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Full Length Research Paper

Effect of Artificial Pollution of Cadmium and Lead sprays on Growth, Yield and Fiber properties of two Egyptian Cotton cultivars.

Badawy, S.H.[1*], Abdallah, Amany M.[2], El-Motaium, R.A.[3], and Husein, M.E.[1]

[1] *Soils Department, Faculty of Agriculture, Cairo University, Giza, Egypt.*
[2] *Agronomy Department, Faculty of Agriculture, Cairo University., Giza, Egypt.*
[3] *Plant Resource Department, Nuclear Research Center, Atomic Energy Authority, Inshas- Egypt.*

**Corresponding Author: Badawy S.H.*

Abstract
Two field experiments were carried out in Giza Agricultural and Experimental Research Station, Faculty of Agriculture, Cairo University in two seasons (2012 and 2013) to study the effect of some heavy metals (cadmium and lead) on growth, yield and fiber quality of some cotton cultivars (Giza 88 and Giza 92). The experiment was laid out in a split plot design in a randomized complete block design arrangement with four replications. The two cultivars were allocated in the main plots whereas seven foliar applications of heavy metals (control, Cd100, 200 and Pb 100, 200, and Cd+Pb 100, 200 mgl^{-1}) were allocated in the sub-plots. Spraying took place three times, 30 days after planting, at the commence of flowering and 15 days later. Cotton cultivars were planted on first week of April and harvested in commence the second week of October in both seasons. The results showed that, cultivars varied significantly in each of open boll number per plant, boll weight in first season, seed cotton yield per plant second season, seed cotton yield per feddan and fiber fineness in both seasons. No significant varietal difference could be detected regarding plant height, position of 1st sympodial node, no. of sympodial branches per plant, lint%, seed index, and earliness%, each of fiber length, uniformity% and strength in both seasons. The increase of Cd, Pb or Cd+Pb level significantly decreased the number of sympodial branches per plant, number of open bolls per plant, boll weight, seed cotton yield per plant and per feddan, lint%, earliness%, and fiber length, fiber uniformity, fiber strength and fiber fineness in both seasons, spraying of Cd+Pb at 200 mgl^{-1} gave the maximum percentage decrease which represented; 37.09% (15.01), 44.33% (8.5), 21.93% (1.81 gm), 74.83% (15.83 gm), 35.85% (4.91 kent.), 12.94% (33.60%), 11.94% (7.5gm), 24.95 (55.36%), 13.63 (31.19 mm), 8.78% (79.86%), 20.65% (37.9 g/tex), 18.92% (4.32), for the above mentioned characters ,respectively. The interaction between cultivars and heavy metals had a significant effect on all studied parameters except for plant height and position of 1st sympodial node. The two cultivars varied in their response to the increase of lead or cadmium level but the former had more adverse effect on the seed cotton yield per plant than the latter.

Key words: cotton, seed cotton yield, fiber properties, heavy metals, cadmium, lead, *Gossypium barbadense L.*

Introduction

Cotton a fiber producing crop, typically grown in the Mediterranean, is considered as one of the most profitable agricultural product, as it covers an important percentage of the available arable agricultural land of that region. Over the last decades, environmental contamination with heavy metals has been increased drastically (Alloway and Ayres 1993; Vaculk et al., 2009). Industrial emissions, municipal and industrial wastes are the main source of soil pollution by cadmium and lead (Gorlach and Gambus, 1991). Agricultural practices with chemical fertilizers, pesticides, irrigation water and disposal of chemicals nearby result in some heavy metals deposition in soil (Kaplan et al., 2005). Soil pollution with heavy metals leads to losses in agricultural yield and hazardous health effects as they enter into the food chain (Schickler and Caspi, 1999). Cdmium and lead are considered among the most dangerous and toxic heavy metals concerning human health. Excess Cd has been found to impair kidney function, disturb phosphorus and calcium metabolism and cause bone disease. According to (U.S.FDA, 1993) excess Pb cause brain damage.

The principal soil factors affecting heavy metals uptake by plants are the soil heavy metal content, sorptive capacity of soil, redox conditions, organic matter and pH (Alloway, 1995). The concentration of bioavailable soil Cd (in contrast to total Cd) is the key factor for uptake and in certain concentration interval it may be proportional to accumulated Cd (Moraghan ,1993). Cadmium is toxic to plants as it disturbs enzyme activity (Kabata-Pendias and Pendias, 1992).

In regions of metallurgical enterprises the environmental pollution exerts complex influence on the grown crops, as the plants roots absorb heavy metals from the soil and aerosol pollutants penetrate from the atmosphere into the plant through the leaves. The aerosol concentration changes depending on the source distance, the weather conditions and the size of the particles. They stick to the plant leaves, some of them being absorbed. Lead (Pb) remains as a surface precipitate, while Cd can partially penetrate into the leaves (Kabata-Pendias and Pendias, 1992). Leafy vegetables growing close to metal smelters are the highest bioaccumulators of Pb from both soil and air (Kabata-Pendias and Pendias, 1992). They also stated that there is a toxic effect of Pb on photosynthesis, respiration, and mitosis and water absorption due to the disturbance of electron transfer reaction.

Heavy metals such as Cd and Pb are non-essential elements for plants but if plentiful amounts are accumulated in plants they adversely affect the absorption and translocation of essential elements, disturb the metabolism and have an impact on growth and reproduction (Xu and Shi 2000). In this connection, Shuiping (2003) reported that effects of heavy metals on plants result in growth inhibition, structure damage, a decline of physiological and biochemical activities as well as the function of plant. Cadmium is easily taken up by plants and then transferred into the food chain where it becomes a serious health issue. Pollution with Cd which had two possible mechanism for toxicity on photosynthesis, the first mechanism is that Cd alters chlorophyll biosynthesis by inhibiting the enzyme protochlorphyllide reductase, the second one is that Cd can alter the photosynthetic electron transport by inhibiting the water splitting enzyme located at the oxidizing site of photosystem (Lagriffoul et al., 1998). Lead (Pb) toxicity in the environment causes significant toxic effects on plant processes including depression of seed germination (Reddy et al., 2005), disorders in mitosis (Liu et al., 1994), root and shoot growth reduction (Fargasova, 1994).

Many species of plants have been reported to absorb contaminants such as lead, cadmium, chromium, arsenic, and various radionuclides from soils. One of phytoremediation categories, phytoextraction, usually can be used to remove heavy metals from soil using its ability to uptake metals which are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo, and Ni). Some metals with unknown biological function (Cd, Cr, Pb, Co, Ag, Se, and Hg) can also be accumulated (Cho-Ruk et al., 2006). Gorlach and Gambus (1992) found out that maize is the most resistant to increased heavy metals concentration in the soil, followed by wheat, barley, sunflower and hemp. Qin et al. (2000), Kramer (2005) and ling et al., (2012) determined that more lead and cadmium are localized in cotton plants' leaves, compared to the leaves of rice, while Schubert (1999) ascertained that flax accumulades more cadmium in the seeds than wheat did. However, the studies connected with growing fiber crops on heavy metals polluted soils are limited and incomplete. Spaite et al. (1992) and Schneider et al. (1996) recommended growing flax in industrially polluted regions, while Sengalevitch (1999) and Yanchev et al. (2000) consider cotton and hemp as suitable crops.

Dango et al., (2004) found that, root length, plant height, fruiting branch number, and chlorophyll content were decreased with increasing Cd concentration. On average of seven cotton genotypes (*Gossypium hirsutum* L) exposed to 0.1 mM Cd and 1 mM Cd concentrations treatments, plant height was reduced by 15.4 and 24.9% compared to control, respectively. Root length, chlorophyll content, leaf numbers were reduced by 6.8, 7.6%, and 0.2, 6.8%, and 2.6, 5.0% relative to control, respectively. Cadmium also had a significant effect on fruiting branch number, which was reduced by 52.9 and 64.8% at 0.1 and 1 mM Cd treatments compared to the control, respectively. Ling et al. (2012) found that Cd stress significantly reduced boll number/plant, boll weight, seed cotton yield, lint yield and fiber qulity. Cadmium accumulation in different parts of cotton plant was increased in the following order: fiber > seed >seed shell > root > leaf > shoot > boll shell > petiol. While Bharwana et al. (2013) reported non-significant differences between the plants subjected to low lead (Pb) level (25μM) and lead untreated ones (control), while at high lead levels (50 and 100 μM) all growth parameters were worsly affected where a significant decrease in plant biomass, chlorophyll contents and photosynthetic attributes were observed.

The aim of this work was to assess of cadmium and lead tolerance in two Egyptian cotton cultivars (*Gossypium barbadense* L.) and their effect on growth, yield and fiber properties, through artificial sprays of the two elements individually or in combination.

Materials and Methods

a. Field experiments:

Two field experiments on Egyptian cotton *(Gossypium barbadense* L.) were conducted in the Agricultural Experimental and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt in two seasons (2012 and 2013) to assess tolerance of Giza 88 and Giza 92 cultivars to foliar application of cadmium and lead and their effects on growth characters, yield, yield components and fiber properties. Three levels; 0, 100 and 200 mgl^{-1} (0, 40 and 80 g fed^{-1}) for cadmium and lead, respectively were used. Cadmium was applied as cadmium chloride ($CdCl_2$) while lead as lead chloride ($PbCl_2$). The treatments were replicated four times and the foliar solution rate was 400 liter fed^{-1}. Surfactant (super film ®) was added according to the recommendation of its label. Spraying took place three times, 30 days after planting, at the beginning of the flowering stage and 15 days later. The application was carried out between 09:00 and 11:00 am. The control treatment received water spray.

The seeds were planted on the first week of April in both seasons in rows 60 cm apart and hills 20 cm apart where two plants per hill were left after thinning. The other cultural practices were carried out according to the common practices in the cotton fields. The preceding crop was Egyptian clover (berseem) in both seasons. Nitrogen at a level of 60 kg N fed^{-1} as ammonium nitrate (33.5% N) and potassium at level of 48 kg K_2O fed^{-1} as potassium sulphate (48% K_2O) were partly split and side dressed at the first and second irrigations. Phosphorus at 30 kg P_2O_5 fed^{-1} level as ordinary superphosphate (15.5% P_2O_5) was applied as broadcast during seed bed preparation.

b. Analytical procedures:
A composite soil sample was collected from 0-30 cm depth during the two seasons and was analyzed for particle size distribution, pH, EC, total $CaCO_3$, organic matter (OM), available N, P and K according to standard methods outlined by Jackson (1973). Soil total Cd and Pb was determined by the use of aqua regia methods (Cottenie et al, 1982) and measured by atomic absorption spectrophotometer (AAS). Available cadmium and lead was determined by AAS after extracting the soil with DTPA as proposed by Lindsay and Norvell (1978). Details of soil properties on the research site during years of the study (2012 and 2013) are given in Table (1). The experiment was laid out in a split plot design in a randomized complete block design arrangement with four replications. The two cotton cultivars were randomly assigned in the main plots and the seven heavy metals treatments of cadmium and lead foliar application were randomly arranged in the subplots. Each sub plot (experimental unit) had five ridges, each of 0.6 m in width and 4.0 m in length, occupying an area of 12.0 m^2. All agronomic practices were kept as normal and uniform for all the treatments.

c. Collection of experimental data:
c_1 Growth parameters: Ten plants from each treatment were taken at 120 days after sowing (DAS) at random from each plot to determine growth attributes i.e.g.; plant height (cm), position of 1st sympodial node and number of sympodial branches per plant.

c_2 Yield and yield components: Ten guarded plants were taken at random from each plot to determine, no. of open bolls/ plant, boll weight (g), seed index (g). Earliness) %(determined as percentage of seed cotton yield at the first pick to total seed cotton/ plot and lint percentage calculated from sample lint weight relative to seed cotton weight expressed as percentage and seed cotton yield/plant. The seed cotton yield/fed. (kentar =157.5 kg and feddan = 4200 m^2) was calculated from the three central ridges, of each plot.

c_3 Fiber properties: The following fiber properties were measured: fiber length (mm), uniformity ratio (%) was determined by the digital fibrograph, fiber strength (g/tex) by using the pressely tester at zero gauge length and fiber fineness (micronair reading) measured by micronair apparatus. Fiber properties were measured in fiber laboratory at the Department of Agronomy, Faculty of Agriculture, Cairo University.

d. Statistical analysis: The obtained data were subjected to statistical analysis of variance for each season, for all characters under study according to the procedure described by Snedecor and Cochron (1981). The response of seed cotton yield per plant to the increase of cadmium or lead leaves was also calculated according to the same for mentioned authors. Significance of differences among variables was done according to Least Significant Differences test (LSD) at 5% level of probability. Finally, all statistical analysis was carried out using "MSTAT-C" computer software package (Freed *et al*., 1989).

Table 1. Some soil physical and chemical properties of the experimental sites (0-30 cm depth) during 2012 and 2013 seasons.

	Season	
Soil properties	**2012**	**2013**
Physical analysis:		
C. Sand%	2.3	4.0
F. Sand%	35.5	30.9
Silt%	29.7	31.2
Clay%	32.5	33.9
Texture	Clay loam	Clay loam
Chemical analysis:		
pH (paste extract)	7.61	7.73
EC (dS/m)	1.87	1.91
Total calcium carbonate (%)	3.67	3.47
Organic matter (%)	2.25	2.09
Available nitrogen (mgkg^{-1})	34. 8	41.3
Available phosphorus (mgkg^{-1})	9.23	8.86
Available potassium (mgkg^{-1})	223	242
Total Cd content (mgkg^{-1})	1.25	1.27
DTPA-extractable Cd (mgkg^{-1})	0.24	0.23
Total Pb content (mgkg^{-1})	7.65	7.31
DTPA-extractable Pb (mgkg^{-1})	2.43	2.25

Results and Discussion

Plant growth attributes

It is quite evident from Table (2) that the two cotton cultivers did not vary significantly regarding plant height , position of the 1 st sympodial node and as well the number of sympodial branches / plant in both seasons. These growth attributes except the number of sympodial branches / plant were not significantly affected by Cd or Pb treatments. In both seasons, this number was significantly decreased due to doubling the level of Cd or the application of any Pb level or their combination.This decrease was more adverse and drastic duo to doubling the level of the Cd + Pb combination, when compared with the control treatment. The application rates of cadmium and lead in both seasons significantly decreased the number of sympodial branches per plant, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in number of sympodial branches with percentage decrease of 12.50, 15.78 and 29.87%, respectively comparing with control as an average of both seasons. However, use of 200 mgl^{-1} of Cd, Pb and Cd+Pb significantly ($P \leq 0.05$) decreased the number of sympodial branches per plant with decrease percentage of 25.19, 24.74 and 37.09%, respectively comparing with control as an average in both seasons. This result may be due to use of high level of Cd and Pb raised position of the first sympodial node and decreased the no. of sympodial branches/plant. Also, the interaction between cultivars and heavy metals treatments showed that, the number of sympodial branches per plant in both tested cultivars was decreased due to foliar application of these tested heavy metals. Whereas, use of high level of Cd and Pb with Giza 88 or Giza 92 recorded the lowest mean values of no. of sympodial branches in both seasons (Table 3). This data agree with Shuiping (2003) who reported that effects of heavy metals on plants result in growth inhibition, structure damage, a decline of physiological and biochemical activities as well as the function of plant. Dango et al., (2004) found that, plant height, fruiting branch number were decreased with increasing Cd concentration. On average of seven cotton genotypes (*Gossypium hirsutum* L exposed to 0.1 and 1 mM Cd treatments, plant height was reduced by 15.4 and 24.9% compared to control, respectively as they added. Cadmium also had a significant effect on fruiting branch number, which was reduced by 52.9 and 64.8% at 0.1 and 1 mM Cd treatments compared to the control, respectively. Bharwana et al. (2013) cleared that, low level of Pb (25 µM)did not show any significant effect in all growth characters while, high level (50 and 100 µM Pb) decreased significantly all growth characters under study (plant height, plant biomass and chlorophyll contents.

Table 2. Main effect of cultivars and heavy metals on some growth attributes of the two cotton cultivars in 2012 and 2013 seasons.

Main effects	Plant height (cm)		Position of 1st sympodial node		Number of sympodial branches/plant	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Cultivars:						
Giza 88	131.64	130.62	9.10	8.98	18.15	16.87
Giza 92	136.45	134.60	9.27	9.04	18.23	16.96
L.S.D at 0.05	N.S	N.S	N.S	N.S	N.S	N.S
Heavy metals (mgl-1)						
Control	139.79	136.23	9.50	9.38	20.83	21.10
Cd 100	135.67	134.76	8.85	9.28	18.40	18.31
Cd200	130.12	131.91	9.40	8.84	16.70	15.99
Pb 100	132.47	133.66	8.50	9.14	18.87	17.91
Pb200	133.15	131.38	8.82	8.87	16.85	15.99
Cd 100 + Pb 100	131.60	131.15	9.92	8.86	17.10	15.03
Cd 200 + Pb 200	129.78	129.22	9.00	8.73	15.93	14.09
L.S.D at 0.05	N.S	N.S	N.S	N.S	2.99	3.06

Table 3. The interaction effect between cultivars and heavy metals on some growth attributes of the two cotton cultivar in 2012 and 2013 seasons.

Treatments	Plant height (cm)		Position of 1st sympodial node		Number of sympodial branches/plant	
	cultivars		cultivars		cultivars	
	G88	G92	G88	G92	G88	G92
Heavy metals (mgl-1)	1st season					
Control	136.87	138.71	9.67	9.33	21.53	20.13
Cd 100	134.13	137.20	8.60	9.10	18.27	18.53
Cd200	125.13	135.10	9.33	9.47	16.00	17.40
Pb 100	130.80	134.13	8.00	9.00	18.87	18.87

Pb200	129.70	136.60	8.87	8.77	16.83	16.87
Cd 100 + Pb 100	130.60	132.60	9.80	10.03	16.40	17.80
Cd 200 + Pb 200	129.03	130.53	8.87	9.13	15.73	16.13
L.S.D at 0.05	N.S		N.S		4.23	
Heavy metals (mgl-1)			2nd season			
Control	134.92	137.53	9.21	9.54	20.87	21.32
Cd 100	132.78	136.74	9.23	9.32	18.96	17.65
Cd200	127.94	135.87	8.91	8.76	16.54	15.44
Pb 100	132.65	134.67	9.07	9.21	17.65	18.17
Pb200	128.87	133.89	8.75	8.98	15.87	16.11
Cd 100 + Pb 100	129.53	132.76	8.95	8.76	14.21	15.85
Cd 200 + Pb 200	127.67	130.76	8.76	8.69	14.01	14.16
L.S.D at 0.05	N.S		N.S		3.96	

Yield and yield components:

2-a. Number of open bolls/plant: Results presented in Tables (4) and (5) cleared that, cultivars, heavy metals and the interaction between them had significant effects on number of open bolls/plant in both seasons. Statistical results of the study indicated that the different foliar application levels of Cd, Pb and Cd+Pb significantly ($P \leq 0.05$) affected the open bolls number. The application rates of cadmium and lead in both seasons significantly ($P\leq 0.05$) decreased number of open bolls/plant, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in the number of open bolls/plant by 15.65, 21.24 and 34.77%, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb by 25.94, 30.73 and 44.33%, respectively comparing with control as an average of both seasons. The lowest bolls number (8.50 and 9.39) were obtained in case of Cd+Pb at 200 mgl^{-1} and Cd+Pb at 100 mgl^{-1} treatments, respectively as an average of two seasons compared with the control. This results may be due to use of high level of Cd or Pb decreased the no. of sympodial branches/plant comparing with control (Table 2). These results are in agreement with those obtained by Dango et al., (2004) and Ling et al., (2012) who found that, Cd stress reduced no. of boll/plant. Also, the interaction between cultivars and heavy metals showed that, the number of bolls per plant in both cultivars was decreased due to foliar application of heavy metals, but with different magnitudes where Giza 92 cultivar was more tolerant than Giza 88 in the 1st season whereas the reverse was true in the second season (Table 5).

2-b. Boll weight: Results in Tables (4) and (5) cleared that, boll weight was significantly ($P \leq 0.05$) affected by cultivars (1st season) and foliar application of Cd, Pb and Cd+Pb in both seasons. The heaviest boll weight was recorded by Giza 92 (2.03 g) in the first season only compared with Giza 88 (1.95 gm). Statistical results of the study indicated that, the different foliar application rates of these heavy metals affected boll weight (Table 4). Results showed that, boll weight was significantly decreased with the increase in Cd, Pb and Cd+Pb application rates. The application rates of the combination of cadmium and lead in both seasons significantly ($P\leq 0.05$) decreased boll weight, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in boll weight by 10.16, 13.25 and 18.47%, respectively. However, use of 200 mgl^{-1} of Cd, Pb and Cd+Pb decreased boll weight by 14.79, 16.54 and 21.93%, respectively comparing with control as an average of both seasons. The lightest boll weight was obtained in case of Cd+Pb at 200 mgl^{-1} (1.81 gm) and Cd+Pb at 100 mgl^{-1} (1.87 gm) treatments as an average of the two seasons compared with the control. These results are in agreement with ling et al., (2012). Regarding to heavy metals and their interaction with cultivars, the results showed that all application rates of Cd, Pb and Cd+Pb significantly decreased boll weight in both cultivars and two seasons (Table 5). Giza 88 with use of 200 mgl^{-1} Cd+Pb recorded the lowest values of boll weight in both seasons.

2-c Seed cotton yield: Data in Tables (4) and (5) indicated that, cotton cultivars varied significantly in seed cotton yield/plant in only the second season where Giza92 outyielded Giza 88.The former recorded 22.17 gm/plant compared with 19.78gm/plant produced by the latter.The main effects of cultivars, heavy metals (Cd, Pb and Cd+Pb) and the interaction between them had significant effect on seed cotton yield per feddan.Regarding the seed cotton yield /fad., Giza 92 produced significantly higher average (5.85 Kent./fad.) than Giza 88 (5.47 Kent/fad.) in the second season following the same trend of seed cotton yield /plant.The reverse was true in the first season where Giza 88 produced significantly higher yield average (6.30 kent. /fad.) than Giza 92 (5.84 kent./fad.) Results cleared that seed cotton yield was significantly decreased by increasing Cd, Pb and Cd+Pb application rates. The application rates of cadmium and lead in both seasons significantly ($P \leq 0.05$) decreased the seed cotton yield per plant and per faddan, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in seed cotton yield by 24.87, 40.91 and 61.45% per plant, and by 9.77, 17.34 and 29.36% per feddan, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb redused seed cotton by 44.28, 51.17 and 74.83% per plant, and by 23.86, 24.89 and 35.85% per feddan, respectively comparing with control as an average of both seasons. In both seasons the lowest seed cotton yield per plant (15.41 g and 17.52 g) and per fed. (4.91 and 5.22 kent.) were recorded from Cd+Pb at 200 mgl^{-1} and Cd+Pb at 100 mgl^{-1}, respectively as an average of both seasons compared with the control (Table 4). This result may be due to the high level of heavy metals which decreased no. of sympodial branches, no, of open bolls/plant and seed cotton yield/plant in both seasons. This result is in agreement with those obtained by Ling et al, (2012). The interaction between heavy metals with cultivars showed that all application rates of Cd, Pb and Cd+Pb significantly decreased seed cotton yield in the two cultivars in both seasons but with different magnitudes (Table 5). Control treatment with Giza 88 gave the highest average of no of open bolls/plant, open bolls/plant and seed cotton yield/plant and per feddan.

Table 4. Main effect of cultivars and heavy metals on yield and yield components of the two cotton cultivar in 2012 and 2013 seasons.

Main effects	No. of open bolls/plant		Boll weight (g)		Seed cotton yield/plant (g)		Seed cotton yield/fed. (ken.)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Cultivars:								
Giza 88	11.40	9.98	1.95	1.96	22.38	19.78	6.30	5.47
Giza 92	9.68	10.89	2.03	2.01	19.77	22.17	5.84	5.85
L.S.D at 0.05	1.05	0.38	0.06	N.S	N.S	0.78	0.45	0.11
Heavy metals (mgl^{-1})								
Control	12.40	12.93	2.23	2.20	27.58	28.52	7.33	6.79
Cd 100	11.05	10.58	1.99	2.00	21.90	21.19	6.35	5.85
Cd200	9.98	9.75	1.93	1.92	19.22	18.74	5.84	4.83
Pb 100	10.63	10.52	1.95	1.98	20.70	20.81	5.93	5.80
Pb200	9.51	9.33	1.88	1.91	17.94	17.86	5.40	5.26
Cd 100 + Pb 100	9.64	9.15	1.86	1.88	17.83	17.21	5.39	5.06
Cd 200 + Pb 200	8.71	8.30	1.82	1.80	15.83	14.99	4.98	4.85
L.S.D at 0.05	0.88	0.76	0.07	0.05	1.91	2.04	0.29	0.42

Table 5. The interaction effect between cultivars and micronutrients on yield and yield components of the two cotton cultivar in 2012 and 2013 seasons.

Treatments	No. of open bolls/plant		Boll weight (g)		Seed cotton yield/plant (g)		Seed cotton yield/fed. (ken.)	
	Cultivars		Cultivars		cultivars		Cultivars	
	G88	G92	G88	G92	G88	G92	G88	G92
Heavy metals (mgl-1)	1st season							
Control	13.47	11.33	2.21	2.25	29.74	25.42	7.51	7.14
Cd 100	11.87	10.23	1.96	2.01	23.22	20.58	6.77	5.94
Cd200	10.87	9.10	1.87	1.99	20.37	18.08	6.20	5.49
Pb 100	11.20	10.07	1.94	1.95	21.76	19.64	6.21	5.66
Pb200	10.09	8.93	1.84	1.93	18.57	17.30	5.45	5.35
Cd 100 + Pb 100	10.89	8.40	1.78	1.94	19.29	16.37	5.68	5.11
Cd 200 + Pb 200	9.35	8.07	1.75	1.90	16.33	15.32	4.98	4.97
L.S.D at 0.05	1.25		0.10		2.71		0.51	
Heavy metals (mgl-1)	2nd season							
Control	12.17	13.70	2.19	2.22	26.59	30.44	6.49	7.10
Cd 100	10.27	10.90	1.94	2.06	19.89	22.49	5.65	6.06
Cd200	9.47	10.03	1.87	1.97	17.67	19.80	4.66	5.00
Pb 100	10.23	10.80	1.95	2.00	19.95	21.66	5.67	5.94
Pb200	9.00	9.67	1.90	1.92	17.14	18.58	5.15	5.37
Cd 100 + Pb 100	8.57	9.73	1.87	1.89	16.03	18.39	4.88	5.25
Cd 200 + Pb 200	8.00	8.60	1.79	1.81	14.38	15.59	4.75	4.94
L.S.D at 0.05	1.08		0.07		2.88		0.73	

2-d Lint percentage: Data in Table (6) indicated that, both cultivars did not significantly vary in lint percentage in both seasons. All foliar application rates of Cd, Pb and Cd+Pb significantly decreased lint percentage in both seasons whereas, the lowest lint% (33.6 and 34.3%) were recorded from foliar application of Cd+Pb at 200 mgl^{-1} and Cd+Pb at 100 mgl^{-1}, respectively as an average of both seasons compared with the control. The application rates of cadmium and lead in both seasons significantly ($P \leq 0.05$) decreased the lint percentage, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in lint percentage by 5.59, 6.48 and 10.95%, respectively. However, use of 200 mgl^{-1} of Cd, Pb and Cd+Pb decreased by 8.83, 9.98 and 12.94%, respectively comparing with control as an average of both seasons. These results could be attributed to the decrease in boll weight caused by using heavy metals. The interaction between heavy metals and cultivars showed that, all application rates of Cd, Pb and Cd+Pb significantly decreased lint percentage in both cultivars and seasons, but with different magnitudes (Table 7).

2-e Seed index: Data in Table (6) indicated that, cotton cultivars did not significantly vary in seed index in both seasons. Statistical results indicated that, foliar application rates of Cd, Pb and Cd+Pb significantly ($P \leq 0.05$) affected seed index in both seasons, where seed index was significantly decreased with the increase of the heavy metals application rates compared with the control. The application rates of cadmium and lead in both seasons significantly ($P \leq 0.05$) decreased the seed index, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in seed index by 5.32, 5.41 and 10.92%, respectively while, use of 200 mgl^{-1} of Cd, Pb and Cd+Pb decreased seed index by 7.49, 7.28 and 11.91%, respectively comparing with control as an average of both seasons. Heavy metals and their interactions with cultivars cleared that, the different application rates of Cd, Pb and Cd+Pb significantly decreased seed index in the tested cultivars except Giza 92 in the second season (Table 7). The decrease in seed index with use of heavy metals may be related to decreasing boll weight. Whereas, Ling et al., (2012) reported that, Cd significantly reduced boll weight and the higher rate of heavy metals reduced seed index which caused a reduction in boll weight. The reduction of seed index could be attributed to the enhancing effect on boll opninig before complete seeds filling.

2-f Earliness percentage: Data in Table (6) showed that, cultivars did not significantly vary in earliness percentage in both seasons. Foliar application rates of Cd, Pb and Cd+Pb significantly ($P \leq 0.05$) affected earliness percentage in both seasons. Results showed that earliness percentage was significantly decreased with increase in these tested heavy metals application rates compared with the control. The application rates of cadmium and lead in both seasons significantly ($P \leq 0.05$) decreased the earliness percentage, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in earliness percentage by 11.54, 17.56 and 20.64%, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb by 17.50, 15.49 and 24.95%, respectively comparing with control as an average of both seasons. The interactions between heavy metals and cultivars cleared that, the different application rates of Cd, Pb and Cd+Pb significantly decreased earliness percentage in both seasons but with different magnitudes (Table 7). Control treatment was superior in earliness percentage in both seasons compared with other treatments; these results may be referring to differences in fruiting architecture between the control and other treatments. Whereas, control had large number of early open bolls through enhancing boll maturation than the other treatments. These treatments cleared that, mature bolls on the treated plants with heavy metals opened 10 to 16 days later than of untreated ones.

Table 6. Main effect of cultivars and heavy metals on yield and yield components of the two cotton cultivar 2012 and 2013 seasons.

Main effects	Lint (%)		Seed index (g)		Earliness (%)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Cultivars:						
Giza 88	35.51	36.06	8.14	7.78	62.59	60.93
Giza 92	34.50	36.42	8.12	7.91	59.27	61.05
L.S.D at 0.05	N.S	N.S	N.S	N.S	N.S	N.S
Heavy metals (mgl-1)						
Control	37.29	38.79	8.61	8.30	69.92	69.32
Cd 100	35.56	36.27	8.18	7.84	60.41	62.76
Cd200	34.12	35.62	8.01	7.71	55.73	61.96
Pb 100	35.04	36.52	8.17	7.90	56.42	62.15
Pb200	34.65	34.29	8.07	7.68	60.27	60.60
Cd 100 + Pb 100	33.19	35.34	7.72	7.48	57.37	56.92
Cd 200 + Pb 200	32.89	34.32	7.57	7.54	57.46	53.26
L.S.D at 0.05	1.49	1.90	0.21	0.54	5.32	5.09

Table 7. The interaction effect between cultivars and heavy metals on yield and yield components of the two cotton cultivar in 2012 and 2013 seasons.

Treatments	Lint (%)		Seed index (g)		Earliness (%)	
	cultivars		cultivars		cultivars	
	G88	G92	G88	G92	G88	G92
Heavy metals (mgl-1)	1st season					
Control	37.86	36.74	8.55	8.68	70.48	69.36
Cd 100	36.12	35.01	8.23	8.12	62.28	52.34

Cd200	34.96	33.29	8.10	8.09	59.66	51.79
Pb 100	35.26	34.83	8.27	8.06	56.08	56.76
Pb200	35.24	34.06	8.08	8.07	61.94	58.60
Cd 100 + Pb 100	33.61	32.77	7.72	7.71	57.53	57.20
Cd 200 + Pb 200	33.20	32.58	7.61	7.58	56.14	58.78
L.S.D at 0.05	2.10		0.29		7.52	
Heavy metals (mgl-1)			2nd season			
Control	38.32	39.27	8.46	8.14	69.43	70.21
Cd 100	36.50	36.04	7.76	7.92	62.37	63.15
Cd200	35.62	35.62	7.57	7.86	61.93	61.98
Pb 100	35.61	37.43	7.96	7.85	61.76	62.54
Pb200	34.98	33.60	7.52	7.84	60.32	60.87
Cd 100 + Pb 100	35.13	35.55	7.19	7.77	56.86	56.98
Cd 200 + Pb 200	34.05	34.58	7.36	7.73	54.87	51.65
L.S.D at 0.05	2.68		0.76		6.45	

3- Seed cotton yield analysis: The present study seeks answers regarding the tolerance of cotton plants to artificial pollution caused by three sprays of two levels of cadmium and lead and their combination. Sprays were tried 30 days after planting and at the commence of flowering and 15 days later .Results in Tables (2), (3) and (4) indicated varietal negative response to doubling the level of cadmium or lead or their combination as expressed in a significant interaction on seed cotton yield /plant and its two main components i.e the number of open bolls/plant and boll weight. Serving the response equations of the seed yield /plant rather than the seed cotton yield /faddan which its response to the heavy metal level might be masked by uncontrolled variation in the cotton plant population clearly indicated the following findings:

3-a Response of seed cotton yield /plant to cadmium level:

$\hat{Y} = a - bx + cx^2$

$\hat{Y}_{88}\,(1^{st}) = 29.74 - 8.36\,x + 1.84\,x^2$

$\hat{Y}_{88}\,(2^{nd}) = 26.59 - 8.94\,x + 2.22\,x^2$

$\hat{Y}_{88}\,(\bar{Y}) = 28.17 - 8.65\,x + 2.03\,x^2$

$\hat{Y}_{92}\,(1^{st}) = 25.42 - 6.01\,x + 1.17\,x^2$

$\hat{Y}_{92}\,(2^{nd}) = 30.44 - 10.58\,x + 2.63\,x^2$

$\hat{Y}_{92}(\bar{Y}) = 27.93 - 8.30\,x + 1.90\,x^2$

3-b Response of seed cotton yield/plant to lead:

$\hat{Y} = a - bx + cx^2$

$\hat{Y}_{88}\,(1^{st}) = 29.74 - 10.39x + 2.40\,x^2$

$\hat{Y}_{88}\,(2^{nd}) = 26.59 - 8.55x + 1.92\,x^2$

$\hat{Y}_{88}\,(\bar{Y}) = 28.17 - 9.47x + 2.16x^2$

$\hat{Y}_{92}\,(1^{st}) = 25.42 - 7.50x + 1.72\,x^2$

$\hat{Y}_{92}\,(2^{nd}) = 30.44 - 11.63x + 2.85\,x^2$

$\hat{Y}_{92}(\bar{Y}) = 27.93 - 9.57\,x + 2.29\,x^2$

Where $\hat{Y}_{88}$ and $\hat{Y}_{92}$ are the predicted seed cotton yield / plant of Giza 88 and Giza 92 in the first and second season and their average.
These equations clearly indicate that the response of seed cotton yield /plant to the increase of either cadmium or lead level is quadratic i.e of the second order where the decrease of yield was diminishing .In other words, the decrease of seed cotton yield/plant due to the second heavy metal increment is lower than that caused by the first increment. Yield analysis through these equations could be summarized in two clear points as follows:

(1) The varietal response of seed cotton yield /plant to the increase of either cadmium or lead level was seasonal i.e varied between the two seasons. This response was governed by the yield productivity i.e the higher the yield average, the higher was the sensitivity of cotton plant to the increase of heavy metal level. This was expressed by a higher negative response by Giza 88 in the 1 st season and by Giza 92 in the 2 nd one. Therefore, on the average of the two seasons, the two cotton cultivars showed an almost similar sensitivity and hence tolerance to the increase of the heavy metal level.

(2) Lead reflected greater damage to the cotton plants than cadmium in the two seasons and their average as was expressed in greater negative response by the seed cotton /plant to the increase of lead level than to the increase of cadmium level. These negative

responses are quite clear when the (b) values in the response equations are compared . These values were always higher and hence the reduction of yield due to the increase of lead than the increase of cadmium level.Finally the more adverse effect caused by the combination of the two heavy metals could be attributed to lead than to cadmium,though the two individually caused adverse effects on cotton growth (Table 2,3,4) and yield(Table 5).

4. Fiber Properties: Statistical results of the study showed that, the application rates of Cd , Pb and Cd+ Pb significantly ($P \leq 0.05$) affected some studied fiber properties (Tables 8 and 9).

4.a Fiber length: Data in Table (8) indicated that in both seasons cotton cultivars insignificantly varied in fiber length, where Giza 88 (33.30 mm) was at par with Giza 92 (33.11 mm) as an average of both seasons. Foliar application rates of Cd, Pb and Cd+ Pb led to a significant ($P \leq 0.05$) decrease in fiber length compared with the control, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in fiber length by 6.96, 6.69 and 10.58%, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb by 9.87, 9.59 and 13.63%, respectively comparing with control as an average of both seasons. The shortest fiber length (31.19mm) was recorded in case of foliar application of Cd + Pb at 200 mgl^{-1} as an average of both seasons (Table 8). The interaction between cultivars and heavy metals caused a significant decrease in fiber length in both seasons compared with control Table (9). Control treatment with Giza 88 or 92 gave the longest fibers compared with other treatments. Ling et al., (2012) reported that Cd stress reduced fiber quality.

4.b Uniformity index : Data in Table (8) showed that, in both seasons cotton cultivars insignificantly varied in uniformity index, where Giza 88 (83.62%) was at par with Giza 92 (83.38%) as an average of both seasons. Foliar application of all rates of the heavy metals significantly decreased the uniformity ratio in both seasons compared with the control. The application rates of cadmium and lead in both seasons significantly ($P \leq 0.05$) decreased the uniformity index, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in uniformity index by 2.79, 4.30 and 6.76%, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb by 4.57, 6.68 and 8.78%, respectively comparing with the control. The lowest average of uniformity index (79.86%) was recorded from Cd + Pb at 200 mgl^{-1} treatment as an average of both seasons (Table 8). Also the interaction between cultivars and heavy metals indicated that the different application rates of Cd, Pb and Cd+ Pb significantly decreased the uniformity in fiber length in Giza 88 and Giza 92 cotton cultivars in both seasons compared with control (Table 9). Control treatment with Giza 88 or 92 gave the best uniformity index compared with other treatments in both seasons.

4.c Fiber strength: Data in Table (8) showed that, there was no significant variation in fiber strength due to the different cultivars in both seasons where Giza 88 (42.55 g/tex) was at par with Giza 92 (42.41 g/tex) as an average of both seasons. Results revealed that all levels of Cd, Pb and Cd+ Pb caused a significant decrease in fiber strength in both seasons compared with control treatment, where the control treatment gave the strongest fibers in both seasons. The interaction between cultivars and heavy metals showed that, fiber strength in Giza 88 was significantly decreased due to the application of Pb at 200 mlg^{1} and Cd + Pb at 100 and 200 mgl^{-1} in both seasons compared with the control treatment. All levels of the studied heavy metals decreased fiber strength in Giza 92 in both seasons compared with control (Table 9). The application rates of cadmium and lead in both seasons significantly ($P \leq 0.05$) decreased the fiber strength, whereas, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in fiber strength by 4.71, 6.78 and 15.85%, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb by 9.48, 11.32 and 20.65%, respectively comparing with the control as an average of both seasons.

4.d Micronaire reading: Results in Table (8) indicated that, cotton cultivars, heavy metals and their interactions had a significant effect on micronaire reading in both seasons, where Giza 88 gave the best reading for fineness in both seasons. Fiber fineness was significantly decreased by increasing application rate of Cd, Pb and Cd+Pb. The application rates of cadmium and lead significantly ($P \leq 0.05$) decreased the fiber fineness, where, application of 100 mgl^{-1} of Cd, Pb and Cd+Pb recorded a decrease in fiber fineness by 13.88, 12.91 and 15.34%, respectively. However, 200 mgl^{-1} of Cd, Pb and Cd+Pb by 17.16, 16.56 and 18.92%, respectively comparing with the control. Control treatment with Giza 88 gave the best average of micronaire reading compared with other treatments in both seasons (Table 9). To conclude the effect of the level of either Cd or Pb on fiber properties, it was quite evident that the decrease of boll weight (Table 4) due to foliar application of these elements was the resultant of a decrease in seed index (Table 5) and hence a significant decrease in fiber length and thereby fiber strength and fineness as observed herein (Table 8).

Table 8. Main effect of cultivars and heavy metals on fiber quality properties of the two cotton cultivar in 2012 and 2013 seasons.

Main effects	Fiber properties							
	Length (mm)		Uniformity index (%)		Strength (g/tex)		Micronaire reading	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Cultivars:								
Giza 88	33.69	32.91	84.86	82.38	42.06	43.04	3.82	3.79
Giza 92	33.49	32.73	84.50	82.27	42.90	41.91	4.17	4.53
L.S.D at 0.05	N.S	N.S	N.S	N.S	N.S	N.S	0.29	0.14
Heavy metals (mgl-1)								
Control	35.48	35.65	87.43	86.60	46.20	45.94	3.40	3.66
Cd 100	33.22	32.97	84.77	84.42	43.80	44.00	3.98	4.06
Cd200	32.68	31.93	83.63	82.67	41.47	42.35	4.18	4.26
Pb 100	33.37	33.45	84.22	82.67	43.53	42.93	4.00	4.15
Pb200	33.08	31.65	83.15	79.75	40.57	41.78	4.08	4.33
Cd 100 + Pb 100	33.22	31.07	83.95	79.08	39.67	39.42	4.08	4.27
Cd 200 + Pb 200	32.20	30.18	82.87	76.85	38.40	37.41	4.23	4.41
L.S.D at 0.05	0.76	1.15	1.15	1.36	2.27	0.72	0.23	0.20

Table 9. The interaction effect between cultivars and heavy metals on fiber quality properties of the two cotton cultivar in 2012 and 2013 seasons.

Treatments	Fiber properties							
	Length (mm)		Uniformity index (%)		Strength (gm/tex)		Micronair reading	
	Cultivars		Cultivars		cultivars		Cultivars	
	G88	G92	G88	G92	G88	G92	G88	G92
Heavy metals (mgl-1)	1st season							
Control	35.90	35.07	87.50	87.37	46.40	46.00	3.13	3.67
Cd 100	33.13	33.30	84.60	84.93	43.20	44.40	3.83	4.13
Cd200	32.83	32.53	83.90	83.37	40.13	42.80	3.93	4.43
Pb 100	33.73	33.00	84.37	84.07	42.27	44.80	3.83	4.17
Pb200	32.77	33.40	83.30	83.00	39.53	41.60	3.97	4.19
Cd 100 + Pb 100	33.07	33.37	84.40	83.50	40.13	39.20	3.93	4.23
Cd 200 + Pb 200	32.23	32.17	83.30	82.43	38.40	38.40	4.1	4.36
L.S.D at 0.05	1.07		1.63		3.22		0.33	
Heavy metals (mgl-1)	2nd season							
Control	35.70	35.60	86.30	86.90	46.73	45.15	3.30	4.02
Cd 100	33.40	32.53	84.05	84.33	44.43	43.57	3.73	4.39
Cd200	32.03	31.83	83.47	81.87	43.57	41.14	3.91	4.61
Pb 100	33.50	33.40	82.53	82.80	43.57	42.28	3.77	4.53
Pb200	31.70	31.60	79.83	79.67	42.14	41.42	3.93	4.73
Cd 100 + Pb 100	31.07	31.07	79.07	79.10	39.42	39.42	3.89	4.65
Cd 200 + Pb 200	30.20	30.17	77.07	76.63	37.69	37.12	4.01	4.81
L.S.D at 0.05	1.62		1.92		1.02		0.28	

Conclusion

Sprays of heavy metals (Cd and Pb) on Egyptian cotton cultivars “Giza 88 and Giza 92” was applied as a simulation of aerosol pollution. All heavy metals treatments reduced growth parameters, yield and fiber quality. The reduction was higher at 200 mgL^{-1} than at 100 mgL^{-1} concentration. The combination effect of Cd and Pb aggravated the effect of Cd or Pb alone and gave the maximum reduction. This proved to be true in both cultivars.

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