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Mineral fertilizers and plant growth retardants: Its effects on cottonseed yield; its quality and contents

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Abstract: 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, Ca, 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 calcium, the use of a plant growth retardant (Pix), 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 Ca, the use of PGR Pix, 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.

ABOUT THE AUTHORS

It can be concluded that addition of phosphorus (P) at 74 kg ha^{-1}, and foliar application of zinc (Zn) and calcium (Ca) at different concentrations (especially Ca concentration of 60 ppm) beneficially affected cottonseed yield, seed index, seed oil content, oil and protein yields ha^{-1}, seed oil unsaponifiable matter, and total unsaturated fatty acids (oleic and linoleic). Application of nitrogen (N) at the rate of 143 kg ha^{-1} and two applications of both potassium (K) (foliar; at the rate of 957 g K ha^{-1}) and (PGR) mepiquat chloride (at a rate of 48 + 24 g *a.i.* ha^{-1}, respectively) have the most beneficial effects among the treatments examined, affecting not only the seed quantity (to obtain higher oil and protein yields ha^{-1}) but also the oil seed quality (as indicated by better fatty acid profile in the oil of cotton) in comparison with the usual cultural practices adopted by Egyptian cotton procedures.

PUBLIC INTEREST STATEMENT

Most previous has focused on studying the effect of nitrogen (N), phosphorus (P), potassium (K), foliar application of zinc (Zn) and calcium(Ca), the use of plant growth retardants (PGRs) (mepiquat chloride, "Pix", chloromequat chloride, "Cycocel", and daminozide, "Alar") on cotton yield and fiber quality. However, there is limited information about the most suitable management practice for application of N, P, K, Ca, Zn, Ca and PGRs in order to optimize the quantity and quality of oil and protein of cottonseed. 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.).

Subjects: Agriculture & Environmental Sciences; Plant & Animal Ecology; Agronomy

Keywords: calcium; cottonseed; nitrogen; phosphorus; plant growth retardants; potassium; zinc

1. Introduction

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. 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 (Sawan, Hafez, Basyony, & Alkassas, 2007a).

1.1. 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 (Reddy, Reddy, Padjung, & Hodges, 1996), 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 (Rinehardt, Edmisten, Wells, & Faircloth, 2004). Therefore, errors made in N management that can impact the crop can be through either deficiencies or excesses. Ansari and Mahey (2003) 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 (Patil, Lakkineni, & Bhargava, 1996). On the other hand, nitrogen plays the most important role in building the protein structure (Frink, Waggoner, & Ausubel, 1999). 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 (Kheir, Harb, Moursi, & El-Gayar, 1991).

1.2. 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 (Taiz & Zeiger, 1991). Phosphorus deficiency reduces the rate of leaf expansion and photosynthetic rate per unit leaf area (Rodriguez et al., 1998). Sasthri, Thiagarajan, Srimathi, Malarkodi, and Venkatasalam (2001) found that application of 2% diammonium phosphate to cotton plants increased seed yield. Improvements in cotton yield resulting from P application were reported by several authors (Gebaly Sanaa & El-Gabiery, 2012; Ibrahim, Bekheta, El-Moursi, & Gaafar, 2009; Singh, Pallaghy, & Singh, 2006; Stewart, Reiter, & Krieg, 2005).

1.3. 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 (Sangakkara, Frehner, & Nösberger, 2000). 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 (Colomb, Bouniols, & Delpech, 1995), 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 (2002) applying K rates of 66.4, 132.8 and 199.2 kg ha^{-1} K; Aneela, Muhammad, and Akhtar (2003) increase K levels, the effect being highest at 166 kg K ha^{-1}; Pervez, Ashraf, and Makhdum (2004) using K rates of 62.5, 125 and 250 kg ha^{-1}; Pettigrew, Meredith, and Young (2005) with a K fertilizer rate of 112 kg ha^{-1}; Sharma and Sundar (2007) with a foliar application of K at 4.15 kg ha^{-1}.

1.4. 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 (Welch, 1995). 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 (Oosterhuis, Hake, & Burmester, 1991). Zinc deficiency occurs in cotton on high-pH soils, and where high rates of P are applied (Oosterhuis et al., 1991). Rathinavel, Dharmalingam, and Paneersel vam (2000) found that application of $ZnSO_4$, to the soil at 50 kg ha^{-1} increased 100-seed weight. Li, Ma, Wang, and Tai (2004) 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.

1.5. Calcium

Calcium (Ca) is essential in cell nucleus matrix. It activates enzymes, particularly those that are membrane-bound (Rensing & Cornelius, 1980). It is thought that Ca is important in the formation of cell membranes and lipid structures. Ma and Sun (1997), suggested that Ca might be involved in light signal transduction chain for phototropism. Calcium deficiency as one of the causes of abscission and suggested this plus the role of Ca in the middle lamella (Ca pectates) as the possible reason. A likely reason was that Ca deficiency affected translocation of carbohydrates, causing accumulation in the leaves and a decline in stems and roots. It seems probable that young bolls abscised because of starvation. Thus, Ca may inhibit abscission because it is a component of the middle lamella, because it promotes translocation of sugars and auxin, and because it helps prevent senescence. Ochiai (1977) notes that Ca^{2+} can bridge phosphate and carboxylate groups of phospholipids and proteins; that it increases hydrophobicity of membranes; that it generally increases membrane stability and reduces water permeability.

1.6. 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 (Zhao & Oosterhuis, 2000). 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, Yin, and Sun (1995) 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, Patil, and Chetti (2004) evaluated the effects of Chamatkar, 5% Pix, at a concentration of 500, 750, and 1,000 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 (Palomo Gil & Chávez González, 1997). However, there is limited information about the most suitable management practice for application of N, P, K, Zn, Ca, and PGRs in order to optimize the quantity and quality of oil and protein of cottonseed (Patil, Naphade, Wankhade, Wanjari, & Potdukhe, 1997). 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 (*Gossypium barbadense* L.) (Aneela et al., 2003; Ansari & Mahey, 2003; Colomb et al., 1995; Frink et al., 1999; Gebaly Sanaa & El-Gabiery, 2012; Gormus, 2002; Ibrahim et al., 2009; Kheir et al., 1991; Kumar et al., 2004; Li et al., 2004; Ma & Sun, 1997; Ochiai, 1977; Oosterhuis et al., 1991; Palomo Gil & Chávez González, 1997; Patil et al., 1996, 1997; Pervez et al., 2004; Pettigrew et al., 2005; Rathinavel et al., 2000; Reddy et al., 1996; Rensing & Cornelius, 1980; Rinehardt et al., 2004; Rodriguez et al., 1998; Sangakkara et al., 2000; Sarwar Cheema, Akhtar, & Nasarullah, 2009; Sasthri et al., 2001; Sawan, Hafez, & Basyony, 2001a, 2001b; Sawan, Hafez, Basyony, & Alkassas, 2007b; Sawan et al., 2007a; Sharma & Sundar, 2007; Singh et al., 2006; Stewart et al., 2005; Taiz & Zeiger, 1991; Wang et al., 1995; Welch, 1995; Zhao & Oosterhuis, 2000).

2. Methods and measurements

2.1. Design

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. The soil type was a clay loam. Average textural and chemical properties of soil are reported in Table 1 (Sawan, Fahmy, & Yousef, 2009). Range and mean values of the climatic factors recorded during the growing seasons are presented in Table 2 (Sawan et al., 2009). 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 (Sawan et al., 2009).

2.2. Experiments

2.2.1. Effect of P, Zn and Ca on cottonseed, protein and oil yields and oil properties

A field experiment was conducted on the cotton cultivar Giza 75. Each experiment included 16 treatments, using combinations: (i) Two P rates, 44 (farmer's dose) and 74 kg of P_2O_5 ha^{-1} were applied (as a concentrated band close to the seed ridge) as calcium super-phosphate (15% P_2O_5) before the first irrigation, i.e. 3 weeks after planting (during seedling stage). (ii) Two Zn rates at 0.0 and 40 ppm, as chelated form [ethylenediaminetetraacetic acid (EDTA)] each was foliar sprayed twice, 75 and 90 days after planting (during square initiation and boll setting stage) at solution volume of 960 l ha^{-1}. (iii) Four chelated Ca rates at 0.0, 20, 40, and 60 ppm were each foliar sprayed twice, 80 and 95 days after planting, at solution volume of 960 l ha^{-1} (Sawan et al., 2001b).

2.2.2. Effects N, K, and PGR on oil content and quality of cotton seed

A field experiment was conducted, using the cotton cultivar "Giza 86". The experiment included 16 treatments: (i) soil application of N (95.2 'the ordinary', and 142.8 kg of N ha^{-1} as ammonium nitrate), (ii) foliar application of K (0, 319, 638 and 957 g K ha^{-1} as potassium sulfate) and (iii) foliar spray of the PGR (1,1-dimethylpiperidinium chloride (mepiquat chloride 'MC' or 'Pix') 75 days after planting at 0 or 48 g *a.i.* ha^{-1}, and 90 days after planting at 0 or 24 g *a.i.* ha^{-1}). The solution volume applied was also 960 L ha^{-1}. Nitrogen fertilizer (NH_4NO_3, "3.5% N") was applied half at 6 and the rest at 8 weeks

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]	50.0	57.5
(1% K_2SO_4, extract)		
Available phosphorus (mg kg^{-1} soil)	15.7	14.2
($NaHCO_3$ 0.5 N, extract)		
Available potassium (mg kg^{-1} soil)	370.0	385.0
(NH_4OAC 1 N, extract)		
Total Sulfur (mg kg^{-1} soil)	21.3	21.2
Calcium (meq/100 g)	0.2	0.2
(with Virsen, extract)		

Note: The Physical analysis (soil fraction) added to the organic matter, calcium carbonate, and total soluble salts to a sum of about 100% (Sawan et al., 2009).

[a]Total nitrogen, i.e. organic N + inorganic N.

[b]Available nitrogen, i.e. NH_4^+ & NO_3^-.

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)	
	Range	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

Source: Sawan et al. (2009).

after planting. The fertilizer was placed beside each hill in the form of pinches and followed immediately by irrigation. Potassium (K_2SO_4, '40% K') was applied as foliar spray during square initiation and boll development stage, 70 and 95 days after planting, respectively. The solution volume applied was 960 l ha^{-1}. The K and MC were applied to the leaves uniformly using a knapsack sprayer (Sawan et al., 2007b).

2.3. 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 the Association of Official Analytical Chemists (AOAC) standards (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 American Oil Chemists' Society (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 after acidification of the saponifiable materials. The free fatty acids were methylated with diazomethane (Vogel, 1975). 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, Basyony, & Ebad (1989).

2.4. 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 (1980) 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 (Sawan et al., 2007a).

3. Results and discussion

3.1. Effect of P, Zn, and Ca on cottonseed, protein and oil yields and oil properties
Seed yield ha^{-1} was significantly increased (11.24%) when phosphorus was applied at the highest rate (Table 3) (Sawan et al., 2001b). Phosphorus as a constituent of cell nuclei is essential for cell division and development of meristematic tissue, and hence it should have a stimulating effect on the plants, increasing the number of flowers and bolls per plant. Further, P has a well-known impact in photosynthesis as well as synthesis of nucleic acids, proteins, lipids and other essential compounds (Guinn, 1984), all of which are major factors affecting boll weight and consequently cottonseed. These results are confirmed by those of Abdel-Malak, Radwan, and Baslious (1997), Ibrahim et al. (2009), Saleem, Shakeel, Bilal, Shahid, and Anjum (2010), Gebaly and El-Gabiery (Sugiyama, Mizuno, & Hayashi, 1984). Application of Zn significantly increased cottonseed yield ha^{-1} (8.61%), as compared with the untreated control (Sawan et al., 2001b). This may be due to its favorable effect on photosynthetic activity, which improves mobilization of photosynthates and directly influences of boll weight (Cakmak, Hengeler, & Marschner, 1994; Glass, 1989). Also, Zn enhances the activity of tryptophan synthesis, which is involved in the synthesis of the growth control compound IAA, the major hormone that inhibits abscission of squares and bolls. The application of Zn increased the number of retained bolls plant^{-1}. Similar results were obtained by Zeng (1996), Ibrahim et al. (2009) on cotton, Bybordi and Mamedov (2010) on canola. Calcium application also significantly increased seed yield (7.06–12.16%), as yields resulting from the three concentrations applied exceeded the control. In general, it can be stated that the highest Ca concentration (60 ppm) was more effective than the other two concentrations (20 or 40 ppm) (Sawan et al., 2001b). The role of Ca in increasing seed yield can possibly be ascribed to its involvement in the process of photosynthesis and the translocation of carbohydrates to young bolls. Calcium deficiency depressed the rate of photosynthesis (rate of CO_2 fixation). Guinn (1984) stated that Ca deficiency would cause carbohydrates to accumulate in leaves and not in young bolls. The results obtained agree with those reported by Shui and Meng (1990), Wright et al. (1995).

The application of P at the rate of 74 kg P_2O_5 ha^{-1} significantly increased seed index (weight of 100 seed in g) relative to the application at 44 kg P_2O_5 ha^{-1} (Table 3) (Sawan et al., 2001b). A possible

Table 3. Effect of P rate and foliar application of Zn and Ca 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]
P_2O_5 rate (kg ha^{-1})							
Control	44	1,837.1	10.19	19.67	361.6	22.35	410.6
	74	2,043.5	10.40	19.86	406.0	22.38	457.5
L.S.D. 0.05[c]		41.2	0.05	–	–	–	–
S.E.[d]		–	–	0.09	22.2	0.01	23.4
Zn rate (ppm)							
Control	0	1,860.2	10.24	19.59	364.5	22.22	413.4
	40	2,020.4	10.36	19.94	403.0	22.51	454.7
L.S.D. 0.05[c]		41.2	0.05	–	–	–	–
S.E.[d]		–	–	0.17	19.2	0.14	20.6
Ca rate (ppm)							
Control	0	1,807.1	10.16	19.74	356.8	22.43	405.3
	20	1,934.6	10.31	19.76	382.7	22.36	432.9
	40	1,992.7	10.34	19.75	394.2	22.34	445.5
	60	2,026.8	10.37	19.82	401.3	22.34	452.4
L.S.D. 0.05 [c]		58.2	0.07	–	–	–	–
S.E.[d]		–	–	0.01	9.7	0.02	10.3

[a]Combined statistical analysis from the two seasons.

[b]Mean data from a four replicate composite for the two seasons.

[c]L.S.D. = Least significant differences.

[d]S.E. = standard error (Sawan et al., 2001b).

explanation for increased seed weight due to the application of P at the higher rate is that this nutrient activated biological reactions in the cotton plants, particularly CO_2 fixation and the synthesis of sugar, amino acids, protein, lipids, and other organic compounds. It also increased the translocation of assimilates from photosynthetic organs to the sink (Kosheleva, Bakhnova, Semenova, & Mil'Kevich, 1984). Similar results were obtained by El-Debaby, Hammam, and Nagib (1995). Application of Zn significantly increased seed index, compared to the control (Sawan et al., 2001b). This may be due to its favorable effect on photosynthetic activity. Zinc improves mobilization of photosynthates and directly influences boll weight that coincide directly with increased seed index. These results are confirmed by those obtained by Ibrahim et al. (2009). Calcium applied at all rates significantly increased seed index over the control (Sawan et al., 2001b). The highest rate of Ca (60 ppm) showed the highest numerical value of seed index. Similar results were obtained by Ibrahim (2009).

Raising the phosphorus rate increased seed oil content and oil yield ha^{-1} (Table 7) (Sawan et al., 2001b). This may be attributed to the fact that P is required for production of high quality seed, since it occurs in 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 photosynthetic fixation of CO_2 and in the synthesis of lipids and other essential organic compounds (Taiz & Zeiger, 1991). These results agree with those obtained by Pandrangi, Wankhade, and Kedar (1992) and Gebaly and El-Gabiery (2012). Spraying plants with zinc resulted in an increase in seed oil content and oil yield ha^{-1} when compared with the untreated control (Sawan et al., 2001b). This could be attributed to the increase in total photo assimilates (e.g. lipids) and the translocated assimilates to the sink as a result of applying zinc. Similar results were reached by Ibrahim et al. (2009). Application of Ca at all concentration tended to increase the seed oil content and oil yield ha^{-1} over the control; the best result was from the highest Ca concentration (60 ppm) (Sawan et al., 2001b). These results agreed with those obtained by Bora (1997) on rape; Ibrahim et al. (2009) on cotton; Bybordi and Mamedov (2010) on canola. A possible role of Ca as an activator of the enzyme phospholipase in cabbage leaves has been investigated by Davidson and Long (1958).

Applying P at the higher rate slightly increased seed protein content (Table 3) (Sawan et al., 2001b). It also increased the protein yield 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 (Guinn, 1984). Similar results were obtained by Ibrahim et al. (2009); Gebaly and El-Gabiery (2012) in cotton. The application of Zn increased the seed protein content and protein yield ha^{-1}, compared with the untreated control (Sawan et al., 2001b). Shchitaeva (1984) found that the synthesis of metabolically active amino acids depends on Zn, which increases the synthesis of asparagine and tryptophan. These results agree with studies reported by Ibrahim et al. (2009). Calcium applied at all rates tended to decrease the seed protein content slightly, but protein yield ha^{-1} increased compared with the untreated control, which is attributed to the increase in cottonseed yield. The best protein yield was obtained at the highest Ca concentration (60 ppm) (Sawan et al., 2001b).

The oil refractive index and unsaponifiable matter tended to increase, while the acid value and saponification value tended to decrease as phosphorus rate was raised (Table 4) (Sawan et al., 2001b). The increase in unsaponifiable matter is known to be beneficial, as it increases oil stability. Spraying plants with Zn resulted in a slight increase in the oil refractive index and unsaponifiable matter and a slight decrease in acid value and saponification value, compared with the untreated control (Sawan et al., 2001b). Similar results were obtained by Sawan, El-Farra, & Mohamed (1988) concerning the effect of applied Zn on oil refractive index, unsaponifiable matter and saponification value. Application of Ca at any concentration tended to decrease the oil acid value and saponification value and to increase the unsaponifiable matter, especially as the applied Ca concentration

Table 4. Effect of P rate and foliar application of Zn and Ca on seed oil properties[a]

Treatments		Refractive index	Acid value	Saponification value	Unsaponifiable matter (%)
P_2O_5 rate (kg ha^{-1})					
Control	44	1.4688	0.1332	192.9	0.3575
	74	1.4691	0.1327	191.5	0.3662
S.E[b]		0.0001	0.0002	0.7	0.0043
Zn rate (ppm)					
Control	0	1.4687	0.1331	192.4	0.3538
	40	1.4692	0.1328	192.0	0.3700
S.E[b]		0.0002	0.0001	0.2	0.0081
Ca rate (ppm)					
Control	0	1.4689	1.1340	194.9	0.3550
	20	1.4688	0.1330	191.4	0.3575
	40	1.4688	0.1324	191.3	0.3650
	60	1.4692	0.1324	191.2	0.3700
S.E[b]		0.0001	0.0003	0.9	0.0034

[a]Mean data from a four replicate composite for the two seasons.
[b]S.E. = standard error (Sawan et al., 2001b).

increased, compared with the untreated control (Sawan et al., 2001b). This became especially apparent as the applied calcium concentration was increased. The effect of Ca concentrations on oil refractive index was very limited and without a defined trend. These results are in agreement with those reported by Sawan et al. (1988) concerning the effect of applied Ca on oil refractive index, saponification value and unsaponifiable matter. The studied oil quality characters seemed to be genetically controlled.

The high rate of applied P decreased the oil saturated fatty acids capric, myristic, palmitic, and stearic, while it increased lauric acid (Table 5). The total saturated fatty acids also decreased. Palmitic acid was the predominant saturated fatty acid. Low content of saturated fatty acids is desirable for edible uses (Sawan et al., 2001b). The application of Zn decreased the abundant saturated fatty acids palmitic and myristic, while it increased capric, lauric, and stearic saturated fatty acids, compared to the control. The total saturated fatty acids decreased (Sawan et al., 2001b). Calcium applied at all concentrations decreased in the saturated fatty acids capric, lauric, myristic, palmitic, and stearica as well as the saturated fatty acids compared with the untreated control with one exception (Sawan et al., 2001b). Spraying plants with Ca at 60 ppm tended to increase stearic acid, compared with the control. Applied Ca at 40 ppm gave the lowest capric, lauric, palmitic and stearic acids contents, compared with the other two concentrations (20 and 60 ppm). Calcium at 20 ppm gave the lowest myristic acid content, compared with 40 and 60 ppm. 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 raising P rate (Table 6). Linoleic acid was the most abundant unsaturated fatty acid. Gushevilov and Palaveeva (1991) studied the changes in sunflower oil contents of linoleic, oleic, stearic and palmitic acids due to application rate of phosphorus and found that oil quality remained high at a high P rate. The application of Zn resulted in an increase in total unsaturated fatty acids and TU/TS ratio, over the control (Sawan et al., 2001b). Calcium applied at all rates increased the total unsaturated fatty acid and TU/TS ratio, compared with untreated control. Calcium at 40 ppm gave the highest increment, total unsaturated fatty acid and TU/TS ratio, followed by 60 ppm concentration. Spraying plants with Ca at 20 ppm produced seed oil characterized by the highest oleic acid content, while spraying with 40 ppm gave the highest linoleic acid content, compared with the other concentrations (Sawan et al., 2001b).

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

Treatments		Relative % of saturated fatty acids					
		Capric	Lauric	Myristic	Palmitic	Stearic	Total
P_2O_5 rate (kg ha^{-1})							
Control	44	0.0812	0.1212	0.5100	21.65	1.844	24.206
	74	0.0688	0.1538	0.2612	19.95	1.746	22.180
S.E[b]		0.0062	0.0163	0.1244	0.85	0.049	1.013
Zn rate (ppm)							
Control	0	0.0500	0.0988	0.3912	21.67	1.752	23.962
	40	0.1000	0.1762	0.3800	19.93	1.838	22.424
S.E[b]		0.0250	0.0387	0.0056	0.87	0.043	0.769
Ca rate (ppm)							
Control	0	0.1375	0.2575	0.5025	22.36	2.090	25.347
	20	0.0600	0.1100	0.2900	21.15	1.742	23.352
	40	0.0300	0.0825	0.3000	19.59	1.090	21.092
	60	0.0725	0.1000	0.4500	20.09	2.258	22.970
S.E[b]		0.0226	0.0404	0.0534	0.61	0.258	0.872

[a]Mean data from a four replicate composite for the two seasons.

[b]S.E. = standard error (Sawan et al., 2001b).

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

Treatments		Relative % of unsaturated fatty acids			TU/TS[b] ratio
		Oleic	Linoleic	Total	
P_2O_5 rate (kg ha^{-1})					
Control	44	21.89	53.90	75.79	3.13
	74	21.91	55.91	77.82	3.51
S.E[c]		0.01	1.00	1.01	0.19
Zn rate (ppm)					
Control	0	21.70	54.33	76.03	3.17
	40	22.09	55.48	77.57	3.46
S.E[c]		0.19	0.57	0.77	0.14
Ca rate (ppm)					
Control	0	21.34	53.31	74.65	2.94
	20	22.26	54.38	76.64	3.28
	40	22.00	56.90	78.90	3.74
	60	22.00	55.02	77.02	3.35
S.E[c]		0.19	0.75	0.87	0.16

[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 (Sawan et al., 2001b).

3.2. Effects N, K, and PGR on oil content and quality of cotton seed

The seed yield of cotton significantly ($p < 0.05$) increased (as much as 13.03%) by increasing N-application rate from 95.2 to 142.8 kg ha^{-1} (Table 7) (Sawan et al., 2007b). There is an optimal relationship between the nitrogen content in the plant and CO_2 assimilation, where decreases in CO_2 fixation are well documented for N-deficient plants. Nitrogen deficiency is associated with elevated levels of ethylene (which increase boll shedding), suggesting ethylene production in response to N-deficiency stress (Legé, Cothren, & Morgan, 1997). Nitrogen is also an essential nutrient in creating plant dry matter, as well as many energy-rich compounds which regulate photosynthesis and plant production, thus influencing boll development, increasing the number of bolls per plant and boll weight. Similar findings were obtained by McConnell and Mozaffari (2004) and Saleem, Bilal, Awais, Shahid, & Anjum (2010) when N fertilizer was applied at 120 kg ha^{-1} and Wiatrak, Wright, and Marois (2006) when N fertilizer was applied at 67-202 kg ha^{-1}. Also, similar results were obtained by Sarwar Cheema et al. (2009), Hamed, Abo El-Hamd, Ibrahim, & El-Sayed (2012). Foliar application of K significantly increased seed yield by 10.02–16.25% as compared to the control (0 g K ha^{-1}) (Table 7) (Sawan et al., 2007b). The differences between the effects of the three concerned K rates were statistically insignificant; with the exception of the 957 g K ha^{-1} concentration that proved to produce significantly higher seed yield ha^{-1} (5.66%) than the 319 g K ha^{-1} concentration. These increases could be due to the favorable effects of this nutrient on yield components such as number of opened bolls plant^{-1}, boll weight, or both, leading to higher cotton yield. Zeng (1996) indicated that, K fertilizer reduced boll shedding. 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 boll weight. Cakmak et al. (1994) found that, the K nutrition had pronounced effects on carbohydrate partitioning by affecting either the phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs. Mullins, Schwab, and Burmester (1999) evaluated cotton yield under a long-term soil application of K at 75-225 kg K_2O ha^{-1}, and found that K application increased yield. Results obtained here confirmed those obtained by Aneela et al. (2003) when applying

Table 7. Effect of soil application of N and foliar application of K and mepiquat chloride (MC) on the yield, 100-seed weight, oil and protein of the cotton

Treatments	Cottonseed yield (kg ha^{-1})[a]	100-seed weight (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})						
95.2	1862.4	10.09	19.73	367.5	22.24	414.2
142.8	2105.0	10.32	19.60	413.0	22.44	472.2
L.S.D. 0.05[c]	78.7	0.07	–	–	–	–
S.D.[c]	–	–	0.16	33.6	0.11	35.5
K rate (g ha^{-1})						
0	1804.4	10.03	19.49	351.6	22.32	402.9
319	1985.2	10.19	19.61	389.3	22.32	443.1
638	2047.7	10.27	19.73	404.2	22.34	457.7
957	2097.6	10.32	19.83	415.8	22.37	469.3
L.S.D. 0.05[c]	111.4	0.10	–	–	–	–
S.D.[c]	–	–	0.12	35.0	0.16	41.8
MC rate (g ha^{-1})						
0	1891.8	10.13	19.61	371.1	22.31	422.1
48 + 24	2075.6	10.27	19.72	409.4	22.37	464.4
L.S.D. 0.05[c]	78.7	0.075	–	–	–	–
S.D.[d]	–	–	0.17	36.1	0.15	41.3

[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 (Sawan et al., 2007b).

200 kg K_2O ha^{-1}, Pervez et al. (2004) under 62.5, 125, 250 kg K ha ha^{-1}, Pettigrew et al. (2005) under K fertilizer (112 kg ha^{-1}); Gebaly Sanaa (2012). Application of the PGR mepiquat chloride significantly increased seed yield ha^{-1} (by 9.72%), as compared with untreated plants. Such increases could be due to the fact that, the application of mepiquat chloride restrict vegetative growth and thus enhance reproductive organs by allowing plants to direct more energy toward the reproductive structure (Pípolo, Athayde, Pípolo, & Parducci, 1993). This means that bolls on treated cotton would have a larger photo synthetically supplied sink of carbohydrates and other metabolites than did those on untreated cotton (Wang et al., 1995). Results agreed with those obtained by Ram, Prasad, & Pachauri (2001) when mepiquat chloride was applied at 50 ppm, Mekki (1999) when mepiquat chloride was applied at 100 ppm, and Kumar et al. (2004). Also, similar results were obtained by Sarwar Cheema et al. (2009), Gebaly and El-Gabiery (2012).

Seed weight significantly increased by adding the high N-rate (Table 7) (Sawan et al., 2007b). This may be due to increased photosynthetic activity that increases accumulation of metabolites, with direct impact on seed weight. Reddy et al. (1996), in a pot experiment under natural environmental conditions, where 20-day old cotton plants received 0, 0.5, 1.5 or 6 mM NO_3, found that, net photosynthetic rates, stomatal conductance, and transpiration were positively correlated with leaf N concentration. Similar findings were reported by Palomo Gil, Godoy Avila, & Chávez González (1999), when N was applied at 40–200 kg ha^{-1}; Ali and El-Sayed (2001), when N was applied at 95 to 190 kg ha^{-1}; Hamed et al. (2012) when N was applied up to 178 kg ha^{-1}. 100-seed weight significantly increased with K application at all the three concentrations as compared to the control (Sawan et al., 2007b). The highest rate of K (957 g K ha^{-1}), resulted the highest seed weight. The difference between the high rate and low rate (319 g K ha^{-1}) was also significant. Increase in seed weight might be due to the effect of K on mobilization of photosynthates, which would directly influence boll weight and increase seed weight (Sawan et al., 2009). Ibrahim et al. (2009) reported that, the application of K fertilizer resulted in an increase in seed weight. The application of mepiquat chloride significantly increased 100-seed weight as compared to the plots that had not received mepiquat chloride, the untreated control (Sawan et al., 2007b). Increased seed weight as a result of mepiquat chloride applications may be due to an increase in photosynthetic activity, which stimulates photosynthetic activity, and dry matter accumulation (Kumar et al., 2004), and in turn increases the formation of fully mature seed and thus increases seed weight. Similar results to the present study were obtained by Ghourab, Wassel, and Raya (2000) and Lamas (2001).

Seed oil content was slightly decreased with an increase in the N rate from 95.2 to 142.8 kg ha^{-1}, but seed oil yield ha^{-1} had significantly increased (45.5 kg oil ha^{-1}), which is attributed to the significant increase in seed yield (Table 7) (Sawan et al., 2007b). Similar results were obtained by Froment, Turley, and Collings (2000), in linseed; Zubillaga, Aristi, and Lavado (2002) in sunflower. Yield increases in this study were attributed to the fact that N was an important nutrient in controlling new growth, thus influencing boll development, increasing the number of bolls $plant^{-1}$ and boll weight. Synthesis of fat requires both N and carbon skeletons during the course of seed development (Patil et al., 1996). The application of K at all the three concentrations tended to increase seed oil content and yield over the control (37.7–64.2 kg oil ha^{-1}), but was statistically significant only for 638 and 957 g K ha^{-1} concentrations on the seed oil content, and with K application at all the three concentrations on the oil yield ha^{-1} (Sawan et al., 2007b). The highest rate of K (957 g K ha^{-1}) showed the highest numerical values of seed oil content and oil yield ha^{-1} compared with the other two concentrations (319 and 638 g K ha^{-1}) (Sawan et al., 2007b). This could be attributed to the role of K in biochemical pathways in plants. 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 yield and quality found in cotton. Madraimov (1984) indicated that, increasing the rates of applied K_2O from 0 to 150 kg ha^{-1} produced linear increases in cottonseed oil contents. Previously, favorable effects of K on seed oil content and oil yield were mentioned by Ibrahim et al. (2009); Gebaly Sanaa (2012). They reported that, increasing K supply to maternal cotton plants increased crude fat content of seed. The application of mepiquat chloride resulted in an insignificant increase in seed oil content over that of the control (Sawan et al., 2007b). Also significantly increased the seed oil yield ha^{-1} compared with the untreated control (by 38.3 kg oil ha^{-1}). These results could be attributed to the increase in total photoassimilates (e.g. lipids) and the translocated assimilates to the sink as a result of applying mepiquat chloride (Fan, Xu, & Zhang, 1999). This result agreed with those obtained by Gebaly Sanaa & El-Gabiery (2012).

High N-rate significantly increased the seed protein content and yields (58.0 kg protein ha^{-1}) (Table 7) (Sawan et al., 2007b). Stitt (1999) indicated that, nitrate (NO_3^-) induces genes involved in different aspects of carbon metabolism, including the synthesis of organic acids used for amino acid synthesis. These results suggest that the highest N rate of the added N in this study compared with the lowest rate increases the amino acids synthesis in the leaves and this stimulate the accumulation of protein in the seed. The present results confirmed the findings of Patil et al. (1997). Averaged seed protein content tended to increase when applying 638 and 957 g K ha^{-1} compared with untreated control (0 g K ha^{-1}) (Sawan et al., 2007b). Applied K at all rates also, increased the protein yield numerically (40.2–66.4 kg protein ha^{-1}), resulting from an improvement in both seed yield and seed protein content. The increase in protein yield ha^{-1} was statistically significant when applying the 638 and 957 g K ha^{-1} concentrations. Best protein yield was obtained at the high K concentration (957 g K ha^{-1}) compared with the other two concentrations (319 and 638 g K ha^{-1}) (Sawan et al., 2007b). This could be attributed to the role of K in biochemical pathways in plants. Potassium has favorable effects on metabolism of nucleic acids and proteins (Bednarz & Oosterhuis, 1999). These are manifested in metabolites formed in plant tissues, and directly influence the growth and development processes, thereby producing changes in yield and quality of cotton (Sawan et al., 2007b). These results were in agreement with those obtained by Ibrahim et al. (2009), Gebaly Sanaa (2012). Seed protein content tended to increase numerically, while seed protein yield was significantly increased (42.3 kg protein ha^{-1}) in plants treated with mepiquat chloride as compared with the untreated plants. The increase in seed protein content and yield may be caused by the role of mepiquat chloride in protein synthesis, encouraging the conversion of amino acids into protein (Kar, Barua, & Gupta, 1989) along with the favorable and significant effect of mepiquat chloride on cottonseed yield. These results were confirmed by Gebaly and El-Gabiery (2012).

The seed oil refractive index, unsaponifiable matter, and iodine value tended to increase, while the oil saponification and acid values tended to decrease by raising N-rate (Table 8) (Sawan et al., 2007b). Narang, Mahal, and Gill (1993) indicated that, N application increased the oil-quality index (iodine number) in rape. The application of K at different concentrations tended to increase the seed oil refractive index, unsaponifiable matter and iodine value, and to decrease the oil saponification value and acid value, numerically, compared with the untreated control, especially when applied K at the high concentration (957 g K ha^{-1}) (Sawan et al., 2007b). The effect was significant for the two concentrations 638 and 957 g K ha^{-1} on acid value, and unsaponifiable matter, and for all different concentrations on iodine value. The effect of K concentrations on oil refractive index was very limited. 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, where K acts as an activator for several enzymes involved in carbohydrates metabolism (Taiz & Zeiger, 1991). These may be reflected in distinct changes in seed oil quality (Sawan et al., 2007b). Mekki, El-Kholy, & Mohamed (1999) stated that, foliar application with K (0 or 3.5% K_2O) on sunflower at the seed-filling stage, decreased oil acid value. Froment et al. (2000), when working with linseed found that, the iodine value, which indicates the degree of unsaturation of the final oil, was highest in treatment receiving extra K. The application of mepiquat chloride tended to significantly increase the oil refractive index, unsaponifiable matter and iodine value, while it tended to insignificantly decrease the oil acid value and saponification value, compared with the untreated control (Sawan et al., 2007b). The application of plant growth regulators, particularly growth retardants may maintain internal hormonal balance, and efficient sink source relationship. This may be reflected in distinct changes in seed oil quality.

Table 8. Effect of N rate and foliar application of K and mepiquat chloride (MC) on seed oil properties[a]

Treatments	Refractive index	Acid value	Saponification value	Unsaponifiable matter (%)	Iodine value
N rate (kg ha^{-1})					
95.2	1.4684	0.1339	190.8	0.3762	128.9
142.8	1.4695	0.1313	189.7	0.3913	131.1
S.D.[b]	0.0011	0.0025	1.4	0.0178	3.3
K rate (g ha^{-1})					
0	1.4682	0.1352	190.8	0.3675	125.8
319	1.4689	0.1337	190.1	0.3825	130.3
638	1.4692	0.1315	190.3	0.3875	131.6
957	1.4694	0.1300	190.1	0.3975	132.4
S.D.[b]	0.0012	0.0021	1.5	0.0170	2.5
MC rate (g ha^{-1})					
0	1.4683	0.1331	190.6	0.3750	128.3
48 + 24	1.4696	0.1321	189.9	0.3925	131.7
S.D.[b]	0.0011	0.0028	1.6	0.0172	3.0

[a]Mean data from a four replicate composites for the two seasons.
[b]S.D. = standard deviation (Sawan et al., 2007b).

Saturated fatty acids in oil, lauric, myristic, palmitic and their total decreased, while capric and stearic increased by raising the N-rate (Table 9) (Sawan et al., 2007b). The effect was significant only on palmitic acid, which was the dominant saturated fatty acid. A low content of saturated fatty acids is desirable for edible. 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 2.42, and 10.69%, respectively) by raising N-rate (Table 10) (Sawan et al., 2007b). The effect was significant only on oleic acid. Linoleic acid was the most abundant unsaturated fatty acid. Holmes and Bennett (1979) commented that, the fatty acid composition of rape oil is mainly under genetic control, but can be modified to some extent by N nutrition. Seo, Jo, & Choi (1986) found that, when sesame was given 0–160 kg N, oleic acid content was highest at the highest N rates and linoleic acid content was highest at the intermediate rates. Khan, Ansari, & Samiullah (1997) indicated that, oleic acid increased by increasing levels of N added to rapeseed-mustard. Kheir et al. (1991), in flax, found that the higher N-rate increased the percentage of unsaturated fatty acids and decreased saturated fatty acids in the seed oil. Potassium applied at all concentrations resulted in a decrease in the total saturated fatty acids (capric, lauric, myristic, palmitic and stearic) compared with the untreated control (Table 9) (Sawan et al., 2007b). Spraying plants with the high K concentration 957 g K ha^{-1} gave the lowest total saturated fatty acids oil, compared with the other two concentrations (638 and 957 g K ha^{-1}). The effect was significant for the two concentrations 638 and 957 g K ha^{-1} on capric, and palmitic, and for all different concentrations on lauric, myristic, stearic, and the total saturated fatty acids. Potassium applied at all rates increased the total unsaturated fatty acid (oleic and linoleic) and TU/TS ratio (by 1.84–4.48, and 15.70–26.27%, respectively), compared with untreated control (Table 10) (Sawan et al., 2007b). Applied K at 957 g ha^{-1} gave the highest increment, followed by 638 g ha^{-1} concentration. The effect was significant for all different concentrations on linoleic, the total unsaturated fatty acid and TU/TS ratio (Sawan et al., 2007b). Linoleic acid was the most abundant unsaturated fatty acid. The beneficial effect of applied K on TU and TU/TS ratio suggests that it might be due to the regulated effect of K which acts as an activator on many enzymic processes, where some of these enzymes may affect the seed oil content from these organic matters. Seo et al. (1986) found that, when sesame was given 0 to180 kg K_2O, oleic acid content was the highest at the highest K rates and linoleic acid content was the highest at the intermediate rates. Salama (1987)

Table 9. Effect of N rate and foliar application of K and mepiquat chloride (MC) 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)						
95.2	0.068	0.068	0.691	21.77	2.157	24.753
142.8	0.069	0.067	0.645	20.18	2.969	22.934
S.D.[c]	0.009	0.006	0.451	1.44	0.470	2.283
K rate (g ha⁻¹)						
0	0.077	0.074	1.307	22.40	2.602	26.467
319	0.072	0.070	0.675	21.02	1.955	23.792
638	0.065	0.063	0.350	20.52	1.905	22.903
957	0.061	0.062	0.340	19.96	1.790	22.212
S.D.[c]	0.006	0.004	0.180	1.47	0.369	1.925
MC rate (g ha⁻¹)						
0	0.074	0.065	0.775	21.97	2.336	25.221
48 + 24	0.064	0.069	0.561	19.98	1.790	22.465
S.D.[c]	0.007	0.006	0.437	1.29	0.382	1.998

[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 (Sawan et al., 2007b).

Table 10. Effect of N rate and foliar application of K and mepiquat chloride (MC) 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})				
95.2	21.59	53.65	75.24	3.069
142.8	22.99	54.08	77.06	3.397
S.D.[c]	1.35	1.14	2.28	0.403
K rate (g ha^{-1})				
0	21.26	52.26	73.53	2.790
319	22.11	54.10	76.20	3.228
638	22.60	54.50	77.09	3.390
957	23.18	54.60	77.78	3.523
S.D.[c]	1.37	0.63	1.92	0.351
MC rate (g ha^{-1})				
0	21.27	53.51	74.77	2.974
48 + 24	23.31	54.22	77.53	3.451
S.D.[c]	1.09	1.10	1.99	0.349

[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 (Sawan et al., 2007b).

indicated that, K fertilizer applied to sunflower, favored fatty acid composition (high oleic acid content). Mekki et al. (1999) stated that, foliar application with K on sunflower increased the oleic acid fatty acid. Froment et al. (2000) found that, linoleic acid content was greatest in linseed oil in treatments receiving extra K. The application of MC resulted in a decrease in the total saturated fatty acids, the abundant saturated fatty acid palmitic, capric, myristic, and stearic, while it resulted in an increase in lauric saturated fatty acid, compared to the untreated control (Table 9) (Sawan et al., 2007b). The effect was significant only on capric, palmitic, stearic and the total. The application of mepiquat chloride resulted in an increase in total unsaturated fatty acids (oleic and linoleic) and TU/TS ratio (by 3.69, and 16.69%, respectively), over the control (Table 10). The effect was significant only on the total unsaturated fatty acid, oleic and TU/TS ratio (Sawan et al., 2007b). The stimulatory residual effects of the application mepiquat chloride on TU and TU/TS ratio was probably due to its favorable effects on fundamental metabolic reactions in plant tissues, and would have direct impact through utilization on growth processes, which are reflected in distinct changes in seed oil quality (Sawan et al., 2007b). Some of these changes may affect the seed oil fatty acids composition, which may attribute to their encouraging effects on enzymes that catalyzed the biosynthesis of unsaturated fatty acids. Mekki and El-Kholy (1999) investigated the response of rape oilseed to 0, 200 or 400 ppm mepiquat chloride and found that; palmitic acid was only decreased using 400 ppm mepiquat chloride as compared with 200-ppm treatment or control plants. A low content of saturated fatty acids is desirable for edible purposes. Also, regarding oil quality, higher levels of linoleic acid and oleic acid are considered good for oil quality (Downey & Rimmer, 1993).

4. Conclusion

It can be concluded that addition of P at 74 kg ha^{-1}, and foliar application of Zn and Ca at different concentrations (especially Ca concentration of 60 ppm) beneficially affected cottonseed yield, seed index, seed oil content, oil and protein yields ha^{-1}, seed oil unsaponifiable matter, and total unsaturated fatty acids (oleic and linoleic) (Sawan et al., 2001b).

Application of N at the rate of 143 kg ha^{-1} and two applications of both K (foliar; at the rate of 957 g K ha^{-1}) and mepiquat chloride (at a rate of 48 + 24 g *a.i.* ha^{-1}, respectively) have the most beneficial effects among the treatments examined, affecting not only the seed quantity (to obtain higher oil and protein yields ha^{-1}) but also the oil seed quality (as indicated by better fatty acid profile in the oil of cotton) in comparison with the usual cultural practices adopted by Egyptian cotton procedures (Sawan et al., 2007b).

Abbreviations

Ca	calcium
N	nitrogen
P	phosphorus
PGRs	plant growth retardants
K	potassium
Zn	zinc

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