3

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## Estimation of Straw, Seed and Oil Yields for Flax Plants *(Linum usitatissimum* L.) Cultivars of Foliar Application of Mn, Fe and Zn under Dry Environment

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TWO years field work were accomplished at Demo experimental farm, Faculty of Agriculture, Fayoum University, Egypt during 2015/2016 and 2016/2017 years to study the effect of Mn, Fe and Zn foliar spraying on three flax cultivars productivity. The arrangement of split-plot in RCBD with three replications was applied. Three flax cultivars (Sakha-1, Sakha-2 and Giza-9) occupied the main plots while, three micro-nutrients levels (Zero, 300 and 600ppm fed$^{-1}$) distributed in the sub-plot. The form of applied micro-nutrients was EDTA 13% Mn, EDDHSA 6% Fe and EDTA 14% Zn. Results showed that Sakha-1 exceeded other cultivars in straw yield parameters (i.e., plant height, technical stem height and straw yield. While, Sakha-2 cultivar gave utmost values of stem diameter and number of branches plant$^{-1}$ as well as seed yield traits (i.e., number of fruiting branches plant$^{-1}$, fruiting zone length, number of capsules plant$^{-1}$, 1000-seed weight and seed and oil yields. Seed oil and micro-nutrients (Mn, Fe and Zn) content were highest with Sakha-2 variety. Micro-nutrients foliar spraying at 600ppm/feddan gave significantly the highest values for all traits two years as compared to zero or 300ppm/feddan. There are two traits, i.e., 1000-seed weight and number of fruiting branches plant$^{-1}$ in 2015/2016 year and two ones, i.e., seed yield plant$^{-1}$ and number of capsules plant$^{-1}$ in 2016/2017 year, were significantly ($P \leq 0.001$) participated to variation in seed yield/feddan.

**Keywords:** Flax, Cultivars, Micro-nutrients, Dry environment.

### Introduction

Flax plant (*Linum usitatissimum* L.) is an aged agronomic crop having more than 300 species (Conforti & Cachaper, 2009). Flax is cultivated in numerous regions of world for oil, fiber, medicinal aims and nutritional product. The total protein content in flax seed ranges between 20 to 30 percent composed of fundamentally 80 percent globulins and 20 percent glutelin (Hall et al., 2006). The flax seed protein has an amino acid paradigm comparable to that of soybean protein, which is appeared as one of wildly nutritious of the plant proteins (Morris, 2007). Oil content in flax seed is about 36 to 48%. Flax oil is a primary source of essential fatty acids for human regimens, and has various health benefits (Millis, 2002). The seed oil of flax as drying oil, is mainly used in paints, varnishes, other pharmaceutical materials and industry purposes. The oil extracted from unheated seeds is used in nutrition (El-Kady & Abd El-Fatah, 2009).

Flax seed in Egypt, is grown as a twin purpose crop i.e., for fibers and oil since pharaoh age. Hence, linen textile was used only for princesses and kings. The cultivated area in Egypt which devoted for flax production is relatively small and dramatically decreased during the last decade to reach 9201 ha in 2017 (FAO, 2019). This reduction was due to the strong competition between flax and other winter crops like wheat, clover and other crops especially in old lands at Nile Valley which make a great gap between the production and consumption of flax (El-Nagdy et al., 2010). This shortage could be depressed by raising yields per unit area by availability nutrition requirements especially micro-nutrients in order to flax genotypes gave expected yields in new reclaimed soil. In Egypt, many studies stated that

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many flax genotypes can successfully grow under newly reclaimed soil conditions (Kandil et al., 2008; Bakry, 2009; El-Seidy et al., 2015; Nawar et al., 2017; Emam, 2019). Many investigators found statistical differences among flax genotypes related straw,seed and oil yields per unit area as well as flax seed quality (Khalifa et al., 2011; Bakry et al., 2012; Homayouni et al., 2013; Gallardo et al., 2014; Bakry et al., 2015; El-Shafey & Hassan, 2016; Sadi et al., 2017; Emam, 2019).

Micro-nutrients play a major and significant role in growth and metabolic operations of plant associated with photosynthesis, chlorophyll genesis, cell wall development and respiration, absorption of water, also xylem permeability, resistance to plant diseases, enzyme activities implicated in the synthesis of metabolites, and nitrogen fixation (Senthilkumar, 2018). In Egypt, many studies indicated that the spraying of micro-elements as foliar spraying gave an increase in seed yield and quality of flax (El-Gazzar & El-Kady, 2000; Mostafa & El–Deeb, 2003; Kineber et al., 2006; Khalifa et al., 2011; Homayouni et al., 2013; Bakry et al., 2015) who stated that micro-nutrients foliar spraying increased and improved the straw and seed yields of flax.

Thus, this study aimed to inspect the effect of foliar spraying by Mn, Fe and Zn on yields of three flax cultivars as well as seed quality under new soil conditions.

## Materials and Methods

Two years field experiment were conducted during the two successive seasons 2015/16 and 2016/17 at Demo Experimental Farm (29º 17'N; 30º 53'E), Faculty of Agriculture, Fayoum University, Egypt to study some micro-nutrients as foliar application on three flax cultivars.

Each experiment includes three flax cultivars and three levels of micro-nutrients. A split-plot arrangement in (RCBD) with 3 replications was applied. The main plots were occupied by the flax cultivars (Sakha-1, Sakha-2 and Giza-9), whereas the three levels of micro-nutrients application (zero, 300 and 600 ppm) were distributed randomly in sub-plots as follow:

1- Zero ppm (Control).
2- 300ppm foliar spraying combination from Mn + Fe + Zn.
3- 600ppm foliar spraying combination from Mn + Fe + Zn.

The form of applied micro-nutrients was EDTA 13% Mn, EDDHSA 6% Fe and EDTA 14% Zn. Spraying treatments was carried out equally in two doses in 45 and 60 days from sowing. The sub-plot comprised 6m$^2$ (1/700 feddan, one feddan= 4200m$^2$) with 3m long x 2m wide. Healthy seeds of three flax cultivars were broadcasting on 7 and 10 November for the 1$^{st}$ and 2$^{nd}$ seasons, respectively. Healthy certified flax seeds were received from Field Crop Research Institute, Agricultural Research Centre, Giza, Egypt. Seeds were sown at the equivalent of 70kg fed$^{-1}$ to get the planting density. Maize was the preceding crop in both years.

Conventional tillage was applied in the experimental site. During tillage and before ridging, calcium supper-phosphate (15.5% $P_2O_5$) at the rate of 150 kg fed$^{-1}$ was added. Nitrogen was applied equally in two doses at the rate of 75kg fed$^{-1}$ (as ammonium nitrate 33.5% N) before 2$^{nd}$and 3$^{rd}$ irrigation. All other recommended agricultural practices in a newly reclaimed soil for flax production were adopted throughout the growing seasons according to Egyptian Ministry of Agriculture Bulletin No (1086/2007). Soil properties of the experimental site were presented in Table 1. Analytical procedures were those recommended by Wilde et al. (1985).

*Yield measurements of flax*

Ten plants were taken randomly at maturity from each experimental plot to record the following attributes:

- Straw yield attributes: Plant height (cm), technical length (cm), stem diameter (cm), number of branches plant$^{-1}$ and straw yield plant$^{-1}$ (g).

- Seed yield attributes: Number of fruiting branches plant$^{-1}$, fruiting zone length (cm), number of capsules plant$^{-1}$ and seed yieldplant$^{-1}$ (g).

From middle of each sub-plot, plants were used to determine the following traits:

- 1000-seed weight (g), straw yield (ton fed$^{-1}$) and seed yield (kg fed$^{-1}$).

- Oil yield kg $fed^{-1}$ was calculated by seed yield kg $fed^{-1}$ x seed oil %.

- Seed quality: [Oil %, Mn, Fe, and Zn (mg/100 g)].

**TABLE 1. Physical and chemical features of the experimental soil in the two growing winter seasons 2015/2016 and 2016/2017.**

| Properties | 2015/2016 | 2016/2017 |
|---|---|---|
| **Particle size distribution** | | |
| Sand % | 66.17 | 66.32 |
| Silt % | 15.23 | 15.43 |
| Clay % | 18.60 | 18.25 |
| Soil texture | **Sandy loam** | **Sandy loam** |
| **Chemical properties:** | | |
| Bulk density (g $cm^{-3}$) | 1.43 | 1.41 |
| $K_{sat}$ (cm $h^{-1}$) | 3.22 | 2.46 |
| pH | 7.67 | 7.63 |
| $Ec_e$ (dS $m^{-1}$) | 3.13 | 2.99 |
| $CaCO_3$ (%) | 7.93 | 7.86 |
| Organic matter (%) | 0.95 | 0.92 |
| Total N ( mg $kg^{-1}$) | 0.043 | 0.042 |
| Available P ( mg $kg^{-1}$) | 3.26 | 3.51 |
| Available K ( mg $kg^{-1}$) | 42.45 | 41.10 |
| Available Mn ( mg $kg^{-1}$) | 1.48 | 1.37 |
| Available Fe ( mg $kg^{-1}$) | 5.47 | 4.73 |
| Available Zn ( mg $kg^{-1}$) | 0.85 | 0.83 |

Soxhelt extraction device was used to determine seed oil content (%) by using solvent of petroleum ether and then the oil % in seed was computed on dry weight basis according to A.O.A.C (1990). To assess the micro-nutrients contents (i.e., iron; Fe, manganese; Mn, and zinc; Zn), seeds were dried and grounded to powdered form. The content of micro-nutrient mean value was assessed by an Atomic Absorption Spectrophotometer device (Perkin-Elmer, Model 3300). The determination of parameters is shown in Table 1.

*Statistical analysis*

The analysis of variance (ANOVA) technique for the split-plot arrangement was used to statistically analyzed all data as published by Gomez & Gomez (1984), using the GenStat 12th edition software . LSD test at 5 and 1% probability level was applied to test the differences among treatment means.

## Results and Discussion

*Straw yield and its attributes*

*Varietal differences*

Table 2 shows the straw the mean values of yield attributes (i.e., plant height, technical length, stem diameter, number of branches $plant^{-1}$ and straw yield per plant and per feddan were significantly affected by the varietal differences in the two years. Sakha-1 surpassed Giza-9 in plant height, technical length, stem diameter, number of branches $plant^{-1}$and straw yield per plant and per feddan in both seasons. Range of increment was 21.43, 26.82, 5.41, 22.78, 48.48 and 18.34% in the 1st season and 17.72, 23.89, 4.55, 4.00, 47.46 and 29.89%, in the second one, respectively. Meanwhile, Sakha-2 cultivar gave significantly the higher stem diameter in both seasons and number of branches $plant^{-1}$ in the second season when compared with Giza-9. In conclusion, Sakha-1 cultivar surpassed the other two cultivars in respect of straw yield and its components, while Giza-9 recorded the lowest mean values of straw yield $fed^{-1}$ and related traits. El-Hariri et al. (1998, 2004) found that there were large differences in straw yield attributes among flax genotypes. The differences among the tested cultivars would mainly be imputed to the differences in genetic structure constitution and their abilities responses to the environmental conditions. There are a good conformity of results with those mentioned by Sharief et al. (2005), Khalifa et al. (2011), Bakry et al. (2012), Mirshekari et al. (2012), Homayouni et al. (2013), Afifi et al. (2014), Gallardo et al. (2014), Bakry et al. (2015), Elayan et al. (2015), El-Seidy et al. (2015), Chopra & Badiyala (2016), El-Borhamy (2016), El-Shafey & Hassan (2016), Sadi et al. (2017) and Emam (2019).

*Micro-nutrients foliar application*

Micro-nutrients foliar application significantly affected straw yield attributes as compared to control Table 2. Data clearly indicated that foliar application of the 600ppm of micro-nutrients (Fe + Mn + Zn) significantly increased plant height, technical length, stem diameter, number of branches $plant^{-1}$ and straw yield as compared to Zero ppm. The interpretation of increasing in straw yield and its components would find due to applied the maximum rate of micro-nutrients (Fe + Mn + Zn) supplied at least serious part of genotype nutritive needs and through affecting the metabolic activities of plant growth (Amberger, 1991). The role Fe is acting as a chlorophyll formation catalyst (Mengel & Kirkby, 1982) and improves the processes of photosynthesis, maybe leading to more dry matter production. The positive effect of micro-nutrients on flax straw yield and its attributes was mentioned by Moawed (2001), Mostafa & El- Deeb (2003), Khalifa et al. (2011), Homayouni et al. (2013), Esmail et al. (2014), Tavakoli et al. (2014) and Bakry et al. (2015).

*Effect of the interaction*

Data summarized in Table 3 show that the interaction between flax cultivars and micro-nutrients foliar application was significant for straw yield attributes i.e., plant height and technical length in the 1$^{st}$ season while, technical length and straw yield plant$^{-1}$ in the 2$^{nd}$ season. It is clearly observed that the highest values for most studied characteristics of straw yield and its components were obtained when sprayed Sakha-1 cultivar by 600ppm micro-nutrients.

*Seed yield and its attributes*

*Varietal differences*

Table 4 shows the effect of flax cultivars and micro-nutrients foliar application on seed yield attributes. The seed yield attributes of the studied cultivars were significantly in number of fruiting branches plant$^{-1}$, fruiting zone length, number of capsules plant$^{-1}$, seed index, seed yield plant$^{-1}$and oil yield kg fed$^{-1}$. We can notice here that Sakha-2 cultivar surpassed other cultivars in seed yield (754.68 and 738.85kg fed$^{-1}$) and oil yield (310.37 and 298.83kg fed$^{-1}$) in the 1$^{st}$ and 2$^{nd}$ season, respectively. The superiority of Sakha-2 may be due to the highest mean values of number of fruiting branches plant$^{-1}$ (7.33, 7.21), fruiting zone length (31.27, 30.28cm), number of capsules plant$^{-1}$ (22.11, 21.67), seed index (9.63, 9.36g) and seed yield plant$^{-1}$ (1.88, 1.86g) in the 1$^{st}$ and 2$^{nd}$ season, respectively. The same trend was reported by Gaffer et al. (1985), Sorour et al. (1992), El-Hariri et al. (1998), Sharief et al. (2005), Afifi et al. (2014), Gallardo et al. (2014), Elayan et al. (2015), El-Seidy et al. (2015), Chopra & Badiyala (2016), El-Borhamy (2016), El-Shafey & Hassan (2016) and Emam (2019) who decided that the flax genotypes varied in production of seed yield. These results cleared that the variability among tested flax genotypes which may be predictable due to the differences of these genotypes in habits of growth, origin, genetic constituent high variation and effect of the environmental conditions of tested genotypes under new soil.

*Micro-nutrients foliar application*

The results in Table 4 show that micro-nutrients effect on seed yield and its related attributes were significant in comparison with the zero ppm treatment. Data revealed that the higher rate (600ppm) of micronutrients gave statistically higher yield components i.e., number of fruiting branches plant$^{-1}$, zone length of fruiting, 1000-seed weight, number of capsules plant$^{-1}$, seed yield plant$^{-1}$, seed and oil yields (kg fed$^{-1}$). The great role of micro-nutrients which may be affecting the metabolism processes and plant growth consequently increases in seed yield and most yield characters were enhanced. These results of increasing yield and its related attributes by applying foliar spraying of micronutrients are confirmed by the finding of El-Gazzar & El-Kady (2000), Moawed (2001), Mostafa & El-Deeb (2003), Mousa et al. (2010), Khalifa et al. (2011), Nofal et al. (2011), Homayouni et al. (2013), Esmail et al. (2014) and Bakry et al. (2015).

*Effect of the interaction*

Table 5 cleared that there were statistical effects due to the interaction seed among flax cultivars and micro-nutrients application for some seed yield attributes. Number of capsules plant$^{-1}$, seed index, seed and oil yield feddan were significantly affected by flax cultivars x micro-nutrient application interaction under new soil condition, Sakha-2 cultivar when sprayed with a rate of (600ppm) of micro-nutrients gave the highest mean values of seed yield characters. On the other hand, Giza-9 gave the lowest values without foliar spraying by micro-nutrient (zero ppm) in the two seasons.

*Seed quality*

*Varietal differences*

Table 6 showed that seed quality of the studied cultivars differed significantly in Mn, Fe, Zn (mg 100g$^{-1}$) and seed oil percentage. Shakh-2 cultivar exceeded the other two tested flax cultivars. The superiority of this cultivar may be fit to good adaptation in newly reclaimed soil. The differences in seed chemical composition among flax cultivars were detected by many investigators (Khalifa et al., 2011; Bakry et al., 2012; Homayouni et al., 2013; Gallardo et al., 2014; Bakry et al., 2015; El-Shafey & Hassan, 2016; Sadi et al., 2017; Emam, 2019).

**TABLE 2. Straw yield attributes (mean values) affected by flax cultivars and micro-nutrients foliar spraying in 2015/16 and 2016/17 seasons.**

| Treatments | Plant height (cm) | Technical length (cm) | Stem diameter (cm) | Number of branches plant$^{-1}$ | Straw yield plant$^{-1}$ (g) | Straw yield (ton fed$^{-1}$) |
|---|---|---|---|---|---|---|
| | | | 2015/2016 season | | | |
| Cultivars (A) | ** | ** | * | NS | * | ** |
| Sakha-1 | 106.93 | 80.91 | 1.95 | 1.94 | 2.94 | 3.42 |
| Sakha-2 | 105.16 | 73.88 | 2.13 | 2.22 | 2.65 | 3.12 |
| Giza -9 | 88.06 | 63.80 | 1.85 | 1.58 | 1.98 | 2.89 |
| **LSD 0.05** | **4.20** | **1.47** | **0.24** | **-** | **0.61** | **0.25** |
| Micro-nutrients (B) | ** | ** | ** | NS | ** | ** |
| 0ppm | 90.72 | 65.84 | 1.61 | 1.58 | 2.14 | 2.64 |
| 300ppm | 100.40 | 74.02 | 1.99 | 1.94 | 2.55 | 3.23 |
| 600ppm | 109.02 | 78.74 | 2.33 | 2.22 | 2.88 | 3.57 |
| **LSD 0.05** | **4.00** | **3.07** | **0.14** | **-** | **0.23** | **0.29** |
| | | | 2016/2017 season | | | |
| Cultivars (A) | * | * | * | * | * | NS |
| Sakha-1 | 106.69 | 80.64 | 1.84 | 1.04 | 2.92 | 3.39 |
| Sakha-2 | 101.47 | 71.19 | 2.11 | 1.52 | 2.62 | 2.96 |
| Giza -9 | 90.63 | 65.09 | 1.76 | 1.00 | 1.98 | 2.61 |
| **LSD 0.05** | **10.03** | **9.95** | **0.26** | **0.40** | **0.48** | **-** |
| Micro-nutrients (B) | ** | ** | ** | ** | ** | ** |
| 0ppm | 89.97 | 64.53 | 1.58 | 0.92 | 1.87 | 2.49 |
| 300ppm | 99.75 | 73.08 | 1.96 | 1.24 | 2.69 | 3.05 |
| 600ppm | 109.08 | 79.31 | 2.17 | 1.40 | 2.95 | 3.42 |
| **LSD 0.05** | **4.15** | **2.86** | **0.15** | **0.18** | **0.23** | **0.28** |

*P≤ 0.05, ** P ≤ 0.01, NS: Not significant.

**TABLE 3. Effect of interaction between flax cultivars and micro-nutrients on straw yield and related attributes.**

| Treatments | | Plant height (cm) | Technical length(cm) | Technical length(cm) | Straw yield plant$^{-1}$(g) |
|---|---|---|---|---|---|
| Cultivars | Micro-nutrients | 2015/2016 season | | 2016/2017 season | |
| | | * | * | ** | * |
| Sakha-1 | 0 ppm | 96.78 | 72.45 | 68.58 | 2.01 |
| Sakha-1 | 300 ppm | 105.80 | 81.38 | 83.00 | 3.33 |
| Sakha-1 | 600 ppm | 118.20 | 88.91 | 90.33 | 3.41 |
| Sakha-2 | 0 ppm | 92.35 | 63.49 | 64.83 | 2.15 |
| Sakha-2 | 300 ppm | 106.86 | 76.42 | 70.50 | 2.82 |
| Sakha-2 | 600 ppm | 116.26 | 81.74 | 78.25 | 2.88 |
| Giza-9 | 0 ppm | 83.04 | 61.58 | 60.17 | 1.45 |
| Giza-9 | 300 ppm | 88.54 | 64.25 | 65.75 | 1.93 |
| Giza-9 | 600 ppm | 92.59 | 65.58 | 69.35 | 2.57 |
| **LSD 0.05** | | **6.93** | **5.31** | **4.95** | **0.39** |

*P≤ 0.05, ** P ≤ 0.01, NS: Not significant.

TABLE 4. Seed yield attributes affected by flax cultivars and micro-nutrients foliar spraying in 2015/16 and 2016/17 seasons .

| Treatments | Number of branches plant$^{-1}$ | Fruiting Zone Length (cm) | Number of capsules plant$^{-1}$) | 1000 seed weight (g) | Seed yield plant$^{-1}$ (g) | Seed yield (kg fed$^{-1}$) | Oil yield ( kgfed$^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | **2015/2016 season** | | | |
| Cultivars (A) | * | * | ** | ** | * | NS | * |
| Sakha-1 | 5.09 | 26.01 | 18.31 | 8.84 | 1.50 | 630.03 | 250.85 |
| Sakha-2 | 7.33 | 31.27 | 22.11 | 9.63 | 1.88 | 754.68 | 310.37 |
| Giza-9 | 3.33 | 24.25 | 15.11 | 8.20 | 1.32 | 513.79 | 201.90 |
| **LSD 0.05** | **2.53** | **4.78** | **2.33** | **0.39** | **0.36** | **-** | **88.13** |
| Micro-nutrients (B) | ** | ** | ** | ** | ** | ** | ** |
| 0ppm | 3.99 | 24.88 | 14.61 | 8.03 | 1.35 | 481.32 | 184.63 |
| 300ppm | 5.40 | 26.38 | 19.03 | 8.93 | 1.56 | 658.30 | 265.82 |
| 600ppm | 6.36 | 30.28 | 21.89 | 9.70 | 1.80 | 758.87 | 312.66 |
| **LSD 0.05** | **1.00** | **2.15** | **1.84** | **0.54** | **0.09** | **32.98** | **11.10** |
| | | | | **2016/2017 season** | | | |
| Cultivars (A) | ** | NS | ** | NS | ** | NS | NS |
| Sakha-1 | 5.03 | 26.06 | 17.11 | 8.30 | 1.38 | 626.84 | 247.90 |
| Sakha-2 | 7.21 | 30.28 | 21.67 | 9.36 | 1.86 | 738.85 | 298.83 |
| Giza-9 | 4.32 | 25.54 | 14.51 | 8.00 | 1.25 | 508.19 | 197.53 |
| **LSD 0.05** | **1.35** | **-** | **3.33** | **-** | **0.17** | **-** | **-** |
| Micro-nutrients (B) | ** | * | ** | ** | ** | ** | ** |
| 0ppm | 4.16 | 25.44 | 13.29 | 7.07 | 1.16 | 506.89 | 194.37 |
| 300ppm | 5.81 | 26.67 | 18.29 | 8.81 | 1.58 | 642.23 | 254.23 |
| 600ppm | 6.58 | 29.77 | 21.71 | 9.77 | 1.75 | 724.77 | 295.66 |
| **LSD 0.05** | **0.47** | **3.03** | **1.89** | **0.45** | **0.19** | **53.87** | **21.74** |

*P≤ 0.05, ** P ≤ 0.01, NS: Not significant.

TABLE 5. Effect of interaction between flax cultivars and micro-nutrients on seed yield and related attributes.

| Treatments | | Number of Capsules plant$^{-1}$ | Seed yield (kg fed$^{-1}$) | Oil yield (kg fed$^{-1}$) | Number of Capsules plant$^{-1}$ | 1000 Seed weight (g) | Seed yield (kg fed$^{-1}$) | Oil yield (kg fed$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Cultivars | Micro-nutrients | 2015/2016 season | | | 2016/2017 season | | | |
| | | ** | ** | ** | ** | * | ** | ** |
| Sakha-1 | 0ppm | 15.92 | 482.25 | 180.10 | 14.96 | 6.94 | 544.33 | 208.42 |
| Sakha-1 | 300ppm | 20.25 | 642.84 | 257.58 | 17.15 | 8.26 | 614.01 | 242.77 |
| Sakha-1 | 600ppm | 18.75 | 764.99 | 314.86 | 19.22 | 9.69 | 722.19 | 292.51 |
| Sakha-2 | 0ppm | 15.75 | 541.54 | 212.28 | 13.39 | 7.42 | 536.56 | 209.07 |
| Sakha-2 | 300ppm | 21.58 | 814.75 | 336.89 | 22.83 | 9.86 | 777.55 | 311.82 |
| Sakha-2 | 600ppm | 29.00 | 907.74 | 381.93 | 28.78 | 10.80 | 902.45 | 375.60 |
| Giza-9 | 0ppm | 12.17 | 420.17 | 161.52 | 11.51 | 6.85 | 439.79 | 165.62 |
| Giza-9 | 300ppm | 15.25 | 517.33 | 203.00 | 14.88 | 8.31 | 535.14 | 208.10 |
| Giza-9 | 600ppm | 17.92 | 603.87 | 241.19 | 17.13 | 8.83 | 549.65 | 218.88 |
| **LSD 0.05** | | **3.18** | **57.12** | **19.23** | **3.27** | **0.77** | **93.31** | **37.65** |

*P≤ 0.05, ** P ≤ 0.01, NS: Not significant.

**TABLE 6. Mean values of seed quality affected by flax cultivars and micro-nutrients foliar application in 2015/16 and 2016/17 seasons.**

| Treatments | Mn mg/100g | Fe mg/100g | Zn mg/100g | Oil % |
|---|---|---|---|---|
| | | **2015/2016 season** | | |
| Cultivars (A) | ** | | * | ** |
| Sakha-1 | 5.67 | 15.36 | 9.14 | 39.52 |
| Sakha-2 | 7.57 | 18.89 | ** | 40.88 |
| Giza-9 | 4.87 | 13.11 | 8.08 | 39.17 |
| **LSD 0.05** | **0.47** | **2.39** | **2.00** | **0.66** |
| Micro-nutrients (B) | ** | ** | ** | ** |
| 0ppm | 4.63 | 12.40 | 7.70 | 38.33 |
| 300ppm | 5.99 | 15.80 | 9.59 | 40.18 |
| 600ppm | 7.49 | 19.15 | 11.14 | 41.07 |
| **LSD 0.05** | **1.12** | **0.97** | **0.81** | **0.71** |
| | | **2016/2017 season** | | |
| Cultivars (A) | ** | * | ** | **NS** |
| Sakha-1 | 5.19 | 15.02 | 8.33 | 39.38 |
| Sakha-2 | 6.16 | 17.09 | 9.70 | 40.24 |
| Giza-9 | 4.22 | 13.06 | 7.06 | 38.89 |
| **LSD 0.05** | **0.39** | **2.87** | **0.89** | **-** |
| Micro-nutrients (B) | ** | ** | ** | ** |
| 0ppm | 4.05 | 12.18 | 7.08 | 38.32 |
| 300ppm | 5.28 | 15.01 | 8.09 | 39.52 |
| 600ppm | 6.24 | 17.99 | 9.91 | 40.67 |
| **LSD 0.05** | **0.49** | **1.37** | **0.51** | **0.54** |

*P≤ 0.05, ** P ≤ 0.01, NS: Not significant.

*Micro-nutrients foliar application*

Table 6 cleared that 600ppm micro-nutrients foliar application resulted in an increase on seed Mn, Fe and Zn concentration by 61.77, 54.44 and 44.68% in the 1st season and by 54.07, 47.70 and 39.97% in the 2nd one with compared to the control treatment. In presented study, micro-nutrients foliar application (Mn, Fe and Zn) resulted in an increase in the seed oil percent by 7.15 and 6.13%, in the 1st and 2nd season, respectively. Flax seed of Mn, Fe and Zn content was ranged from 4.05 to 7.49 for Mn, 12.40 to 19.15 for Fe and 7.06 to 11.21 for Zn mg100g$^{-1}$. These results are supported by the finding of Amberger (1991), Mousa et al. (2010), Khalifa et al. (2011), Nofal et al. (2011), Bakry et al. (2012), Esmail et al. (2014), Tahir et al. (2014), Bakry et al. (2015).

*Effect of the interaction*

The interaction between flax cultivars and micro-nutrients foliar spraying was significant on Mn in the 1st season and Zn in the 2nd season (Table 7). The highest mean value of seed oil % was achieved when Sakh-2 cultivar sprayed with 600 ppm. Foliar spraying of the high rate of Mn, Fe and Zn micro-nutrients increased seed oil % of all cultivars when compared with the rate of 300ppm or control treatment. Seed element content, i.e., Mn, Fe and Zn, were significantly affected by AxB interaction. Moreover, Sakha-2 cultivar sprayed by 600ppm micro-nutrients foliar spraying gave the highest mean values.

*Yield analysis*

*Straw yield*

The correlation coefficients data are listed in Table 8. Positive and highly statistic (P≤ 0.01) correlations coefficients were obtained between straw yield (ton fed$^{-1}$) and each of plant height (r= 0.674**, 0.696**), technical stem length (r= 0.701**, 0.733**), stem diameter (r= 0.740**, 0.545**), number of branches plant$^{-1}$ (0.526**, 0.524**) and straw yield plant$^{-1}$ (r= 0.698**, 0.802**) in the 1st and 2nd seasons, respectively. Also, positive and highly significant correlation coefficient were seen between plant height and technical length (r= 0.947**, 0.923**). According to stepwise regression analysis, results in Table 9 explained that, there are 2 traits i.e., stem diameter and straw yield plant$^{-1}$ in 2015/2016 season and straw yield plant$^{-1}$ in 2016/2017 season, were significantly (P≤ 0.001) participant to variation in straw yield fed$^{-1}$.

*Seed yield*

Table 10 showed that the seed yield (kg fed$^{-1}$) and number of fruiting branches plant$^{-1}$, fruiting zone length (cm), number of capsules plant$^{-1}$, seed index (g), seed yield plant$^{-1}$, Mn mg 100g$^{-1}$, Fe mg 100g$^{-1}$ and Zn mg 100g$^{-1}$ were computed to expected the relationship of the actual traits interest. Remarkable and highly significant (P≤ 0.01) coefficients of correlation were found among seed yield and all its attributes and ranged from r= 0.700** to r= 0.862**. Stepwise regression results, in Table 11 elucidated that, there are two traits, i.e., seed index and number of fruiting branches plant$^{-1}$ in 2015/2016 season and two ones, i.e., seed yield plant$^{-1}$ and number of capsules plant$^{-1}$ in 2016/2017 season, were statistically (P≤ 0.001) participated to variation in seed yield kg fed$^{-1}$.

**TABLE 7. Effect of interaction between flax cultivars and micro-nutrients foliar spraying on seed quality.**

| Treatments | | Mn (mg/100g) | Oil % | Zn (mg/100g) |
|---|---|---|---|---|
| Cultivars | Micro-nutrients | 2015/2016 season | | 2016/2017 season |
| | | ** | * | * |
| Sakha-1 | 0 ppm | 5.08 | 37.32 | 7.40 |
| Sakha-1 | 300 ppm | 5.10 | 40.05 | 8.13 |
| Sakha-1 | 600 ppm | 6.83 | 41.17 | 9.47 |
| Sakha-2 | 0 ppm | 4.78 | 39.21 | 7.72 |
| Sakha-2 | 300 ppm | 7.17 | 41.36 | 9.43 |
| Sakha-2 | 600 ppm | 10.75 | 42.08 | 11.94 |
| Giza-9 | 0 ppm | 4.02 | 38.44 | 6.13 |
| Giza-9 | 300 ppm | 5.70 | 39.12 | 6.72 |
| Giza-9 | 600 ppm | 4.90 | 39.96 | 8.32 |
| **LSD 0.05** | | **1.94** | **1.22** | **0.88** |

*P≤ 0.05, ** P ≤ 0.01, NS: Not significant.

**TABLE 8. Simple correlation coefficient matrix of straw yield (ton fed$^{-1}$) and other related traits estimated in 2015/2016 and 2016/2017 season.**

| Characters | Plant height (cm) | | Technical stem length (cm) | | Stem diameter (cm) | | Number of branches/plant | | Straw yield/ plant (g) | | Straw yield kg/fed | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015/ 2016 | 2016/ 2017 | 2015/ 2016 | 2016/ 2017 | 2015/ 2016 | 2016/ 2017 | 2015/ 2016 | 2016/ 2017 | 2015/ 2016 | 2016/ 2017 | 2015/ 2016 | 2016/ 2017 |
| Plant height | 1 | 1 | 0.947** | 0.923** | 0.733** | 0.664** | 0.389* | 0.398* | 0.695** | 0.815** | 0.674** | 0.696** |
| Technical length | | | 1 | 1 | 0.647** | 0.520** | 0.339 | 0.198 | 0.684** | 0.821** | 0.701** | 0.733** |
| Stem diameter | | | | | 1 | 1 | 0.397* | 0.749** | 0.549** | 0.655** | 0.740** | 0.545** |
| Number of branches/ plant | | | | | | | 1 | 1 | 0.526** | 0.524** | 0.3650 | 0.469* |
| Straw yield/ plant | | | | | | | | | 1 | 1 | 0.698** | 0.802** |
| Straw yield kg/fed | | | | | | | | | | | 1 | 1 |

* Correlation coefficient is significant at P≤ 0.05.
** Correlation coefficient is significant at P≤ 0.01.

**TABLE 9. Correlation coefficient (r), coefficient of determination ($R^2$) and standard error of the estimates (SEE) for predicting straw yield (kg $fed^{-1}$) in 2015/2016 and 2016/2017 seasons.**

| Season | R | $R^2$ | SEE | Sig. | Fitted equation |
|---|---|---|---|---|---|
| 2015/2016 | 0.819 | 0.670 | 0.305 | ** | Straw yield (ton $fed^{-1}$) =0.795+0.744 stem diameter +0.348 straw yield $plant^{-1}$ |
| 2016/2017 | 0.802 | 0.644 | 0.371 | ** | Straw yield (ton $fed^{-1}$) =1.168+0.726 straw yield $plant^{-1}$ |

**TABLE 10. Simple correlation coefficient matrix in 2015/2016 season (above diagonal line) and in 2016/2017 season (below diagonal line) of seed yield (kg $fed^{-1}$) and other related traits.**

| Characters | Number of fruiting branches/ plant | Fruiting zone length (cm) | Number of capsules/ plant | 1000 Seed weight (g) | Seed yield/ plant (g) | Mn mg/100g | Fe mg/100g | Zn mg/100g | Seed yield kg/fed |
|---|---|---|---|---|---|---|---|---|---|
| Number of fruiting branches/plant | 1 | 0.464* | 0.881** | 0.761** | 0.904** | 0.865** | 0.793** | 0.871** | 0.826** |
| Fruiting Zone Length (cm) | 0.728** | 1 | 0.551** | 0.657** | 0.519** | 0.623** | 0.537** | 0.554** | 0.442* |
| Number of capsules/ plant | 0.738** | 0.701** | 1 | 0.769** | 0.840** | 0.869** | 0.834** | 0.905** | 0.826** |
| 1000 Seed weight (g) | 0.743** | 0.812** | 0.884** | 1 | 0.769** | 0.815** | 0.799** | 0.796** | 0.715** |
| Seed yield/plant (g) | 0.801** | 0.709** | 0.805** | 0.811** | 1 | 0.797** | 0.840** | 0.866** | 0.837** |
| Mn mg/100g | 0.665** | 0.732** | 0.803** | 0.739** | 0.693** | 1 | 0.838** | 0.896** | 0.766** |
| Fe mg/100g | 0.751** | 0.831** | 0.864** | 0.874** | 0.906** | 0.796** | 1 | 0.900** | 0.700** |
| Zn mg/100g | 0.809** | 0.736** | 0.864** | 0.790** | 0.800** | 0.768** | 0.837** | 1 | 0.831** |
| Seed yield kg/fed | 0.795** | 0.793** | 0.797** | 0.807** | 0.747** | 0.737** | 0.853** | 0.862** | 1 |

* Correlation coefficient is significant at $P \leq 0.05$.
** Correlation coefficient is significant at $P \leq 0.01$.

**TABLE 11. Correlation coefficient (r), coefficient of determination ($R^2$) and standard error of the estimates (SEE) for predicting seed yield (kg $fed^{-1}$) in 2015/2016 and 2016/2017 seasons.**

| Season | R | $R^2$ | SEE | Sig. | Fitted equation |
|---|---|---|---|---|---|
| 2015/2016 | 0.858 | 0.737 | 92.00 | ** | Seed yield (kg $fed^{-1}$)= -255.99+80.48 1000-seed weight +32.81 number of branches $plant^{-1}$ |
| 2016/2017 | 0.867 | 0.752 | 83.53 | ** | Seed yield (kg $fed^{-1}$)= 105.73+ 197.20 seed yield $plant^{-1}$ + 12.59 number of capsules $plant^{-1}$ |

## Conclusion

Eventually, it could be noticed that the straw, seed and oil yields of tested flax cultivars were significantly responded to foliar application of micro-nutrients. Sakha-2 cultivar showed its superiority in most seed yield traits, whereas Sakha-1 cultivar exceeded the other in straw yield characters. The highest rate of micro-nutrient gave the highest mean values for all studied traits. It seemed evident that Sakha-2 cultivar gave the best result when sprayed by the highest rate of micro-nutrient (600ppm $fed^{-1}$). There are two traits, i.e., 1000 seed weight and number of fruiting branches $plant^{-1}$in 2015/2016 season and two ones *i.e.,* seed yield $plant^{-1}$ and number of capsules $plant^{-1}$ in 2016/2017 season, were significantly ($P \leq 0.001$) participated to variation in seed yield kg $fed^{-1}$.

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## تقدير محصول القش والبذور والزيت لأصناف الكتان *Linum usitatissimum* L. تحت تطبيق الرش الورقى بالمنجنيز والحديد والزنك فى البيئة الجافة

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إجريت تجربتين حقليتين بمزرعة دمو، كلية الزراعة، جامعة الفيوم، مصر خلال عامى 2015/ 2016 و2017/2016 لدراسة تأثير الرش الورقى بعناصر المنجنيز والحديد والزنك على إنتاجية ثلاث أصناف من الكتان. وتم إستخدام القطع المنشقة مرة واحدة فى تصميم القطاعات كاملة العشوائية. تم وضع أصناف الكتان وهى سخا1، سخا 2، جيزة 9 فى القطع الرئيسية بينما وزعت ثلاث معدلات من العناصر الصغرى وهى صفر، 300 جزء فى المليون و 600 جزء فى المليون فى القطع الشقية. وكانت العناصر الصغرى فى صورEDTA .EDTA 14% Zn - EDDHSA 6% Fe - 13% Mn

وأظهرت النتائج المتحصل عليها:

- تفوق الصنف سخا 1 على باقى الأصناف فى محصول القش ومكوناته مثل إرتفاع النبات، الطول الفعال، محصول القش.
- فى حين أعطى الصنف سخا 2 أعلى القيم لقطر الساق وعدد الفروع للنبات وكذلك محصول البذور ومكوناته مثل عدد الفروع الثمرية، طول المنطقة الثمرية، عدد الكبسولات للنبات، وزن 1000 بذرة، محصول البذور والزيت.
- محتوى البذور من العناصر الصغرى والزيت كانت مرتفعة مع الصنف سخا 2 .
- أعطى الرش الورقى للعناصر الصغرى بمعدل 600 جزء فى المليون أعلى القيم معنويا لكل الصفات المدروسة خلال الموسمين عند مقارنته بمعاملة الكنترول أو 300 جزء فى المليون/فدان.
- أظهر تحليل الأنحدار لمحصول البذور إلى أن هناك صفتين هما وزن 1000 بذرة وعدد الفروع الثمرية/نبات فى عام 2016/2015 وصفتين هما محصول البذور/نبات و عدد كبسولات/نبات في العام 2017/2016 قد ساهمت بشكل كبير ($P \leq 0.001$) في الأختلاف في محصول البذور/فدان.