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Cottonseed: protein, oil yields, and oil properties as influenced by potassium fertilization and foliar application of zinc and phosphorus

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RESUMEN

Efecto de la fertilización con potasio y de la aplicación foliar de zinc y fósforo en el rendimiento de aceite y proteína y en las propiedades del aceite de algodón.

Para maximizar la cantidad y calidad del valor nutricional de una semilla en términos de ácidos grasos y proteínas es necesario identificar los factores que los afectan y proponer métodos que favorezcan los resultados deseados a través de cambios o mejoras en las prácticas utilizadas. Los experimentos se llevaron a cabo en dos campañas sucesivas en el Agricultural Research Center, Giza, Egipto, en el cultivo "Giza 86" (*Gossypium barbadense* L.) para estudiar los efectos de la fertilización con potasio (a 0.0 y 47.7 kg por ha) y las aplicaciones foliares de zinc (a 0.0 y 57.6 g por ha, dos veces, 70 y 85 días después de la plantación) y fósforo (a 0.0, 576, 1152, y 1728 g por ha, dos veces, 80 y 95 días después de la plantación). La aplicación del potasio junto con la pulverización de las plantas con zinc y fósforo causó un incremento en el rendimiento del algodón, el índice de semilla, el contenido graso, los rendimientos de aceite y proteína, el contenido de materia insaponificable en el aceite y el contenido total de ácidos grasos insaturados (oleico y linoleico). Por el contrario estos tratamientos disminuyeron el índice de acidez, el índice de saponificación y el contenido de ácidos grasos saturados. La mayor concentración de fósforo produjo los mejores rendimientos de algodón, de índice de semilla, de los rendimientos de aceite y proteína, y de materia insaponificable en el aceite.

PALABRAS-CLAVE: Algodón - Ácidos grasos - Fósforo - Potasio - Propiedades del aceite-Zinc.

SUMMARY

Cottonseed: protein, oil yields, and oil properties as influenced by potassium fertilization and foliar application of zinc and phosphorus.

In maximizing the quantity and quality of a crop's nutritional value in terms of fatty acids and protein, it is necessary to identify the constraints which may affect it and to devise methods of overcoming them through the use of inputs or changes in management practices. Field experiments were conducted during two successive seasons at the Agricultural Research Center, Giza, Egypt, on the cotton cultivar "Giza 86" (*Gossypium barbadense* L.) to study the effects of potassium fertilization (at 0.0 and 47.4 kg of K ha^{-1}) and foliar application of zinc (at 0.0 and 57.6 g of Zn ha^{-1}, two times, 70 and 85 days after planting, "during square initiation and boll setting stage") and phosphorus (at 0.0, 576, 1152 and 1728 g of P ha^{-1}, two times, 80 and 95 days after planting) on cottonseed. The application of potassium along with spraying plants with zinc and phosphorus caused an increase in cottonseed yield ha^{-1}, seed index, seed oil content, oil and protein yields ha^{-1}, seed oil unsaponifiable matter and total unsaturated fatty acids (oleic and linoleic). However, those treatments resulted in a decrease in oil acid value, saponification value and total saturated fatty acids. The highest P concentration of 1728 g ha^{-1} gave the best values of cottonseed yield/ha, seed index, and seed oil and protein yields/ha and oil saponifiable matter.

KEY-WORDS: Cottonseed - Oil fatty acids - Oil properties - Phosphorus - Potassium - Zinc

1. INTRODUCTION

In Egypt, the need to increase the national supply of oil and protein, in quantity and quality must be a goal for cotton breeders and producers. Agricultural scientists believe that this challenge can be met. It is expected that plant nutrition, using a balanced fertilization program with both macro and micro-nutrients is becoming very important in the production of high yield with high quality products especially with the large variation in soil fertility and the crop's need for macro and micronutrients. The breeding and production of cotton have traditionally been guided by the consideration of fiber quality and yield. However, cottonseed characteristics except for viability and vigor have generally been ignored. Cottonseed oil is an important source of fat. Also, cottonseed meal is classed as a protein supplement in the feed trade and is almost as important as soybean meal. Potassium, zinc and phosphorus belong to the essential nutrients for crop production and crop reproduction (Pettigrew, 1999; Sharma *et al.*, 1982; Taiz and Zeiger, 1991).

Potassium (K) is an essential macro-element required in large amounts for normal plant growth and development. This attributed to the role of K in plant biochemical pathways (Marschner, 1995). Potassium increases the photosynthetic rates of crop leaves, CO_2 assimilation and facilitates carbon movement (Sangakkara *et al.*, 2000). Furthermore, K plays an important role in the translocation of photosynthates from sources to sinks (Cakmak *et al.*, 1994). Pettigrew (1999), stated that the elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks and thereby producing changes in the yield and quality of cotton. Studies have shown increased yield and quality in response to K fertilization (Zhang *et al.*, 2002). Notable improvements in cotton yield and quality resulting from K input may be reflected in distinct changes in seed weight and quality.

Crop yields are often limited by low levels of mineral micronutrients in the soil such as zinc (Zn), especially in calcareous soils of arid and semiarid regions. Zinc deficiency occurs in cotton in high-pH soils, particularly where topsoil has been removed in preparing fields for irrigation and thereby exposing the Zn-deficient subsoil. Also, Zn deficiencies have occurred where high rates of P are applied (Oosterhuis *et al.*, 1991). Zinc is an essential mineral nutrient and a cofactor of over 300 enzymes and proteins involved in cell division, nucleic acid metabolism and protein synthesis (Marschner, 1986). Zinc is a component of a number of dehydrogenases, proteinases and peptidases; thus Zn influences electron transfer reactions including those of the Krebs cycle and hence affects the plant's energy production. Zinc binds tightly to Zn-containing essential metabolites, such as in Zn-activated enzymes, e.g., carbonic anhydrase, which plays a role in photosynthesis and it is localized in the cytoplasm and chloroplasts and may facilitate the transfer of CO_2/HCO_3^- for photosynthetic CO_2 fixation (Sharma *et al.*, 1982).

Phosphorus (P) has been found to be the limiting element in natural ecosystems because it is often bound in highly insoluble compounds and therefore becomes unavailable for plant intake or utilization. High soil pH (> 7.6) and high quantities of $CaCO_3$ result in precipitation of P, which reduces the availability of P (Hearn, 1981). Phosphorus is an essential nutrient and an integral component of several important compounds in plant cells, including the sugar-phosphates involved in respiration, the phospholipids of plant membranes and the nucleotides used in plant energy metabolism and in molecules of DNA and RNA (Taiz and Zeiger, 1991). Rodriguez *et al.* (1998) observed that with a P deficiency, there was a reduction in the rate of leaf expansion and in photosynthetic rate per unit of leaf area. Phosphorus, as a constituent of the cell nucleus, is essential for cell division and the development of meristematic tissue (Russell, 1973). Moreover, P plays a decisive role in carbon assimilate transport and metabolic regulation (starch, sucrose biosynthesis) on a whole-plant scale (Bisson *et al.*, 1994). Further, it has a well-known impact on photosynthesis as well as synthesis of nucleic acids, proteins, lipids and other essential compounds (Taiz and Zeiger, 1991).

Due to the economic importance of cottonseed as the main source of edible oil for human consumption and feed for livestock in Egypt, this study was designed. Protein and oil yield, oil properties and fatty acid profiles of oil in the seed of Egyptian cotton (*G. barbadense*) were measured after potassium fertilization and foliar application of chelated zinc and phosphorus during the square initiation and boll setting stage.

2. MATERIALS AND METHODS

Two field experiments were conducted at the Agricultural Research Center, Ministry of Agriculture in Giza, Egypt (30°N, 31°28'E and 19 m altitude) on the cotton (*Gossypium barbadense* L.) cultivar "Giza 86", in two successive seasons. The soil type in both seasons was clay loam. The average mechanical analysis (Kilmer and Alexander, 1940) and chemical characteristics (Chapman and Pratt, 1961) of soil in both seasons are recorded in Table 1. A randomized complete block design with four replicates was used. Seeds were planted on the 3rd and the 20th of April in seasons I and II, respectively, in plots having a size of 1.95 m x 4.0 m., including three ridges (after the precaution of border effect was taken into consideration). Hills were spaced 25 cm apart on one side of the ridge and seedlings were thinned to two plants per $hill^{-1}$ 6 weeks after planting, providing for a plant density of 123,000 plants ha^{-1}. The total irrigation amount during the growing season (surface irrigation) was about 6,000-m^3 ha^{-1}. The first irrigation (after sowing irrigation) was done 3 weeks after sowing and the second was 3 weeks later. Thereafter, the plots were irrigated every 2 weeks until the end of the season, providing a total of nine irrigations. On the basis of soil test results, phosphorus fertilizer was applied at the rate of 54

Table 1
Mechanical and chemical analyses of soil samples

Season	I	II
Mechanical analysis[a]		
Clay (%)	43.00	46.46
Silt (%)	28.40	26.38
Fine sand (%)	19.33	20.69
Coarse sand (%)	4.31	1.69
Texture	Clay loam	Clay loam
Chemical analysis[b]		
Organic matter (%)	1.83	1.92
Calcium carbonate (%)	3.00	2.73
Total soluble salts (%)	0.13	0.13
pH (1:2.5)	8.10	8.08
Total nitrogen (%)	0.12	0.12
Available nitrogen (mg/kg soil)	50.00	57.50
Available phosphorus (mg/kg soil)	15.66	14.19
Available potassium (mg/kg soil)	370.00	385.00
Available zinc (mg/kg soil)	1.30	1.90
Calcium (meq/100g)	0.20	0.20

[a] According to Kilmer and Alexander (1940).
[b] According to Chapman and Pratt (1961). Note: The field was divided into uniform soil areas; eight soil samples to plow depth 30 cm were collected at random over the field and mixed to give a composite sample.

kg P_2O_5 ha^{-1} as calcium super phosphate during land preparation. Nitrogen fertilizer was applied at the rate of 144 kg N ha^{-1} as ammonium nitrate split at two equal doses; the first one was applied after thinning just before the second irrigation and the other one was applied before the third irrigation (the recommended level for semi-fertile soil). Standard cultural practices of the experimental station were used. Each experiment included 16 treatment combinations of the following: (i) Two potassium rates (0.0 and 47.4 kg of K ha^{-1}) were applied as potassium sulfate (K_2SO_4, "48% K_2O), eight weeks after sowing (as a concentrated band close to the seed ridge) and the application was followed immediately by irrigation. (ii) Two zinc rates (0.0 or 57.6 g of Zn ha^{-1}) were applied as chelated form [ethylenediaminetetraacetic acid (EDTA)] and each was foliar sprayed two times (70 and 85 days after sowing, during square initiation and boll stage). (iii) Four phosphorus rates (0.0, 576, 1152 and 1728 g of P ha^{-1}) were applied as calcium superphosphate (15% P_2O_5) and each was foliar sprayed two times (80 and 95 days after sowing). The Zn and P were both applied to the leaves with uniform coverage at a volume solution of 960 L ha^{-1}, using a knapsack sprayer. The pressure used with the sprayer used in the study was 0.4 kg / cm^2, resulting in a nozzle output of 1.43 L min^{-1}. The application was carried out between 09.00 and 11.00 h. A summary of all treatments is shown in Table 2.

At harvest (11^{th} and 17^{th} of October in the first and second season, respectively), the total cotton yield $plot^{-1}$ was determined. Following ginning, the cottonseed yields were determined in kg ha^{-1}, along with seed index weight in g/100 seeds. Laboratory tests were conducted on a 200-g random sample of seeds representative of each plot. A composite seed sample of the four replicates of each treatment in the two seasons was used for the chemical analyses. The following chemical analyses were conducted: (i) seed crude protein content according to AOAC (1985); (ii) seed oil content in which oil was extracted three times with chloroform/methanol (2:1, vol/vol) mixture according to the method outlined by Kates (1972); (iii) oil quality traits, i.e., refractive index, acid value, saponification value, unsaponifiable matter and iodine value were determined according to methods described by AOCS (1985); and (iv) identification and determination of oil fatty acids by gas-liquid chromatography. The lipid materials were saponified, unsaponifiable matter was removed and the fatty acids were separated. The free fatty acids were methylated with diazomethane (Vogel, 1985). The fatty acid methyl esters were analyzed by a Hewlett Packard model 5890 gas chromatograph (Palo Alto, CA) equipped with dual flame-ionization detectors. The separation procedures were similar to those reported by Ashoub *et al.* (1989) as follows: The chromatograph was fitted with an FFAP (cross-linked) 30 m (length) x 0.32 mm (column i.d.) x 0.25 μm (film thickness) capillary column coated with polyethylene glycol. The column oven temperature was programmed at 7 °C/min from 50 to 240 °C and kept constant after 30 min. Injector and detector temperatures were 250 and 260 °C, respectively. Under these conditions, all peaks from C8 to C20 homologous series were well defined. Peak identification was performed by comparison of the relative retention time (RRT) for each peak with those of standard chromatograms. The RRT of oleic acid was given a value of 1.0. Results were expressed as the area percentage of chromatograms.

Statistical analysis. Data obtained for the cottonseed yield and seed index were statistically analyzed as a factorial experiment in a randomized complete block design following the procedure outlined by Snedecor and Cochran (1980) and the least significant difference (L.S.D.) was used to determine the significance of differences between treatment means at 0.05 level. As for the chemical properties considered in the study, the t-test computed in accordance with standard deviation was used to verify the significance between treatment means at the 0.05 level of significance.

3. RESULTS AND DISCUSSION

3.1. Cottonseed yield

Cottonseed yield per hectare significantly increased when K was applied (by as much as 13.99%) (Table 3). Potassium would have a

Table 2
Treatment numbers and summary

Treatments			**Treatment No.**	**Treatments**			**Treatment No.**
K rate (kg ha^{-1})	**Zn rate (g ha^{-1})**	**P rate (g ha^{-1})**		**K rate (kg ha^{-1})**	**Zn rate (g ha^{-1})**	**P rate (g ha^{-1})**	
0.0	0.0	0.0	1	47.4	0.0	0.0	9
		576	2			576	10
		1152	3			1152	11
		1728	4			1728	12
	57.6	0.0	5		57.6	0.0	13
		576	6			576	14
		1152	7			1152	15
		1728	8			1728	16

Table 3
Effect of K rate and foliar application of Zn and foliar, additional P on cottonseed yield, seed index, seed oil, seed protein, oil and protein yields

Treatments	Cottonseed yield (kg ha^{-1})[a]	Seed index (g)[a]	Seed Oil (%)[b]	Oil yield (kg ha^{-1})[b]	Seed Protein (%)[b]	protein yield (kg ha^{-1})[b]
K rate (kg ha^{-1})						
0, control	1828.0	10.01	19.55	357.5	22.24	406.6
47.4	2083.8[d]	10.16[d]	19.82[d]	413.2[d]	22.27	464.1[d]
L.S.D. 0.05 [c]	80.61	0.054	–	–	–	–
S.D. [c]	–	–	0.153	34.22	0.038	36.25
Zn rate (g ha^{-1})						
0, control	1868.3	10.04	19.59	366.2	22.25	415.7
57.6	2043.5[d]	10.13[d]	19.78[d]	404.4	22.26	455.0
L.S.D. 0.05 [c]	80.61	0.054	–	–	–	–
S.D. [c]	–	–	0.184	40.50	0.040	42.62
P rate (g ha^{-1})						
0, control	1775.8	9.97	19.56	347.5	22.23	394.8
576	1944.3[d]	10.08[d]	19.64	382.1	22.25	432.7
1152	2023.7[d]	10.13[d]	19.76	400.3[d]	22.26	450.5[d]
1728	2079.8[d]	10.16[d]	19.77	411.5[d]	22.28	463.3[d]
L.S.D. 0.05 [c]	114.01	0.077	–	–	–	–
S.D. c	–	–	0.202	40.21	0.040	41.78

[a] Combined statistical analysis from the two seasons.
[b] Mean data from a four replicate composites for the two seasons.
[c] L.S.D. = least significant differences, S.D. = standard deviation was used to conduct t-test to verify the significance between every two treatment means at 0.05 level.
[d] Significant at 0.05 level.

favorable impact on yield components, including a number of open bolls/plant and boll weight, leading to a higher cotton yield. The role of K suggests that it affects abscission (reduced boll shedding) and it certainly affects yield (Zeng QingFang, 1996). Gormus (2002) also found that K application increased yield.

Application of Zn significantly increased cottonseed yield per hectare, as compared with the untreated control (by 9.38%). A possible explanation of such results might be the improvement of yield components due to the application of Zn. Zinc could have a favorable effect on the photosynthetic activity of leaves (Welch, 1995), which improves the mobilization of photosynthates and directly influences boll weight. Further, Zn is required in the synthesis of tryptophan, a precursor of indole-3-acetic acid (Oosterhuis *et al.*, 1991), which is the major hormone which inhibits abscission of squares and bolls. Thus the number of retained bolls $plant^{-1}$ and consequently cottonseed yield per hectare would be increased (Rathinavel *et al.*, 2000).

Phosphorus extra foliar application at all three concentrations (576, 1152 and 1728 g of P ha^{-1}) also significantly increased cottonseed yield per hectare, where the three concentrations applied proved to excel the control (by 9.49-17.12%). The best yield was obtained at the highest P concentration tested. Such results reflect the pronounced improvement of yield components due to the application of P which is possibly ascribed to its involvement in photosynthesis and translocation of carbohydrates to young bolls (Bisson *et al.*, 1994; Rodriguez *et al.*, 1998). Phosphorus as a constituent of cell nucleus is essential for cell division and the development of meristematic tissue and hence it would have a stimulating effect on increasing the number of flowers and bolls per plant (Russell, 1973). This result agreed with that reported by Katkar *et al.* (2002).

On the basis of soil test results, phosphorus fertilizer was applied at the rate of 54 kg P_2O_5 ha^{-1} as calcium super phosphate during land preparation. Generally, the soil nutrients available during the early growth stages, before applying P (as foliar spray), could be sufficient to fulfill the needs of plants to a large extent. However, during the extended period of flowering and boll setting (about 60 days), additional P fertilizer (as foliar spray) might be needed.

3.2. Seed index

Seed index significantly increased with the application of K (Table 3). A possible explanation for the increased seed index due to the application of K may be due in part to its favorable effects on the photosynthetic activity rate of crop leaves and CO_2 assimilation (Sangakkara *et al.*, 2000), which improves mobilization of photosynthates and directly influences boll weight which in turn directly affects seed weight (Ghourab *et al.*, 2000).

The application of Zn significantly increased seed index as compared to the control. A possible explanation for the increased seed weight might be due to an increased photosynthesis activity resulting from the application of Zn (Welch, 1995) which improves mobilization of photosynthates and the amount of photosynthate available for reproductive sinks and thereby influences boll weight, factors that coincide with increased seed weight (Rathinavel *et al.*, 2000).

The phosphorus applied at all three rates significantly increased seed index over the control. The highest rate of P (1728 g ha^{-1}) showed the highest numerical value of seed index. A possible explanation for this increased seed weight is the fact that P activated the biological reaction in the cotton plant, particularly the photosynthesis fixation of CO_2 and the synthesis of sugar and other organic compounds (Taiz and Zeiger, 1991). This indicates that treated cotton bolls had larger photosynthetically supplied sinks for carbohydrates and other metabolites than untreated bolls.

3.3. Seed oil content and yield

The applied K caused a significant increase in seed oil content and oil yield per hectare (55.7 kg oil ha^{-1}), compared with the untreated control (Table 3). This could be attributed to the role of K in biochemical pathways in plants. Potassium increases the photosynthetic rates of crop leaves, CO_2 assimilation and facilitates carbon movement (Sangakkara *et al.*, 2000). The favorable effects of K on seed oil content and oil yield were mentioned by Abou El-Nour *et al.* (2000).

Spraying plants with Zn resulted in an increase in seed oil content and oil yield per hectare (38.2 kg oil ha^{-1}), compared with the untreated control. Cakmak (2000) has speculated that Zn deficiency stress may inhibit some antioxidant enzymes, resulting in extensive oxidative damage to membrane lipids. Similar results were obtained by Rathinavel *et al.* (2000).

The foliar application of P at all the three concentrations tended to increase the seed oil content and oil yield per hectare (34.6-64.0 kg oil ha^{-1}), over the control. The effect was the most significant at the highest P concentration (1728 g ha^{-1}) on oil yield per hectare. This may be attributed to the fact that P is required for the production of high quality seeds, since it occurs as coenzymes involved in energy transfer reactions; energy is tapped in photosynthesis in the form of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADP). This energy is then used in the photosynthetic fixation of CO_2 and the synthesis of lipids and other essential organic compounds (Taiz and Zeiger, 1991). These results agreed with those obtained by Rajendran and Veeraputhiran (2001), in sunflower.

3.4. Seed protein content and yield

The applied K caused a slight increase in seed protein content and significantly increased protein yield per hectare (57.5 kg protein ha^{-1}), compared with the untreated control (Table 3). It also increased the protein yield per hectare, resulting in an improvement in both cottonseed yield and seed protein content. This could be attributed to the role of K in biochemical pathways in plants. Potassium increases the photosynthetic rates of crop leaves, CO_2 assimilation and facilitates carbon movement (Sangakkara *et al.*, 2000). Also, K has favorable effects on metabolism of nucleic acids and proteins (Bisson *et al.*, 1994; Bednarz and Oosterhuis, 1999; Pettigrew, 1999). These are manifested in metabolites formed in plant tissues and directly influence the growth and development processes. Similar results were obtained by Abou El-Nour *et al.* (2000), and Ghourab *et al.* (2000).

The application of Zn slightly increased the seed protein content and increased protein yield per hectare (39.3 kg protein ha^{-1}) numerically compared with the untreated control. Because Zn is directly involved in both gene expression and protein synthesis, Cakmak (2000) has speculated that Zn deficiency stress may inhibit the activities of a number of antioxidant enzymes, resulting in extensive oxidative damage to proteins, chlorophyll and nucleic acids. These results agreed with those reported by Babhulkar *et al.* (2000) in safflower.

The phosphorus applied at all rates tended to increase the seed protein content and the protein yield per hectare (37.9-68.5 kg protein ha^{-1}) compared with the untreated control. The effect was significant on protein yield per hectare when applied at a high P concentration (1728 g ha^{-1}), resulting from an improvement in both cottonseed yield and seed protein content. Best protein yield was obtained at a high P concentration. Phosphorus is a component of nucleic acids, which are necessary for protein synthesis (Taiz and Zeiger, 1991). Similar results were obtained by Tomar *et al.* (1996) in sunflower.

3.5. Seed oil properties

The oil refractive index, unsaponifiable matter and iodine value significantly increased, while saponification value significantly decreased by applying K, compared with the untreated control (Table 4). On the other hand, the acid value was not significantly affected due to the K application. The increment of the unsaponifiable matter is known to be beneficial for its role in oil stability. Potassium is an essential nutrient and an integral component of several important compounds in plant cells. This attributed to the role of K in biochemical pathways in plants (Marschner, 1995). These may be reflected in distinct changes in seed oil quality. Mekki *et al.* (1999) stated that, foliar application of K (0 or 3.5% K_2O) on sunflower at the seed-filling stage resulted in decreased oil acid content. Froment *et al.* (2000), in linseed, found that the iodine value, which indicates the degree of unsaturation in the final oil, was highest in treatments receiving extra K.

Table 4
Effect of K rate and foliar application of Zn and foliar, additional P on seed oil properties[a]

Treatments	Refractive index	Acid value	Saponification value	Unsaponifiable matter (%)	Iodine value
K rate (kg ha^{-1})					
0, control	1.4684	0.1343	190.81	0.3538	127.48
47.4	1.4698[c]	0.1316	189.74[c]	0.3950[c]	132.76[c]
S.D.[b]	0.00136	0.00322	0.742	0.02234	3.633
Zn rate (g ha^{-1})					
0, control	1.4683	0.1336	190.71	0.3625	128.39
57.6	1.4699[c]	0.1323	189.84[c]	0.3863	131.85
S.D.[b]	0.00129	0.00346	0.809	0.02870	4.211
P rate (g ha^{-1})					
0, control	1.4681	0.1350	190.75	0.3525	125.33
576	1.4693	0.1343	190.33	0.3725	131.46[c]
1152	1.4696	0.1323	190.10	0.3800	131.93[c]
1728	1.4695	0.1309	189.92	0.3925	131.76[c]
S.D.[b]	0.00152	0.00339	0.944	0.02947	3.801

[a] Mean data from four replicate composites for the two seasons.
[b] S.D. = standard deviation.
[c] Significant at 0.05 level.

Spraying plants with Zn resulted in a significant increase in the oil refractive index, and a significant decrease in unsaponifiable matter, compared with untreated control. The other oil properties (acid, saponification, and iodine values,) were not significantly affected. Zn activates a large number of enzymes, either due to binding enzymes and substrates, or the effects of Zn on the conformation of enzymes or substrate, or both (Klug and Rhodes, 1987; Romheld, and Marschner, 1991), these would have a direct impact through utilization in the growth processes, which are reflected in distinct changes in seed oil quality.

The application of P at all concentrations significantly increased iodine value, compared with the untreated control, while the other oil properties (oil refractive index; acid and saponification values, and the unsaponifiable matter) were not significantly affected. The studied oil quality characteristicss seemed to be enzymatically controlled.

3.6. Oil fatty acids composition

The applied K decreased the oil-saturated fatty acids (capric, lauric, myristic, palmitic and stearic) (Table 5). A significant effect was found only on capric, palmitic, and the total saturated fatty acids. The total unsaturated fatty acids (oleic and linoleic) and the ratio between total unsaturated fatty acids and total saturated fatty acids (TU/TS) was increased (by 4.31, and 19.77%, respectively) by applied K (Table 6). The effect was significant on linoleic acid, the total unsaturated fatty acids (oleic and linoleic) and the ratio between total unsaturated fatty acids and total saturated fatty acids (TU/TS). The beneficial effect of applied K on TU and TU/TS ratio may be due to the regulated effect of K, which acts as an activator on many enzymaticic processes, where some of these enzymes may affect the seed oil content from these organic matters. To our knowledge, no information on the effect of K on the cottonseed oil fatty acids is available in the literature. Mekki *et al.* (1999) stated that, foliar application with K on sunflower increased the oleic acid fatty acid. Froment *et al.* (2000), in linseed oil, found that the linoleic acid content was greatest in treatments receiving extra K.

The application of Zn resulted in a decrease in the saturated fatty acids, i.e. palmitic, capric, myristic, and stearic, and the total but resulted in an increase in lauric acid, compared to the untreated control. The effect was significant only on palmitic acid, and the total saturated fatty acids in the oil. The application of Zn resulted in an increase in total unsaturated fatty acids (by 3.49%) and TU/TS ratio (by 15.25%), over the control. The effect was significant on oleic acid, total unsaturated fatty acids (oleic and linoleic) and the ratio between total unsaturated fatty acids and total saturated fatty acids (TU/TS). The stimulatory residual effects of the application Zn on TU and TU/TS ratio were probably due to the favorable effects of Zn on fundamental metabolic reactions in plant tissues (Sharma *et al.*, 1982).

The phosphorus applied at all concentrations resulted in a decrease in the total saturated fatty acids compared with the untreated control. Spraying plants with P at 1728 g ha^{-1} gave the lowest total saturated fatty acids oil, followed by P at 1152 g ha^{-1} concentration compared with the control. Application at a high P concentration (1728 g ha^{-1}) gave the lowest capric, lauric, palmitic and stearic acid contents compared with the other two concentrations (576 and 1152 g of P ha^{-1}), while applying P at 1152 g ha^{-1} gave the lowest myristic acid content compared with the other two concentrations (576 and 1728 g of P ha^{-1}). The effect was significant for the two concentrations 1152 and 1728 g of P ha^{-1} on capric acid and the total saturated fatty acids in the oil, and for all

Table 5
Effect of K rate and foliar application of Zn and foliar, additional P on the relative percentage of saturated fatty acids[a]

Treatments	Relative % of saturated fatty acids					
	Capric	Lauric	Myristic	Palmitic	Stearic	Total
K rate (kg ha^{-1})						
0, control	0.0774	0.0626	0.8275	22.21	2.271	25.4525
47.4	0.0728[c]	0.0599	0.4863[c]	19.72[c]	1.915	22.2501[c]
S.D.[b]	0.00369	0.00794	0.34079	1.482	0.4512	2.33093
Zn rate (g ha^{-1})						
0, control	0.0769	0.0609	0.6763	22.16	2.185	25.1590
57.6	0.0733	0.0616	0.6375	19.77[c]	2.001	22.5436[c]
S.D.[b]	0.00400	0.00496	0.38598	1.796	0.4798	2.53159
P rate (g ha^{-1})						
0, control	0.0795	0.0665	1.1075	22.80	2.728	26.7760
576	0.0748[c]	0.0623[c]	0.5925[c]	20.70	1.855[c]	23.2870[c]
1152	0.0733[c]	0.0595[c]	0.4375[c]	20.30	1.905[c]	22.7703[c]
1728	0.0728[c]	0.0568[c]	0.4900[c]	20.07	1.885[c]	22.5720[c]
S.D.[b]	0.00368	0.00340	0.28269	2.026	0.3173	2.42171

[a] Mean data from a four replicate composites for the two seasons.
[b] S.D. = standard deviation.
[c] Significant at 0.05 level.

Table 6
Effect of K rate and foliar application of Zn and foliar, additional P on the relative percentage of unsaturated fatty acids[a]

Treatments	Relative % of unsaturated fatty acids			TU/TS [b] ratio
	Oleic	Linoleic	Total	
K rate (kg ha^{-1})				
0, control	21.61	52.94	74.54	2.954
47.4	22.73	55.01[d]	77.75[d]	3.538[d]
S.D.[c]	1.407	1.498	2.332	0.4037
Zn rate (g ha^{-1})				
0, control	21.43	53.40	74.84	3.016
57.6	22.90[d]	54.55	77.45[d]	3.476[d]
S.D[c]	1.311	1.761	2.533	0.4469
P rate (g ha^{-1})				
0, control	21.11	52.11	73.22	2.755
576	21.96	54.75[d]	76.71[d]	3.331[d]
1152	22.52	54.70[d]	77.23[d]	3.427[d]
1728	23.09[d]	54.33[d]	77.43[d]	3.472[d]
S.D.[c]	1.421	1.571	2.422	0.4392

[a] Mean data from four replicate composite for the two seasons.
[b] TU/TS ratio = (total unsaturated fatty acids) / (total saturated fatty acids).
[c] S.D. = standard deviation.
[d] Significant at 0.05 level.

different P concentrations on lauric, myristic, and stearic. Phosphorus applied at all rates increased the total unsaturated fatty acid (by 4.77-5.75%) and TU/TS ratio (by 20.91-26.03%) compared with untreated control. Applied P at 1728 g ha^{-1} gave the highest increment, followed by the concentration 1152 g of P ha^{-1} . Spraying plants with P at 1728 g ha^{-1} produced seed oil characterized by the highest oleic acid content, while spraying with 576 g of P ha^{-1} gave the highest linoleic acid content compared with the other concentrations. The effect was significant for the high P concentration (1728 g ha^{-1}) on oleic, for the two concentrations, 1152 and 1728 g of P ha^{-1} on the TU/TS ratio, and for all different concentrations on linoleic, and total unsaturated fatty acids. The beneficial effect of applied P at different concentrations on TU and the TU/TS ratio may be due to the regulated effect of P on many enzymatic processes and the fact that P also acts as an activator of some enzymes (Epestein, 1971) which may affect the seed oil fatty acid composition. Gushevilov and Palaveeva (1991) studied the changes in the contents of linoleic, oleic, stearic and palmitic acids in sunflower oil due to the P-application rate and found that oil quality remained high at a high P-rate. Khan *et al.* (1997) indicated that oleic acid increased by increasing levels of P added to rapeseed-mustard.

High properties of unsaturated fatty acids are desirable for edible oils. Especially high levels of linoleic acid and oleic acid are considered good for oil quality (Downey and Rimmer, 1993).

During the two growing seasons no significant interactions were found between the variables in the present study (application of K, Zn and P_2O_5 concentrations) on quantitative and qualitative characteristicss under investigation. Regarding insignificant interaction effects, the F ratios worthy exceed unity, but within the level of probability take $P \leq 0.05$, they did not show significance.

4. CONCLUSIONS

From the findings of the present study, the addition of K at 47.4 kg ha^{-1}, spraying cotton plants with Zn twice (at 57.6 g ha^{-1}), the foliar application of P, also twice (especially the P concentration of 1728 g ha^{-1}) along with the soil fertilization used P at sowing time have been proven beneficial to the quality and yield of cotton plants. These combinations appeared to be the most effective treatments, affecting not only the quantity but also the quality of oil, and to obtain higher oil and protein yields and a better fatty acid profile in the oil of cotton. In comparison with the ordinary cultural practices adopted by Egyptian cotton producers, it is apparent that the applications of such treatments could produce an improvement in cottonseed yield, seed protein content, oil and protein yields, oil refractive index, unsaponifiable matter, iodine value, unsaturated fatty acids and a decrease in oil acid value and saponification value. The increase in seed yield and the subsequent increase in oil and meal due to the addition of K, spraying cotton plants with Zn and the addition of P are believed to be sufficient to cover the cost of using those chemicals and obtain an economic profit at the same time.

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