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Review

Biological effects of electromagnetic fields

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Recently, the possible effects of extra low frequency electromagnetic fields on the public health have become an interesting subject. Generally, electromagnetic fields occur around the high voltage lines. However, electromagnetic fields also occur with some electrical machines use for fun and TV used routinely at our home and offices. Epidemiological researches explained that the effects of electromagnetic fields are related with the childhood cancer such as leukemia and melanoma. The results of some researches focused on cellular level which shows that electromagnetic fields have no direct mutagenic effects on DNA, but also changed the cellular metabolism and arrangement. In this review, the results of some researches on the effects of electromagnetic fields on the biological systems have been compiled.

Key words: Electromagnetic fields, magnetic fields.

INTRODUCTION

The effects of extremely low frequency electromagnetic field on public health have become an increasingly interesting issue recently. Electromagnetic field usually forms around high voltage power lines and electric transformers. It is a fact that electromagnetic field also results from electrical devices such as hair dryers and televisions used daily at houses and workplaces, and it affects the user and the people nearby. In addition, radiofrequency emitting sources are radars, mobile phones and their base stations, radio and television broadcasting, microwave oven, devices used in medical and industrial applications, could have effect on living organisms.

Epidemiological studies have revealed that electromagnetic field is related with some childhood cancers like leukemia and melanoma. On the other hand, cell level studies have shown that electromagnetic fields do not have a directly mutagenic effect but it has a modifying effect on the metabolism and normal operation order of the cell. In this review, the results of the studies on the effects of electromagnetic field on biological systems are presented.

THE BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELD

The motivation of people is increasing towards the possible effects of extremely low frequency, electromagnetic field on public health. With industrialization and gradual improvement in quality of life, the chances of more frequent and more intense exposure of people to extremely low frequency (elf) electromagnetic field (EMF) are on the increase. Therefore, people from many groups of the society, particularly scientists, have started to spend effort to relate EMF exposure and some cancer types that are seen in both children and adults, and which are ever increasing, and so far, many epidemiological studies have been produced.

EMF at power-line frequencies produced by specific voltages on high-voltage transmission lines can be classified by different properties of it. EMF is created during the flow of electrical current along a conductor. Normally, EMF under 200 to 300 Hz is labeled as elf and many people are exposed to elf EMF because of

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Abbreviations: EMF, Electromagnetic field; **elf,** extremely low frequency.

conditions of their house and work environments. Although EMF is usually created intensively around high voltage power lines and electrical transformation systems, elf EMF is also created during the daily use of any electrically driven device like television, video and hair dryer, which are present in our homes and workplaces. The people operating such devices or are around such during their operation are likely to be exposed to these fields (Goodman et al., 1993). The first studies on the biological effects of EMF, which started to attract more and more attention, was a constant source of doubt. The first experiment on EMF has been run by Galvani (1737-1798) around mid-18th century. In the last 20 to 25 years, various effects created by EMF on biological organisms have been examined by respected studies that are carried out on both cellular and organism levels (Goodman et al., 1993; Elhasoĵ lu, 2006; Funk et al., 2009; RŁcucēu et al., 2009; Çenesiz et al., 2011).

The possible adverse effects of low-frequency electro magnetic fields on reproductive outcome have been studied both epidemiologically and experimentally (Saadat, 2005; Aydin et al., 2009;Türkkan and Pala 2009). The epidemiological studies that are carried out for revealing the relationship between EMF and cancer have put forth that there are no specific cancer types that are directly linked in EMF. Yet EMF is a positive risk factor for many cancer types including leukemia, lymphoma, melanoma, lung cancer and others (Savitz et al., 1988, 1990; Jauchem and Merritt, 1991; London et al., 1991; Theriault, 1992; Feychting and Ahlbom, 1993; Goodman et al., 1993, Mezei et al., 2006; Henry and Singh, 2010; Seyhan, 2010). The research on how EMF physically interacts with biological systems makes up an important part of the studies on biological effects created by exposures to it. During these periods, some studies were made about animal groups and cell systems and it is found that elf EMF interacts with biological systems and causes some biological effects (Anderson, 1991; Luben, 1991; Tenforde, 1991; Liburdy, 1992). The interaction mechanisms of EMFs can be explained as follows (ķeker and Çerezci, 1991):

1. Gravitation of ferromagnetic particles that are made up of biological molecules carrying magnetic characteristics.
2. Gravitation of diamagnetic and paramagnetic anisotropic molecules.
3. Creation of potential difference that is vertical to the ionic flow due to the magnetic force.
4. Structural arrangements or changes in mid-products in the electron transfer caused by Zeeman shift in molecular energy level.
5. The currents that are created in the organism by the induction of electrical and static areas.

Many biological molecules take place in the cells and in a cell, especially from elements like C, O, H, N and S, which are the building blocks of protein molecule; more than 10^{14} H and O atoms in average and 10^{12} to 10^{14} C and N atoms. Besides, in each cell, 10^{10} to 10^{12} Si, P, Na, K, Mg, Ga, Cl; 10^{6} to 10^{8} Sn, Ti, Mo, Co, I, Pb, Ag, Br, Sr, Ni, V, Sc, Cd, Cr, Se; about 10^{4} to10^{6} U, Be, Hg and 10^{2} to 10^{4} trace elements of about 40 types also exist. The spins of most of the atoms (such as ${}_{8}O^{16}$ ve ${}_{6}C^{12}$) occur in these cells. In these types of atoms, extremely thin (ultra structural) structure is not formed. In an EMF sensitive atom, there are uncoupled head value electrons. When biological objects are exposed to EMF, with respect to increasing intensity of the field, a change in their ultra thin structure is observed. Changes occur in the energy levels of uncoupled EMF sensitive electrons of molecules which are in the cells of living beings that are exposed to EMF and which are partially unstable. Therefore, the changes that are reflected on the lives of molecules and the energy which comes out, affects the ratios of chemical reactions and thus noticeable chemical changes will occur at different EMF intensities.

Since biological molecules are highly heterogeneous in structures, when they are exposed to electrical fields, important changes occur in their properties. The current that passes through the biological system, causes the positively and negatively charged molecules in the environment to drift towards opposite directions. In this way, the structural ingredient order of the environment changes and there is an increase in the concentration of certain loaded ions in different parts of the cell. This system, which is known as electrophoresis (also the basis of an experimental method in molecular biology) is used for separating loaded biological molecules. The degree of the effect of electrical field is up to the conductivity value of the media. In biological systems, the most important factors of determination of the conductivity level are the ionic strength and viscosity. For this reason, the fastest and easiest affected cellular part from EMF is the cytosolic fraction which is made up of molecules soluble in cytoplasm. The ionic flows, which can be formed in case these molecules are affected from EMF, change the degrees and structures of ionic and hydrogen bonds itself and between different molecules and Van der Waals interactions. This situation creates differences in both the three dimensional structures of cellular proteins and their biological activities, as well as the interaction levels of other protein and nucleic acid type molecules. As provided by some studies, there is a delay in G_1 phase and RNA and protein synthesis, which is realized in the previous phase of synthesis phase. The ion flow on DNA increases with respect to the effect of EMF; ornithine decarboxylase synthesis of cells that are exposed to EMF is five times greater than that of normal cells (Byus et al., 1987; Goodman et al., 1995; Blank and Goodman, 1997; Alikamanoĵ lu et al., 2007). Besides, in a study which was aimed at revealing the effects of EMF on DNA-protein interaction on a protein-DNA complex that was created with a synthetic DNA molecule carrying "zinc-finger" structured DNA binding domain of GAL4 protein and a specific response element, chemical shifts in the amide nitrogen number 15 of the DNA binding domain of the protein due to EMF were identified (Bax, 1997). In another study examining the "zinc-finger" synthetic peptide of 26 amino acids, it was shown that EMF causes a shift on the peptide skeleton and this effect is seen in different degrees on tetramers made with its own monomers (Kemple et al., 1997).

THE RESPONSES OF CELLULAR STRUCTURES TO ELECTROMAGNETIC OR MAGNETIC FIELDS

It is difficult to evaluate the effects on organisms that are exposed to electromagnetic or magnetic fields. The main reason for this is the complex structure of biological systems. Many experiments about the effects of electrical or magnetic fields are completed on both complex structured and simple structured organisms. Since most of the biological structures are non homogenous, when they are exposed to electrical or magnetic fields, they show important cellular changes. This situation can be explained by the examination of the responses of molecules, ions and membranes under electrical and magnetic fields. The cell level effects of electrical and magnetic fields can be listed as (Goodman et al., 1995; Simko, 2004; Funk et al., 2009):

1) Membrane changes
2) Ionic effects
3) Nucleic acid and gene expression
4) Enzymatic activity
5) Biorhythms and hormones
6) Genotoxic effects

Membrane changes

The cellular structures that are affected by EMF in the first degree are the cellular membrane structures. While the membranes act like porous solids against electrical fields that are applied vertical to their surfaces, they respond like viscose liquids against such fields in membrane plane. Membranes have non-homogenous structures composed of different parts, and can be affected differently by the electrical fields. Besides, membranes, when they are electrically or chemically stimulated, create active biochemical reactions which can change the ionic channels inside them according to the requirements of the cell. This is why electrical fields affect the semi-permeable character of membranes for various molecules and ions; they change the lipid and protein configuration of the membrane and change the interaction level of molecules that interact with the membrane. As a result of the changes in the activities of active ion and molecule channels, differences can be seen in the functioning of cells, tissues and organs compared to their normal functioning. Since calcium most especially is an important element of cellular communication system, it is not complicated to predict the results this situation can cause in a cell (Adey, 1993).

In some studies that examined the effects of EMF on the structure of cellular membrane and on the activity of transportation systems on the membrane, changes of cellular membrane structure of *Physarum polycephalum* were noted as a result of EMF effect and Na, K-ATPase activity was found to be affected by both electrical and magnetic fields in different ways (Goodman et al., 1986). While magnetic field always increases the activity of the enzyme, the electrical field affects enzymes differently with respect to the power level (Blank and Goodman, 1997). In a study that was made on chicken muscle cells, cells were exposed to 50 Hz sinusoidal magnetic field. While there was a decrease in the conductivity and permeability of muscle cells, there were no differences at the connections of muscle cells. The decrease in the transportation of various ions can be interpreted as a proof for changes in permeability, but the regions which block the transit are not evident. This decrease in permeability is interpreted as a change in the electrical loads on the cells due to the changes in lipids, proteins or in both (Grandolfo et al., 1991). Chionna et al. (2003) also reported changes in human lymphocytes and U937 cells due to a static magnetic field (MFs). They were investigated in the morphological structure of cells by transmission (TEM) and scanning (SEM) electron microscopy. They found out that static magnetic field modified cell shape, plasma membrane, and increased the level of intracellular [Ca^{++}] which plays an antiapoptotic role in both cell types.

When the erythroleukemia series of K 562 cells were exposed to 2.5 mT EMF for 24 to 72 h and the cellular surfaces of the control and experiment groups were compared under the electron microscope, cellular surfaces with many microvillus and bubble like structures that were created quickly are seen in cells that reproduced under direct EMF exposure (Paradisi et al., 1993). According to the data obtained after the laboratory experiments, it was concluded that changes in both the structures forming the membrane and in surface loads are as a result of EMF exposure. Furthermore, 60 Hz, 0.1 mT, 1.0V/m sinusoidal EMF was applied on the cells of a microorganism named *Paramecium polycephalum*. Another group of microorganisms were exposed to only electrical or magnetic fields. When the ones exposed to electrical or magnetic field both separately and in combination for 24 h were compared, it was observed that the negativity of the surface loads increased. Besides, it is reported that the membranes of these cells are more hydrophobic. As one can understand from these studies, hydrophobic structure is altered where electrical or magnetic field is applied on cells, or hydrophobic characteristic is decreased due to negative oriented membrane load changes (Marron et al., 1983, 1988).

Tiber and Garip (2008) exposed human lymphocytes to (50 Hz, 5 mT) extremely low frequency electromagnetic field (ELF-EMF) for 90 min. Researchers noted that magnetic field lymphocytes showed hyperpolarization with respect to control. These results show that ELF-EMF affected membrane potential and cell proliferation. 10 V/cm DC electrical field was applied on chicken embryos for 60 min and some changes in the morphological structure of the cells were determined (Hamada et al., 1989). An EMF between 0.35 and 1.77 T was applied to HeLa cells and if the application was carried out in a period less than 10 s, the inflow of ouabaine sensitive Rb^+ would be significantly decreased. In later times, an increase in the outflow of K^+ would also be observed (Yamaguchi et al., 1992).

Ionic effects

Calcium

As aforementioned, the changes that occur in the ionic channels in the membrane when the cellular membrane structures are affected by EMF change the concentration of channel specific ions inside the cell and the cellular activities connected to these ions. Jurkat E_6 human leukemia cells were reproduced in 60 Hz EMF media and research has been carried out on how EMF affects intracellular Ca^{2+} concentrations. As a result of this study, it is found that there were no important changes in the intracellular Ca^{+2} concentrations of the cells that were reproduced in EMF media (Lyle et al., 1992). Kindzelskii and Petty (2005) investigated similar effects on cell electromagnetically treated. In high field concentration experiments that were carried out on Jurkat type cells, cells were reproduced in an electrical field of 50 Hz sinusoidal 50 mV/cm and Ca^{2+} and Mn^{2+} levels were evaluated by fluorescent Fura-2 paint. The result obtained indicate that there is an important increase in the intracellular Mn^{2+} concentrations of the cells which were exposed to the electrical field for 4 min, but the intracellular Ca^{2+} concentration was found unaffected (Walleczek and Budinger, 1992).

In another study, 50 Hz, 0.1 mT EMF was applied to Jurkat cells and it was found that EMF is affected on the free intracellular Ca^{2+} concentrations. The researchers passed the cells through Helmholtz coil for periods between 15 and 200 s. During this process, the intracellular Ca^{2+} level increased two to four-fold, from its normal values of 50 to 100 nM to values of 200 to 400 nM. Similar studies were carried out on peripheral lymphocytes and the response of the intracellular Ca^{2+} concentrations was found to be the same. Thus, 10% of the lymphocytes responded to magnetic field. On the other hand, it was observed that 85% of the Jurkat cells responded to EMF. Furthermore, there is an increase in the intracellular Ca^{2+} concentration (Lindström et al., 1993).

In a similar study on this field, HL-60 cells were exposed to various strengths of magnetic field in 6.25 MHz for various time periods between 10 and 60 min by using magnetic resonance system (MRI) and the changes in Ca^{2+} inflow were determined by indo-1 fluorescence paint. As a result of this study, it was seen that 23 min application increased the Ca^{2+} intake by 25% compared to that of the normal (Carson et al., 1990). More also, in another study on calcium, radioactive Ca^{2+} flagged microsomes were used as a model system. The flagged microsomes were exposed to 60 Hz, 0.1 mT magnetic field. The dependence of Ca^{2+} increase in the vesicle on ATP was also measured. In this experiment, it was observed that the Ca^{2+} amount decreased by 20% after 3, 5 and 10 min of EMF incubation in comparison to the control group. It is stated that this result is due the inhibition of Ca-ATPase which is connected to the membrane or leaking from microsome vesicles (Stagg et al., 1992).

Sodium and potassium

When compared with calcium, there are fewer studies on the effects of EMF on sodium and potassium. In studies that were carried out by Tsong and his colleagues, it was observed that there is an increase in the Rb^+ transportation which is potassium analog. Despite the concentration gradient, there is no change in the ATP hydrolysis. In view of this result, it is suggested that Na^+-K^+ ATPase enzyme increases the Rb^+ transportation by using the energy coming from EMF (Teissie and Tsong, 1981; Serpersu and Tsong, 1983; Serpersu and Tsong; 1984). This mechanism shows similarities with the mechanism proposed by Blank and Soo (1992, 1993) in the later years (Blank and Soo, 1992, 1993).

Nucleic acid and gene expression

DNA

In many studies that were carried out on the *in vivo* effects of electrical and magnetic fields, it is reported that the DNA is not affected negatively. However, it is put forward that EMF increases the risks associated with some cancer types like leukemia, central nervous system and lymphoma (Fiorani et al., 1992). On the other hand, it is believed that epidemiological research has to be carried out whether there exists a possible interaction between cancer risk and EMF. The results of such studies will make important contributions to question whether EMF increases cancer risk, although the results of some epidemiological studies that are in the literature show that EMF will not cause genetic changes (Cohen et al., 1986).

Experiments on the cellular responses of rat fibroblasts are separately carried out in both 50 Hz electrical field and 2 mT magnetic fields. While the magnetic field has increased the fibroblast deposit in G1 phase of cellular cycle, it has caused more accumulation of the electrical field in S, G2 and M phases (Schimmelpfeng and Dertinger, 1993). Similarly, in another study on rat osteoblasts, it was found that EMF with 50 Hz value lengthened the S phase of cellular cycle and decreased the apoptosis rate in cells (Tang and Zhao, 1999). The effect of EMF on DNA replication was also studied and it is determined that EMF at a level of 0.1 to 0.4 mT inhibits the DNA synthesis in Jurkat cells (Nindl et al., 1997). The studies that were carried out presented the idea that EMF does not directly affect DNA in *in vivo* conditions, but it may affect DNA indirectly by changing some important cellular responses (Blank and Goodman, 1997; Kindzelski and Petty,2000). In another study on brain cells of the rat were exposed to 0.01 mT of magnetic field in 60 Hz for 24 h by using electromagnetic field, it was observed that 24 h application increased the DNA single and double strand breaks in brain cells compared to that of the normal (Lai and Singh, 2004).

RNA

The research on the order of gene expression is progressively getting more attention and becoming more important. Researchers are carrying out some studies on the arrangement of oncogene precursor genes in order to reveal the interaction of EMF with cancer formation. In a study on this subject, CEM CM-3 T lymphoblasts were left in a 60 Hz, 0.1 mT strength EMF environment for 15 to 120 min and the transcription levels of *c-fos, c-jun, c*-myc and protein kinase C genes were examined. As a result of this study, significant changes compared to the normal in the transcription rates with respect to increasing cellular density and incubation time were recorded. For example at *c-fos* transcription level, a 2.5 times increase was observed without any connection to cellular density (Phillips et al., 1992). Similarly, when 50 MHz radio frequency and 16 Hz non ionized radiation were applied to Jurkat T-lenfoblast and Leydig TM3 cells, it was observed that 16 Hz EMF caused a high increase in the RNA synthesis rate of *ets1* oncogenes (Romano-Spica et al., 2000).

In a study on this subject, the mRNA expression of the receptor activator of NF-kappa-B (RANK) and carbonic anhydrase II (CA II) in ovariectomized rat osteoclast-like cells were exposed to 8 H, 3.8 mT, strength pulsed electromagnetic fields (PEMF) for three days and 40 min per day. The expression of RANK and CA II mRNA was determined with real-time fluorescent-nested quantitative polymerase chain reaction. Consequently, PEMF could regulate the expression of RANK and CA II mRNA in the marrow culture system (Chen et al., 2010).

Protein

Along with the effects of EMF on transcription, its effect on translation phase was also a questioned issue. In studies that were carried out, findings showed that EMF generally increases the protein synthesis. For example, the translation level of *Escherichia coli* RNA polymerase enzyme was measured between 72 Hz and 0.07 to 1.1 mT EMF strength for periods between 5 and 60 min, and it was observed that translation rate increased in low EMF density (0.07 mT). The decrease in the translation rate in high value EMF presence is connected to the instability of RNA in *in vitro* conditions (Goodman et al., 1993). Therefore, it is now generally accepted that weak EMF in the power frequency range can activate DNA to synthesize proteins. In an investigation, the effects of 50 Hz frequency 30 εT EMF on the reproduction behaviors and the protein synthesis of *E. coli* and *Saccharomyces cerevisiae* cells were obtained. EMF was generated with Helmholtz coil and EMF level (50 Hz, 30 εT) was especially selected in a range to which human beings can exposed in their daily lives. According to the results of the study, EMF decreased the total protein amount of the bacteria and yeast cells and also reduced the reproduction speed (Erol et al., 2003).

Enzymatic activity

There are some enzymes which directly respond to an electromagnetic field. One of these enzymes is ornithine decarboxylase (ODC). In most of the studies, an increase in the activity of ODC enzyme in cells which were exposed to magnetic or EMF is observed. When it is considered that this enzyme is active especially in fast growing cells and induces tumor growth, it can be thought that a connection for the possible interaction between EMF and cancer risk exists (Byus et al., 1987; Litovitz et al., 1991). Another enzyme whose interaction with EMF was also examined is the acetylcholinesterase. When the acetylcholinesterase activity is examined in rat bone marrow cells which were exposed to 1.4 T fixed magnetic field for 30 min, a decrease in the enzymatic activities of cells after 2 h on which static magnetic field is applied at 37°C was observed. At 27°C, an increase in the enzymatic activity was detected after 3.5 h of the same static magnetic field (Stegemann et al., 1993).

Besides these, the effects of EMF especially on enzymes that take part in cellular communication system are important to reveal the rising of cancer risk. For example, when 20 Hz and 7 - 8 mT strength EMF is applied on human skin fibroblast culture, a significant decrease in the reproduction and differentiation of fibroblasts are observed. This result is connected to the graded induction of EMF on cAMP dependent protein kinase A activity (Loeschinger et al., 1998). In addition, the effect of magnetic field on carbonic anhydrase isoenzyme *in vitro* was also determined by Coskun (2007). In this study, the effect of magnetic field on purified isoenzymes was investigated and it was found that the enzymes were affected by magnetic field in terms of both the magnetic field intensity and the time intervals.

Biorhythm and hormones

In mammals, the biorhythm system is a function organized by the pineal gland. Pineal gland cells make melatonin synthesis over serotonin. It is shown that EMF modifies melatonin synthesis and melatonin primers. Melatonin is a substance which has oncostatic effect on active estrogen receptor expressing human cells (Wilson et al., 1986; Loeschinger et al., 1998). The effect of 60 Hz, 0.19 to 1.19 mT EMF on human breast cancer cell (MCF-7) reproduction in the presence and lack of melatonin was studied. It was observed that EMF does not have any effect when the cells were left to reproduce in an environment without melatonin. In contrast, when EMF is applied for 24 h on cells that were reproduced in an environment having 10^{-9} M melatonin, it was observed that their development was inhibited by 18%. This inhibition is interpreted as the mutual effect of 60 Hz, 1.19 mT EMF and melatonin which has an oncostatic activity characteristic (Cos et al., 1991).

Furthermore, Koyu et al. (2005) exposed adult male rats to 1800 MHz electromagnetic field (EMF) for 30 min/day five days/wk for four weeks. The researchers noted that 1800 MHz EMF emitting cellular phones increase serum T_3, T_4 and cortisol levels, but it has no effect on serum thyroid stimulating hormone (TSH) and testosterone levels in rats.

Genotoxic effects

Studies on EMF's genotoxic effects are increasingly becoming more popular in the light of the results of epidemiological studies (Savitz et al., 1988; McCann, 1998; Lai and Singh 2010). When the effects on sister chromatid mutations are examined by applying 50 Hz 0.1 to 7.5 mT EMF on lymphocytes taken from adults and that are stimulated by mitosis activating substances, it was found that EMF does not have any effect neither on chromosome breaks nor on the frequency of chromosome mutations (Liburdy et al., 1993). There are some other studies in the literature which support these findings (Cohen et al., 1986; Rosenthal and Obe, 1989; Frazier et al., 1990). Besides, in another study when 0.4 mT EMF was applied on lymphocytes, it was observed that there is a statistically important increase in chromosome breaks. The EMF that was used in this study is of "pulsed" character (Garcia-Sagrego et al, 1990; Garcia-Sagrego and Monteagudo, 1991). 50 Hz EMF is applied on lymphocytes on which mitosis activity is stimulated for 24, 48, and 72 h and it is determined that the sister chromatid mutations in these cultures did not change significantly under 24 and 48 h trials, but an important increase in the mutation frequency under 72 h period was found (Khalil and Qassem, 1991). In another study on adult male rat exposed to 9450 MHz at power density 2.65 mW/cm^2 of microwave radiation for 1 h a day during 13 day, the standard bone marrow chromosome analyses were carried out and experimental group was compared with control group. The result indicates that the 13 days application resulted in an increased abnormal metaphase and mitotic index decreased in chromosomal of rats compared to that of the normal (Akdağ et al., 1998).

In many studies that were carried out on biological structures on the effects of electrical and magnetic fields, it is reported that the DNA is affected negatively (Andrei and Petty, 2000; Rłcucęu. 2011). Aksoy (2006) observed similar effects on human cell and plant cell electromagnetically treated. For example, 1000, 1500 and 2000 V/m power density of electric fields and 0.25, 0.50, and 1 mT, strength of magnetic fields were established for *Allium cepa* L. and human peripheral lymphocytes in order to investigate the effects of electromagnetic fields. To investigate the genetic effects of electromagnetic fields on DNA levels, randomly amplified polymorphic DNA-polymerase. chain reaction (RAPD-PCR) methods were applied and it was found that electromagnetic fields affected the mitotic index and increased the chromosomal aberrations in all the treatment groups.

PERSPECTIVES

It can be easily understood from these studies that there is a direct connection among the biological effects of EMF and the type, degree and exposure duration of the field. These effects of EMF changes on biological systems have attracted the attention of many researchers all around the world who work on biology, medicine, and agriculture. Particularly in the recent years, many scientists have started to do research on the positive biological effects of magnetic field as well as its negative effects on living beings. According to the data gathered as a result of experiments, it is determined that magnetic field causes some changes in the biological activities of organisms. Besides these studies which were performed to determine the effect of magnetic field on the molecules and cells of living beings, researchers have started accelerating plant growth and productivity (Belyavskaya, 2004; Hajnorouzi, 2011). Successful results were obtained from studies on cotton and grains in terms of productivity in Romania. It is found that it promotes growth in corn and wheat. In India, an increase in the growth and productivity of peanuts were provided. It is determined that EMF accelerates pollen creation and tube development in *Corica papaya*. In Japan, increases in the leaf numbers and areas of strawberries and strawberry productivity under EMF exposure were detected (Akhmedova et al., 1985; Bosica and Zeriu, 1989; Alexander and Ganeshan, 1990; Vakharia et al., 1991; Matsuda et al., 1993). In addition, Dardeniz and Tayyar (2007) have found that electromagnetic field positively affects some of the vegetative development parameters in Cardinal grape type clefts. Dao-liang et al. (2008) have also reported that the effect of a 10-min treatment of beach plum explants with a strength of 97kA/m on the regeneration and growth was highest, and the number of the sprouts induced was 2.3 times greater than that in the control group.

The findings above show the positive effects of magnetic field on plants. Nevertheless, there are studies on the negative effects of magnetic field on plants too (Magnusson, 1984; Hanafy et al., 2006). Various factors like some ambiguities in the starting mechanism of the magnetic field effect, the differences in determining the strength, and exposure period of the magnetic field are questioned. However, biological characteristics of the seeds that are used in such studies were not fully determined and this might be taken as the reason of such different results subject to exposure to magnetic field.

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