EFFECT OF ELECTRIC POWER LINES STRESS ON GROWTH, SOME METABOLIC ACTIVITIES, AND YIELD OF MAIZE (ZEA MAYS L.)

ABSTRACT:
Exposure to power lines of the electric power stations generates electromagnetic fields (EMFs) which have been documented to produce various biological effects. In the present investigation, EMFs showed two diverse directions; one is stimulatory at low EMFs while the other is inhibitory at high EMFs. In maize (Zea mays), both the percentage of germination, the subsequent vegetative growth and yield criteria, significantly increased in plants grown at low EMFs as compared to the control. The fluorescence emission intensity of leaf chlorophyll had significantly increased in response to the low EMFs. In addition significant increments in the total soluble sugars, total soluble nitrogen and total phenol were recorded. Moreover, the contents of mineral ions as K, Ca, Mg, and P were significantly increased in low EMFs. Plants grown at low EMFs showed remarkable and significant increments in both the quantity and quality of the produced oil through decreasing the contents of saturated fatty acids by 57.5% and increasing those of unsaturated ones by 13%. Exposure of maize plants to high level of EMF significantly enhanced the content of H₂O₂, compared concurrently with significant increase in malondialdehyde (MDA) as being compared with control plants. Furthermore, MDA content was utilized as biomarker for lipid peroxidation parallel to H₂O₂ content. Moreover, total phenols showed higher increases above those of the control and low EMFs. In addition, the level of unsaturated fatty acids of the yield grains was increased. In conclusion, electromagnetic fields of low dose have been known to act as bio-stimulators for the growth of maize plants.

INTRODUCTION:
Studies related to the biological effects of electromagnetic fields (EMFs) are new and dynamic area of scientific research, involving both physics and biology (Hernandez-Aguilar et al., 2009; El-Bakatoushi, 2010). Electromagnetic field is a source for electromagnetic energy, it can be both natural and man made, the latter has many known commercial and defence applications. Electric field between two points is created when there is difference in voltage between the two points. Higher the potential difference the stronger is the resultant electric field. Magnetic field, on the other hand, is created due to current flow in a conductor. The higher the current the stronger is the magnetic field. Both electric and magnetic fields are components of electromagnetic waves and in vacuum they both move at the same frequency. Ultra-high-voltage (UHV) power lines are required in order to reduce power energy losses, and to transfer more power across long distances (Aoki and Ikezawa, 1982). The study of the effect of electromagnetic field from a high voltage power line on the yield of agricultural crops cultivated underneath and near the power line has been becoming one of the popular issues in biology (Soja et al., 2003).

The effect of electromagnetic fields is not limited; it generates some side effects. Elansky et al. (2001) showed that high voltage power lines (HVLs) are able to change significantly the ozone concentration within the atmospheric surface layer over regions where the HVLs are high. Ozone is an air pollutant with significant effects on agriculture. Vaida et al. (2008) proved that the ozone concentration near high-voltage power lines changed from 10 to 51 ppb.

Effects of electromagnetic radiations on biology had been reported of many researchers (Lacy-Hulbert et al., 1998; Goiceanu et al., 2001). A wide range of physiological effects, stimulation of the biological processes and nutrient metabolism has been observed in plants as a result of the exposure to a high voltage electric field (Zhang and Hashinaga, 1997; Ynikiene and Pozeliene, 1998).

The effect of electric field on living cells during decades is mainly attributed to its
Maize plant (Zea mays L.) is an important agricultural crop for animals and humans. For both economic and technical reasons, maize represents the highest potentials for narrowing the edible oils production gap in Egypt (Amin et al., 2007).

The purpose of this study was to obtain information on the biological effects of an electromagnetic field from a high voltage power line on the growth and yield of an agricultural crop (maize plant) cultivated at high EMFs and low EMFs (underneath and away from the power lines).

MATERIAL AND METHODS:

A strain of maize grains (Zea mays L. cv hageen fardy) was kindly obtained from the Agriculture Research Center, Cairo, Egypt. The grains were selected for uniformity in size.

The experiment was carried out in 2009 near Qaha Power Station, Qalyubia Governorate (Egypt). Influence of high voltage on plant growth, plant metabolism and final yield of maize was studied under open field condition.

Two electromagnetic field strengths (low EMFs and high EMFs) were obtained by planting the grains at different distances from the power line. Maize grains were soaked overnight in pure water then cultivated at standard agricultural practices at different distances from the power lines in three adjacent fields the first one is directly below the lines (high EMF), the second is 250 m apart the lines (low EMFs) and the third was at distance of 500 m apart the lines which considered as control. Plants were left to grow, then samples were collected at the vegetative stage (30 day-old plants) for measuring growth (shoot and root lengths, fresh and dry weights of shoots and roots) and some physiological analyses. At the physiological maturity, the plants were harvested from each field and the yield parameters (length and diameter of cob, number and weight of grains per cob, weight of grains per plant, weight of 100 grains and weight of grains per hectare) and some physiological analysis of mature grains were determined.

Determination of pigments:

The photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids) were determined Spectrophotometrically by the method recommended by Metzner et al. (1965).

Fluorescence Spectroscopy:

In vivo fluorescence emission spectra were recorded using Shimadzu RF5301 Spectrofluorophotometer in the range (290–750 nm). Leaf samples were homogenized in 85% acetone. The absorption spectra were recorded with a Unicam UV–visible double beam spectrophotometer from Helios Company Ltd-England. Spectrofluorophoto-

Regardless the harmful effects of electromagnetic field, it provides a simple and ecologically well compatible method to improve seed vigour in maize but it is necessary to find the optimum irradiation parameters to induce a positive bio stimulation in the maize seeds which also depends on the seed genotype (Hernandez-Aguilar et al., 2009).
Estimation of carbohydrates:

Total soluble sugars were extracted following the method adopted by Homme et al. (1992) and determined with the anthrone reagent (Whistler et al., 1962). Polysaccharides as starch were determined by the method of Thayermanavan and Sadasivam (1984).

Estimation of proline:

Free proline was extracted from 0.5 g fresh leaf samples in 3% (w/v) aqueous sulphosalicylic and was estimated by ninhydrin reagent (Bates et al., 1973).

Estimation of metal ions:

Samples were digested in nitric– perchloric acid mixture (Miller, 1998) and analyzed with an atomic absorption Spectrometer, where they were analyzed in triplicates. Metals as calcium, magnesium and phosphorus were determined simultaneously by ICP Spectrophotometry according to the method described by Meara (1955). Methylation process was carried out according to Stahl (1967). Identification of the fatty methyl ester was performed by GLC (Stahl, 1967).

Estimation of nitrogen:

Total soluble nitrogen was determined in the acid digested samples by the conventional micro-Kjeldelh method as described by Yemm and Willis (1956).

Estimation of total phenol contents:

Total phenol contents were determined in maize leaves according to the method described by Malik and Singh (1980) using Folin-Ciocalteau reagent. The absorbance was read at 650nm.

Determination of H$_2$O$_2$:

The H$_2$O$_2$ of the leaves was colorimetrically measured as described by Mukherjee and Choudhuri (1983).

Determination of lipid peroxidation:

Lipid peroxidation (MDA) in the leaf samples was measured by accumulation of malondialdehyde (MDA) as described by Hodges et al. (1999) to assess the membrane damage. The amount of MAD-TBA complex (red pigment) was calculated from the extinction coefficient 155 mM$^{-1}$ cm$^{-1}$.

Estimation of total soluble protein:

Total soluble protein was determined according to the method described by Bradford (1976).

Oil content and fatty acid profile:

Extract of oil content was done by Soxhlet apparatus according to the method of Meara (1955). Methylation process was carried out according to Stahl (1967). Identification of the fatty methyl ester was performed by GLC (Stahl, 1967).

Statistical analysis:

The obtained data were statistically analyzed according to procedures outlined by Snedecor and Cochran (1980) and least significant differences (L.S.D.) test was run to compare the mean values at 5% level of probability using SAS program (SAS Institute, 1994).

RESULTS AND DISCUSSION:

The effect of EMFs on biological systems and human beings is a subject of considerable concern. Various biological effects of exposure to EMFs have been documented (Tkalec et al., 2005; El-Bakatoushi, 2010). Electromagnetic fields of low dose have been known to act as bio-stimulators for the growth of many types of plant and seeds (Celestino et al., 2000; Martinez et al., 2002). In contrast, several studies have shown that strong magnetic fields change cell membrane characteristics, cell metabolism, cell reproduction and various other cellular functions like mRNA quantity, gene expression, and protein biosynthesis and enzyme activities. Also, it has been reported that magnetic fields affect plant growth characteristics at the organ and tissue level in seeds, young seedlings and plants (Pietruszewski, 2007; Hernandez-Aguilar et al., 2007).

Germination and growth vigour:

Results obtained in this investigation showed two diverse directions, one is stimulatory while the other is inhibitory. In table 1, both the percentage of germination and the subsequent vegetative growth (shoot & root lengths fresh and dry weights of shoots and roots) significantly increased in plants which were growing at low EMFs, the reverse pattern was observed in plants growing just beneath the high lines (at high EMFs) as compared to those which were growing 500 m away from the high power lines (the control). In accordance with these results, Alexander and Doijode (1995) found that onion and rice seeds exposed to weak electromagnetic fields (WEF) for 12 h showed significant increases in germination percentage shoot and root lengths, fresh and dry weights of seedlings. Similarly, Celestino et al. (2000) reported that WEFs increased the germination and their subsequent growth (shoot length, dry weight) of oak seedlings. Moreover, Carbonell et al. (2000) confirmed that low-frequency magnetic fields increased the germination rate and percentage of rice seeds. Exposure of maize seedlings to a continuous electromagnetic
field (EMFs) for 30 h induced 30% stimulation in the rate of root elongation compared with the controls. It also resulted in a significant increase of cell expansion (Bitonti et al., 2006). Furthermore, Martinez et al. (2009) indicated that germination of tomato seeds was affected by the magnetic treatment; in general, the germination rate of treated seeds was higher than the untreated ones. In contrast to the above results, the germination of *Raphanus sativus* L. exposed to high voltage at 60 Hz was suppressed when the electric field is strong. In the agriculture field, the source of the electric field was the high voltage power lines "50 Hz, 6 k V/m" (Aoki and Ikezawa, 1982). In addition, Tkalec et al. (2005) observed that the growth of *Lemna minor* L. plants exposed to electromagnetic radiations at the frequencies 900MHz for 2 hours was significantly decreased in comparison with the control. Moreover, Singh and Prakash (2011) reported that, Cell phone EMR inhibits *Brassica* root growth by inducing ROS-generated oxidative stress.

Table 1. Effect of electric power lines stress on the percentage of germination, shoot and root lengths, fresh and dry weights of shoots and roots of *Zea mays* L. plants

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length (cm)</th>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
<th>Length (cm)</th>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>95</td>
<td>25</td>
<td>5.1</td>
<td>0.25</td>
<td>10</td>
<td>0.72</td>
</tr>
<tr>
<td>Low EMFs</td>
<td>100</td>
<td>35</td>
<td>7.1</td>
<td>0.36</td>
<td>15</td>
<td>1.60</td>
</tr>
<tr>
<td>High EMFs</td>
<td>85</td>
<td>15</td>
<td>3.0</td>
<td>0.15</td>
<td>7</td>
<td>0.50</td>
</tr>
<tr>
<td>LSD at 5%</td>
<td>2.8</td>
<td>4.2</td>
<td>0.7</td>
<td>0.08</td>
<td>2.1</td>
<td>0.11</td>
</tr>
</tbody>
</table>

The retardation of growth of *Zea mays* plants in response to the higher EMFs might be attributed to its mutagenic effects, while the stimulation of growth could be ascribed to its effect on enhancing the biochemical and physiological effects of *Zea mays* plant.

**Metabolic activities:**

**Photosynthetic pigments and carbohydrate contents:**

The intense electrostatic fields can affect the biological systems, either directly or indirectly, through several mechanisms (Cramariuc et al., 2005). Magnetic field (MF) can have different effects on plant metabolism depending on its application style, intensity, and environmental conditions (Cakmak et al., 2010).

The present experimental study was focused on the assimilatory and accessory pigments levels in young maize plants provided by germinated seeds in electromagnetic field. The data recorded significant increments at low EMFs with consequent increase in the total soluble sugars (Figs 1 & 2). A slight increase of about 25% of chlorophyll; a level for the plants grown at of 250 m away from the power lines, and of about 5/1 for chlorophyll a/b ratio (not shown). The chlorophylls ratio “chlorophyll a / chlorophyll b” (Fig. 1) is considered the best indicator upon the efficiency of photosynthesis process. Similar results were obtained by Răcuciu et al. (2008) who found a slight significant increase (of about 3%), for chlorophylls ratio value was obtained for low magnetic field induction while for high magnetic field exposure a diminished value for chlorophylls ratio was revealed (of about 4%). The assimilatory pigments levels offered the main information upon the photosynthesis complex processes since they are able to reveal the response of the Light Harvesting Complex II.

Fig. 1. Effect of electric power lines stress on the photosynthetic pigment of *Zea mays* L. plants.

* Means significant differences.

Fig. 2. Effect of electric power lines stress on some metabolites of *Zea mays* L. leaves. 1-Total soluble sugars, 2-Total soluble nitrogen, 3-Soluble proteins and 4-Total phenols

The changes in the secondary pigments (chlorophyll b and total carotenoid pigments) comparatively to the control are presented in figure 1. The increases in carotenoid contents in *Zea mays* leaves exposed to high EMF in the present work may be attributed to the effect of EMF on their biosynthesis (Răcuciu et al., 2009). Carotenoids function as antioxidant compounds scavenging the reactive oxygen species and protecting the chlorophylls against photooxidation (Taiz and Zeiger, 2006).

**Fluorescence emission spectra:**

To underline the electric power power lines stress on maize plants, the fluorescence emission spectra (excitation wavelength at 400 nm) were analyzed in 70% methanolic
extracts of maize leaf (Fig. 3). The chlorophyll spectra from control plants presented main fluorescence emission peaks stabilized at 678.5 nm, at 678 nm in all plants. Moreover, all the samples showed increase in the fluorescence emission at 500 nm due to the effect of EMF exposure. This indicates that the fluorescence emission intensity had significantly increased in response to the low electromagnetic effect (Fig. 3) and this may be explained by increase in the excitation energy of chlorophyll molecules in response to low EMFs.

**Mineral composition of maize plant:**
Macronutrients (K⁺, Ca²⁺, Mg²⁺ and P) are essentially required for the activities of enzymes, protein synthesis, integrity of cell wall and plasma membrane and as component of protein photosynthetic complex, photosynthetic pigments, RNA and DNA (Marschner, 1995). Mineral composition (K⁺, Ca²⁺, Mg²⁺ and P) of *Zea mays* plant was affected by abiotic stresses such as EMF during its life time course through their effects on nutrients availability, transport and partitioning in plants. The prolonged exposures of plants to weak magnetic field might cause different biological effects at the cellular, tissue and organ levels. They might be functionally related to systems that regulate plant metabolism including the intracellular Ca²⁺ homeostasis (Belyavskaya, 2004). The contents of elements as K, Ca, and P were significantly decreased in group 3 those grown directly beneath the power lines (high EMFs), while those growing at low EMFs showed the reverse pattern as being compared to those of the control plants (Fig. 4). In this connection, Hanafy et al. (2006) recorded many changes in the elements level for the exposed seeds. Levels of calcium inside of plant cells increase following exposure to magnetic fields, which is one of the proposed mechanisms by which magnetic fields may affect plant growth. Calcium ions participate in many plant growth processes and responses to stress (heat and salt stress, wounding, etc.). The loss of calcium makes cell membranes leaky. Calcium ions bound to the surfaces of cell membranes are important in maintaining their stability. They help hold together the phospholipid molecules that are an essential part of their make-up. Without these ions, cell membranes are weakened and are more likely to tear under the stresses and strains imposed by the moving cell contents. Barley seedlings that grown under static magnetic and electromagnetic fields were influence under the applied MF and EMF, affecting Ca²⁺ levels, via mechanisms of ion-cyclotron resonance (Pazur et al., 2006).

![Fig. 3. Effect of electric power lines stress on the fluorescence emission *Zea mays* L. plants. The spectra are normalized at the highest peak. Excitation wavelength 400 nm.](image)

**Change in H₂O₂ and MDA:**
One of the possible mechanisms for an explanation of the observed effects of radiofrequency is an increased level of ROS due to radiofrequency exposure (Zmyslony et al., 2004). In the present investigation, the exposure of maize plants to high level of EMFs (expressed by short distance from the EMFs) significantly enhanced the content of H₂O₂, while the low level of EMFs (expressed by long distance from the EMFs did not significantly change this content compared to that of control plants (Table 2).
The level of MDA, a decomposition product of cellular level (Tkalec et al., 2007). Therefore, the level of MDA, a decomposition product of polyunsaturated fatty acids produced during peroxidation of membranes lipids is used as indicator of oxidative damage (Eraslan et al., 2007).

In the present work MDA content was utilized as biomarker for lipid peroxidation. Parallel to $\text{H}_2\text{O}_2$ content, the high level of radiofrequency EMFs induced the highest content of MDA, while the low radiofrequency of EMFs recorded no significant change in this content compared to the control plant (Table 2). Afzal and Mansoor (2012) concluded that cell phones can negatively affect germination, relative water content, fresh and dry weight of two entirely different plant genotypes. This reduction is associated with decrease in protein synthesis and increased membrane damage and antioxidant enzymes activity. Therefore, the increase in $\text{H}_2\text{O}_2$ content concomitantly with the increase in lipid peroxidation (MDA content), decrease in chlorophyll content and reduction of Zea mays growth confirmed the good correlation between the growth and induced oxidative stress induced by the high radiofrequency EMFs.

Total soluble nitrogen, protein, proline and phenol contents:

Figure 3 and table 2 reveal that there were significant increases in total soluble nitrogen, protein, proline contents of maize plants grown at either low and high EMFs as being compared to the control ones. In addition the phenols showed highly significantly increments in plants exposed to different levels of EMFs (Fig. 2). Generally, stress induces oxidative responses in plants, total soluble nitrogen, protein, proline and phenol contents. The significant increase in proline content concomitant with significant reduction in chlorophyll contents in plants exposed to high EMFs (Fig. 1) may explain that nitrogen is directed toward the synthesis of proline instead of chlorophyll. Proline functions as a radical scavenger, electron sink, stabilizer of macromolecules, cell wall components and osmoregulator (Matsyik and Mohanty, 2002). Phenols are particularly attractive as prophylactic agent in the management of ROS-mediated disorder due to their pleiotropic effects; free radical scavenging, metal chelating, antioxidant and modulation of cell signaling pathways (Soobrate et al., 2008).

**Yield components:**

Yield components were significantly increased in the studied vigour parameters of maize plants exposed to low electromagnetic field. These increases over the control values were shown to be 33.3% in diameter of cob, 20% in length of cob, 23.6% in number of grains per cob, 17.6% in number of grains per plant, 32.9% in weight of 100 grains, 56.30% in weight of grains per plant and 156% in the weight of grain per hectare (Table 3). These results are confirmed by those obtained by (Soja et al., 2003) who found that wheat grain yields were 7% higher in the plots with the lowest field exposure than in the plots nearer to the power line. On the other hand, the contents of soluble sugars, starch, protein, nitrogen and mineral ion contents as Ca, P, K, and Mg were decreased in response to high EMF directly beneath the power lines, while those growing at low EMFs showed the reverse pattern as being compared to those of the control plants (Fig. 5).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>H$_2$O$_2$ (mmol g $^{\text{FW}}$)</th>
<th>MDA (umol g $^{\text{FW}}$)</th>
<th>Proline (mg g $^{\text{FW}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15.8</td>
<td>1.42</td>
<td>17.10</td>
</tr>
<tr>
<td>Low EMFs</td>
<td>16.9</td>
<td>1.44</td>
<td>20.32</td>
</tr>
<tr>
<td>High EMFs</td>
<td>24.2*</td>
<td>2.30*</td>
<td>27.16*</td>
</tr>
<tr>
<td>L.S.Dat 5%</td>
<td>1.4</td>
<td>0.08</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* Means significant differences.

**Fig. 5. Effect of electric power lines stress on yield morphology of Zea mays L. plants**

Maize is the major cereal grain used for the commercial production of vegetable oil. For both economic and technical reasons, maize represents the highest potentials for narrowing the edible oils production gap in Egypt (Amin et al., 2007). The obtained results (Fig. 6) revealed that, there was no
significant change in the total oil content of stressed plant growing just underneath the high voltage power lines. It is of great interest that the results of figure 6 show that although the oil contents of both the stressed plants and control ones were similar but the contents of fatty acid composition was different as the contents of saturated fatty acid were decreased while the level of unsaturated fatty acids were increased.

![Graph showing effect of electric power lines stress on growth](image)

Table 4. Effect of exposure to electric power lines on fatty acid composition of Zea mays L. plants

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fatty acid composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>C14:0 1 C16:0 3 C18:1 2 C18:2 1 C18:3 3 c20:0 1 c20:1 2</td>
</tr>
<tr>
<td>Low EMFs</td>
<td>7 0.7 1 35 59 2 1</td>
</tr>
<tr>
<td>High EMFs</td>
<td>18 3 5 25 49 1 2</td>
</tr>
</tbody>
</table>

In conclusion, there are known physiological risks for plants living near high-voltage power lines. Conversely, the cultivation of plants under low electromagnetic field could be the background of crop improving in the frame of future agricultural techniques.

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Tأثير الإجهاد الناتج عن خطوط الطاقة الكهربائية على نمو بعض الأنشطة الأنبية والمحصول

لبنات الدرجة

سجح أحمد الخواص

قسم البذور، كلية العلوم، جامعة عين شمس، مصر

إن تعرض المواقع الكروماطيسية المنيعة من خطوط نسيج محطة الطاقة الكهربائية يؤثر العديد من التأثيرات البيولوجية. فإن هذه الدراسة تناولت مصاعب عدد نباتات الدرجة المركابية، الانتوا الأول تعزى عديد النمو تحت المجال الكروماطيسية المنيعة، والناحيتي بنيطي في حالة النمو تحت المجالات الماينة. يظهر الجدل المختفي في الزراعة المفتوحة لمعدلات الدرجة والنمو من البذور والمحصول متمايل في زيادة كلا من عدد البذور ووزن البذور وكذلك وزن البذور لكل كرت وعدد البذور، وضعف الماينة عند الزراعة المفتوحة. لكن الفرق الواضح هي زراعة مفتوحة عند خطوط النسبة المئوية، بالإضافة إلى ذلك فقد سجلت زراعة مفتوحة في مستويات الرطوبة الذائبة والمستونتين الكليذ الذائبة والفيتامينات الكليذ وتدهور أبينات كل من البوليمر ود. الألياف، ومضادات الإوكسایو، تحمل المجمل الكروماطيسية المخضعة زراعة مفتوحة مملودة في محتوى النبتة الناتج لحليب محصول الدرجة. ومن أبرز النتائج

المحكم:

أ.د. محمد الأمور عثمان قسم البذور، علوم طبخ
أ.د. أميرة حسنين قسم النبات، علوم عين شمس