed^{-1} (2485.38 kg) which obtained from Sakha 3 cultivar when received 30 kg N fed^{-1} at plant density of 1500 seeds m^{-2}. The results agree with those reported by [8, 10].

Table 10. Mean values of straw yield and its related traits of flax as affected by interaction among flax cultivar, nitrogen fertilizer rates and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Nitrogen rate (kg fed^{-1})	Plant density (seeds m^{-2})	Total plant height (cm)	Technical stem length (cm)	No. of basal branches plant^{-1}	Stem diameter (mm)	Straw yield plant^{-1} (g)	Straw yield fed^{-1} (kg)
Sakha 3	30	1500	88.24	62.37	1.635	1.374	1.788	2485.38
		2000	93.77	69.72	1.445	1.227	1.578	2893.88
		2500	101.22	78.90	1.050	1.069	1.469	3331.25
	50	1500	93.72	66.67	1.740	1.431	2.133	2985.38
		2000	97.39	72.42	1.510	1.289	1.874	3650.38
		2500	105.91	82.56	1.080	1.120	1.734	4025.50
	70	1500	96.97	68.65	1.820	1.468	2.336	3291.88
		2000	101.23	74.70	1.580	1.331	2.093	3974.25
		2500	111.00	86.69	1.110	1.175	1.938	4562.38
Giza 11	30	1500	76.90	56.66	2.235	1.994	2.093	2958.25
		2000	82.69	64.72	1.970	1.803	1.799	3395.50
		2500	89.62	74.40	1.490	1.626	1.540	3640.00
	50	1500	82.19	61.10	2.385	2.070	2.450	3458.00
		2000	86.41	67.02	2.035	1.876	2.141	4033.88
		2500	94.35	77.90	1.575	1.727	1.873	4416.00
	70	1500	85.28	63.38	2.500	2.115	2.667	3761.13
		2000	90.53	70.04	2.100	1.922	2.369	4459.50
		2500	98.06	80.25	1.640	1.768	2.028	4778.75
Giza 12	30	1500	79.33	57.11	2.940	1.814	2.168	3035.13
		2000	84.78	65.14	2.530	1.656	1.872	3494.50
		2500	90.48	74.72	1.975	1.504	1.592	3713.50
	50	1500	85.13	62.31	3.100	1.888	2.530	3541.38
		2000	88.48	68.34	2.640	1.722	2.255	4209.25
		2500	95.97	78.75	2.050	1.555	1.941	4527.88
	70	1500	88.76	64.67	3.270	1.942	2.814	3939.63
		2000	92.28	70.42	2.785	1.765	2.492	4650.75
		2500	98.83	80.78	2.110	1.592	2.122	4950.25
L.S.D. at 5%			6.21	5.82	N.S.	N.S.	0.246	779.67

3.2 Seed Yield and its Related Traits

3.2.1 Effect of flax cultivars

The differences among the three flax cultivars under study in seed yield and its related traits of flax under study were significantly affected, but the differences between Giza 12 and Giza 11 in upper branching zone length, No. of upper branches plant^{-1}, No. of seeds capsule^{-1}, seed index, seed oil content, oil yield plant^{-1} and oil yield fed^{-1} were not significant in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 11. Giza 11 cultivar significantly gave the maximum No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed index, seed yield plant^{-1}, seed yield fed^{-1}, harvest index, oil yield plant^{-1} and oil yield fed^{-1}. The superiority ratios between Giza 11 cultivar and each of Giza 12 and Sakha 3 were 11.12 and 108.78% for No. of capsules plant^{-1}; 15.17 and 91.44% for No. of seeds plant^{-1}; 19.79 and 228.67% for seed yield plant^{-1}; 7.43 and 79.52% for seed yield fed^{-1} in addition to 9.35 and 51.52% for harvest index, respectively. Also, in the rest traits, the excess ratios between Giza 12 and Giza 11 cultivars over Sakha 3 were 50.52 and 53.10% for No. of upper branches plant^{-1}; 65.17 and 71.87% for seed index; 208.60 and 266.06% for oil yield plant^{-1} in addition to 87.84 and 99.75% for oil yield fed^{-1}, respectively. The maximum seed oil content was obtained from Giza 12 cultivar. Giza 11 and Giza 12 cultivars significantly increased seed oil content by 11.40 and 12.48% respectively, over seed oil content of Sakha 3 cultivar. Sakha 3 cultivar significantly gave the maximum upper branching zone length and No. of seeds capsule^{-1}. Sakha 3 cultivar significantly increased the upper branching zone length by 32.98 and 24.75% and No. of seeds capsule^{-1} by 8.95 and 13.00% as compared to upper branching zone length and No. of seeds capsule^{-1} of Giza 11 and Giza 12 flax cultivars, respectively. These differences may be due to the genetic differences between Sakha 3 cultivar (fiber flax type) and Giza 11 and Giza 12 cultivars (dual purpose type). Also, Giza 11 cultivar surpassed the other flax cultivars to increase seed yield fed^{-1} may be due to more likely attributed to the increase in No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed index and seed yield plant^{-1}. These results are in agreement with those obtained by [12,15,17,18] whose reported also marked differences in seed and oil yields and its related traits among flax cultivars.

3.2.2 Effect of nitrogen fertilizer rates

Results in Table 12, indicated that seed yield and its related traits of flax were significantly increased with increasing nitrogen fertilizer rates from 30 to 50 and 70 kg N fed^{-1} under study over two seasons. But, the differences between nitrogen fertilizer rates of 30 and 50 kg N fed^{-1}, as well as between 50 and 70 kg N fed on upper branching zone length did found non-significant. Meanwhile, No. of seeds capsule^{-1}, seed index and harvest index were not significantly affected by increasing nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons. Flax planting when received 70 kg N fed^{-1} significantly gave the maximum seed yield and its related traits. On the other hand, the

Table 11. Mean values of seed yield and its related traits of flax cultivars in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Upper branching zone length (cm)	No. of upper branches plant^{-1}	No. of capsules plant^{-1}	No. of seeds capsule^{-1}	No. of seeds plant^{-1}	Seed index (g)
Sakha 3	25.20	34.52	13.21	8.00	106.23	5.539
Giza 11	18.95	52.85	27.58	7.34	203.37	9.520
Giza 12	20.20	51.96	24.82	7.08	176.58	9.149
L.S.D. at 5%	1.85	3.98	2.17	0.29	10.78	0.381
Flax cultivar	**Seed yield plant^{-1} (g)**	**Seed yield fed^{-1} (kg)**	**Harvest index (%)**	**Seed oil content (%)**	**Oil yield plant^{-1} (g)**	**Oil yield fed^{-1} (kg)**
Sakha 3	0.593	406.13	10.50	36.93	0.221	150.44
Giza 11	1.949	729.07	15.91	41.14	0.809	300.50
Giza 12	1.627	678.66	14.55	41.54	0.682	282.59
L.S.D. at 5%	0.093	27.59	0.35	0.95	0.142	24.71

lowest seed yield and its related traits of flax were recorded from flax planting when received the lowest nitrogen fertilizer rate (30 kg N fed^{-1}). The increase ratios when flax received 70 kg N fed^{-1} over each of 50 and 30 kg N fed^{-1} were 5.66 and 10.95% for upper branching zone length; 7.83 and 18.58% for No. of upper branches plant^{-1}; 10.21 and 27.83% for No. of capsules plant^{-1}; 12.84 and 35.15% for No. of seeds plant^{-1}; 14.67 and 41.81% for seed yield plant^{-1}; 10.10 and 27.61% for seed yield fed^{-1}; 3.31 and 6.90% for seed oil content; 18.37 and 51.44% for oil yield plant^{-1} in addition to 13.67 and 35.96% for oil yield fed^{-1}, respectively. The increase in seed yield and its attributes because of increasing nitrogen fertilizer rates up to 70 kg N fed^{-1} can be easily ascribed to the role of nitrogen in activating growth of plants, consequently enhancement seed yield and its attributes. It could be concluded that nitrogen fertilizer application encouraged the seeds filling of flax plants leading to a greater seed index and increasing oil content of flax seeds. It was clear that the increase in oil yield fed^{-1} may be due to the increase in seed yield plant^{-1}, seed yield fed^{-1} and seed oil content of flax resulting from a good supply of adequate nitrogen rate. These results are in compatible with those found by [13,22,23].

3.2.3 Effect of plant densities

Seed yield and its related traits under study were significantly affected by plant densities, but the differences in oil yield fed^{-1} between plant densities of 2000 and 2500 seeds m^{-2} found non-significant. Meanwhile, No. of seeds capsule^{-1}, seed index and seed oil content were not significantly affected by plant densities under study in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 13. Flax growing at 1500 seeds m^{-2} markedly gave the greatest upper branching zone length, No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed yield plant^{-1}, harvest index and oil yield plant^{-1}. On the other hand, the lowest upper branching zone length, No. of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed yield plant^{-1}, harvest index and oil yield plant^{-1} were obtained from flax planting at 2500 seeds m^{-2}. The superiority ratios between growing flax with plant density of 1500 seeds m^{-2} and each of 2000 and 2500 seeds m^{-2} were 9.51 and 25.22% for upper branching zone length; 12.91 and 32.91% for No. of upper branches plant^{-1}; 13.30 and 32.36% for No. of capsules plant^{-1}; 14.72 and 36.58% for No. of seeds plant^{-1}; 17.42 and 44.06% for seed yield plant^{-1}; 5.93 and 8.58% for harvest index in addition to 20.53 and 51.32% for oil yield plant^{-1}, respectively. Such increases in seed yield plant^{-1} at planting density of 1500 seeds m^{-2} could be due to the increase in upper branching zone length, No. of upper branches plant^{-1}, No. of capsules plant^{-1} and No. of seeds plant^{-1}. This trend could be explained on the fact that in case of low density resulted in low competition between flax plants for nutrient elements, soil moisture and sun light, plants would have better opportunity to produce more metabolite contents and positive effect on related traits of seed yield plant^{-1}. The results agree with those reported by [13,26]. The highest plant density (2500 seeds m^{-2}) caused maximum estimates of seed yield fed^{-1} and oil yield fed^{-1} as resulted from more plants were planting in unit area in comparison with the other two plant densities either 1500 or 200

Table 12. Mean values of seed yield and its related traits of flax as affected by nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons

Nitrogen rate (kg N fed^{-1})	Upper branching zone length (cm)	No. of upper branches plant^{-1}	No. of capsules plant^{-1}	No. of seeds capsule^{-1}	No. of seeds plant^{-1}	Seed index (g)
30	20.37	42.41	19.08	7.268	136.98	7.828
50	21.39	46.64	22.13	7.491	164.07	8.117
70	22.60	50.29	24.39	7.655	185.13	8.262
L.S.D. at 5%	1.48	2.87	1.76	N.S.	7.89	N.S.
Nitrogen rate (kg N fed^{-1})	**Seed yield plant^{-1} (g)**	**Seed yield fed^{-1} (kg)**	**Harvest index (%)**	**Seed oil content (%)**	**Oil yield plant^{-1} (g)**	**Oil yield fed^{-1} (kg)**
30	1.141	528.04	13.87	38.54	0.451	206.29
50	1.411	612.01	13.53	39.88	0.577	246.76
70	1.618	673.81	13.57	41.20	0.683	280.48
L.S.D. at 5%	0.067	23.11	N.S.	0.81	0.093	17.97

seeds m^{-2}. On the other hand, sowing flax with plant density of 1500 seeds m^{-2} produced the lowest seed yield fed^{-1} and oil yield fed^{-1}. The increase ratios between growing flax with plant density of 2500 seeds m^{-2} and each of 2000 and 1500 seeds m^{-2} were 5.66 and 16.13% for seed yield fed^{-1} in addition to 3.28 and 10.63% for oil yield fed^{-1}, respectively. Such results agree with those reported by [13,26].

3.2.4 Effect of interaction between flax cultivars and nitrogen fertilizer rates

Results in Table 14 showed significant interaction between flax cultivars and nitrogen fertilizer rates obtained for almost seed yield and its related traits of flax. While, No. of seeds $capsule^{-1}$, seed index and seed oil content were not significantly affected by interaction between flax cultivars and nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons. Giza 11 cultivar under soil fertilized by 70 kg N fed^{-1} recorded the greatest No. of upper branches $plant^{-1}$ (57.00), No. of capsules $plant^{-1}$ (30.60), No. of seeds $plant^{-1}$ (231.60), seed yield $plant^{-1}$ (2.259 g), seed yield fed^{-1} (800.13 kg), oil yield $plant^{-1}$ (0.966 g) and oil yield fed^{-1} (340.32 kg). On the other hand, the lowest No. of upper branches $plant^{-1}$ (31.38), No. of capsules $plant^{-1}$ (11.19), No. of seeds $plant^{-1}$ (87.60), seed yield $plant^{-1}$ (0.470 g), seed yield fed^{-1} (325.08 kg), oil yield $plant^{-1}$ (0.169 g) and oil yield fed^{-1} (115.92 kg) were obtained from Sakha 3 cultivar when received 30 kg N fed^{-1}. The longest upper branching zone length (26.39 cm) was obtained from Sakha 3 cultivar when received 70 kg N fed^{-1}. Meanwhile, Giza 11 cultivar when received 30 kg N fed^{-1} gave the shortest upper branching zone length (17.81 cm). The highest harvest index (16.48%) was obtained from Giza 11 cultivar when received 30 kg N fed^{-1}. On the other hand, Sakha 3 cultivar under the same rate of nitrogen (30 kg N fed^{-1}) gave the lowest harvest index (10.10%). Similar results were also reported by [13,16] whose found variations in seed and oil yields and its related traits among flax cultivars and nitrogen fertilizer rates interaction.

3.2.5 Effect of interaction between flax cultivars and plant densities

Upper branching zone length, No. of upper branches $plant^{-1}$, No. of capsules $plant^{-1}$, No. of seeds $plant^{-1}$, seed yield $plant^{-1}$, seed yield fed^{-1}, harvest index, oil yield $plant^{-1}$ and oil yield fed^{-1} were significantly affected by interaction between flax cultivars and plant densities. Meanwhile, No. of seeds $capsule^{-1}$, seed index and seed oil content were not significantly affected by interaction between flax cultivars and plant densities in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 15. Giza 11 cultivar at 1500 seeds m^{-2} recorded the greatest No. of upper branches $plant^{-1}$ (60.08), No. of capsules $plant^{-1}$ (31.39), No. of seeds $plant^{-1}$ (233.34), seed yield $plant^{-1}$ (2.289 g), harvest index (16.67%) and oil yield $plant^{-1}$ (0.969 g). However, flax planting at 2500 seeds m^{-2} from the same flax cultivar significantly gave the maximum seed yield fed^{-1} (773.50 kg) and oil yield fed^{-1} (311.59 kg). On the other hand, Sakha3 cultivar with 2500 seeds m^{-2} produced the lowest No. of upper branches $plant^{-1}$ (29.25),

Table 13. Mean values of seed yield and its related traits of flax as affected by plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Plant density (seeds m^{-2})	Upper branching zone length (cm)	No. of upper branches $plant^{-1}$	No. of capsules $plant^{-1}$	No. of seeds $capsule^{-1}$	No. of seeds $plant^{-1}$	Seed index (g)
1500	23.73	52.82	24.87	7.587	186.72	8.274
2000	21.67	46.78	21.95	7.481	162.76	8.062
2500	18.95	39.74	18.79	7.347	136.71	7.871
L.S.D. at 5 %	1.38	2.69	1.69	N.S.	7.08	N.S.
Plant density (seeds m^{-2})	**Seed yield $plant^{-1}$ (g)**	**Seed yield fed^{-1} (kg)**	**Harvest index (%)**	**Seed oil content (%)**	**Oil yield $plant^{-1}$ (g)**	**Oil yield fed^{-1} (kg)**
1500	1.638	556.33	14.30	40.84	0.687	230.86
2000	1.395	611.47	13.50	39.84	0.570	247.28
2500	1.137	646.06	13.17	38.93	0.454	255.40
L.S.D. at 5%	0.059	20.55	0.20	N.S.	0.089	16.34

No. of capsules plant^{-1} (11.68), No. of seeds plant^{-1} (92.19), seed yield plant^{-1} (0.501 g), harvest index (9.98%) and oil yield plant^{-1} (0.181 g). However, flax planting at 1500 seeds m^{-2} from the same flax cultivar significantly gave the minimum seed yield fed^{-1} (367.96 kg) and oil yield fed^{-1} (140.28 kg). The longest upper branching zone length (27.08 cm) was obtained from Sakha 3 cultivar with plant density of 1500 seeds m^{-2}. While, Giza 11 cultivar at 2500 seeds m^{-2} gave the shortest upper branching zone length (16.50 cm). The results agree with those reported by [13,16] whose concluded that seed and oil yields and its related traits were significantly affected by interaction among flax cultivars and plant densities.

3.2.6 Effect of interaction between nitrogen fertilizer rate and plant densities

Number of upper branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds plant^{-1}, seed yield plant^{-1} and seed yield fed^{-1} were significantly affected by interaction between nitrogen fertilizer rates and plant densities. While, upper branching zone length, No. of seeds capsule^{-1}, seed index, harvest index, seed oil content, oil yield plant^{-1} and oil yield fed^{-1} were not significantly affected by interaction between flax cultivars and plant densities in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 16. The greatest No. of upper branches plant^{-1} (56.59), No. of capsules plant^{-1} (27.61), No. of seeds plant^{-1} (212.69) and seed yield plant^{-1} (1.890 g) were obtained from flax planting when received 70 kg N fed^{-1} at plant density of 1500 seeds m^{-2}, also sowing flax under the same nitrogen fertilizer rates with 2500 seeds m^{-2} recorded the maximum seed yield fed^{-1} (715.88 kg). On the other hand, the lowest No. of upper branches plant^{-1} (35.71), No. of capsules plant^{-1} (16.41), No. of seeds plant^{-1} (116.16) and seed yield plant^{-1} (0.931 g) were obtained from flax planting under soil fertilized by 30 kg N fed^{-1} at plant density of 2500 seeds m^{-2}, also sowing flax under the same nitrogen fertilizer rates with 1500 seeds m^{-2} recorded the lowest seed yield fed^{-1} (483.63 kg). These results are in agreement with that were obtained by [13,16].

Table 14. Mean values of seed yield and its related traits as of flax affected by interaction among flax cultivars and nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Nitrogen rate (kg N fed^{-1})	Upper branching zone length (cm)	No. of upper branches plant^{-1}	No. of capsules plant^{-1}	No. of seeds capsule^{-1}	No. of seeds plant^{-1}	Seed index (g)
Sakha 3	30	24.08	31.38	11.19	7.807	87.60	5.339
	50	25.12	34.31	13.47	8.037	108.66	5.559
	70	26.39	37.89	14.97	8.147	122.43	5.718
Giza 11	30	17.81	48.45	24.43	7.105	173.96	9.266
	50	18.98	53.12	27.71	7.363	204.56	9.583
	70	20.07	57.00	30.60	7.552	231.60	9.710
Giza 12	30	19.21	47.40	21.63	6.892	149.38	8.879
	50	20.06	52.49	25.22	7.073	178.99	9.208
	70	21.34	55.99	27.61	7.267	201.38	9.359
L.S.D. at 5%		2.56	4.97	3.05	N.S.	13.67	N.S.
Flax cultivar	**Nitrogen rate (kg N fed^{-1})**	**Seed yield plant^{-1} (g)**	**Seed yield fed^{-1} (kg)**	**Harvest index (%)**	**Seed oil content (%)**	**Oil yield plant^{-1} (g)**	**Oil yield fed^{-1} (kg)**
Sakha 3	30	0.470	325.08	10.10	35.73	0.169	115.92
	50	0.607	418.21	10.57	36.91	0.225	154.26
	70	0.703	475.08	10.84	38.16	0.269	181.15
Giza 11	30	1.620	655.71	16.48	39.75	0.647	260.68
	50	1.969	731.38	15.61	41.12	0.814	300.51
	70	2.259	800.13	15.64	42.56	0.966	340.32
Giza 12	30	1.334	603.33	15.02	40.13	0.538	242.28
	50	1.656	686.44	14.40	41.61	0.693	285.52
	70	1.891	746.22	14.23	42.89	0.815	319.98
L.S.D. at 5%		0.116	40.03	0.61	N.S.	0.161	31.12

Table 15. Mean values of seed yield and its related traits of flax as affected by interaction among flax cultivars and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Plant density (seeds m^{-2})	Upper branching zone length (cm)	No. of upper branches $plant^{-1}$	No. of capsules $plant^{-1}$	No. of seeds $capsule^{-1}$	No. of seeds $plant^{-1}$	Seed index (g)
Sakha 3	1500	27.08	39.47	14.89	8.128	121.53	5.656
	2000	25.19	34.86	13.05	8.002	104.97	5.550
	2500	23.33	29.25	11.68	7.860	92.19	5.410
Giza 11	1500	21.08	60.08	31.39	7.407	233.24	9.780
	2000	19.28	53.19	27.67	7.375	204.97	9.513
	2500	16.50	45.29	23.68	7.238	171.91	9.266
Giza 12	1500	23.05	58.91	28.33	7.225	205.38	9.385
	2000	20.55	52.28	25.14	7.065	178.34	9.123
	2500	17.01	44.69	21.00	6.942	146.02	8.938
L.S.D. at 5%		2.39	4.66	2.93	N.S.	12.26	N.S.
Flax cultivar	**Plant density (seeds m^{-2})**	**Seed yield $plant^{-1}$ (g)**	**Seed yield fed^{-1} (kg)**	**Harvest index (%)**	**Seed oil content (%)**	**Oil yield $plant^{-1}$ (g)**	**Oil yield fed^{-1} (kg)**
Sakha 3	1500	0.691	367.96	11.12	37.96	0.264	140.28
	2000	0.587	408.92	10.41	36.96	0.218	151.86
	2500	0.501	441.50	9.98	35.87	0.181	159.18
Giza 11	1500	2.289	677.38	16.67	42.06	0.969	285.84
	2000	1.960	736.33	15.71	41.19	0.812	304.07
	2500	1.599	773.50	15.36	40.19	0.645	311.59
Giza 12	1500	1.934	623.66	15.11	42.51	0.828	266.44
	2000	1.637	689.17	14.37	41.37	0.681	285.92
	2500	1.311	723.17	14.17	40.74	0.536	295.42
L.S.D. at 5%		0.102	35.59	0.35	N.S.	0.154	28.30

3.2.7 Effect of interaction between flax cultivars, nitrogen fertilizer rate and plant densities

The effect of interaction among flax cultivars, nitrogen fertilizer rates and plant densities was found significant on No. of upper branches $plant^{-1}$, No. of capsules $plant^{-1}$, No. of seeds $plant^{-1}$, seed yield $plant^{-1}$, seed yield fed^{-1} and harvest index. While, upper branching zone length, No. of seeds $capsule^{-1}$, seed index, seed oil content, oil yield $plant^{-1}$ and oil yield fed^{-1} were not significantly affected by interaction in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 17. The greatest No. of upper branches $plant^{-1}$ (64.37), No. of capsules $plant^{-1}$ (34.55), No. of seeds $plant^{-1}$ (263.55) and seed yield $plant^{-1}$ (2.626 g) were obtained from Giza 11 cultivar under soil fertilized by 70 kg N fed^{-1} at plant density of 1500 seeds m^{-2}. On the other hand, Sakha 3 cultivar when received 30 kg N fed^{-1} at plant density of 2500 seeds m^{-2} gave the lowest No. of upper branches $plant^{-1}$ (26.12), No. of capsules $plant^{-1}$ (10.10), No. of seeds $plant^{-1}$ (77.93), seed yield $plant^{-1}$ (0.405 g). The maximum seed yield fed^{-1} (847.88 kg) was obtained from Giza 11 cultivar with received 70 kg N fed^{-1} at plant density of 2500 seeds m^{-2}. On the other hand, the lowest seed yield fed^{-1} (290.13 kg) was obtained from Sakha 3 cultivar under soil fertilized by 30 kg N fed^{-1} at plant density of 1500 seeds m^{-2}. The highest harvest index (17.10%) was obtained from Giza 11 cultivar with received 30 kg N fed^{-1} at plant density of 1500 seeds m^{-2}. On the other hand, the lowest harvest index (9.74%) was obtained from Sakha 3 cultivar when received 30 kg N fed^{-1} with plant density of 2500 seeds m^{-2}. The results agree with those reported by [13,16].

Table 16. Mean values of seed yield and its related traits of flax as affected by interaction among nitrogen fertilizer rates and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Nitrogen rate (kg N fed^{-1})	Plant density (seeds m^{-2})	Upper branching zone length (cm)	No. of upper branches $plant^{-1}$	No. of capsules $plant^{-1}$	No. of seeds $capsule^{-1}$	No. of seeds $plant^{-1}$	Seed index (g)
30	1500	22.78	48.94	21.74	7.375	158.04	8.102
	2000	20.55	42.58	19.09	7.258	136.75	7.781
	2500	17.76	35.71	16.41	7.170	116.16	7.601
50	1500	23.66	52.93	25.26	7.598	189.43	8.311
	2000	21.50	47.04	22.11	7.512	164.25	8.122
	2500	19.01	39.94	19.03	7.363	138.53	7.918
70	1500	24.77	56.59	27.61	7.787	212.69	8.409
	2000	22.96	50.71	24.66	7.672	187.28	8.282
	2500	20.06	43.58	20.92	7.507	155.44	8.096
L.S.D. at 5%		N.S.	4.66	2.93	N.S.	12.26	N.S.
Nitrogen rate (kg N fed^{-1})	**Plant density (seeds m^{-2})**	**Seed yield $plant^{-1}$ (g)**	**Seed yield fed^{-1} (kg)**	**Harvest index (%)**	**Seed oil content (%)**	**Oil yield $plant^{-1}$ (g)**	**Oil yield fed^{-1} (kg)**
30	1500	1.360	483.63	14.29	39.33	0.547	192.89
	2000	1.132	533.25	13.77	38.61	0.447	208.90
	2500	0.931	567.25	13.53	37.67	0.360	217.10
50	1500	1.664	561.57	14.22	40.92	0.696	232.72
	2000	1.412	619.42	13.34	39.84	0.576	249.91
	2500	1.157	655.04	13.01	38.88	0.459	257.65
70	1500	1.890	623.80	14.38	42.28	0.818	266.96
	2000	1.640	681.75	13.37	41.07	0.688	283.04
	2500	1.322	715.88	12.96	40.25	0.544	291.45
L.S.D. at 5%		0.102	35.59	N.S.	N.S.	N.S.	N.S.

Table 17. Mean values of seed yield and its related traits of flax as affected by interaction among flax cultivar, nitrogen fertilizer rates and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Nitrogen rate (kg fed^{-1})	Plant density ($seedsm^{-2}$)	Upper branching zone length (cm)	No. of upper branches $plant^{-1}$	No. of capsules $plant^{-1}$	No. of seeds $capsule^{-1}$	No. of seeds $plant^{-1}$	Seed index (g)	Seed yield $plant^{-1}$ (g)	Seed yield fed^{-1} (kg)	Harvest index (%)	Seed oil content (%)	Oil yield $plant^{-1}$ (g)	Oil Yield fed^{-1} (kg)
Sakha 3	30	1500	25.88	36.12	12.57	7.940	99.95	5.491	0.550	290.13	10.44	36.89	0.203	107.08
		2000	24.06	31.89	10.89	7.780	84.93	5.336	0.454	325.63	10.11	35.86	0.163	116.86
		2500	22.32	26.12	10.10	7.700	77.93	5.190	0.405	359.50	9.74	34.44	0.139	123.82
	50	1500	27.05	39.40	15.26	8.165	124.79	5.694	0.712	376.50	11.19	37.91	0.270	142.80
		2000	24.97	34.51	13.41	8.055	108.26	5.563	0.604	421.25	10.34	36.81	0.222	155.21
		2500	23.35	29.01	11.74	7.890	92.92	5.421	0.505	456.88	10.18	36.01	0.182	164.75
	70	1500	28.32	42.89	16.86	8.280	139.84	5.784	0.811	437.25	11.72	39.10	0.317	170.97
		2000	26.53	38.17	14.85	8.170	121.73	5.751	0.702	479.88	10.78	38.22	0.269	183.53
		2500	24.32	32.62	13.21	7.990	105.72	5.620	0.595	508.13	10.02	37.16	0.221	188.97
Giza 11	30	1500	20.24	55.81	28.05	7.185	201.72	9.590	1.938	610.38	17.10	40.38	0.785	246.81
		2000	17.97	48.59	24.47	7.120	174.45	9.205	1.609	660.00	16.27	39.83	0.642	263.05
		2500	15.22	40.96	20.78	7.010	145.71	9.003	1.314	696.75	16.06	39.05	0.513	272.19
	50	1500	21.09	60.07	31.58	7.415	234.44	9.807	2.304	679.88	16.43	42.19	0.973	286.93
		2000	19.39	53.55	27.63	7.420	205.57	9.610	1.982	738.38	15.47	41.26	0.819	304.76
		2500	16.46	45.73	23.92	7.255	173.67	9.334	1.623	775.88	14.94	39.92	0.649	309.83
	70	1500	21.90	64.37	34.55	7.620	263.55	9.944	2.626	741.88	16.48	43.61	1.149	323.79
		2000	20.49	57.44	30.91	7.585	234.89	9.724	2.290	810.63	15.38	42.48	0.974	344.40
		2500	17.82	49.19	26.34	7.450	196.35	9.462	1.859	847.88	15.07	41.59	0.774	352.77
Giza 12	30	1500	22.22	54.90	24.62	7.000	172.44	9.226	1.593	550.38	15.33	40.74	0.651	224.77
		2000	19.64	47.25	21.91	6.875	150.88	8.802	1.331	614.13	14.94	40.14	0.536	246.78
		2500	15.76	40.05	18.35	6.800	124.83	8.610	1.076	645.50	14.80	39.52	0.426	255.28
	50	1500	22.83	59.32	28.94	7.215	209.04	9.431	1.976	628.33	15.06	42.67	0.845	268.43
		2000	20.14	53.06	25.29	7.060	178.93	9.195	1.650	698.63	14.23	41.44	0.686	289.76
		2500	17.23	45.08	21.44	6.945	148.99	9.000	1.343	732.38	13.92	40.71	0.547	298.37
	70	1500	24.10	62.50	31.43	7.460	234.67	9.500	2.233	692.28	14.94	44.14	0.989	306.12
		2000	21.86	56.54	28.22	7.260	205.22	9.372	1.928	754.75	13.96	42.53	0.822	321.21
		2500	18.06	48.93	23.20	7.080	164.24	9.205	1.513	791.63	13.78	42.00	0.636	332.63
L.S.D. at 5%			N.S.	8.07	5.07	N.S.	21.24	N.S.	0.177	61.65	0.60	N.S.	N.S.	N.S.

3.3 Fiber Yield and its Related Traits

3.3.1 Effect of flax cultivars

Fiber yield and its related traits of flax were significantly affected by the cultivars under study, but the differences in total fiber percentage, fiber yield plant^{-1} and fiber yield fed^{-1} between Giza 11 and Giza 12 were not significant in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 18. Sakha 3 cultivar significantly produced the maximum total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1}, fiber length and fiber fineness. On the other hand, the lowest total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1}, fiber length and fiber fineness were obtained from Giza 11 cultivar. The superiority ratios between Sakha 3 cultivar and each of Giza 12 and Giza 11 were 42.88 and 48.18% for total fiber percentage; 22.67 and 32.70% for fiber yield plant^{-1}; 23.80 and 32.49% for fiber yield fed^{-1}; 3.85 and 8.87% for fiber length in addition to 38.44 and 46.00% for fiber fineness, respectively. The differences among flax cultivars were mainly due to the differences in their genetic constituents. As well as, the increase in fiber yield fed^{-1} (kg) of Sakha 3 cultivar may be due to the increase in total fiber percentage and fiber yield plant^{-1}. Also, the increase in the fiber fineness with Sakha 3 cultivar resulted from the decreases in fiber weight for 20 fibrils X 10 cm long. These results are reported by [19,20] indicated great variations in fiber yield and its related traits with flax cultivars.

3.3.2 Effect of nitrogen fertilizer rates

Results in Table 19 showed that increasing nitrogen fertilizer rates from 30 up to 70 kg N fed^{-1} caused significant increases in total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1} and fiber length of flax. On the other hand, fiber fineness which significantly decreased with increasing nitrogen rates, but the differences in total fiber percentage between 30 and 50 kg N fed^{-1} as well as among 50 and 70 kg N fed^{-1} found non-significant in the combined analysis of 2018-19 and 2019-20 seasons. The maximum total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1} and fiber length were obtained when flax planting under soil fertilizer by 70 kg N fed^{-1}. Whereas, flax planting with the lowest nitrogen fertilizer rate (30 kg N fed^{-1}) significantly gave the minimum total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1} and fiber length. The increase ratios when flax received 70 kg N fed^{-1} over each of 50 and 30 kg N fed^{-1} were 3.99 and 9.66% for total fiber percentage; 14.95 and 44.37% for fiber yield plant^{-1}; 14.60 and 45.93% for fiber yield fed^{-1} in addition to 3.33 and 9.25% for fiber length, respectively. The increase in the fiber length with increasing nitrogen fertilizer rates might be due to increase in technical stem length [19,20]. In addition to, the increase in fiber yield fed^{-1} of flax due to the increase in nitrogen rates is attributed to the increase in total plant height, technical stem length, stem diameter, straw yield plant^{-1}, straw yield fed^{-1}, total fiber percentage and fiber yield plant^{-1}. These results are in harmony with those obtained by [19,24]. The softness fiber fineness was recorded from flax planting at the minimum rate of 30 kg N fed^{-1}, being 172.27 Nm. On the other hand, the hardness fiber fineness was obtained from flax planting with 70 kg N fed^{-1} which recorded 159.46 Nm. The applying of 50 and 70 kg N fed^{-1} induced a significant decrease in fiber fineness over 30 kg N fed^{-1} by 3.83 and 7.44%, respectively. The decrease in fiber fineness with increasing in nitrogen fertilizer rates may be attributed to increase in fiber thickness. The finding is agreement with those obtained by [20,24].

3.3.3 Effect of plant densities

Results in Table 20 show that increasing plant density from 1500 to 2500 seeds m^{-2} caused significantly increment in total fiber percentage, fiber yield fed^{-1}, fiber length and fiber fineness. On the other hand, fiber yield plant^{-1} were significantly decreased, but the differences in total fiber percentage between plant densities of 2000 and 2500 seeds m^{-2}, as well as the

Table 18. Mean values of fiber yield and its related traits of flax cultivars in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Total fiber (%)	Fiber yield plant^{-1} (g)	Fiber yield fed^{-1} (kg)	Fiber length (cm)	Fiber fineness (Nm)
Sakha 3	22.39	0.422	784.38	69.00	206.63
Giza 11	15.11	0.318	592.04	63.38	141.53
Giza 12	15.67	0.344	633.61	66.44	149.26
L.S.D. at 5%	0.99	0.280	55.87	1.32	4.89

differences in fiber yield plant^{-1} between plant densities of 2000 and 1500 seeds m^{-2} found non-significant in the combined analysis of 2018-19 and 2019-20 seasons. Flax sowing with plant density of 2500 seeds m^{-2} significantly produced the maximum total fiber percentage, fiber yield fed^{-1}, fiber length and fiber fineness as well as gave the lightest fiber yield plant^{-1}. On the other hand, flax planting with plant density of 1500 seeds m^{-2} gave the lowest total fiber percentage, fiber yield fed^{-1}, fiber length and fiber fineness as well as gave the heaviest fiber yield plant^{-1}. The superiority ratios between sowing flax at plant density of 2500 seeds m^{-2} and each of 2000 and 1500 seeds m^{-2} were 4.01 and 12.94% for total fiber percentage; 14.09 and 46.46 % for fiber yield fed^{-1}; 15.15 and 27.57% for fiber length in addition to 6.33 and 18.02% for fiber fineness, respectively. Flax sowing at plant density of 2500 seeds m^{-2} caused significantly decreased in fiber yield plant^{-1} by 7.95 and 12.04% compared with the flax growing at plant density of 2000 and 1500 seeds m^{-2}, respectively. The decreases in fiber yield plant^{-1} with increasing plant densities from 1500 to 2500 seeds m^{-2} could be due to the decreases in straw yield plant^{-1}. Such increases in fiber yield fed^{-1} at 2500 seeds m^{-2} could be due to the increase in No. of flax plants m^{-2}, straw yield fed^{-1} and total fiber percentage of flax. It was clear that the increase in fiber length with plant density of 2500 seeds m^{-2} may be due to the increase in total plant height and technical stem length. The increase in fiber fineness with increasing in plant densities may be attributed to decrease in fiber thickness. The finding is agreement with those obtained by [19,20,25].

3.3.4 Effect of interaction between flax cultivars and nitrogen fertilizer rates

Interaction effect between flax cultivars and nitrogen fertilizer rates was significant on fiber yield and its related traits of flax in the combined analysis of 2018-19 and 2019-20 seasons, as shown in Table 21. Sakha 3 cultivar with received 70 kg N fed^{-1} recorded the highest total fiber percentage (23.23%), fiber yield plant^{-1} (0.492 g), fiber yield fed^{-1} (921.12 kg) and fiber length (71.90 cm). On the other hand, the lowest total fiber percentage (14.34%), fiber yield plant^{-1} (0.258 g), fiber yield fed^{-1} (480.22 kg) and fiber length (60.26 cm) which obtained from Giza 11 cultivar fertilized with 30 kg N fed^{-1}. Sakha 3 cultivar when received 30 kg N fed^{-1} significantly produced the softness fiber fineness by 215.15 Nm. Whereas, Giza 11 cultivar and soil fertilized by 70 kg N fed^{-1} gave the hardness fiber fineness was 136.70 Nm. These results are in agreement with that obtained by [19,20] found that fiber yield and its related traits were significantly affected by interaction between flax cultivars and nitrogen fertilizer rates.

3.3.5 Effect of interaction between flax cultivars and plant densities

As shown in Table 22 the interaction between flax cultivars and plant densities on total fiber percentage, fiber yield plant^{-1}, fiber yield fed^{-1}, fiber length and fiber fineness were significant in the combined analysis of 2018-19 and 2019-20 seasons. The highest total fiber percentage (23.48%), fiber yield fed^{-1} (937.18 kg), fiber

Table 19. Mean values of fiber yield and its related traits of flax as affected by nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons

Nitrogen rate (kg N fed^{-1})	Total fiber (%)	Fiber yield plant^{-1} (g)	Fiber yield fed^{-1} (kg)	Fiber length (cm)	Fiber fineness (Nm)
30	16.88	0.293	538.48	63.12	172.27
50	17.80	0.368	685.73	66.74	165.68
70	18.51	0.423	785.82	68.96	159.46
L.S.D. at 5%	0.93	0.022	49.23	0.95	3.87

Table 20. Mean values of fiber yield and its related traits of flax as affected by plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Plant density (seeds m^{-2})	Total fiber (%)	Fiber yield plant^{-1} (g)	Fiber yield fed^{-1} (kg)	Fiber length (cm)	Fiber fineness (Nm)
1500	16.54	0.382	536.24	58.76	151.18
2000	17.96	0.365	688.39	65.10	167.80
2500	18.68	0.336	785.40	74.96	178.43
L.S.D. at 5%	0.87	0.017	46.57	0.92	3.66

length (77.63 cm) and fiber fineness (229.20 Nm) were obtained from Sakha 3 cultivar at plant density of 2500 seeds m^{-2} also, planting the same flax cultivar with 1500 seeds m^{-2} recorded the maximum fiber yield $plant^{-1}$ (0.438 g). Meanwhile, Giza 11 cultivar with 1500 seeds m^{-2} gave the lowest total fiber percentage (13.95%), fiber yield fed^{-1} (474.98 kg), fiber length (55.62 cm) and fiber fineness (132.03 Nm), as well as planting the same flax cultivar with 2500 seeds m^{-2} recorded the lowest fiber yield $plant^{-1}$ (0.293 g). These results in good accordance with those reported by [19,20] found that fiber yield and its related traits were significantly affected by flax cultivars and plant densities interaction.

3.3.6 Effect of interaction between nitrogen fertilizer rate and plant densities

The data in Table 23 indicate that the interaction between nitrogen fertilizer rates and plant densities showed significant effect on fiber yield $plant^{-1}$, fiber yield fed^{-1}, fiber length and fiber fineness of flax, while total fiber percentage were not significantly affected by interaction in the combined analysis of 2018-19 and 2019-20 seasons. Flax fertilized with 70 kg N fed^{-1} at plant density of 2500 seeds m^{-2} gave the heaviest fiber yield fed^{-1} (923.28 kg) and longest fiber length (77.89 cm). On the other hand, the lightest fiber yield fed^{-1} (438.83 kg) and shortest fiber length (55.22 cm) were obtained from flax applied with 30 kg N fed^{-1} under plant density of 1500 seeds m^{-2}. Flax planting when received 70 kg N fed^{-1} at 1500 seeds m^{-2} gave the heaviest fiber yield $plant^{-1}$ (0.447 g) as well as gave the hardness fiber fineness (144.35 Nm). On the other hand, the lightest fiber yield $plant^{-1}$ (0.271 g) as well as the softness fiber fineness (184.30 Nm) were obtained from flax applied with 30 kg N fed^{-1} at plant density of 2500 seeds m^{-2}. Similar results were reported by [19,20].

Table 21. Mean values of fiber yield and its related traits of flax as affected by interaction among flax cultivars and nitrogen fertilizer rates in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Nitrogen rate (kg N fed^{-1})	Total fiber (%)	Fiber yield $plant^{-1}$ (g)	Fiber yield fed^{-1} (kg)	Fiber length (cm)	Fiber fineness (Nm)
Sakha 3	30	21.34	0.343	623.07	65.86	215.15
	50	22.60	0.430	808.95	69.24	206.23
	70	23.23	0.492	921.12	71.90	198.50
Giza 11	30	14.34	0.258	480.22	60.26	146.88
	50	15.14	0.324	604.67	63.81	141.00
	70	15.85	0.371	691.22	66.08	136.70
Giza 12	30	14.94	0.279	512.14	63.25	154.77
	50	15.65	0.349	643.57	67.18	149.82
	70	16.44	0.405	745.12	68.91	143.18
L.S.D. at 5%		1.61	0.038	85.27	1.65	6.70

Table 22. Mean values of fiber yield and its related traits of flax as affected by interaction among flax cultivars and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Plant density (seeds m^{-2})	Total fiber (%)	Fiber yield $plant^{-1}$ (g)	Fiber yield fed^{-1} (kg)	Fiber length (cm)	Fiber fineness (Nm)
Sakha 3	1500	20.92	0.438	614.03	61.65	181.68
	2000	22.78	0.422	801.94	67.71	209.00
	2500	23.48	0.404	937.18	77.63	229.20
Giza 11	1500	13.95	0.336	474.98	55.62	132.03
	2000	15.31	0.324	610.07	62.16	143.05
	2500	16.08	0.293	691.06	72.37	149.50
Giza 12	1500	14.76	0.371	519.72	59.00	139.83
	2000	15.79	0.350	653.14	65.44	151.35
	2500	16.48	0.312	727.97	74.89	156.58
L.S.D. at 5%		1.51	0.029	80.66	1.59	6.34

Table 23. Mean values of fiber yield and its related traits of flax as affected by interaction among nitrogen fertilizer rates and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Nitrogen rate (kg N fed^{-1})	Plant density (seeds m^{-2})	Total fiber (%)	Fiber yield plant^{-1} (g)	Fiber yield fed^{-1}(kg)	Fiber length (cm)	Fiber fineness (Nm)
30	1500	15.77	0.313	438.83	55.22	157.28
	2000	17.12	0.296	549.75	62.64	175.22
	2500	17.74	0.271	626.86	71.50	184.30
50	1500	16.49	0.386	541.76	59.48	151.92
	2000	18.08	0.373	709.37	65.24	166.93
	2500	18.82	0.345	806.06	75.51	178.20
70	1500	17.36	0.447	628.13	61.58	144.35
	2000	18.68	0.428	806.04	67.42	161.25
	2500	19.48	0.393	923.28	77.89	172.78
L.S.D. at 5%		N.S.	0.029	80.66	1.59	6.34

Table 24. Mean values of fiber yield and its related traits of flax as affected by interaction among flax cultivar, nitrogen fertilizer rates and plant densities in the combined analysis of 2018-19 and 2019-20 seasons

Flax cultivar	Nitrogen rate (kg fed^{-1})	Plant density (seeds m^{-2})	Total fiber (%)	Fiber yield plant^{-1} (g)	Fiber yield fed^{-1} (kg)	Fiber length (cm)	Fiber fineness (Nm)
Sakha 3	30	1500	19.92	0.356	495.19	58.30	188.65
		2000	21.88	0.345	633.31	65.28	220.15
		2500	22.24	0.327	740.71	74.01	236.65
	50	1500	20.85	0.445	622.66	62.39	183.65
		2000	23.05	0.432	841.47	67.85	206.90
		2500	23.92	0.415	962.72	77.48	228.15
	70	1500	22.00	0.514	724.22	64.27	172.75
		2000	23.42	0.490	931.05	70.02	199.95
		2500	24.29	0.471	1108.10	81.40	222.80
Giza 11	30	1500	13.35	0.279	394.98	52.40	137.70
		2000	14.41	0.259	489.71	59.59	149.00
		2500	15.27	0.235	555.98	68.78	153.95
	50	1500	13.94	0.342	482.10	56.15	131.65
		2000	15.43	0.330	622.65	62.25	141.90
		2500	16.06	0.301	709.26	73.05	149.45
	70	1500	14.56	0.388	547.86	58.31	126.75
		2000	16.10	0.381	717.84	64.64	138.25
		2500	16.91	0.343	807.95	75.28	145.10
Giza 12	30	1500	14.05	0.305	426.31	54.97	145.50
		2000	15.06	0.282	526.23	63.07	156.50
		2500	15.72	0.250	583.88	71.70	162.30
	50	1500	14.69	0.372	520.52	59.90	140.45
		2000	15.77	0.356	663.98	65.63	152.00
		2500	16.48	0.320	746.22	76.00	157.00
	70	1500	15.53	0.437	612.32	62.15	133.55
		2000	16.54	0.412	769.23	67.61	145.55
		2500	17.25	0.366	853.80	76.98	150.45
L.S.D. at 5%			N.S.	0.051	139.71	2.76	10.98

3.3.7 Effect of interaction between flax cultivars, nitrogen fertilizer rate and plant densities

Results in Table 24 revealed that the interaction of flax cultivars X nitrogen fertilizer rates X plant densities had significant effect on fiber yield plant^{-1}, fiber yield fed^{-1}, fiber length and fiber fineness of flax, while total fiber percentage were not significantly affected by interaction in the combined analysis of 2018-19 and 2019-20 seasons. The maximum fiber yield plant^{-1} (0.0514 g) was obtained from Sakha 3 cultivar when soil fertilized by 70 kg N fed^{-1} and using plant density of 1500 seeds m^{-2}. On the other hand, the minimum fiber yield plant^{-1} (0.235 g) was produced from Giza 11 cultivar when received 30 kg N fed^{-1} at plant density of 2500 seeds m^{-2}. The heaviest fiber yield fed^{-1} (1108.10 kg) and the longest fiber length (81.40 cm) were obtained by planting Sakha 3 cultivar with 70 kg N fed^{-1} at plant density of 2500 seeds m^{-2}. Whereas, Giza 11 cultivar when received 30 kg N fed^{-1} at plant density of 1500 seeds m^{-2} gave the lowest fiber yield fed^{-1} (394.98 kg) and the shortest fiber length (52.40 cm). The most effective interaction treatment for produced the softness fiber fineness was Sakha 3 cultivar with 30 kg N fed^{-1} at plant density of 2500 seeds m^{-2} was 236.65 Nm. Meanwhile, Giza 11 cultivar under soil fertilized by 70 kg N fed^{-1} with plant density of 1500 seeds m^{-2} recorded the hardness fiber fineness (137.70 Nm). These results agree with those obtained by [19,20].

4. CONCLUSION

Based on the results from this study it could be concluded that Sakha 3 cultivar fertilized with 70 kg N fed^{-1} under the plant density of 2500 seeds m^{-2} produced the maximum fiber yield fed^{-1}, while Giza 11 cultivar with the same rates of nitrogen and plant density produced the maximum seed and oil yields fed^{-1}.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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