GRASAS Y ACEITES, 58 (3),
JULIO-SEPTIEMBRE, 243-251, 2007,
ISSN: 0017-3495

Nitrogen, potassium and plant growth retardant effects on oil content and quality of cotton seed

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RESUMEN

Efecto del nitrógeno, potasio y retardantes del crecimiento de plantas sobre el contenido en aceite y sobre la calidad de la semilla de algodón

El objetivo de los experimentos de campo fue investigar el efecto del nitrogeno, potasio y retardantes del crecimiento de plantas sobre el contenido en proteínas y aceite de una semilla de algodón cultivada en Egipto (*Gossypium barbadense* Giza 86). Los tratamientos consistieron en la aplicación en suelo de N (95 and 143 kg N ha^{-1} en forma de nitrato amónico), aplicación foliar de K (0, 319, 638 or 957 g K ha^{-1} como sulfato potásico) y aplicación foliar de cloruro de m mepiquat (MC) (0 and 48 + 24 g de ingrediente activo ha^{-1}) sobre un cultivar de algodón «Giza 86» (*Gossypium barbadense*). La aplicación de la cantidad más elevada de N, unida a la aplicación de potasio y del retardador MC, aumentó significativamente el rendimiento en semilla, así como el contenido en proteinas y en aceite. Respecto al aceite, aumentó el índice de refracción, la fracción insaponificable y el contenido total en ácidos insaturados (oleico y linoleico). Por el contrario, la acidez del aceite y su índice de saponificación disminuyó con la aplicación foliar de K y MC. El contenido en aceite de la semilla disminuyó cuando sólo se aplicó N.

PALABRAS-CLAVE: Aceite de semilla – Ácidos grasos – Algodón – Cloruro de mepiquat – Nitrógeno – Potasio – Proteina.

SUMMARY

Nitrogen, potassium and plant growth retardant effects on oil content and quality of cotton seed

The aim of this field experiment was to investigate the effect of nitrogen, potassium and a plant growth retardant (PGR) on seed yield and protein and oil content of an Egyptian cotton cultivar (*Gossypium barbadense* Giza 86). Treatments consisted of: soil application of N (95 and 143 kg N ha^{-1} in the form ammonium nitrate), foliar application of potassium (0, 319, 638 or 957 g K ha^{-1} as potassium sulfate) and foliar application of mepiquat chloride (MC) (0 and 48 + 24 g active ingredient ha^{-1}) on seed, protein and oil yields and oil properties of Egyptian cotton cultivar “Giza 86” (*Gossypium barbadense*). After applying the higher N-rate, foliar application of potassium and plant growth retardant MC significantly increased seed yield and the content of seed protein and oil, seed oil refractive index, unsaponifiable matter and total unsaturated fatty acids (oleic and linoleic). In contrast, oil acid and saponification value as well as total saturated fatty acids were decreased by foliar application of potassium and MC. The seed oil content was decreased with soil application of N.

KEY-WORDS: Cotton – Fatty acids – Mepiquat chloride – Nitrogen – Potassium – Seed oil – Seed protein.

1. INTRODUCTION

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 (e.g., oil crops). Oil crop production can be improved by improving the metabolic activity and nutritional status of crop plants. There are several factors, which can cause such high yields, i.e., the development of new high yielding varieties, pest control, and the application of appropriate agronomic practices are potential solutions.

Cotton is one of the most important fiber crops in the world (Texier, 1993). This crop is also the second source of plant proteins after soybean, and the fifth oil-producing plant after soybean, palm oil, canola and sunflower (Texier, 1993). Cotton is an important crop in Egypt that is cultivated both for its fiber and seed oil. Cotton fiber is the main raw material for the textile industry which is the largest industry in Egypt. In addition, cotton seed is used as a protein supplement in the feed trade.

Therefore, there is a need to increase the quantity and quality of oil and protein in cotton seed. Oil quality is determined by both nutritional and functional aspects, which are, in turn, primarily determined by the fatty acid profile (i.e., fatty acid composition) of the oil.

The fatty acid composition of seed oil in crops is mainly under genetic control, but can be affected to some extent by nitrogen (N) nutrition (Holmes and Bennett, 1979). Nitrogen is an essential nutrient for the synthesis of fat, which requires both N and carbon skeletons during the course of seed development (Patil *et al*., 1996). On the other hand, nitrogen plays the most important role in building the protein structure (Frink *et al.,* 1999). Excess N in combination with adequate moisture and high plant populations can increase mutual leaf shading that decreases light intensity in canopy, leading to decrease the photosynthate supply and subsequent square shed (Cothren, 1999). Elevated levels of ethylene as a result of N deficiency at an early crop development stage, shows that ethylene was probably produced in response to N-deficiency stress (Lege *et al.*, 1997). Another beneficial change in fatty acid composition due to N nutrition would be an increase in the linoleic and oleic acid contents (Seo *et al.*, *1986*), and an increase in the percentage of unsaturated fatty acids and a decrease in saturated fatty acids in the seed oil (Kheir *et al.*, 1991).

Potassium (K) is another important nutrient that has favorable effects on the metabolism of nucleic acids, proteins, vitamins and growth substances (Bisson *et al.*, 1994; Bednarz and Oosterhuis, 1999). Furthermore, K plays an important role in the translocation of photosynthates from sources to sinks (Cakmak *et al.*, 1994). Notable improvements in cotton yield and quality resulting from K input have been reported by Mullins *et al.* (1991) and Cassman *et al.* (1992). The results suggest distinct changes in seed weight and quality in the presence of added K (Mullins *et al.*, 1991; Cassman *et al.* 1992). Pettigrew (1999) suggested that the elevated carbohydrate concentrations in source tissues (e.g., leaves) under K deficiency conditions might be partly due to a reduction in the amount of photosynthate available for reproductive sinks. Accordingly, K-deficiency decreases quantity and quality yield in cotton.

Plant growth regulators, particularly growth retardants (PGR) may also enhance crop productivity by maintaining internal hormonal balance and improving sink-source relationships (Singh *et al.*, 1987). Mepiquat chloride (MC) has been found to restrict the vegetative growth in the cost of enhanced reproductive organs (Wang *et al.*, 1995). Fan *et al.* (1999) reported that MC application improved photosynthetic efficiency. In addition, good population type and canopy structure for dwarf plants, short sympodia, smaller leaves and bigger bolls could be achieved by MC application.

There is limited information about the most suitable management practice for the application of N, K, and MC in order to optimize cotton seed yield and protein and oil content and oil properties. The aim of this study was to investigate the effects of soil application of N as well as foliar application of K and MC on protein and oil content and oil properties in the seed of an Egyptian cotton cultivar (*Gossypium barbadense* L., cv. Giza 86). The study was designed to identify the best combination of these production treatments in order to improve seed yield and quality. We tested the hypothesis that soil application of N as well as foliar application of K and MC will stimulate growth and improve seed yield and quality (protein and oil content and oil properties in the seed).

2. MATERIALS AND METHODS

A field experiment was conducted at the Agricultural Research Center, Ministry of Agriculture in Giza, Egypt (30°N, 31°: 28'E and 19 m altitude) in two successive seasons 1999 and 2000 using the cotton cultivar 'Giza 86'. Average physical (mechanical) analysis (Kilmer and Alexander, 1940) and chemical characteristics (Chapman and Pratt, 1961) of the soil in both seasons are illustrated in Table 1. The soil in both seasons was a clay loam. In each season, the experimental field was divided into uniform soil areas; eight soil samples to plow depth 30 cm were collected at random over the field and mixed to give a composite sample to measure its physical chemical properties. The experiment included 16 treatments: (i) soil application of N (95 (the ordinary) and 143 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 960 L ha^{-1}. Nitrogen fertilizer was applied with lime (NH_4NO_3 + $CaCO_3$, 33.5% N) half at 6 and the rest at 8 weeks 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 also 960 L ha^{-1}. The K and MC were applied to the leaves uniformly using a knapsack sprayer in the morning. The pressure used was 0.4 kg/cm^2, resulting in a nozzle output of 1.43 L min^{-1}.

Table 1
Selected physical and chemical properties of the soil studied.

Season	I	II
Clay (%)	43.00	46.46
Silt (%)	28.40	26.38
Fine sand (%)	19.33	20.69
Coarse sand (%)	4.31	1.69
Soil texture	Clay loam	Clay loam
Organic matter (%)	1.83	1.92
$CaCO_3$ (%)	3.00	2.73
Total soluble salts (%)	0.13	0.13
pH (1:2.5)	8.1	8.1
Total nitrogen (%)[a]	0.12	0.12
Nitrogen (mg/ kg)[b] (1% K_2SO_4, extract)	50.00	57.50
Phosphorus (mg/ kg) ($NaHCO_3$ 0.5 N, extract)	15.66	14.19
Potassium (mg/ kg) (NH_4OAC 1N, extract)	370.00	385.00
Calcium (meq/100g) (with Virsen, extract)	0.20	0.20

[a]Total nitrogen, i.e. organic N + inorganic N
[b]Available nitrogen, i.e. NH_4^+ & NO_3^-

A randomized complete block design with four replications was used. Seeds of cotton were planted in 1.95 (three rows) $\times$ 4.0 m (row length) plots on April 3 and 8 in the first and second years, respectively, Row spacing (wide) was 0.65-m and plant density was 123,000 per ha. Total irrigation water applied during the growing season was about 6,000 m^3 per ha. The first and second irrigation water were applied at 3 and 6 weeks, respectively. Thereafter, the plots were irrigated every 2 weeks until the end of the season, thus providing a total of nine irrigations (the ordinary cultural practices adapted by the Egyptian cotton growers). Based on the soil testing, phosphorus was applied as calcium superphosphate at planting [54 kg P_2O_5 ha^{-1}] and K as potassium sulfate [57 kg K_2O ha^{-1}] before the first irrigation. Pest and weed management were carried out during the growth season, according to local practices performed at the experimental station.

At harvest (on October 11 and 17 in the first and second seasons, respectively) 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 (1985); (ii) seed oil content in which oil was extracted three times with chloroform/methanol (2:1, vol/vol) mixture according to the method outlined by Kates (1972); (iii) oil quality traits, i.e., refractive index, acid value, saponification value, unsaponifiable matter, and iodine value were determined according to methods described by AOCS (1985); and (iv) identification and determination of oil fatty acids by gas-liquid chromatography. The lipid materials were saponified, unsaponifiable matter was removed, and the fatty acids were separated 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 *et al.* (1989) as follows: The chromatograph was fitted with an FFAP (crosslinked) 30 m (length) $\times$ 0.32 mm (column i.d.) $\times$ 0.25 µm (film thickness) capillary column coated with polyethylene glycol. The column oven temperature was programmed at 7 °C min^{-1} from 50 to 240 °C and kept constant to 30 min. Injector and detector temperatures were 250 and 260 °C, respectively. Gas flow rates were 33, 30, and 330 mL min^{-1} for N_2, H_2, and air, respectively, with N_2 flow rate inside a column of 2 mL min^{-1}. Under these conditions, all peaks from C8 to C20 homologous series were well defined. Peak identification was performed by comparison of the relative retention time (RRT) for each peak with those of standard chromatograms. The RRT of oleic acid was given a value of 1.0. Results were expressed as an area percentage of chromatograms.

2.1. Statistical analysis

Data obtained for the cottonseed yield and seed index were statistically analyzed factorially according to procedures outlined by Snedecor and Cochran (1980) and the least significant difference (LSD) was used to determine the significance of differences between treatment means at 0.05 levels. 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 every two-treatment means at the 0.05 level of significance.

3. RESULTS AND DISCUSSION

Cottonseed yield

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 2). There is an optimal relationship between the nitrogen content in the plant and CO_2 assimilation (Greef, 1994), where decreases in CO_2 fixation are well documented for N-deficient plants. Nitrogen deficiency is associated with elevated levels of ethylene (which increases boll shedding), suggesting ethylene production in response to N-deficiency stress (Legé *et al.* 1997). These results agreed with those obtained by Brar *et al.* (2000), when N was applied up to 150 kg ha^{-1}, and Ram *et al.* (2001), when N was applied up to 100 kg ha^{-1}.

Foliar application of K significantly increased cotton seed yield by 10.02 to 16.25 % as compared to the control (0 g K ha^{-1}) (Table 2). 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 cottonseed 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 potassium nutrition had pronounced effects on carbohydrate partitioning by affecting either the phloem export of photosynthates (sucrose) or the growth rate of sinks and/or source organs. Mullins *et al.* (1999) evaluated cotton (*Gossypium hirsutum*) 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 in this study are similar to those of Howard *et al.* (2000); Gormus (2002).

Table 2
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 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[d]	10.32[d]	19.60	413.0[d]	22.44[d]	472.2[d]
LSD 0.05[c]	78.78	0.075	–	–	–	–
SD[c]	–	–	0.167	33.65	0.113	35.50
K rate (g ha^{-1})						
0	1804.4	10.03	19.49	351.6	22.32	402.9
319	1985.2[d]	10.19[d]	19.61	389.3[d]	22.32	443.1
638	2047.7[d]	10.27[d]	19.73[d]	404.2[d]	22.34	457.7[d]
957	2097.6[d]	10.32[d]	19.83[d]	415.8[d]	22.37	469.3[d]
LSD 0.05[c]	111.41	0.106	–	–	–	–
SD[c]	–	–	0.129	35.06	0.165	41.87
MC rate (g ha^{-1})						
0	1891.8	10.13	19.61	371.1	22.31	422.1
48 + 24	2075.6[d]	10.27[d]	19.72	409.4[d]	22.37	464.4[d]
LSD 0.05[c]	78.78	0.075	–	–	–	–
SD[c]	–	–	0.170	36.11	0.151	41.35

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

Generally, the soil nutrients available (applied K as soil application) during the early growth stages could be sufficient to fulfill the needs of plants to a large extent. However, during the extended period of flowering and boll setting (about 60 days), additional K fertilizer might be needed.

Application of the plant growth retardant MC 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 MC may maintain internal hormonal balance, efficient sink source relationship and thus enhance crop productivity (Singh *et al.*, 1987). Mepiquat chloride has been found to restrict the vegetative growth and thus enhance reproductive organs by allowing plants to direct more energy towards the reproductive structure (Wang *et al.*, 1995). Also, such increases may be due to an increased photosynthetic activity of leaves when this substance is applied (Gardner, 1988). This means that bolls on treated cotton plants would have a larger photosynthetically supplied sink of carbohydrates and other metabolites than those on untreated cotton plants. Results agreed with those obtained by Mekki (1999) when MC was applied at 100 ppm, and Ram *et al.* (2001) when MC was applied at 50 ppm.

100-seed weight

100-seed weight significantly increased by adding the high N-rate (Table 2). 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 *et al.* (1999), when N was applied at 40-200 kg ha^{-1}, and Ali and El-Sayed (2001), when N was applied at 95 to 190 kg ha^{-1}.

100-seed weight significantly increased with K application at all three concentrations as compared to the control. 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. The 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 (Cakmak *et al.*, 1994). Ghourab *et al.* (2000) reported that the application of K fertilizer resulted in an increase in seed weight.

The application of MC significantly increased 100-seed weight as compared to the plots that had not received MC, the untreated control. Increased seed weight as a result of MC applications may be due to an increase in photosynthetic activity, which stimulates photosynthetic activity, and dry matter accumulation (Bednarz and Oosterhuis, 1999), and in turn increases the formation of fully-mature seeds and thus increases seed weight. Similar results to the present study were obtained by Sabino *et al.* (1999); Ghourab *et al.* (2000).

Seed oil content and yield

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 had significantly increased (45.5 kg oil ha^{-1}), which is attributed to the significant increase in cottonseed yield (Table 2). Similar results were obtained by Froment *et al.* (2000), in linseed, and Zubillaga *et al.* (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 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 per hectare. The highest rate of K (957 g K ha^{-1}) showed the highest numerical values of seed oil content and oil yield per hectare compared with the other two concentrations (319 and 638 g K ha^{-1}). 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 the 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 Fan *et al.* (1999); Abou El-Nour *et al.* (2000). They reported that increasing K supply to maternal cotton plants increased crude fat content of seed.

The application of MC resulted in an insignificant increase in seed oil content over that of the control. 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 of total photoassimilates (e.g. lipids) and the translocated assimilates to the sink as a result of applying MC (Fan *et al.*, 1999). This result agreed with those obtained by Mekki and El-Kholy (1999) in rape.

Seed protein content and yield

High N-rate significantly increased the seed protein content and yield (58.0 kg protein ha^{-1}) (Table 2). 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 acid 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).

Average seed protein content tended to increase when applying 638 and 957 g K ha^{-1} compared with the untreated control (0 g K ha^{-1}). 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 cottonseed 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}). This could be attributed to the role of K in biochemical pathways in plants. Potassium has favorable effects on the metabolism of nucleic acids and proteins (Bisson *et al.*, 1994; Bednarz and 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. These results were in agreement with those obtained by Abou El-Nour *et al.* (2000); Ghourab *et al.* (2000).

Seed protein content had no significant change, while seed protein yield was insignificantly increased (42.3 kg protein ha^{-1}) in plants treated with MC as compared with the untreated plants. The increase in seed protein content and yield may be caused by the role of MC in protein synthesis, encouraging the conversion of amino acids into protein (Wang and Chen, 1984) along with the favorable and significant effect of MC on cottonseed yield. These results were confirmed by Abdel-Al *et al.* (1986).

There was no significant relationship between protein and oil content of the seed, which is probably due to this fact that low application doses are not sufficient to allow for expression of the expected inverse relationship between oil and protein.

Seed oil properties

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 the N-rate (Table 3). The increase in unsaponifiable matter is beneficial as it increases oil stability (Downey and Rimmer, 1993). Narang *et al.* (1993) indicated that, N application increased the oil-quality index (iodine number) in rape.

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 applying K at the high concentration (957 g K ha^{-1}). The effect was significant for the two concentrations 638 and 957 g

Table 3
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	190.84	0.3762	128.89
	142.8	1.4695	0.1313[c]	189.74	0.3913	131.14
SD[b]		0.00118	0.00259	1.453	0.01786	3.349
K rate (g ha^{-1})						
	0	1.4682	0.1352	190.78	0.3675	125.79
	319	1.4689	0.1337	190.06	0.3825	130.30[c]
	638	1.4692	0.1315[c]	190.25	0.3875[c]	131.59[c]
	957	1.4694	0.1300[c]	190.07	0.3975[c]	132.39[c]
SD[b]		0.00129	0.00217	1.526	0.01707	2.468
MC rate (g ha^{-1})						
	0	1.4683	0.1331	190.62	0.3750	128.28
	48 + 24	1.4696[c]	0.1321	189.96	0.3925[c]	131.75[c]
SD[b]		0.00110	0.00289	1.658	0.01721	3.036

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

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 carbohydrate metabolism (Taiz and Zeiger, 1991). These may be reflected in distinct changes in seed oil quality. Mekki *et al.* (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 treatments receiving extra K.

The application of MC tended to significantly increase the oil refractive index, unsaponifiable matter and iodine value, although it tended to insignificantly decrease the oil acid value and saponification value, compared with the untreated control. The application of plant growth regulators, particularly growth retardants may maintain internal hormonal balance, and efficient sink source relationship (Singh *et al*., 1987). This may be reflected in distinct changes in seed oil quality.

Oil fatty acids composition

Saturated fatty acids in oils, lauric, myristic, palmitic and their totals decreased, while capric and stearic increased by raising the N-rate (Table 4). 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 oils . 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 the N-rate (Table 4). 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 *et al.* (1986) found that, when sesame was given 0 to160 kg N, oleic acid content was highest at the highest N rates and linoleic acid content was highest at the intermediate rates. Khan *et al.* (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. 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 (319 and 638 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 the untreated control. 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. 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

Table 4
Effect of N rate and foliar application of K and mepiquat chloride (MC) on the relative percentage of saturated fatty acids[a] and unsaturated fatty acids[a].

Treatments	Relative % of saturated fatty acids						Relative % of unsaturated fatty acids			TU/TS[b] ratio
	Capric	Lauric	Myristic	Palmitic	Stearic	Total	Oleic	Linoleic	Total	
N rate (kg ha^{-1})										
95.2	0.0684	0.0680	0.6912	21.77	2.157	24.7526	21.59	53.65	75.24	3.069
142.8	0.0691	0.0666	0.6450	20.18[d]	2.969	22.9345	22.99[d]	54.08	77.06	3.397
SD[c]	0.00929	0.00649	0.45113	1.446	0.4705	2.28338	1.353	1.144	2.284	0.4030
K rate (g ha^{-1})										
0	0.0775	0.0745	1.3075	22.40	2.602	26.4670	21.26	52.26	73.53	2.790
319	0.0722	0.0698[d]	0.6750[d]	21.02	1.955[d]	23.7920[d]	22.11	54.10[d]	76.20[d]	3.228[d]
638	0.0648[d]	0.0632[d]	0.3500[d]	20.52[d]	1.905[d]	22.9030[d]	22.60	54.50[d]	77.09[d]	3.390[d]
957	0.0605[d]	0.0618[d]	0.3400[d]	19.96[d]	1.790[d]	22.2122[d]	23.18	54.60[d]	77.78[d]	3.523[d]
SD[c]	0.00659	0.00384	0.17971	1.477	0.3690	1.92554	1.370	0.634	1.925	0.3519
MC rate (g ha^{-1})										
0	0.0739	0.0655	0.7750	21.97	2.336	25.2206	21.27	53.51	74.77	2.984
48 + 24	0.0636[d]	0.0691	0.5612	19.98[d]	1.790[d]	2.4665[d]	23.31[d]	54.22	77.53[d]	3.482[d]
SD[c]	0.00752	0.00623	0.43717	1.296	0.3826	1.99777	1.095	1.102	1.998	0.3496

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

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) indicated that, K fertilizer applied to sunflower cv. IH-173, 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. The effect was significant only on capric, palmitic, stearic and the totals. The application of MC 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. The effect was significant only on the total unsaturated fatty acid, oleic and the ratio between total unsaturated fatty acids and total saturated fatty acids (TU/TS). The stimulatory residual effects of the application of MC on TU and TU/TS ratio was probably due to its favorable effects on fundamental metabolic reactions in plant tissues, and would have a direct impact through utilization on growth processes, which are reflected in distinct changes in seed oil quality. Some of these changes may affect the seed oil fatty acid 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 MC and found that palmitic acid was only decreased by using 400 ppm MC 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 and Rimmer, 1993).

During the two growing seasons no significant interactions were found between the variables in the present study (N-rate and foliar application of K and the plant growth retardant MC) on quantitative and qualitative characteristics under investigation. Regarding insignificant interaction effects, the F ratios worthy exceed unity but within the level of probability at $P \leq 0.05$, they showed no significance.

4. CONCLUSIONS

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 MC (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. No significant interactions were found among N rate, K rate, and MC. Since N x K, N x MC, K x MC, and N x K x MC interactions were not significant, N applied at 143 kg ha^{-1}, K at 957 g ha^{-1} and MC at 48 + 24 g *a.i.* ha^{-1} should be used to improve cotton seed yield and its quality of Giza 86.

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Recibido: 2/3/06
Aceptado: 6/3/07