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Review Article

Effects of Mineral Fertilizers and Plant Growth Retardants on Cottonseed Yield, Quality and Contents

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Abstract

The increase in the population in Egypt makes it imperative to explore promising approaches to increase food supply, including protein and oil, to meet the needs of the Egyptian people. Cotton is the principal crop of Egyptian agriculture, it is grown mainly for its fiber, but cottonseed products are also of economic importance. Cottonseed is presently the main source of edible oil and meal for livestock in Egypt. Economic conditions in modern agriculture demand high crop yields in order to be profitable and consequently meet the high demand for food that comes with population growth. Oil crop production can be improved by development of new high yielding varieties, and the application of appropriate agronomic practices. There is limited information about the most suitable management practice for application of N, P, K, Zn and PGRs in order to optimize the quantity and quality of oil and protein of cottonseed. In maximizing the quantity and quality of a crop's nutritional value in terms of fatty acids and protein, field experiments were conducted to investigate the effect of nitrogen, phosphorus, potassium, foliar application of zinc and the use of plant growth retardants (Pix, Cycocel or Alar), on cottonseed, protein, oil yields, and oil properties of Egyptian cotton. From the findings of this study, it seems rational to recommended applied of N, P, K, foliar application of Zn, and the use of PGRs (Pix, Cycocel or Alar), could bring about better impact on cottonseed yield, seed protein content, oil and protein yields, oil refractive index, unsaponifiable matter, and unsaturated fatty acids in comparison with the ordinary cultural practices adopted by Egyptian cotton producers.

ABBREVIATIONS

N: Nitrogen; P**:** Phosphorus; PGRs: Plant growth retardants: K: Potassium; Zn: zinc

INTRODUCTION

Plant nutrition, using a balanced fertilization program with both macro and micro-nutrients is becoming necessary 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 micro-nutrients. The breeding and production of cotton have traditionally been guided by 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 [1].

Nitrogen

In cotton culture, nitrogen (N), have the most necessity role in production inputs, which controls growth and prevents abscission of squares and bolls, essential for photosynthetic activity [2], and stimulates the mobilization and accumulation of metabolites in newly developed bolls, thus increasing their number and weight. Additionally, with a dynamic crop like cotton, excess N serves to delay maturity, promote vegetative tendencies, and usually results in lower yields [3]. Therefore, errors made in N management that can impact the crop can be through either deficiencies or excesses. Ansari and Mahey [4] evaluate the effects of N level (0,40, 80, 120 and 160 kg ha^{-1}) on the yield and found that seed yield increased with increasing N level up to 80 kg ha^{-1}. Nitrogen is an essential nutrient for the synthesis of fat, which requires both N and carbon skeletons during the course of seed development [5]. On the other hand, nitrogen plays the most important role in building the protein structure [6]. Another beneficial change in fatty acid composition due to N nutrition would be an increase in the linoleic and oleic acid contents, and an increase in the percentage of unsaturated fatty acids and a decrease in saturated fatty acids in the seed oil [7].

Phosphorus

Phosphorus (P) is the second most limiting nutrient in cotton production after nitrogen. Its deficiency tends to limit the growth of cotton plants, especially when plants are deprived of P at early stages than later stages of growth. Further, P is an essential nutrient and an integral component of several important compounds in plant cells, including the sugar-phosphates involved in respiration, photosynthesis and the phospholipids of plant membranes, the nucleotides used in plant energy metabolism and in molecules of DNA and RNA [8]. Phosphorus deficiency reduces the rate of leaf expansion and photosynthetic rate per unit leaf area [9]. Sasthri et al. [10] found that application of 2% diammonium phosphate to cotton plants increased seed yield. Improvements in cotton yield resulting from P application were reported by Stewart et al. [11]; Singh et al. [12]; Ibrahim et al. [13]; Gebaly and El-Gabiery [14].

Potassium

The physiological role of potassium (K) during fruit formation and maturation periods is mainly expressed in carbohydrate metabolism and translocation of metabolites from leaves and other vegetative organs to developing bolls. Potassium increases the photosynthetic rates of crop leaves, CO_2 assimilation and facilitating carbon movement [15]. The high concentration of K^+ is thought to be essential for normal protein synthesis. Potassium deficiency during the reproductive period can limit the accumulation of crop biomass [16], markedly changes the structure of fruit-bearing organs, and decreases yield and quality. Improvements in cotton yield and quality resulting from K input have been reported by the following authors: Gormus [17] applying K rates of 66.4, 132.8 and 199.2 kg ha^{-1} K; Aneela et al. [18] increase K levels, the effect being highest at 166 kg K ha^{-1}; Pervez et al. [19] using K rates of 62.5, 125 and 250 kg ha^{-1}; Pettigrew et al. [20] with a K fertilizer rate of 112 kg ha^{-1}; Sharma and Sundar [21] with a foliar application of K at 4.15 kg ha^{-1}.

Zinc

Zinc (Zn) is critical for several key enzymes in the plant. Zinc binds tightly to Zn-containing essential metabolites in vegetative tissues, e.g., Zn-activated enzymes such as carbonic anhydrase [22]. Further, Zn is required in the biosynthesis of tryptophan, a precursor of the auxin - indole-3-acetic acid (IAA), which is the major hormone inhibiting abscission of squares and bolls. Zinc deficiency symptoms include: small leaves, shortened internodes, a stunted appearance, reduced boll set, and small bolls size [23]. Zinc deficiency occurs in cotton on high-pH soils, and where high rates of P are applied [23]. Rathinavel et al. [24] found that application of $ZnSO_4$, to the soil at 50 kg ha^{-1} increased 100-seed weight. Li et al. [25] found that when cotton was sprayed with 0.2% zinc sulfate at the seedling stage, the boll number $plant^{-1}$ increased by 17.3% and the cotton yield increased by 18.5% compared with the untreated control.

Plant growth regulators retardants

An objective for using Plant Growth Retardants (PGRs) (mepiquat chloride, "Pix", chloromequat chloride, "Cycocel", and daminozide, "Alar") in cotton is to balance vegetative and reproductive growth as well as to improve yield and its quality [26]. Visual growth-regulating activity of Pix, Cycocel or Alar is similar, being expressed as reduced plant height and width, shortened stem and branch internodes and leaf petioles, influence leaf chlorophyll concentration, structure and CO_2 assimilation, and thicker leaves. This indicates that bolls on treated cotton plants have a larger photo synthetically sink for carbohydrates and other metabolites than those on untreated plants. More specific response from using PGRs include alteration of carbon partitioning, greater root/shoot ratios, enhanced photosynthesis, altered nutrient uptake, and altered crop canopy. In this connection, Wang et al. [27] stated that application of the plant growth retardant Pix to the cotton plants at squaring decreased the partitioning of assimilates to the main stem, the branches and their growing points, and increased partitioning to the reproductive organs and roots. Also, they indicated that, from bloom to boll-setting, Pix application was very effective in restricting the vegetative growth of the cotton canopy and in promoting the partitioning of assimilates into reproductive organs. Kumar et al. [28] evaluated the effects of Chamatkar, 5% Pix, 500, 750 and 1000 ppm, on cotton. These treatments increased the values for photosynthetic rate, transpiration rate, total chlorophyll content, and nitrate reductase activity, number of bolls $plant^{-1}$, boll weight and yield.

Most previous has focused on studying the effect of nitrogen, phosphorus, potassium, foliar application of zinc and calcium, the use of PGRs on cotton yield and fiber quality [29,30]. However, there is limited information about the most suitable management practice for application of N, P, K, Zn and PGRs in order to optimize the quantity and quality of oil and protein of cottonseed [31]. Due to the economic importance of cottonseed (presently the main source of edible oil and meal for livestock) in Egypt, this study was designed to identify the best combination of these production treatments in order to improve cottonseed, protein and oil yields and oil properties of Egyptian cotton (*G. barbadense* L.) [1, 32-34].

METHODS AND MEASUREMENTS

Field experiments were conducted at the Agricultural Research Center, Ministry of Agriculture in Giza (30°N, 31°: 28'E and 19 m altitude), Egypt using the cotton cultivars "Giza 75" and "Giza 86" (*Gossypium barbadense* L.) in the two seasons I and II. Seeds were planted on March, and seed cotton was harvest on October [35]. The soil type was a clay loam. Average textural and chemical properties of soil are reported in Table 1 [35]. Range and mean values of the climatic factors recorded during the growing seasons are presented in Table 2 [35]. No rainfall occurred during the two growing seasons. The experiments were arranged as a randomized complete block design. The plot size was 1.95 × 4 m, including three ridges (beds). Hills were spaced 25 cm apart on one side of the ridge, and seedlings were thinned to two plants $hill^{-1}$ 6 weeks after planting, providing plant density of 123,000 plants ha^{-1}. Total irrigation amount during the growing season (surface irrigation) was about 6,000 m^3 ha^{-1}. The first irrigation was applied 3 weeks after sowing, and the second one was 3 weeks later. Thereafter, the plots were irrigated every 2 weeks until the end of the season, thus providing a total of nine irrigations [35].

Experiments

Effect of N, Zn and PGR's on cottonseed, protein, oil yields, and oil properties: Materials: A field experiment was conducted, using the cotton cultivar Giza 75. Each experiment included 16 treatments the following combinations: (i) Two N-rtes (107 and 161 of N ha^{-1}) were applied as ammonium nitrate (33.5% N) in two equal amounts 6 and 8 weeks after sowing; each application (in the form of pinches beside each hill) was followed immediately by irrigation. (ii) Three PGR's, 1, 1-dimethylpiperidinium chloride (mepiquat chloride, or Pix), 2-chloroethyltrimethylammonium chloride (chloromequat chloride, or Cycocel), and succinic acid 2, 2-dimethylhydrazide

Table 1: Physical and chemical properties of the soil used in I and II seasons.		
Season	**I**	**II**
Soil texture		
Clay (%)	43.0	46.5
Silt (%)	28.4	26.4
Fine sand (%)	19.3	20.7
Coarse sand (%)	4.3	1.7
Soil texture	Clay	Loam
Chemical analysis		
Organic matter (%)	1.8	1.9
Calcium carbonate (%)	3.0	2.7
Total soluble salts (%)	0.13	0.13
pH (1:2.5)	8.1	8.1
Total nitrogen (%)[a]	0.12	0.12
Available nitrogen (mg kg^{-1} soil)[b] (1% K_2SO_4, extract)	50.0	57.5
Available phosphorus (mg kg^{-1} soil) ($NaHCO_3$ 0.5 N, extract)	15.7	14.2
Available potassium (mg kg^{-1} soil) (NH_4OAC 1N, extract)	370.0	385.0
Total Sulphur (mg kg^{-1} soil)	21.3	21.2
Calcium (meq/100g) (with Virsen, extract)	0.2	0.2

[a]Total nitrogen, i.e. organic N + inorganic N
[b]Available nitrogen, i.e. NH_4^+ & NO_3^-
The Physical analysis (soil fraction) added to the organic matter, calcium arbonate and total soluble salts to a sum of about 100% [35].

(daminozide, or Alar) were used. Each was foliar-sprayed once at 288 g active ingredient ha^{-1}, 75 days after planting (during square initiation and boll setting stage) at solution volume of 960 l ha^{-1}. Water was used as the control treatment. (iii) Two chelated Zn rates (0.0 and 48 g of Zn ha^{-1}) were foliar-sprayed twice, 80 and 95 days after planting at solution volume of 960 l ha^{-1} [32].

Cottonseed, protein, oil yields, and oil properties as influenced by K, P and Zn: Materials: A field experiment was conducted on the cotton cultivar "Giza 86". Each experiment included 16 treatment combinations of the following: (i) Two K rates (0.0 and 47.4 kg of K ha^{-1}) were applied as K 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 Zn rates (0.0 or 57.6 g of Zn ha^{-1}) were applied as chelated form and each was foliar sprayed two times (70 and 85 days after planting, during square initiation and boll setting stage). (iii) Four phosphorus rates (0.0, 576, 1152 and 1728 g of P ha^{-1}) were applied as calcium super phosphate (15% P_2O_5) and each was foliar sprayed two times (80 and 95 days after planting). The Zn and P were both applied to the leaves with uniform coverage at a solution volume of 960 l ha^{-1}, using a knapsack sprayer [1].

Measurements

At harvest the seed cotton yield $plot^{-1}$ (handpicking) was determined. Following ginning, the cotton seed yield in kg ha^{-1}as well as 100-seed weight in g was determined. A composite seed sample was collected from each treatment for chemical analyses. The following chemical analyses were conducted: (i) seed crude protein content according to AOAC standards [36]; (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 [37]; (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 [38]; 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 after acidification of the saponifiable materials. The free fatty acids were methylated with diazomethane [39]. 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. [40].

Statistical analysis

Data obtained for the cottonseed yield and seed weight were statistically analyzed as a factorial experiment in a RCBD following the procedure outlined by Snedecor and Cochran [41] and the least significant difference (LSD) was used to determine the significance of differences between treatment means. As for the chemical properties considered in the study, the t-test computed in accordance with standard deviation was utilized to verify the significance between treatments means [1].

ANALYZED DATA FOR MEASUREMENTS

Experiments

Effect of N, Zn and PGR's on cottonseed, protein, oil yields, and oil properties: Seed yield ha^{-1}, was significantly ($P \leq 0.05$) increased (8.96%) by raising N rate (Table 3) [32]. Abdel-Malak et al. [42] stated that cotton yield was higher when N was applied at a rate of 190 kg ha^{-1} than at the rate of 143 kg ha^{-1}. Palomo Gil and Chávez González [29] applied N at a rate ranging from 40 to 200 kg ha^{-1} to cotton plants and found highest yield

Table 2: Range and mean values of the weather variables recorded during the growing seasons (April-October).

Weather variables	**Season I**		**Season II**		**Overall date (Two seasons)**	
	Rang	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Max Temp [°C]	20.8-44.0	32.6	24.6-43.4	32.7	20.8-44.0	32.6
Min Temp [°C]	10.4-24.5	19.4	12.0-24.3	19.3	10.4-24.5	19.3
Max-Min Temp [°C]	4.7-23.6	13.2	8.5-26.8	13.4	4.7-26.8	13.3
Sunshine [h d^{-1}]	0.3-12.9	11.1	1.9-13.1	11.2	0.3-13.1	11.1
Max Hum [%]	48-96	79.5	46-94	74.7	46-96	77.2
Min Hum [%]	6-48	30.1	8-50	33.0	6-50	31.5
Wind speed [m s^{-1}]	0.9-11.1	5.2	1.3-11.1	5.0	0.9-11.1	5.1

Table 3: Effect of N rate and foliar application of plant growth retardants and Zn on cottonseed yield, seed index, seed oil, seed protein, oil and protein yields.

Treatments		Cotton seed 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]
N-rate (kg ha^{-1})							
Control	107	1907.7	10.29	19.92	380.1	21.96	418.8
	161	2078.7	10.44	19.87	413.0	22.51	468.4
L.S.D. 0.05 [c]		67.8	0.06	-	-	-	-
S.E.[d]		-	-	0.02	16.4	0.27	24.8
Plant growth retardants (ppm)							
Control	0	1852.2	10.24	19.86	368.0	22.08	409.1
Pix	300	2076.0	10.44	19.88	413.2	22.35	465.0
Cycocel	300	2048.0	10.41	19.94	407.8	22.24	455.8
Alar	300	1996.5	10.36	19.90	397.3	22.26	444.5
L.S.D. 0.05 [c]		96.0	0.08	-	-	-	-
S.E.[d]		-	-	0.01	10.1	0.05	12.2
Zn rate (ppm)							
Control	0	1912.4	10.30	19.82	379.2	22.10	422.8
	50	2073.9	10.42	19.97	413.9	22.37	464.4
L.S.D. 0.05 [c]		67.8	0.06	-	-	-	-
S.E.[d]		-	-	0.07	17.3	0.13	20.8

[a]Combined statistical analysis from the two seasons.
[b]Mean data from a four replicate composite for the two seasons.
[d]L.S.D. = Least significant differences,
[c]S.E. = standard error. [32].

was associated with high rates of applied N. Similar results were obtained by Sarwar Cheema et al. [30] Saleem et al. [43] when N was applied at 120 kg ha^{-1}; Hamed et al. [44] when N was applied up to 178 kg ha^{-1}. Nitrogen is an important nutrient which control growth and prevents abscission of squares and bolls, essential for photosynthetic activity [2] and stimulate the mobilization and accumulation of metabolites in newly developed bolls and thus their number and weight are increased. All tested PGR (Pix, Cycocel and Alar) significantly increased seed yield ha^{-1} (7.79-12.08%), compared with the untreated control. The most effective was Pix (12.08%), followed by Cycocel (10.57%) [32]. these results may be attributed to the promoting effect of these substances on numerous physiological processes, leading to improvement of all yield components. Pix applications increases CO_2 uptake and fixation in cotton plant leaves. In cotton stems, the xylem was expanded with Pix treatment, perhaps increasing the transport ability and accounting for heavier bolls. Alar and Pix also have been associated with increased photosynthesis [45,46] through increased total chlorophyll concentration of plant leaves, increased photosynthesis greatly increased flowering, boll retention and yield. Abdel-Al [47] indicated that cotton yield significantly increased with Pix treatment at a rate 11.90 ml (formulation) ha^{-1}at the beginning of flowering, and Gebaly and El-Gabiery [14] found that cotton yield significantly increased with Pix application at 1, 2 and 3 cm^3 L (formulation) at pinhead square, start of flowering and peak of flowering stage. Pípolo et al. [48] found that spraying cotton plants at an age of 70 d after emergence with Cycocel at rates ranging from 25 to 100 g ha^{-1} resulted in yield increases. Sawan et al. [49] stated that application of Cycocel and Alar, at rates ranging from 250 to 700 ppm (105 days after planting) increased cotton seed yield ha^{-1}. Similar results were obtained by Sarwar Cheema et al. [30]. Application of Zn significantly increased seed yield ha^{-1} (8.44%), as compared with untreated plants [32]. Zeng [50] stated application of Zn to cotton plants on calcareous soil increased yield by 7.8-25.7%. Similar results were obtained by Ibrahim et al. [13]. Zinc is required in the synthesis of tryptophan, which is a precursor of IAA synthesis which is the hormone that inhibits abscission of squares and bolls. Also, this nutrient has favorable effect on the photosynthetic activity of leaves and plant metabolism [25], which might account for higher accumulation of metabolites in reproductive organs (bolls).

Seed index significantly increased with increasing N rate (Table 3) [32]. This may be partially due to enhanced photosynthetic activity [2]. Similar findings were obtained by Palomo Gil and Chávez González [29]; Hamed et al. [44]. Application of all PGR significantly increased seed index as compared to untreated control; Pix gave the highest seed index, followed by Cycocel [32]. These agree with previous works of Sawan et al. [49], by applying Cycocel and Alar; Carvalho et al. [51] by applying Pix and Cycocel; Abdel-Al [47], by applying Pix. Zinc significantly increased seed index compared with the untreated control [32]. In this connection Ibrahim et al. [13] noted that seed weight increased due to the application of Zn.

Seed oil content was unchanged with increased as N-rate. Oil yield ha^{-1} significantly (32.9 kg ha^{-1}), which is attributed to the increase in seed yield (Table 3) [32]. Pandrangi et al. [52] applied N at a rate of 25 or 50 kg ha^{-1} to cotton plants and found that the percentage of seed oil content decreased but oil yield increased with increasing N rate. Application of all growth retardants resulted in an insignificant increase in seed oil content above the control and also significantly increased the oil yield ha^{-1} over the control (29.3-45.2 kg oil ha^{-1}), with the clearest effect from Pix (45.2 kg ha^{-1}), followed by Cycocel (39.8 kg ha^{-1}) [32]. Sawan et al. [53] indicated that a slight increase in cottonseed oil content was detected with Pix application at rate ranging 10-100 ppm. Pix was sprayed once (90 D) or twice (90 and 110 days after planting). Oil yield also increased due to Pix application compared with the control. Similar results were obtained by Gebaly and El-Gabiery [14]. Sawan et al. [49] observed that application of Cycocel and Alar (250-750 ppm, 105 days after planting) increased oil yield ha^{-1}. Application of Zn resulted in an insignificant increase in seed oil content over that of the control. The seed oil yield was also increased (34.7 kg oil ha^{-1}) compared with the untreated control [32]. These results could be attributed to the increase of total photoassimilates (e.g. lipids) and the translocated assimilates to the sink as a result of applying Zn nutrient. Sawan et al. [54] found that oil yield increased by the application of Zn to cotton plants at a rate of 12 g Zn ha^{-1}. Zinc was sprayed three times, i.e., 70, 85, and 100 d after sowing. Prabhuraj et al. [55] found that applying Zn at 5 ppm rate increased seed and oil yields of sunflower. Similar results were obtained by Ibrahim et al. [13] on cotton; Bybordi and Mamedov [56] on canola.

High N rate significantly increased the seed protein content and yield ha^{-1} (49.6 kg protein ha^{-1}) (Table 3) [32]. According to Sugiyama et al. [57], soluble proteins are increased with better N supply and favorable growth condition. These results suggest that the high N-rate increases the amino acids synthesis in the leaves, and this stimulates the accumulation of protein in the seed rather than oil content. Patil et al. [5] found that N application (50 kg N ha^{-1}) increased the seed protein content. Seed protein content and yield ha^{-1} were increased insignificantly in plants in plants treated with the three growth retardants (35.4-55.9 kg protein ha^{-1}) compared with the untreated control. Highest protein content was produced by Pix application, followed by Alar, while the highest seed protein yield was obtained with Pix (55.9 kg ha^{-1}), and followed by Cycocel (46.7 kg ha^{-1}) [32]. Hedin et al. [58] found that Cycocel increased protein content by 17-50% in leaves and squares harvested 4 wk after the first application. Kar et al. [59] in safflower showed that Cycocel and Alar maintained the level of chlorophyll, protein, and RNA contents. Also, the increase in seed protein content may be caused by the role of Pix in protein synthesis, encouraging the conversion of amino acids into protein [60]. Sawan et al. [53]; Gebaly and El-Gabiery [14] stated that cottonseed protein content and yield ha^{-1} increased due to the application of Pix. Kler et al. [61] found that when cotton was sprayed using Cycocel rates of 40, 60, or 80 ppm at the age 63 days after planting, seed protein content increased. Sawan et al. [49] stated that application of Cycocel or Alar increased seed protein content and protein yield ha^{-1}. Application of zinc increased insignificantly the seed protein content and significantly increased protein yield ha^{-1} (41.6 kg protein ha^{-1}) over the untreated control [32]. In these circumstances Ibrahim et al. [13] found that application of Zn to cotton plants increased seed protein content and protein yield ha^{-1}.

The seed oil refractive index and unsaponifiable matter tended to increase insignificantly, while the oil acid value and saponification value tended to decrease by raising N-rate (Table 4) [32]. The increase in unsaponifiable matter is beneficial as it increases the oil stability. Sawan et al. [54] applied N to cotton plants at rates of 108 and 216 kg ha^{-1} and found that oil unsaponifiable matter tended to increase, while saponification value tended to decrease by raising N-rate. Application of all PGR significantly increased the oil refractive index. However, unsaponifiable matter was insignificantly increased, whereas acid value and saponification value tended to decrease insignificantly as compared with the untreated control [32]. Applied Cycocel gave the highest refractive index and the lowest acid value, while Pix gave the highest unsaponifiable matter. Also, applied Alar gave the lowest saponification value. Sawan et al. [29] stated that application of Cycocel and Alar to cotton plants increased oil refractive index and unsaponifiable matter and decreased oil acid value and saponification value. Osman and Abu-Lila [62] found a negligible variation in refractive index of flax oil when the plants were treated with Cycocel at the application rates of 25-100 ppm twice; the first one 20 d after sowing and the second spray 2 months later. The oil refractive index and unsaponifiable matter tended to increase insignificantly, while acid value and saponification value decreased insignificantly by applied zinc compared with control [32]. Sawan et al. [54] found that application of Zn to cotton plants exhibited negligible effect upon oil-quality characters, i.e., refractive index, oil acid value, unsaponifiable matter, and saponification value.

The oil saturated fatty acids (capric, myristic, palmitic and stearic) decreased insignificantly, while lauric acid increased insignificantly in response to raising the N-rate (Table 5) [32]. Palmitic acid was the dominant saturated fatty acid. Low content of saturated fatty acids is desirable for edible uses. Application of the three PGR's resulted in a decrease in the total saturated fatty acids compared with the untreated control. The decrease was significant with the Cycocel and Alar treatments. Cycocel gave the lowest total saturated fatty acids in oil contents, followed by Alar and also tended to increase insignificantly the saturated fatty acid capric acid compared with the untreated control. Applied Pix gave the highest capric and the lowest stearic acid content, while applied Cycocel gave the lowest lauric acid content. Alar application tended to give the lowest myristic and palmitic acids contents compared with control. Application of Zn resulted in a significant decrease in the total saturated fatty acids (capric, palmitic and stearic) while it resulted in an increase in the lauric and myristic saturated fatty acids, compared with untreated plants [32].

The total unsaturated fatty acids (oleic and linoleic) and the ratio between total unsaturated fatty acids and total saturated fatty acids (TU/TS) increased insignificantly (3.53 and 15.93%, respectively) by raising N-rate (Table 6) [32]. Linoleic acid was the most abundant of the unsaturated fatty acids. Kheir et

Table 4: Effect of N rate and foliar application of plant growth retardants and Zn on seed oil properties[a].

Treatments		Refractive index	Acid value	Saponification value	Unsaponifiable matter (%)
N-rate (kg ha^{-1})					
Control	107	1.4733	0.1336	193.7	0.3700
	161	1.4734	0.1310	191.6	0.3738
S.E.[b]		0.0001	0.0013	1.0	0.0019
Plant growth retardant (ppm)					
Control	0	1.4729	0.1338	193.4	0.3675
Pix	300	1.4734	0.1327	192.9	0.3750
Cycocel	300	1.4738	0.1312	193.1	0.3725
Alar	300	1.4735	0.1317	191.2	0.3725
S.E.[b]		0.0002	0.0005	0.5	0.0015
Zn rate (ppm)					
Control	0	1.4732	0.1325	193.8	0.3688
	50	1.4735	0.1322	191.6	0.3750
S.E[b]		0.0001	0.0001	1.1	0.0031

[a]Mean data from a four replicate composite for the two seasons.
[b]S.E. = standard error [32].

Table 5: Effect of N rate and foliar application of plant growth retardants and Zn on the relative percentage of saturated fatty acids [a].

Treatments		Relative % of saturated fatty acids					
		Capric	Lauric	Myristic	Palmitic	Stearic	Total
N-rate (kg ha^{-1})							
Control	107	0.5887	0.4375	0.7700	20.72	2.767	25.283
	161	0.3212	0.8212	0.6812	18.67	2.152	22.646
S.E[b]		0.1337	0.1918	0.0444	1.02	0.307	1.319
Plant growth retardants (ppm)							
Control	0	0.3350	1.2325	1.4050	23.06	2.427	28.459
Pix	300	0.7500	0.7125	0.9225	20.88	1.982	25.247
Cycocel	300	0.3600	0.2600	0.3200	17.59	2.327	20.857
Alar	300	0.3750	0.3125	0.2550	17.25	3.102	21.294
S.E[b]		0.0986	0.2250	0.2717	1.38	0.234	1.794
Ca rate (ppm)							
Control	0	0.6325	0.5825	0.5825	22.41	2.472	26.679
	50	0.2775	0.6762	0.8687	16.98	2.447	21.249
S.E[b]		0.1775	0.0468	0.1431	2.71	0.012	2.715

[a]Mean data from a four replicate composite for the two seasons.
[b]S.E. = standard error [32].

al. [7] found that the higher N-rate increased the percentage of unsaturated fatty acids and decreased saturated fatty acids of flax oil. All PGR's increased the total unsaturated fatty acids and TU/TS ratio, compared with the control. The increase was significant by the application of Cycocel and Alar. Applied Cycocel gave the highest linoleic acid content, total unsaturated fatty acids (10.64%), and TU/TS ratio (51.0%), and followed by Alar (10.02 and 47.01%, respectively) [32]. The increase in TU/TS as a result of the application of the three PGR may be attributed to their encouraging effects on enzymes that catalyzed the biosynthesis of the unsaturated fatty acids. Spraying plants with Zn significantly increased the total unsaturated fatty acids (7.4%) and TU/TS ratio (35.04%), compared with untreated control [32]. Sawan et al. [53] reported that applying Pix to cotton plants caused a general decrease in oil saturated fatty acids, associated with an increase in oil unsaturated fatty acids. Sawan et al. [49] stated that application of Cycocel and Alar to cotton increased oil unsaturated fatty acids. Osman and Abu-Lila [61] when applied Cycocel at rates of 25-100 ppm to flax plants found that generally the higher concentrations (50 and 100 ppm) caused in the total

Table 6: Effect of N rate and foliar application of plant growth retardants and Zn on the relative percentage of unsaturated fatty acids[a].

Treatments		Relative % of unsaturated fatty acids			TU/TS [b] ratio
		Oleic	Linoleic	Total	
N rate (kg ha^{-1})					
Control	107	21.67	53.04	74.71	2.95
	161	22.57	54.78	77.35	3.42
S.E.[c]		0.45	0.87	1.32	0.23
Plant growth retardants (ppm)					
Control	0	20.67	50.86	71.53	2.51
Pix	300	21.20	53.55	74.75	2.96
Cycocel	300	23.07	56.07	79.14	3.79
Alar	300	23.54	55.16	78.70	3.69
S.E.[c]		0.69	1.14	1.79	0.30
Zn rate (ppm)					
Control	0	21.46	51.86	73.32	2.74
	50	22.79	55.96	78.75	3.70
S.E[c]		0.66	2.05	2.71	0.48

[a]Mean data from a four replicate composite for the two seasons.
[b]TU/TS ratio = (total unsaturated fatty acids) / (total saturated fatty acids).
[c]S.E. = standard error [32].

oil saturated fatty acids, while they increased the unsaturated fatty acids.

Cottonseed, protein, oil yields, and oil properties as influenced by K, P and Zn: Seed yield ha^{-1} significantly increased when K was applied (by as much as 13.99%) (Table 7) [1]. Potassium would have a favorable impact on yield components, including a number of open bolls plant^{-1} 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 [50]. Gormus [17]; Ibrahim et al. [13]; Gebaly [63] also found that K application increased yield. Application of Zn significantly increased seed yield ha^{-1}, as compared with the untreated control (by 9.38%) [1]. 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 photosynthetic activity of leaves [22], which improves mobilization of photosynthates and directly influences boll weight. Further, Zn is required in the synthesis of tryptophan, a precursor of indole-3-acetic acid [23], which is the major hormone, inhibits abscission of squares and bolls. Thus the number of retained bolls plant^{-1} and consequently seed yield ha^{-1} would be increased [24]. Similar results were obtained by Ibrahim et al. [13]. Phosphorus extra foliar application at all the three concentrations (576, 1152 and 1728 g of P ha^{-1}) also significantly increased seed yield ha^{-1}, 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 [1]. Such results reflect the pronounced improvement of yield components due to application of P which is possibly ascribed to its involvement in photosynthesis and translocation of carbohydrates to young bolls [9]. 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 plant^{-1} [64]. These results agree with that reported by Ibrahim et al. [13]; Saleem et al. [65]; Gebaly and El-Gabiery [14].

Seed index significantly increased with applying K (Table 7) [1]. A possible explanation for the increased seed index due to the application of K may be due in part to its favorable effects on photosynthetic activity rate of crop leaves and CO_2 assimilation [15], which improves mobilization of photosynthates and directly influences boll weight which in turn directly affects seed weight [66]. The application of Zn significantly increased seed index, as compared to control [1]. The increased seed weight might be due to an increased photosynthesis activity resulting from the application of Zn [22] which improves mobilization of photosynthates and the amount of photosynthate available for reproductive sinks and thereby influences boll weight, factors that coincide with increased in seed weight [24]. 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 [1]. This increased seed weight may be due to the fact that P activated the biological reaction in cotton plant, particularly photosynthesis fixation of CO_2 and synthesis of sugar, and other organic compounds [22,67]. This indicates that treated cotton bolls had larger photosynthetically supplied sinks for carbohydrates and other metabolites than untreated bolls [1].

The applied K caused significant increase in seed oil content and oil yield ha^{-1} (55.7 kg oil ha^{-1}), compared with untreated control (Table 7) [1]. 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 [15]. The favorable effects of K on seed oil content and oil yield were mentioned by Ibrahim et al. [13]; Gebaly [63]. Spraying plants with Zn resulted in an increase in seed oil content and oil yield ha^{-1} (38.2 kg oil ha^{-1}), compared with the untreated control. Cakmak [68] has speculated that

Table 7: 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	10.16	19.82	413.2	22.27	464.1
L.S.D. 0.05 [c]	80.6	0.05	-	-	-	-
S.D [c]	-	-	0.15	34.2	0.03	36.2
Zn rate (g ha^{-1})						
0, control	1868.3	10.04	19.59	366.2	22.25	415.7
57.6	2043.5	10.13	19.78	404.4	22.26	455.0
L.S.D. 0.05 [c]	80.6	0.05	-	-	-	-
S.D.[c]	-	-	0.18	40.5	0.04	42.6
P rate (g ha^{-1})						
0, control	1775.8	9.97	19.56	347.5	22.23	394.8
576	1944.3	10.08	19.64	382.1	22.25	432.7
1152	2023.7	10.13	19.76	400.3	22.26	450.5
1728	2079.8	10.16	19.77	411.5	22.28	463.3
L.S.D. 0.05 [c]	114.0	0.07	-	-	-	-
S.D [c]	-	-	0.20	40.2	0.04	41.7

[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.
[d] S.D. = standard deviation was used to conduct t-test to verify the significance between every two treatment means at 0.05 level [1].

Zn deficiency stress may inhibit some antioxidant enzymes, resulting in extensive oxidative damage to membrane lipids. Similar results were obtained by Ibrahim et al. [13]. The foliar application of P at all the three concentrations tended to increase the seed oil content and oil yield ha^{-1} (34.6-64.0 kg oil ha^{-1}), over the control [1]. The effect was the most significant at the highest P concentration (1728 g ha^{-1}) on oil yield ha^{-1}. These results agree with those obtained by Ibrahim et al. [13]; Gebaly and El-Gabiery [14].

The applied K caused a slight increase in seed protein content and significantly increased protein yield ha^{-1} (57.5 kg protein ha^{-1}), compared with the untreated control (Table 7) [1]. It also increased the protein yield ha^{-1}, resulting in an improvement in both seed 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 [15]. Also, K has favorable effects on metabolism of nucleic acids, and proteins [69]. These are manifested in metabolites formed in plant tissues and directly influence the growth and development processes. Similar results were obtained by Ibrahim et al. [13]; Gebaly [63]. The application of Zn slightly increased the seed protein content, and increased protein yield ha^{-1} (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 [68] 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 agree with those reported by Ghourab et al. [66]. Phosphorus applied at all rates tended to increase the seed protein content and the protein yield ha^{-1} (37.9-68.5 kg protein ha^{-1}) compared with the untreated control [1]. The effect was significant on protein yield ha^{-1} when applied the high P concentration (1728 g ha^{-1}), resulting from an improvement in both seed yield and seed protein content. Phosphorus is a component of nucleic acids, which are necessary for protein synthesis [8]. Similar results were obtained by Gebaly and El-Gabiery [14].

The oil refractive index, unsaponifiable matter and iodine value significantly increased, while saponification value significantly decreased by applied K, compared with the untreated control (Table 8) [1]. On the other hand, the acid value was not significantly affected due to the K application. 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 [70]. These may be reflected in distinct changes in seed oil quality. Mekki et al. [71] stated that, foliar application with K (0 or 3.5% K_2O) on sunflower at the seed-filling stage resulted in decreased oil acid content. Froment et al. [72], in linseed, found that the iodine value, which indicates the degree of unsaturation in the final oil, was highest in treatments receiving extra K. Spraying plants with Zn resulted in a significant increase in 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. Zinc activates a large number of enzymes, either due to binding enzymes and substrates, or the effects of Zn on conformation of enzymes or substrate, or both [73,74]. These would have a direct impact through utilization in the growth processes, which are reflected in distinct changes in seed oil quality [1]. 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.

Table 8: 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	0.1316	189.74	0.3950	132.76
S.D[b]	0.0013	0.0032	0.74	0.0223	3.63
Zn rate (g ha^{-1})					
0, control	1.4683	0.1336	190.71	0.3625	128.39
57.6	1.4699	0.1323	189.84	0.3863	131.85
S.D[b]	0.0012	0.0034	0.80	0.0287	4.21
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
1152	1.4696	0.1323	190.10	0.3800	131.93
1728	1.4695	0.1309	189.92	0.3925	131.76
S.D[b]	0.0015	0.0033	0.94	0.0294	3.80

[a]Mean data from a four replicate composites for the two seasons.
[b]S.D. = standard deviation [1].

The applied K decreased the oil-saturated fatty acids (capric, lauric, myristic, palmitic, and stearic) (Table 9) [1]. 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) were increased (by 4.31, and 19.77%, respectively) by applied K (Table 10) [1]. The effect was significant on linoleic acid, the total unsaturated fatty acids (oleic and linoleic), and TU/TS ratio. 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 enzymatic 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 literatures [1]. Mekki et al. [71] stated that, foliar application with K on sunflower increased the oleic acid fatty acid. Froment et al. [72], in linseed oil, found that the linoleic acid content was greatest in treatment receiving extra K. The application of Zn resulted in a decrease of 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 [1]. 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 the total unsaturated fatty acids (by 3.49%) and TU/TS ratio (by 15.25%), over the control. The effect was significant on oleic acid, the total unsaturated fatty acids (oleic and linoleic), and TU/TS ratio. 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. 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 [1]. Application the 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 applied 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 concentrations1152 and 1728 g of P ha^{-1} on capric acid and the total saturated fatty acids in the oil, and for all 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 the untreated control. Applied P at 1728 g ha^{-1} gave the highest increment, followed by the concentration 1152 g of P ha^{-1} [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, i.e., 1152 and 1728 g of P ha^{-1} on the TU/TS ratio, and for all different concentrations on linoleic, and the total unsaturated fatty acid [1]. The beneficial effect of applied P at different concentrations on TU and TU/TS ratio may be due to the regulated effect of P on many enzymatic processes and the fact that P acts as an activator of some enzymes which may affect the seed oil fatty acids composition. Gushevilov and Palaveeva [75] 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. [76] indicated that oleic acid increased by increasing levels of P added to rapeseed mustard.

CONCLUSION

From the findings of this study, it seems rational to recommended application of N at a rate of 161 of kg ha^{-1}, spraying of cotton plants with plant PGR, and application of Zn in comparison with the ordinary cultural practices adopted by Egyptian cotton producers, it is quite apparent that applications of such PGR, Zn, and increased N fertilization rates could bring about better impact on cottonseed yield, seed protein content, oil and protein yields, oil refractive index, unsaponifiable matter, and unsaturated fatty acids. On the other hand, there was a decrease in acid value and saponification value. The increase in seed yield and subsequent increase in oil and meal due to the application of PGR, Zn, and increased N fertilization were sufficient to cover the

Table 9: 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	25.452
47.4	0.0728	0.0599	0.4863	19.72	1.915	22.250
S.D[b]	0.0036	0.0079	0.3407	1.48	0.451	2.331
Zn rate (g ha^{-1})						
0, control	0.0769	0.0609	0.6763	22.16	2.185	25.159
57.6	0.0733	0.0616	0.6375	19.77	2.001	22.544
S.D[b]	0.0040	0.0049	0.3859	1.79	0.479	2.532
P rate (g ha^{-1})						
0, control	0.0795	0.0665	1.1075	22.80	2.728	26.776
576	0.0748	0.0623	0.5925	20.70	1.855	23.287
1152	0.0733	0.0595	0.4375	20.30	1.905	22.770
1728	0.0728	0.0568	0.4900	20.07	1.885	22.572
S.D[b]	0.0036	0.0034	0.2826	2.02	0.317	2.422

[a]Mean data from a four replicate composites for the two seasons.
[b]S.D. = standard deviation [1].

Table 10: 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	77.75	3.538
S.D[c]	1.40	1.49	2.33	0.403
Zn rate (g ha^{-1})				
0, control	21.43	53.40	74.84	3.016
57.6	22.90	54.55	77.45	3.476
S.D[c]	1.31	1.76	2.53	0.446
P rate (g ha^{-1})				
0, control	21.11	52.11	73.22	2.755
576	21.96	54.75	76.70	3.331
1152	22.52	54.70	77.23	3.427
1728	23.09	54.33	77.43	3.472
S.D[c]	1.42	1.57	2.42	0.439

[a]Mean data from a four replicate composite for the two seasons.
[b]TU/TS ratio = (total unsaturated fatty acids) / (total saturated fatty acids).
[c]S.D. = standard deviation [1].

cost of using those chemicals and further attain an economical profit [32].

The addition of K at 47.4 kg ha^{-1}, spraying cotton plants with Zn twice (at 57.6 g ha^{-1}), and also with P 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 subsequent increase in oil and meal due to the addition of K, spraying cotton plants with Zn and of P are believed to be sufficient enough to cover the cost of using those chemicals and obtain an economic profit at the same time [1].

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