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Research Article
Effect of Mineral Nitrogen Fertilizer and Foliar Application of Yeast Extract on Some Flax Cultivars

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Abstract

Background and Objective: Flax plays an important role in the national economy because it has many uses, seeds for oil and stems for fiber. Mineral nitrogen fertilizers and foliar application of yeast extract are important for growth and yield. Yeast extract as a foliar application on plants is very safe for humans, animals and the environment. This study aimed to explore the effect of different mineral nitrogen fertilizer sources with or without foliar application of yeast extract on the growth, yield and seed quality of some flax cultivars. **Materials and Methods:** The effect of mineral nitrogen fertilizer with or without foliar application of yeast extract on growth and yield were investigated and chemical analysis for chlorophyll, some endogenous hormones, NPK, oil, protein and total carbohydrates were achieved. **Results:** Sakha 5 cultivar gave the highest number of fruiting branches per plant, number of capsules per plant, seed yield per plant and total chlorophyll content. Also, it had the highest oil and total carbohydrates content for flaxseed in the 1st season only. Sakha 3 had the tallest plant height, technical length and the heaviest fiber yield (t ha^{-1}) followed by Sakha 1. Also, results revealed that 75% urea with yeast extract had a superior effect on most studied characters followed by adding 100% urea. **Conclusion:** It's concluded that flax plants received 75% mineral nitrogen fertilizer (especially urea) with foliar application of yeast extract gave the highest productivity and seed quality.

Key words: Nitrogen fertilizers, urea, ammonium nitrate, ammonium sulphate, yeast, flax, yield and quality

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The flax (*Linum usitatissimum* L.) is a crop where it is grown for fiber and oil as well as many industrial and medical uses[1]. The percentage of oil in flax seeds ranged from 30-48%[2] and the protein ranged 20-30%[3]. Oil of flaxseed has a very healthy fatty acid, approximately 73% of polyunsaturated fatty acids, 18% of monounsaturated fat and 9% of saturated fat and is edible. Flaxseed meal is a source of protein used in the feed of livestock, it is the remaining after oil extraction[4].

We can increase flax productivity by selecting high yielding cultivars and enhancing the agricultural treatments[5,6]. The uses of nitrogen fertilizers are important for growth and higher yield[7]. Nitrogen in plant metabolism is constituent of nucleic and amino acids, cellular compounds and many cofactors[8]. There are many sources of mineral nitrogen fertilizers, which differ in their characteristics such as rates of solubility, volatilization and absorption by plants[9]. Nowadays urea is used as nitrogen fertilizer due to its high nitrogen content[10]. Great attention, under Egyptian conditions is being devoted to reducing the rates of mineral nitrogen fertilizers, environmental pollution and the cost of production via reducing rates of nitrogenous fertilizers by using biofertilized[11,12]. Therefore, it's very important to reduce the dependence of agricultural production on nitrogen fertilizer and decrease the adverse effect of nitrogen loss on the environment[13].

Recently, we can improve the productivity and quality of the plant, by using natural safe substances. However, its application enhances plant growth and physiological processes[14]. Yeast is used as a kind of biofertilizer in foliar application on plants or in soil fertilization[15]. Also, it is very safe for animals, humans and decreases environmental pollution via decreasing the cost and mineral fertilization. In this connection, yeast has a rich source of amino acids, enzymes, vitamins, phytohormones and minerals[16]. Growth, nutrition, yield and quality were improved due to yeast has an important role in releasing CO_2 which increases photosynthesis[17].

The present study was carried out to estimate the yield, its attributes and some physiological traits of flax cultivars with mineral nitrogen fertilizer sources with or without a foliar spray of yeast extract.

MATERIALS AND METHODS

Study area and experimental design: The present study was carried out at the experimental farm of Etay El-Baroud Agricultural Research Station (30°89' E, 30°65' N, 5 m above sea level) El-Beheira Governorate, Egypt during the two successive winter seasons 2018/2019 and 2019/2020 to study the effect of mineral nitrogen fertilizer sources with or without foliar application of yeast extract on yield, its attributes and some physiological traits of flax cultivars. Some physical and chemical properties of the experimental site during the two growing seasons were determined according to Carter and Gregorich[18] (Table 1).

Table 1: Physical and chemical properties of the experimental site during the two growing seasons of 2018-2019 and 2019-2020

Soil properties	2018	2019
Soil texture	Clay	Clay
Sand (%)	12.15	11.83
Silt (%)	33.62	34.80
Clay (%)	54.23	53.37
PH	8.20	8.10
Organic matter (%)	1.85	1.79
Available N (ppm)	40.00	53.00
Available P (ppm)	29.00	31.00
Available K (ppm)	290.00	239.00
EC dSm^{-1} (1:5)	2.23	2.21

A Field experiment was carried out in a split-plot design with four replications. The studied cultivars i.e., Sakha 1, Sakha 3 and Sakha 5 occupied the main plots. Whereas, fertilization treatments (urea (CH_4N_2O) 46.5%, ammonium nitrate (NH_4NO_3) 33.5% and ammonium sulphate ($(NH_4)_2SO_4$) 20.6% with or without foliar application of yeast extract (YE) were randomly distributed in the sub-plots.

Nitrogen fertilization treatments i.e., 100% urea, 100% ammonium nitrate, 100% ammonium sulphate (recommended dose = 150 kg mineral nitrogen ha^{-1}), 75% urea, 75% ammonium nitrate, 75% ammonium sulphate from the recommended dose, 75% urea+yeast, 75% ammonium nitrate+yeast and 75% ammonium sulphate+yeast. Where yeast extract was prepared according to Hafez *et al.*[17] and sprayed as 10 g L^{-1} at 60 and 75 days after sowing (DAS). The sub-plot area was 6 m^2 with 3 m long and 2 m wide. Flax seeds were sown on November 5th 2018 and 7th 2019. Flax was harvested on April 9th and 13th in both seasons, respectively.

Plant materials: Flax seeds were obtained from the Field Crops Research Institute, Agricultural Research Center, Giza, Egypt and were sown by using the broadcasting method at the recommended rate of 145 kg ha^{-1}.

Management: All plots received phosphorous fertilizer in the form of calcium superphosphate (15.5% P_2O_5) at a rate of 240 kg ha^{-1} and potassium fertilizer in the form of potassium sulphate (48% K_2O) at the rate of 120 kg ha^{-1} were added during land preparation. The mineral nitrogen fertilizer was

applied in two equal doses at the rate of 150 kg ha^{-1} (according to previous treatments for all nitrogen sources) before the 1st and 2nd irrigation. Other cultural practices were applied according to the recommendations of the Egyptian Field Crops Research Institute for the commercial production of flax. The preceding summer crop was maize in both seasons.

Studied characters

Shoot dry weight: Shoot dry weight was determined at 90 and 120 days, (an average of 10 randomly chosen and guarded plants). Plant samples were dried in an electric oven with a drift fan at 70°C for 48 hrs, till constant dry weight.

Yield and its attributes: Plant height (cm), technical length (cm), fruiting zone (cm), number of fruiting branches, number of capsules per plant, number of seeds per capsules, 1000-seed weight (g) and seed yield per plant (g) (average of 10 randomly chosen and guarded plants). Seed and fiber yields (t ha^{-1}): Conversion of seed and fiber yields obtained from each sub-plot to its equivalent seed and fiber yields (t ha^{-1}).

Chlorophyll content: Chlorophyll a, b and a+b (mg g^{-1} fresh leaves) was determined after 90 days from sowing, according to Lichtenthaler and Buschmann[19].

Endogenous hormones: Indole acetic acid (IAA), gibberellic acid (GA_3) and cytokinin content (mg g^{-1} fresh leaves) were determined in flax leaves at 90 days old according to Wang *et al.* [20].

Nitrogen, phosphorus and potassium (%) in flax seeds: Nitrogen, phosphorus and potassium percentages were determined in flax seeds. Total nitrogen content (N) was determined using the Micro-Kjeldahl method described by Motsara and Roy[21]. Phosphorus (P) was determined colourimetrically by method Motsara and Roy[21] and potassium (K) were determined by using a flame photometer according to Junsomboon and Jakmunee[22].

Seed oil (%): Oil content in flax seeds was determined by extracting using the Soxhlet apparatus according to the method described by Das *et al.*[23].

Seed protein percentage (%): Total nitrogen was determined according to Motsara and Roy[21]. Protein content was calculated by multiplying the values of total nitrogen by 6.25.

Seed total carbohydrates (%): Total carbohydrates in dried flax seeds were determined using the phenol sulphuric method according to Albalasmeh *et al.*[24].

Farmer's benefit: The net return of flax ha^{-1} was calculated by subtracting the total cost of flax from the total return of flax yield ha^{-1} (seed+straw). By using the average price for the two seasons, the price of flax was 1476 \$ t^{-1} (1273 dollars t^{-1} seed and 203 dollars t^{-1} straw). The above estimations were based on the prices determined by the Ministry of Egyptian Agriculture and Land Reclamation.

Statistical analysis: All data were subjected to the analysis of variance (ANOVA) for split-plot design followed by compared means with LSD at a 5% level of probability according to Snedecor and Cochran[25].

RESULTS AND DISCUSSION

Shoot dry weight: Table 2 indicated that, shoot dry weight $plant^{-1}$ was significantly differing by cultivars at 90 and 120 days from sowing in the 1st season. Sakha 5 gave the heaviest shoot dry weight per plant (2.02 and 3.17 g) at 90 and 120 days from sowing, respectively in the 1st season. El-Borhamy *et al.*[26] found that flax genotypes differed in their genetic factor and their response to environmental conditions.

Nitrogen fertilizer sources with or without foliar application of yeast extract significantly affected shoot dry weight per plant at 90 and 120 days after sowing in both growing seasons. When flax plants received 75% urea plus foliar spraying yeast extract gave the heaviest shoot dry weight per plant (2.40 and 2.45 g) and (3.60 and 3.84 g) at 90 and 120 days after sowing in both seasons, respectively. Soethe *et al.*[27] showed that urea exceeded ammonium sulphate on flax dry weight per plant. The nitrogenous fertilizers especially urea improved the growth of flax plants[28]. Nitrogen is an essential element for building up protoplasm and protein which is important for meristematic activity and cell division increased flax growth[29]. The addition of mineral nitrogen fertilizer especially urea with yeast extract increased plant dry weight[30]. Foliar application of yeast extract increased shoot dry weight of flax plants[6] through its basic functions i.e. CO_2 production and formation of natural hormones also contains amino acids and vitamins B[31].

Yield and its attributes: Table 3 and 4 indicated that plant height, technical length, number of fruiting branches per plant, number of capsules per plant, 1000-seed weight

Table 2: Shoot dry weight of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	Shoot dry weight per plant at 90 days (g)		Shoot dry weight per plant at 120 days (g)	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars				
Sakha 1	1.82^{b}	1.98	2.93^{b}	3.13
Sakha 3	1.93^{a}	2.02	3.05^{ab}	3.16
Sakha 5	2.02^{a}	2.03	3.17^{a}	3.27
L.S.D (0.05)	0.10	NS	0.14	NS
Fertilizations				
100%				
Urea	2.26^{ab}	2.37^{a}	3.47^{a}	3.51^{ab}
Nitrate	2.05^{bc}	2.36^{a}	3.10^{b}	3.19^{b}
Sulphate	1.95^{c}	2.02^{b}	3.02^{b}	3.19^{b}
75%				
Urea	1.61^{d}	1.63^{c}	2.54^{c}	2.71^{c}
Nitrate	1.49^{de}	1.46^{cd}	2.51^{c}	2.71^{c}
Sulphate	1.32^{e}	1.33^{d}	2.42^{c}	2.64^{c}
75%				
Urea+yeast	2.40^{a}	2.45^{a}	3.60^{a}	3.84^{a}
Nitrate+yeast	2.19^{abc}	2.26^{ab}	3.49^{a}	3.52^{ab}
Sulphate+yeast	2.02^{bc}	2.20^{ab}	3.27^{ab}	3.37^{b}
L.S.D (0.05)	0.21	0.25	0.25	0.33

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

Table 3: Yield and its attributes of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	Plant height (cm)		Technical length (cm)		Fruiting zone (cm)		No. of fruiting branches per plant	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars								
Sakha 1	93.0^{a}	99.3^{a}	81.4^{b}	87.0^{a}	11.5^{a}	12.3	4.59^{b}	5.15^{b}
Sakha 3	93.8^{a}	98.3^{a}	83.8^{a}	87.1^{a}	10.0^{b}	11.1	4.11^{c}	5.56^{b}
Sakha 5	85.5^{b}	91.9^{b}	73.5^{c}	79.9^{b}	12.0^{a}	12.0	5.00^{a}	6.37^{a}
L.S.D (0.05)	1.0	3.1	1.0	2.2	1.3	NS	0.37	0.67
Fertilizations								
100%								
Urea	100.1^{a}	106.9^{a}	88.1^{a}	90.9^{b}	12.0	16.0^{a}	5.33^{a}	6.56^{abc}
Nitrate	92.7^{b}	98.9^{bc}	82.4^{b}	87.1^{c}	10.2	11.8^{b}	4.67^{abc}	5.67^{abcd}
Sulphate	90.4^{b}	95.9^{c}	79.1^{b}	85.7^{c}	11.3	10.2^{b}	4.44^{abc}	5.89^{abcd}
75%								
Urea	82.0^{c}	89.9^{d}	70.8^{c}	79.2^{d}	11.2	10.7^{b}	3.78^{bc}	5.00^{cd}
Nitrate	79.0^{c}	86.2^{e}	68.8^{c}	75.9^{e}	10.2	10.3^{b}	3.67^{c}	4.56^{d}
Sulphate	81.0^{c}	85.4^{e}	70.0^{c}	75.4^{e}	11.0	10.0^{b}	3.78^{bc}	4.33^{d}
75%								
Urea+yeast	101.1^{a}	101.0^{a}	89.9^{a}	94.1^{a}	11.2	12.9^{b}	5.56^{a}	7.22^{a}
Nitrate+yeast	98.2^{a}	100.0^{b}	86.8^{a}	87.7^{c}	11.4	12.3^{b}	5.11^{ab}	6.78^{ab}
Sulphate+yeast	92.3^{b}	98.2^{bc}	80.4^{b}	86.0^{c}	11.9	12.2^{b}	4.78^{abc}	5.22^{bcd}
L.S.D (0.05)	2.6	2.7	2.9	2.2	NS	2.3	0.91	1.15

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

and seed yield per plant were significantly affected by the cultivars in the two studied seasons, however, there were insignificant differences between the studied cultivars in the fruiting zone and numbers of seeds per capsule in the 2nd season. Sakha 5 cultivar gave the highest number of fruiting branches per plant (5.00 and 6.37), the number of capsules per plant (20.00 and 20.10) and seed yield per plant (1.06 and 1.11 g) in both studied seasons, respectively. Also, it gave the highest fruiting zone (12.00 cm) and the number of seeds per capsule (6.89) in the 1st season and the heaviest 1000-seed weight (7.56 g) in the 2nd season. However, Sakha 3 gave the highest plant height (93.8 cm) in the 1st season and (83.8 and 87.1 cm) for technical length in both seasons, respectively. Sakha 1 had the highest plant height (99.30 cm) and the heaviest 1000-seed weight (7.45 g) in the 1st season, respectively. These results are in harmony with those obtained by El-Borhamy *et al.*[26] and Omer and Mahmood[32].

Table 4: Yield and its attributes of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	No. of capsules per plant		No. of seeds per capsule		1000-seed weight (g)		Seed yield per plant (g)	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars								
Sakha 1	18.9^{a}	19.1^{ab}	6.56^{ab}	6.96	7.45^{a}	7.48^{a}	0.93^{b}	1.01^{b}
Sakha 3	16.8^{b}	17.7^{b}	6.11^{b}	6.48	7.03^{b}	7.26^{b}	0.89^{b}	0.90^{c}
Sakha 5	20.0^{a}	20.1^{a}	6.89^{a}	7.26	7.34^{a}	7.56^{a}	1.06^{a}	1.11^{a}
L.S.D (0.05)	1.4	1.8	0.55	NS	0.19	0.14	0.05	0.04
Fertilizations								
100%								
Urea	20.3^{ab}	20.7^{ab}	7.22^{a}	7.78^{a}	7.34^{ab}	7.70^{a}	1.03^{ab}	1.08^{a}
Nitrate	18.0^{cd}	18.7^{bc}	7.00^{ab}	7.78^{a}	7.34^{ab}	7.62^{a}	0.99^{bc}	1.07^{a}
Sulphate	17.6^{cd}	18.9^{bc}	6.33^{ab}	6.44^{ab}	7.42^{a}	7.53^{a}	0.98^{c}	1.07^{a}
75%								
Urea	17.3^{cd}	17.8^{c}	6.44^{ab}	7.11^{ab}	6.95^{b}	7.07^{b}	0.87^{d}	0.89^{b}
Nitrate	16.1^{d}	17.2^{c}	5.67^{b}	6.44^{ab}	7.00^{b}	7.06^{b}	0.88^{d}	0.88^{b}
Sulphate	17.0^{cd}	17.4^{c}	5.89^{ab}	6.78^{ab}	6.98^{b}	7.09^{b}	0.88^{d}	0.88^{b}
75%								
Urea+yeast	21.6^{a}	21.8^{a}	7.33^{a}	6.89^{ab}	7.59^{a}	7.68^{a}	1.06^{a}	1.08^{a}
Nitrate+yeast	20.3^{ab}	19.6^{abc}	6.33^{ab}	6.78^{ab}	7.50^{a}	7.56^{a}	0.99^{bc}	1.06^{a}
Sulphate+yeast	18.8^{bc}	19.0^{bc}	6.44^{ab}	6.11^{b}	7.32^{ab}	7.58^{a}	0.95^{c}	1.05^{a}
L.S.D (0.05)	1.8	1.9	0.92	0.90	0.29	0.29	0.03	0.06

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

Table 5: Yield and its attributes of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	Seed yield (t ha^{-1})		Fiber yield (t ha^{-1})		Straw yield (t ha^{-1})		Biological yield (t ha^{-1})	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars								
Sakha 1	0.98	1.03^{b}	1.37^{b}	1.40^{b}	8.68	8.91	9.66	9.94
Sakha 3	0.92	0.95^{c}	1.47^{a}	1.52^{a}	9.44	9.56	10.36	10.51
Sakha 5	1.02	1.10^{a}	1.17^{c}	1.20^{c}	8.30	8.44	9.31	9.54
L.S.D (0.05)	NS	0.05	0.04	0.06	NS	NS	NS	NS
Fertilizations								
100%								
Urea	1.04^{a}	1.06^{a}	1.45^{a}	1.47^{a}	9.39^{ab}	9.59^{ab}	10.44^{a}	10.65^{ab}
Nitrate	1.02^{ab}	1.07^{a}	1.40^{a}	1.43^{a}	9.15^{abc}	9.09^{ab}	10.17^{ab}	10.16^{abc}
Sulphate	1.00^{ab}	1.09^{a}	1.40^{a}	1.41^{a}	8.81^{abc}	9.07^{ab}	9.81^{ab}	10.16^{abc}
75%								
Urea	0.90^{bc}	0.94^{b}	1.19^{b}	1.20^{b}	8.25^{bc}	8.31^{b}	9.15^{b}	9.25^{c}
Nitrate	0.90^{bc}	0.93^{b}	1.16^{b}	1.21^{b}	8.15^{c}	8.55^{ab}	9.05^{b}	9.47^{bc}
Sulphate	0.85^{c}	0.89^{b}	1.13^{b}	1.18^{b}	8.17^{c}	8.28^{b}	9.02^{b}	9.17^{c}
75%								
Urea+yeast	1.05^{a}	1.11^{a}	1.47^{a}	1.51^{a}	9.52^{a}	9.87^{a}	10.58^{a}	10.98^{a}
Nitrate+yeast	1.00^{ab}	1.10^{a}	1.45^{a}	1.47^{a}	9.15^{abc}	9.13^{ab}	10.15^{ab}	10.22^{abc}
Sulphate+yeast	0.99^{ab}	1.05^{a}	1.40^{a}	1.46^{a}	8.62^{abc}	8.84^{ab}	9.62^{ab}	9.88^{abc}
L.S.D (0.05)	0.08	0.09	0.08	0.07	0.78	0.88	0.78	0.90

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

Concerning different nitrogen fertilizer sources with or without foliar application of yeast extract significantly affected the previous traits except for the fruiting zone in the 1st season only. In this regard, 75% urea plus a foliar spray of yeast extract had a superior effect on most studied traits followed by 100% urea. On the contrary, the lowest values of these traits were obtained from plants that received the lowest nitrogen fertilizer. Fertilizing flax plants with mineral nitrogen increased yield and its related traits[12,33,34]. Soethe *et al.*[27] found that urea as a nitrogen source had a positive influence on flax productivity. Nitrogen is a major input in crop production and balanced nitrogen fertility is required to improve flax yield and quality[35]. The addition of mineral nitrogen fertilizer and foliar application with yeast extract enhances yield and its traits[31,36].

Seed yield per plant was significantly affected by the interaction between flax cultivars under study and different sources of mineral nitrogen fertilizer with or without foliar spraying yeast extract in the two studied seasons (Fig. 1a-b).

Table 5 indicated that significant differences among flax cultivars in seed yield in the 2nd season and fiber yield in both seasons. Data illustrated that Sakha 5 cv. gave

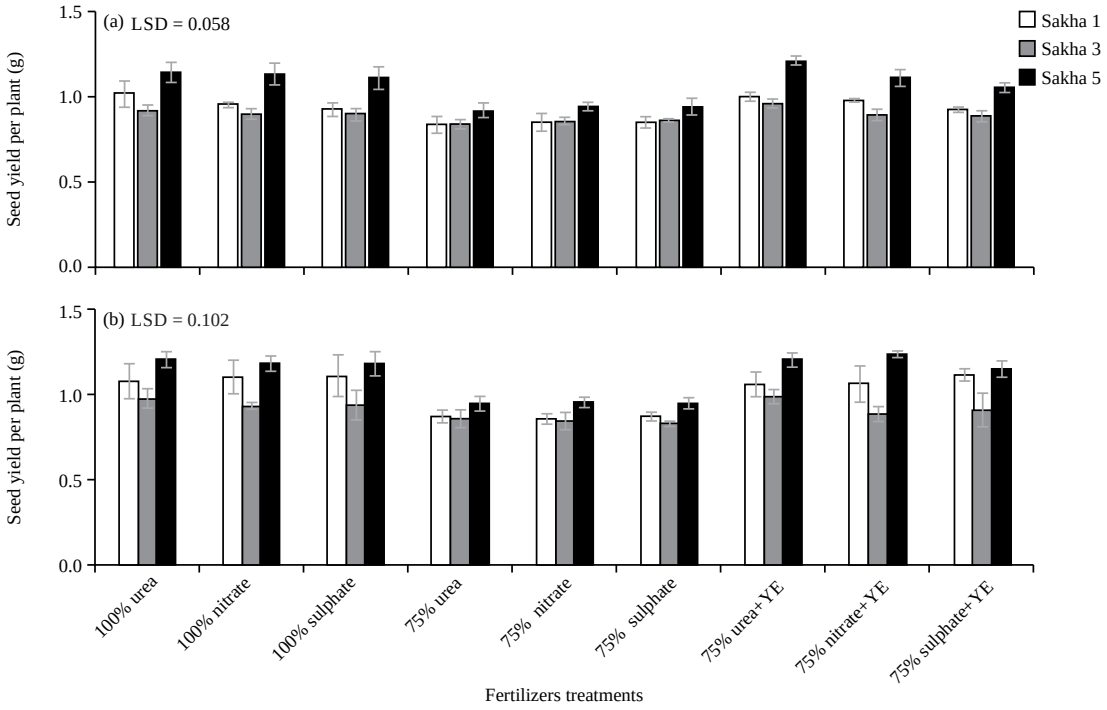

Fig. 1(a-b): Interaction between flax cultivars and fertilization on (a) Seed yield per plant in 2018/2019 and (b) 2019/2020 seasons
YE: Yeast extract

the heaviest seed yield (1.10 t ha^{-1}) in the 2nd season, while Sakha 3 cultivar gave the heaviest fiber yield (1.47 and 1.52 t ha^{-1}) followed by Sakha 1 (1.37 and 1.40 t ha^{-1}) in the two seasons, respectively. These results are in harmony with those obtained by Bakry *et al.*[37] and El-Borhamy *et al.*[26].

Seed, fiber, straw and biological yields t ha^{-1} were significantly affected by fertilization treatments in both seasons. 75% urea plus foliar spraying yeast extract had a superior effect on seed yield (1.05 and 1.11 t ha^{-1}), fiber yield (1.47 and 1.51 t ha^{-1}), straw yield (9.52 and 9.87 t ha^{-1}) and biological yield (10.58 and 10.98 t ha^{-1}) in the two seasons, respectively followed by 100% urea. The addition of mineral nitrogen fertilizer with yeast extract increased plant productivity[30,31,38]. Amino acids and vitamins in yeast extract increased the metabolic process and improve the growth which in turn reflected on increasing the productivity[15].

Chlorophyll content: Table 6 showed that flax cultivars and nitrogen fertilization treatments had a significant effect on chlorophyll content (a, b and a+b) in the two growing seasons. Sakha 5 gave the highest chlorophyll-a (1.463 and 1.540), chlorophyll b (0.879 and 0.901) and chlorophyll a+b (2.342 and 2.442) in the two seasons, respectively followed by Sakha 3, whereas Sakha 1 had higher chlorophyll-a in the 2nd season than Sakha 3 with average (1.498). Similar results were obtained by Nofal *et al.*[38].

Application of 75% from urea, ammonium nitrate and ammonium sulphate with foliar spray of yeast extract or 100 % recorded the maximum increase in chlorophyll a, b and a+b compared with 75% from different nitrogen fertilizer sources. The highest chlorophyll content was observed with urea followed by ammonium nitrate and the lowest with ammonium sulphate. In this regard, the increase in nitrogen rate increased chlorophyll content might be due to the role of mineral nitrogen in chlorophyll formation[29]. The addition of urea or ammonium sulphate with foliar spray of yeast extract increased total chlorophyll[36].

Moreover, foliar application of yeast extract increased the enzymes related to the photosynthetic process that resulted in improving uptake of iron and magnesium as well as other nutrients which are important for chlorophyll biosynthesis[39,40].

The interaction between flax cultivars and nitrogen fertilization treatments had a significant effect on chlorophyll a, b and a+b content in the two growing seasons (Fig. 2a-e).

Endogenous hormones: Table 7 revealed that the flax cultivars under study had a significant effect on gibberellic acid (GA_3) in the 1st season and cytokinin in the two studied

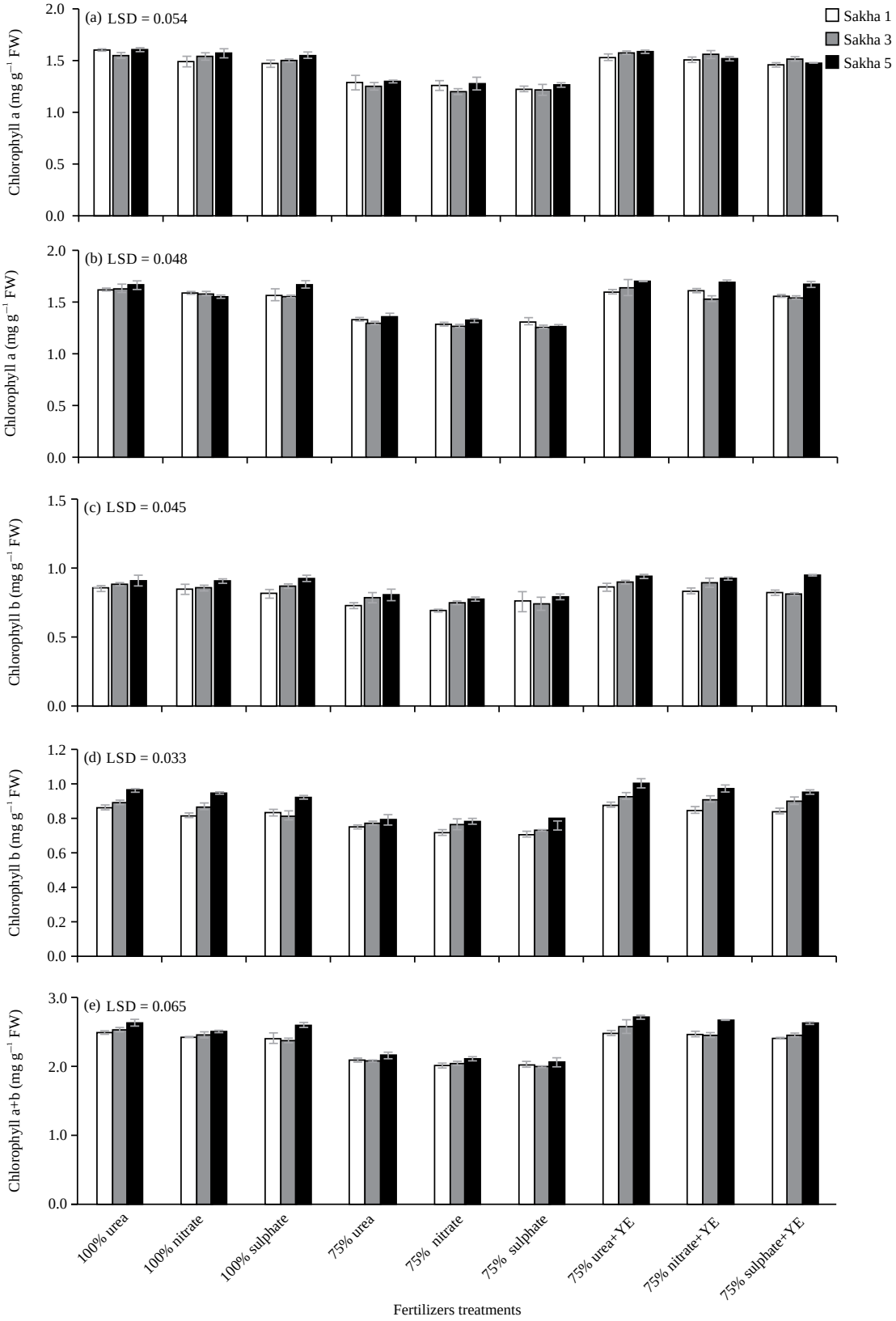

Fig. 2(a-e): Interaction between cultivars and fertilization on (a, b) chlorophyll a, (c, d) chlorophyll b, in 1st and 2nd seasons, and (e) chlorophyll a+b in 2nd season

YE: Yeast extract

Table 6: Chlorophyll content of flax cultivars (mg g^{-1} fresh leaves) as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	Chlorophyll a		Chlorophyll b		Chlorophyll a+b	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars						
Sakha 1	1.427^{b}	1.498^{b}	0.799^{c}	0.805^{c}	2.226^{c}	2.303^{b}
Sakha 3	1.435^{b}	1.479^{c}	0.830^{b}	0.841^{b}	2.265^{b}	2.320^{b}
Sakha 5	1.463^{a}	1.540^{a}	0.879^{a}	0.901^{a}	2.342^{a}	2.442^{a}
L.S.D (0.05)	0.015	0.015	0.017	0.008	0.030	0.017
Fertilizations						
100%						
Urea	1.587^{a}	1.637^{a}	0.879^{ab}	0.904^{b}	2.466^{a}	2.541^{b}
Nitrate	1.536^{bc}	1.574^{b}	0.867^{ab}	0.876^{c}	2.402^{b}	2.450^{d}
Sulphate	1.508^{cd}	1.597^{b}	0.868^{ab}	0.854^{d}	2.376^{bc}	2.451^{d}
75%						
Urea	1.280^{e}	1.330^{c}	0.771^{c}	0.770^{e}	2.051^{d}	2.100^{e}
Nitrate	1.247^{f}	1.292^{d}	0.737^{d}	0.753^{ef}	1.983^{e}	2.046^{f}
Sulphate	1.238^{f}	1.276^{d}	0.762^{cd}	0.746^{f}	2.000^{e}	2.021^{f}
75%						
Urea+yeast	1.567^{ab}	1.646^{a}	0.898^{a}	0.934^{a}	2.464^{a}	2.580^{a}
Nitrate+yeast	1.530^{bc}	1.609^{b}	0.881^{ab}	0.909^{b}	2.411^{b}	2.518^{bc}
Sulphate+yeast	1.486^{d}	1.590^{b}	0.859^{b}	0.897^{b}	2.344^{c}	2.487^{cd}
L.S.D (0.05)	0.031	0.028	0.026	0.019	0.041	0.038

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

Table 7: IAA, GA_3 and cytokinin content of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	IAA (mg g^{-1} fresh leaves)		GA_3 (mg g^{-1} fresh leaves)		Cytokinin (mg g^{-1} fresh leaves)	
Treatments	2018/2019	2019/2020	2018/ 2019	2019/2020	2018/2019	2019/2020
Cultivars						
Sakha 1	0.751	0.805	1.241^{a}	1.243	1.448^{b}	1.634^{b}
Sakha 3	0.765	0.787	1.148^{b}	1.216	1.542^{a}	1.700^{a}
Sakha 5	0.733	0.761	1.185^{b}	1.199	1.543^{a}	1.549^{c}
L.S.D (0.05)	NS	NS	0.051	NS	0.023	0.021
Fertilizations						
100%						
Urea	0.878^{a}	0.877^{ab}	1.265^{b}	1.303^{b}	1.469^{bc}	1.632^{c}
Nitrate	0.803^{b}	0.811^{cd}	1.218^{bc}	1.239^{b}	1.486^{b}	1.600^{cd}
Sulphate	0.729^{c}	0.758^{d}	1.150^{c}	1.239^{b}	1.465^{bc}	1.570^{d}
75%						
Urea	0.661^{d}	0.705^{e}	0.991^{d}	0.968^{c}	1.393^{d}	1.468^{e}
Nitrate	0.610^{de}	0.692^{e}	0.987^{d}	1.017^{c}	1.415^{cd}	1.481^{e}
Sulphate	0.599^{e}	0.651^{e}	0.962^{d}	0.980^{c}	1.412^{cd}	1.474^{e}
75%						
Urea+yeast	0.845^{ab}	0.913^{a}	1.420^{a}	1.424^{a}	1.671^{a}	1.842^{a}
Nitrate+yeast	0.815^{b}	0.844^{bc}	1.383^{a}	1.426^{a}	1.649^{a}	1.806^{ab}
Sulphate+yeast	0.806^{b}	0.807^{cd}	1.346^{a}	1.380^{a}	1.640^{a}	1.777^{b}
L.S.D (0.05)	0.051	0.047	0.071	0.067	0.050	0.045

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

seasons. Sakha 1 had the highest content of GA_3 (1.241) in the 1st season, also Sakha 3 had the same effect for cytokinin (1.700) in the 2nd season. These significant variations between cultivars were confirmed by Bakry *et al.*[41].

Endogenous hormones in flax leave are significantly affected by different nitrogen fertilizers sources with or without foliar application of yeast extract. Flax plants received 100% urea or 75% urea plus the foliar application of yeast extract gave the highest content for IAA in the two seasons. With respect of 75% urea plus yeast extract gave the maximum value followed by ammonium nitrate and ammonium sulphate which had a superior effect on GA_3 and cytokinin content in flax leaves for the two growing seasons. Yeast extract is a rich source of hormones, this leads to increased plant growth regulators such as auxin, cytokinin and gibberellin in plant tissues[6,42].

Interaction between flax cultivars and different mineral nitrogen fertilizer sources with or without a foliar spray of yeast extract significantly affected indole acetic acid (IAA), cytokinin in the two seasons and GA_3 in the 1st season (Fig. 3a-e).

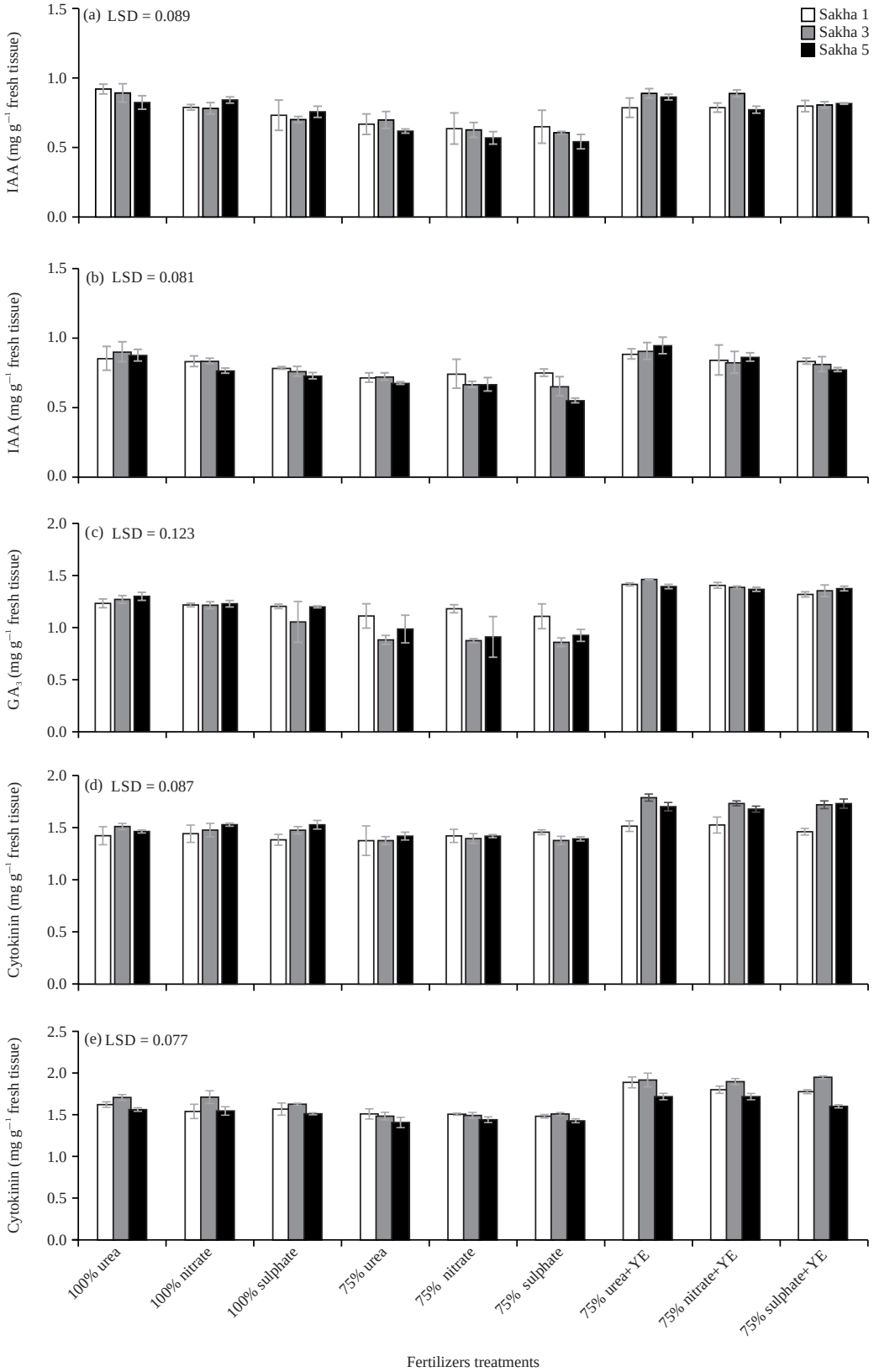

Fig. 3(a-e): Interaction between flax cultivars and fertilization on (a, b) IAA in 1st and 2nd seasons, (c) GA_3 in 1st season and (d, e) cytokinin in 1st and 2nd seasons.

YE: Yeast extract

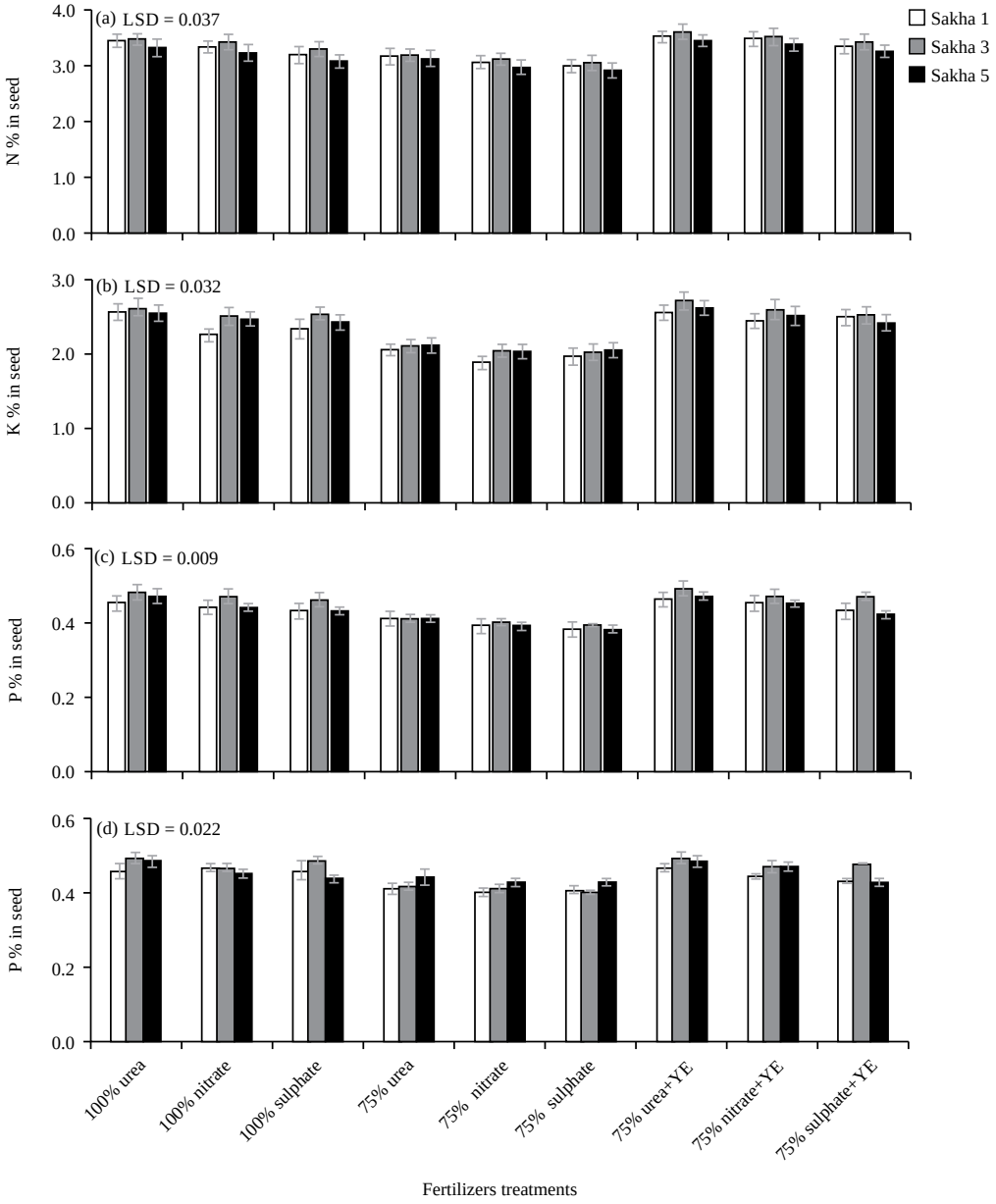

Fig: 4(a-d): Interaction between flax cultivars and fertilization on (a) N%, (b) K% in 1st season and (c, d) P% in seeds in 1st and 2nd seasons

YE: Yeast extract

Nitrogen, phosphorous and potassium content in flaxseed: There were significant differences between the studied cultivars in nitrogen (N) phosphorous (P) and potassium (K) content of flaxseed except for nitrogen content in the 2nd season (Table 8). Sakha 3 cultivar gave the highest nitrogen content (3.35%) in the 1st season, phosphorous (0.450 and 0.460%) and potassium (2.41 and 2.50%) followed by Sakha 5 cv. in the two seasons, respectively. The variations between flax cultivars may be due to the differences in origin, genetic constituent and growth habit[6].

Nitrogen fertilization treatments significantly affected NPK in flax seeds. 75% urea plus the foliar application of yeast extract produced the highest N% (3.53 and 3.67%), P (0.473 and 0.484%) and K (2.63 and 2.71%) in the two seasons, respectively followed by 75% ammonium nitrate plus yeast for N and 100% urea for P and K. Foliar application of yeast extract increased NPK content[15,43].

Concerning interaction between flax cultivars and different nitrogen fertilizer sources with or without a foliar spray of yeast extract significantly affect N, K in the 1st season and phosphorus percentage in the two seasons (Fig. 4a-d).

Table 8: N, P and K percentages in seeds of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	N (%)		P (%)		K (%)	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars						
Sakha 1	3.29^{b}	3.50	0.427^{b}	0.441^{c}	2.28^{c}	2.37^{b}
Sakha 3	3.35^{a}	3.54	0.450^{a}	0.460^{a}	2.41^{a}	2.50^{a}
Sakha 5	3.20^{c}	3.44	0.429^{b}	0.453^{b}	2.35^{b}	2.46^{a}
L.S.D (0.05)	0.01	NS	0.011	0.004	0.01	0.06
Fertilizations						
100%						
Urea	3.42^{c}	3.56^{a}	0.467^{b}	0.481^{a}	2.58^{b}	2.63^{ab}
Nitrate	3.34^{d}	3.53^{a}	0.450^{d}	0.464^{b}	2.41^{f}	2.49^{c}
Sulphate	3.19^{e}	3.47^{ab}	0.440^{e}	0.464^{b}	2.43^{e}	2.55^{bc}
75%						
Urea	3.17^{f}	3.34^{b}	0.410^{f}	0.426^{d}	2.09^{g}	2.16^{d}
Nitrate	3.05^{g}	3.32^{b}	0.393^{g}	0.416^{d}	1.99^{i}	2.13^{d}
Sulphate	2.99^{h}	3.35^{b}	0.384^{h}	0.414^{d}	2.01^{h}	2.18^{d}
75%						
Urea+yeast	3.53^{a}	3.67^{a}	0.473^{a}	0.484^{a}	2.63^{a}	2.71^{a}
Nitrate+yeast	3.46^{b}	3.64^{a}	0.457^{c}	0.464^{b}	2.51^{c}	2.63^{ab}
Sulphate+yeast	3.35^{d}	3.57^{a}	0.440^{e}	0.448^{c}	2.48^{d}	2.54^{bc}
L.S.D (0.05)	0.02	0.14	0.005	0.012	0.02	0.08

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

Table 9: Oil, protein and total carbohydrates content in seeds of flax cultivars as affected by mineral nitrogen fertilizer and a foliar spray of yeast extract in 1st and 2nd seasons

	Oil (%)		Protein (%)		Total carbohydrates (%)	
Treatments	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Cultivars						
Sakha 1	37.01^{b}	37.58	20.53^{b}	21.87	21.62^{b}	21.92
Sakha 3	36.99^{b}	37.48	20.94^{a}	22.14	21.43^{c}	21.84
Sakha 5	37.48^{a}	37.96	19.98^{c}	21.51	21.85^{a}	22.21
L.S.D (0.05)	0.23	NS	0.06	NS	0.04	NS
Fertilizations						
100%						
Urea	38.14^{b}	38.75^{ab}	21.38^{c}	22.23^{a}	22.34^{c}	22.71^{a}
Nitrate	37.64^{d}	38.37^{abc}	20.85^{d}	22.06^{a}	22.09^{e}	22.58^{a}
Sulphate	37.37^{f}	37.65^{c}	19.96^{e}	21.66^{ab}	21.89^{f}	22.51^{a}
75%						
Urea	36.03^{g}	36.46^{d}	19.78^{f}	20.89^{b}	20.59^{g}	20.93^{b}
Nitrate	35.78^{h}	36.34^{d}	19.09^{g}	20.74^{b}	20.06^{h}	20.36^{b}
Sulphate	35.63^{i}	36.17^{d}	18.69^{h}	20.97^{b}	20.05^{h}	20.43^{b}
75%						
Urea+yeast	38.37^{a}	39.13^{a}	22.06^{a}	22.93^{a}	22.98^{a}	23.25^{a}
Nitrate+yeast	37.97^{c}	38.42^{abc}	21.64^{b}	22.74^{a}	22.47^{b}	22.71^{a}
Sulphate+yeast	37.52^{e}	37.80^{bc}	20.91^{d}	22.34^{a}	22.23^{d}	22.44^{a}
L.S.D (0.05)	0.10	0.74	0.13	0.88	0.05	0.65

Means in the same column followed by the same letter(s) are not significant according to L.S.D at the probability of 0.05

Oil, protein and total carbohydrates content in flax seeds: Table 9 showed that the differences among cultivars were significant for oil, protein and total carbohydrates for flax seeds in the 1st season. Sakha 3 gave the highest protein content (20.94%) in the 1st season. As for oil and total carbohydrates content Sakha 5 produced the highest values (37.48 and 21.85%) in the 1st season, respectively. Similar results were obtained by El-Borhamy *et al.*[26].

Table 9 also, revealed that different nitrogen fertilizer sources with or without foliar application yeast extract had a significant effect on oil, protein and total carbohydrates

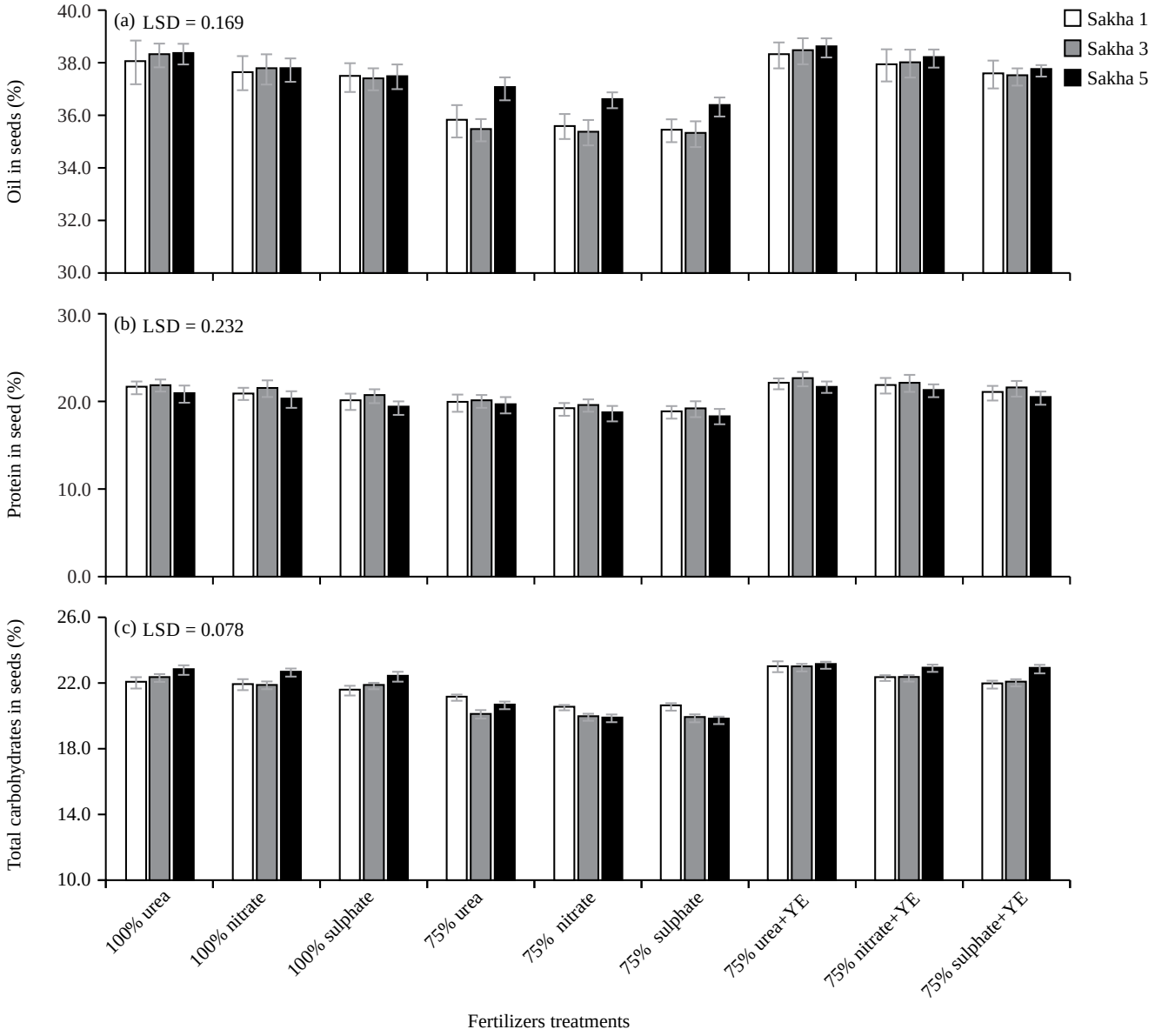

Fig. 5(a-c): Interaction between flax cultivars and fertilization on (a) oil%, (b) protein% and (c) total carbohydrates (%) in seeds in 1st season

YE: Yeast extract

content for flax seeds in the two seasons. About 75% urea plus a foliar spray of yeast extract increased oil (38.37 and 39.13%), protein (22.06 and 22.93%) and total carbohydrates content for flax seeds (22.98 and 23.25%) in the two studied seasons, respectively followed by 75% ammonium nitrate+yeast extract and 100% urea. The increase of mineral nitrogen fertilizer increased seed oil[29] and protein production[35]. Yeast extract contains amino acids and vitamins which increased the metabolic process and may improve the growth which in turn enhances the plant quality[15]. Yeast extract as foliar application increased the oil, protein and total carbohydrates content of flax seeds[6].

Concerning the interaction between flax cultivars and different mineral nitrogen fertilizer sources with or without a foliar spray of yeast extract recorded a significant effect on protein, oil and total carbohydrates percentage for flax seeds in the 1st season (Fig. 5a-c).

Table 10: Some economics of flax productivity ha^{-1} at various fertilization treatments (data over two seasons)

Treatments	Total costs ($ ha^{-1})	Return seed ($ ha^{-1})	Return straw ($ ha^{-1})	Total return ($ ha^{-1})	Net return ($ ha^{-1})
Sakha 1					
100%					
Urea	2240	1344	2100	3444	1204
Nitrate	2318	1338	2034	3372	1054
Sulphate	2491	1339	2002	3341	850
75%					
Urea	2178	1177	1884	3061	883
Nitrate	2236	1171	1897	3068	832
Sulphate	2366	1114	1875	2989	623
75%					
Urea+yeast	2186	1382	2137	3519	1333
Nitrate +yeast	2244	1345	2038	3383	1139
Sulphate +yeast	2374	1306	1965	3271	897
Sakha 3					
100%					
Urea	2240	1250	2236	3486	1246
Nitrate	2318	1245	2165	3410	1092
Sulphate	2491	1245	2130	3375	884
75%					
Urea	2178	1096	2003	3099	921
Nitrate	2236	1060	2017	3077	841
Sulphate	2366	1036	1992	3028	662
75%					
Urea+yeast	2186	1287	2276	3563	1377
Nitrate+yeast	2244	1251	2167	3418	1174
Sulphate+yeast	2374	1216	2111	3327	953
Sakha 5					
100%					
Urea	2240	1418	2019	3437	1197
Nitrate	2318	1412	1956	3369	1050
Sulphate	2491	1413	1925	3338	847
75%					
Urea	2178	1242	1813	3065	887
Nitrate	2236	1236	1825	3061	928
Sulphate	2366	1195	1803	2998	632
75%					
Urea+yeast	2186	1451	2053	3504	1318
Nitrate+yeast	2244	1419	1990	3409	1165
Sulphate+yeast	2374	1379	1916	3295	921

Farmer's benefit: Results in (Table 10) revealed that the total costs are affected by the applied treatments (average of the two growing seasons). The highest values of net return were obtained from the interaction between Sakha 3×75% urea with foliar application of yeast extract (1377 $ ha^{-1}) followed by Sakha 1(1333$ ha^{-1}) and Sakha 5 (1318 $ ha^{-1}) which might be due to the highest seed and straw yield[44].

CONCLUSION

It might be thus concluded that using the most suitable cultivars in the framework of balanced mineral nitrogen fertilization (especially 75% urea from recommended dose) with using the foliar application of yeast extract is recommendable for getting relatively high seed, fiber and straw yields. Also, it can improve seed quality and the net return of flax cultivars. Yeast is eco-friendly and less expensive. In this way, we can decrease mineral nitrogen fertilizer which helps to reduce environmental pollution and the cost of production.

SIGNIFICANCE STATEMENTS

This study discovered the superior yield and seed quality of flax under 75% urea fertilizer from recommended dose plus the foliar application of yeast extract that can be beneficial for farmers to generate better income and reduce environmental pollution.

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