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Effect of plant density and retting method on flax yield and its components under sandy soil conditions

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This investigation was conducted at Ismailia Experimental Station, during 2020/2021 and 2021/2022 seasons to investigate the influence of plant density and retting method of three flax genotypes on yield and its attributes. The results illustrated that increase plant density from 1500 to 2500 plant/m^2 increase straw yield and its components. However, the highest seed yield and its components were obtained with 2000 plant/m^2. Fiber traits were not significantly differed by retting methods. Strain 620/1/3 exhibited the highest values of straw yield/hectare, plant height and technical length with 2500 plant/m^2, also seed yield/hectare, seed yield/plant and number of capsules/plant with 2000 plant/m^2. Strain 620/1/3 recorded the highest fiber yield/hectare and fiber length with 2500 plant/m^2 in both retting methods. However, Sakha 3 scored the highest fiber percentage with 2000 plant/m^2 in both retting method. Straw and fiber yield/hectare traits showed a strong and positive significant correlation with straw yield/plant, plant height, technical length and fiber length traits. Seed yield/plant exhibited significant positive correlation with number of capsules/plant and number of seeds/capsule. Results revealed that the major straw and fiber yield contributors were technical length and plant height traits and straw yield/plant for fiber yield. Thus, selection for improving straw and fiber yields by indirectly selection for high technical length and plant height. For seed yield/plant number of capsules/plant trait was the most important contributor followed by 1000-seed weight trait which has high positive direct effects on seed yield/plant. Therefore, seed yield improvement can be achieved through selection indirectly for more capsules/plant and seed weight.

Keywords: Flax, linseed, plant density, retting method, correlation, path analysis

INTRODUCTION

Flax is considered one of the oldest important fiber crops in the world and is utilized in production of environmental friendly durable composite materials (Baley et al., 2020; Kiryluk and Kostecka, 2020) and industrial paper (Ramirez-Cando et al., 2017) with its non-fiber waste. Egypt has ideal environmental conditions for planting and production of flax for fiber and seed, thus flax in Egypt is considered a dual-purpose crop. From the last decades all flax products have been imported including flax fiber, flax seed, flax oil and its by-products. Flax fibers are mainly used as raw materials for the of textiles industry (Dudarev, 2020).

Flax fiber provides fibers for woven or non-woven textiles, linens, twine and rag- based paper. The biofuel business can use both fiber and seed varieties as feedstock to produce biomass energy (Naik et al., 2010) and both seeds and stems have commercial use (You et al., 2016). For extraction of fiber, flax stems are first thrashed or de-seeded, the next steps are retting, breaking and scutching. The water retting method is more popular because it provides uniform conditions for retting. Fibers from the stem are ategorized for their length, strength and beauty. According to Brutch et al. (2008), the amount of stem fiber has a negative correlation with fiber properties including fineness and flexibility and is a crucial component in achieving high fiber yields. Flax seeds contain oil in the range of 36-46% and this oil is very important in many industries. Flax oil can be utilized in paints, lacquers, inks, linoleum, and other manufactured products since it readily oxidizes and solidifies when exposed to air (Juita et al., 2012). The oil of flax is rich in health-beneficial Omega-3 fatty acids known as Alpha linolenic acid (Oomah, 2001).

The success of any production program depends on choosing suitable varieties and suitable agronomic practices such as plant density to improve yield and its features. The plant density influences the yield and quality of flax and has greater influence on the morphological characteristics of stalks of fiber flax. Increased secondary branching and seeds per capsule are produced at low densities, increasing seed production. Increasing plant density is required to produce high-quality flax fiber, however this density must be managed appropriately between high fiber yield and quality (Dudarev, 2020; Mankowska and Mankowski, 2020). Like the choice of production systems, the choice of cultivars increases the efficiency of flax cropping (Gubbels and Kenaschuk 1989; Freer and Sansome, 1991).

Plant population necessary to obtain optimum linseed yields is influenced by seeding rate (Turner, 1991; Freer and Sansome, 1991; Taylor and Morrice, 1991). Diepenbrock and Porksen (1992) found maximum seed yield with lower densities, 200 and 400 plants/m2. Lisson and Mendham (2000) noticed that the increase in plant density from 390 to 530 seeds/m2 provides increased performance. Based on Turner (1991), when the population increased from 400 to 900 seeds/m2, the number of capsules doubled. The best yields of straw, fiber, and seeds were recorded at 2000 plants/m2 density, while the lowest values were observed at 500 plants/m2 density, according to Arslanoglu et al. (2022). The important step in any plant breeding programs was determined the selection criteria for improving yielding ability in flax. This is possible in the case of estimating the nature of interrelationships among straw, seed yields and their related attributes and find which of them effected directly or indirectly by estimated path coefficient analysis. Therefore, this study was carried out to determine the effect of plant density, retting method on straw, fiber, seed yields and its related traits. In addition to study the interrelationships between all studied traits and their attributes through correlation and path coefficient analysis.

MATERIALS AND METHODS

Field experiments

Through 2020/2021 and 2021/2022 seasons two field trials were established at Ismailia Experimental station, Ismailia Governorate. The soil is sandy with organic matter content of 0.048 % and 0.054, available nitrogen was 6.65 and 6.83 ppm, EC is 0.13 and 0.18 and the values of pH were 7.52 and 7.44 over the two successive seasons 2020/2021 and 2021/2022, respectively. The study is to investigate the impact of plant density and retting method on flax straw, fiber and seed yield and its attributes. Planting date was during the third week of November in the both seasons. The experiment was conducted using a split-split plot design with three replicates, whereas two retting method (I: retting without changing the water and II: retting with changing water every 72 hours) in main plots, and the three plant densities (1500 (D1), 2000 (D2) and 2500 (D3) plant/m2) were allocated in sub plots. Moreover the three genotype (Giza 12, Sakha 3 and S. 620/1/3) were assigned in sub-sub plots (Table 1). The plant densities of 1500, 2000 and 2500 plant/m2 correspond respectively to seeding rates of 145, 165, 190 kg seeds/ha.

Every experimental plot consisted of ten rows, the length of row was 3 m within row to row distance was 20 cm thus the area of each interrow was 0.6 m2. The number of seeds was determined for each row (0.6 m2) by counting and weighting the seeds for each plant density and for each genotype in three replications. Normal operations for planting flax were applied as recommended. At harvest ten randomly protected plants were picked from each sub-sub plot to use for determination of the following traits: straw yield/ plant (g), seed yield/ plant (g), technical length (cm), plant height (cm), number of capsules/ plant, 1000 seed weight (g) and number of seeds/ capsule. Straw and seed yields per hectare were calculated from the whole sub-sub plot area basis (2 x 3 m). After harvest, retting process was concluded in three replications by two methods the first retting without changing the water and the second retting with change of water every 72 hours to measure the following traits fiber length, fiber percentage and fiber yield (ton)/ hectare from the whole sub-sub plot area (6 m2).

Statistical analysis

The data collected were statistically analyzed according to Snedecor and Cochran (1982). Homogeneity test (Bartlett test) was performed and means were compared by least significant differences (LSD) at 5% level of probability. Correlation analysis was determined to assess the strength of relationship among the studied traits. Also, correlation coefficients among traits were used to calculate path-coefficient analysis, direct and indirect effects of the straw, fiber, seed yields and its attributes according to the method of Dewey and Lu (1959).

RESULTS AND DISCUSSION

Genotypes performance

The straw, seed, fiber yields and its features of the three different flax genotypes are presented in Table 2. Genotypes showed significant differences in the twelve studied traits. The genotype S.620/1/3 exhibited the highest values of straw yield/hectare (6.75 ton), seed yield/hectare (1.11 ton), plant height (91.9 cm), technical length (70.6 cm), seed yield/plant (1.18 g), number of capsules/plant (23.1), fiber yield/ hectare (1235 Kg) and fiber length (65.9 cm). Followed by the genotype Giza 12. Sakha 3 which recorded the maximum value of fiber percentage (18.7%). It might be deduced that the differences in behavior and performance of the three genotypes was due to variability in genetic potential. Significant variations were observed among genotypes of flax by many authors such as Abu El-Dahab (2002), Abo-Kaied et al. (2008), Al-Doori (2012), Mirshekari et al. (2012) and El-Shimy et al. (2019).

Plant density effects

Plant density influenced straw, seed, fiber yields and their characteristics. Combined statistical analysis of data showed that plant density treatments significantly affected all studied traits. Main effect of plant density on all studied traits (combined analysis over the two seasons) are presented in Table 3. Results showed that there are significant differences in straw yield and its related traits under different plant densities. Increasing plant densitiy from 1500, 2000 plant/m2 up to 2500 plant/m2 increased straw yield/hectare (7.3 ton), straw yield/plant (2.5 g), plant height (92.6 cm) and technical length (72.6 cm). This was related to the increase in number of plant/m2 which increase straw yield/hectare as well as per plant. The highest values of straw yield and its features were measured at the highest plant density and the lowest ones were measured at the lowest densities, this is attributed to the competition between flax plants and weeds in the low plant densities which lead to short height and low straw yield (Beyene et al., 2022). Results presented in Table 3 demonstrated that increasing plant density from 1500 plant/m2 to 2000 plant/m2 increased seed yield/hectare (1.1 ton), seed yield/plant (1.3 g), number of capsules/plant (27.5), number of seeds/capsule (8.9) and 1000- seed weight (8.5 g). But increasing plant density from 2000 plant/m2 to 2500 plant/m2 decrease seed yield and its related traits, seed yield/plant, number of capsules/plant, number of seeds/capsule and 1000-seed weight. With regard to lower and optimal plant density, the grown plants had a greater area per plant which increase feeding area, absorbed more nutrients, received more light and had greater space around them for photosynthesis to produced more dry matter to be accumulation in seeds and capsules.

In the case of high and optimum plant densities, the competition between plants for light and nutrients increased thus, the dry matter accumulation decreased in seeds which resulted in a decrease in the number of capsules/plant, number of seeds/capsule, 1000-seed weight and seed yield/plant. As showed in Table 3, increasing plant density from 1500, 2000 to 2500 plant/m2 increased fiber yield/hectare (1364 Kg), fiber percentage (18.8%) and fiber length (68.0 cm).

Higher plant density leads to higher fiber content and this was attributed to the increase in plant height, technical length and straw yield/hectare. Increases in plants per unit area causes increasing in the proportion of stem fiber which lead to increase in fiber yield and content. These results were in agreement with those obtained by Abu El-Dahab (2002), Abo-Kaied et al. (2008) and El-Shimy et al. (2019). Generally, to obtain high straw, fiber yields and fiber content it is necessary to increase plant density, however this density needs to be appropriately balanced between high fiber yield and quality (Dudarev, 2020; Mankowska and Mankowski, 2020). Also, to obtain high seed yield it is necessary to use lower plant density which increases seed yield and its related traits. Arslanoglu et al. (2022) found that for high straw fiber and seed yield, 2000 plant/m2 density was suitable for cultivating flax.

Retting method effect and interaction effect between genotypes and retting method

Main effect of retting method and interaction effect between genotypes (G) and retting method (M) on fiber yield/ha, fiber percentage and fiber length (Combined analysis of the two seasons) are presented in Table 4. Results of combined analysis of variance revealed that retting method did not significantly affect the three studied fiber traits. Fiber yield/ha, fiber percentage and fiber length were 1148 kg, 18.5% and 60.5 cm in the first retting method (I) and 1156 Kg, 18.3% and 60.1 cm in the second retting method (II), respectively. Thus, the three fiber traits studied did not differ significantly in the two retting methods. The interaction effect between retting method and genotypes on fiber yield/ha, fiber percentage and fiber length are shown in Table 4. The analysis of data revealed that this interaction was not significant for the three fiber traits studied. The three genotypes Giza 12, Sakha 3 and S. 620/1/3 gave values of fiber yield/ha, fiber percentage and fiber length not significantly different in the two retting methods.

Interaction effect

The interaction effects between the three investigated factors (genotypes, plant density and retting method) on straw, seed, fiber yields and its related traits were presented in Tables 5 and 6. The data in Table 5 showed that the interaction between genotypes and plant density was highly significant for all tested traits except plant height, technical length, number of capsules/plant and fiber length. The highest straw yield/ hectare, straw yield/plant, plant height, technical length were estimated at 2500 plant/m2 (The high plant density) while the lowest values were determined at 1500 plant/m2.

The strain 620/1/3 exhibited the highest values of straw yield/hectare (7.7 ton), plant height (99 cm) and technical length (78.3 cm) when planted under the high plant density (2500 plant/m2), while the same strain 620/1/3 showed the highest values of seed yield/ hectare (1.2 ton) and number of capsules/plant (28.3) when planted with 2000 plant/m2. The genotypes Giza 12 showed the highest values of straw yield/plant (2.68 g) when planted under 2500 plant /m2 and showed the highest values of seed yield/ plant (1.37 g) and 1000-seed weight (9.96 g) when planted under 2000 plant/m2. Regarding fiber yield, data in Table 6 illustrated that the interaction between retting method and genotypes and between retting method and plant density were not significant, but the interaction between plant density and genotypes was significant for fiber yield/hectare and fiber percentage but not significant for fiber length. The interaction between retting methods, plant density and genotypes was not significant that mean the retting method not affected on genotypes and plant density. The promising strain 620/1/3 recorded the highest values of fiber yield/hectare (1436 and 1466 kg) and fiber length (72.7 and 73.5 cm) when planted with 2500 plant/m2 in both two methods of retting, respectively. The genotype Sakha 3 showed the highest fiber percentage (19.0 %) in the two retting methods at 2000 plant/m2. According to the previous results, it has been stated that retting method had no impact on all the studied traits, however the yield of straw, fiber, and seeds is significantly influenced by plant density.

Correlation between traits

Flax breeders needs to select high yielding genotypes and association studies supply information on the nature and directions of selection. The knowledge of correlation coefficients between different yield traits lead flax breeders to measure the strength of the relationship between the traits studied. Correlation coefficient between traits affected by plant density and retting method for the three flax genotypes are presented in Table 7. Straw yield/ hectare trait showed positive significant correlation with straw yield/plant (0.84), plant height (0.76), technical length (0.89), seed yield/plant (0.63), fiber yield/hectare (0.99) and fiber length (0.83), these interrelationships indicating that the flax breeders can use such correlated response to obtain high straw yield by selection for one or more of these traits. Seed yield/plant exhibited significant positive correlation with number of capsules/plant (0.86) and number of seeds/capsule (0.56) thus, these two traits may be used as selection criteria for highly seed yield. From the data in Table 7, it was noticed that straw yield/plant showed positive and significant correlation with plant height (0.72), technical length (0.76), fiber yield/hectare (0.87), fiber percentage (0.62) and fiber length (0.773). Plant height traits exhibited positive and significant correlation with technical length (0.69), fiber yield/hectare (0.78), fiber percentage (0.54) and fiber length (0.95). Also technical length showed positive significant correlation with fiber yield/hectare (0.89) and fiber length (0.72). Data in Table 7 indicated that fiber yield/hectare had positive significant association with straw yield/hectare (0.99), straw yield/plant (0.87), plant height (0.78), technical length (0.89) and fiber length (0.85). It can be concluded that straw yield/plant, plant height and technical length could be used as selection criteria for improving straw and fiber yields. Also, improving number of capsules/plant and number of seeds/ capsule in selection would automatically improve seed yield/plant. Arslanoglu et al. (2022) found that the correlation between fiber yield and straw yield, plant height and technical length were positive and significant. Several authors studied correlation among traits of flax such as Muduli and Patnaik (1994), Nie et al. (1994), Osman et al. (2006), Tadess et al. (2009) and Murali et al. (2014).

Path coefficient analysis

The correlation coefficient recorded in Table 7 was used in the path coefficient analysis to detect the relative importance of each trait to straw, seed and fiber yields. The analysis of path coefficient has been used to determine the essential yield characteristics by estimating the direct effects of the attribute trait on yield and separating the direct effects from the indirect effects through other related traits by partitioning the correlation coefficient and brought out the relative importance of different traits as selection criteria. In this investigation, the traits studied were divided into three groups contributing to straw yield and its components, seed yield and its components and fiber yield and its attribute. The direct and indirect effects of two yield components on straw yield/plant at the combined data over two seasons are presented in Table 8 and the results showed that technical length trait had the highest positive direct effects on straw yield/plant followed by the direct effect of plant height. The indirect effects of plant height via technical length was higher than the indirect effect of technical length via plant height.

Results in Table 9 revealed that the relative importance of indirect effect of plant height and technical length (25.6%) followed by the direct effect of technical length (25.6%) were higher than the direct effect of plant height (13.5%). These results indicated that the contribution of the two traits studied for straw yield variation differed in their relative importance, also the plant height and technical length traits seemed to be the most important sources affecting straw yield/plant variation, thus flax breeders should consider the two traits as the main selection criteria in programs of improving flax yield.

The direct and indirect effects of yield components on seed yield/plant with combined data of two seasons were shown in Table 8. The results revealed that the greatest positive direct effect on seed yield/plant was expressed by number of capsules/plant (1.22), whereas the indirect effect via number of seeds/capsule was negative and the indirect effect via 1000-seed weight was negligible. Also, data in Table 8 illustrated that the direct effect of number of seeds/capsule on seed yield/plant was negative, but the indirect effect via number of capsules/plant was high (0.93). The 1000-seed weight trait had moderate direct effect (0.41) on seed yield/plant, the indirect effect of 1000-seed weight via number of capsules/plant was low and the indirect effect via number of seeds/capsule was negative. The components of direct and joint effects in percentage of the contribution due to seed yield/plant and its components were showed in Table 9. The results revealed that the main sources of seed yield variation in the order to importance were the direct effect of number of capsules/plant (46.2%) followed by the indirect effect of number of capsules/plant via number of seeds/capsule (29.7%), the direct effect of number of seeds/capsule (8.3%), the direct effect of 1000-seed weight (5.1%), the joint effect of number of seeds/capsule via 1000-seeds weight (4.8 %) and the joint effect of number of capsules/plant via number of seeds/capsule. The total effect of three traits was 96.8% and the residual was 3.15% of the total variation.

Generally, the results obtained herein illustrated that the contribution of different traits especially number of capsules/plant and its joint effects with other traits were different on seed yield/plant. Also, the number of capsules/plant followed by 1000-seed weight had positive direct effects on seed yield and may be considered as a selection criteria for improving seed yield of flax in plant breeding programs. Similar results were reported by Rao and singh (1984), Khan and Gupta (1995) and Mirza et al. (1996), whereas Gupta and God Wat (1984) reported that 1000-seed weight followed by capsule number had positive direct effects on seed yield/plant.

In regard to fiber yield and its related traits in Table 8, technical length had the highest direct effect on fiber yield followed by straw yield/plant, but the direct effects of plant height and fiber percentage were low. The indirect effect of the four traits via each of them was moderate and low. The components of direct and joint effects in percentage of contribution due to fiber yield and its attributes are presented in Table 9. The data illustrated that the main sources of fiber yield variation in order to importance were the direct effect of technical length trait (23.1%) followed by the indirect effect of straw yield/plant via technical length (23.1%), the indirect effect of plant height via technical length (10.9 %), the direct effect of straw yield/plant (9.98%), the indirect effect of straw yield/plant via plant height (7.4%), the indirect effect of technical length via fiber percentage (5.2 %) and straw yield/plant via fiber percentage (4.3%). These results revealed that to improve fiber yield we need to select for the high values of straw yield/plant, plant height and technical length and these traits may be considered as the main selection criteria to improve fiber yield in the flax breeding programs. Many investigators studied path coefficient analysis of traits on flax yield like Rao and Singh (1984), Muduli and Patnaik (1994), Nie et al. (1994), Osman et al. (2006) Tadesse et al. (2009) and Murali et al. (2014).

CONCLUSION

In general, it can be recommended that plant density is very important for flax productivity. High plant density 2500 plant/m2 is suitable for producing high straw and fiber yields, but the low plant density 2000 plant/m2 is suitable for producing high seed yield. The effect of two retting methods on fiber traits was similar. The strain 620/1/3 was the best genotype to produce the highest straw and fiber yields when planted with 2500 plant/m2 and to produce the highest seed yield when planted with 2000 plant/m2. Selection for improved straw and fiber yields could be achieved by indirectly selecting for high technical length and plant height, and seed yield improvement can be achieved through selection for more capsules and more seed weight.

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