Turkish Journal of Biology

Volume 31 | Number 1 Article 1

1-1-2007

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Turk J Biol
31 (2007) 1-5

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Received: 01.12.2006

Abstract: In this study, the effects of microwave frequency electromagnetic fields (EMF) on the fecundity of *Drosophila melanogaster* were investigated. The Oregon strain females of *Drosophila melanogaster* were exposed to 10 GHz EMF continuously (3 h, 4 h and 5 h) and discontinuously (3 h exposure + 30 min interval + 3 h exposure). The fecundity of females were determined. In the 4 h and 5 h exposed groups, it was found a statistically significant decrease in mean fecundity as compared to the control ($P < 0.05$). There was a reduction in the 3 h and 3 + 3 h exposed groups but this reduction was not significant statistically ($P > 0.05$).

Key Words: *Drosophila melanogaster*, electromagnetic fields, fecundity

Mikrodalga Frekasındaki Elektromanyetik Alanın *Drosophila melanogaster*'in Yumurta Verimi Üzerine Etkileri

Özet: Bu çalışmada, mikrodalga frekansındaki elektromanyetik alanların (EMA) *Drosophila melanogaster*'in yumurta verimi (fekundite) üzerine olan etkileri incelendi. *Drosophila melanogaster*'in yabanıl Oregon soyu dişilerine, aralıksız 3 saat, 4 saat, 5 saat ve 30 dakika aralıklı 6 (3 + 3) saat olmak üzere 10 GHz (gigahertz)'lik EMA uygulandı. Dişilerin yumurta verimi belirlendi. 4 ve 5 saatlik uygulama gruplarında, ortalama yumurta veriminin kontrole kıyasla istatistiksel olarak azaldığı ($P < 0.05$) görüldü. 3 ve 3 + 3 saatlik uygulama gruplarında da bir azalma gözlendi ancak bu azalma istatistiksel olarak önemli değildi ($P > 0.05$).

Anahtar Sözcükler: *Drosophila melanogaster*, elektromanyetik alanlar, yumurta verimi

Introduction

Over the last decade, the exponential growth of mobile communications has been accompanied by a parallel increase in the density of electromagnetic fields (EMF). As such, the continued expansion of mobile communications raises important questions because EMF have long been suspected of having biological effects. It has been claimed that EMF, especially microwave frequency EMF, cause biological effects by increasing the temperature, changing the chemical reactions, or inducing an electrical current (1-4).

The effects of EMF have been handled by using different features in various organisms by many researchers and different results have been obtained. In these studies, determining the effects of EMF upon *Drosophila* fecundity also considered. For example, Pay et al. (5) investigated the effects of long term 2450 MHz EMF on reproduction of *Drosophila melanogaster* and showed that exposed field reduced the egg production among the females compared to control. In another work, pulsed radiofrequency (RF) EMF from common GSM (Global System for Mobile Telecommunications) with a carrier frequency at 900 MHz, "modulated" by human voice, (speaking emission) was decreased the reproductive capacity of *Drosophila melanogaster* by 50-60%, whereas the corresponding "nonmodulated" field (nonspeaking emission) was decreased the reproductive capacity by 15-20% (6). Similarly, Ramirez et al. (7) observed that oviposition of *Drosophila* was decreased by exposure to pulsated (extremely low frequency (ELF) (100 Hz, 1.76 miliTesla (mT)) and sinusosidal fields (50 Hz, 1 mT). In contrast, it was reported that 50 Hz 8 mT EMF exposure did not have any effect on fecundity when EMF were exposed to the third instar larvae of *Drosophila melanogaster* (8). In a similar work, Walters and Carstensen (9) reported that 60 Hz magnetic field did not affect egg production of *Drosophila melanogaster*.

The X band, ranging from 7 to 12.5 GHz, is part of the microwave band of the electromagnetic spectrum. It is used by some communications satellites and for radars, primarily for fire control, but also for longer-range ground and weather mapping. It is used primarily by militaries and space agencies. In this study, the effects of 10 GHz EMF on the fecundity of *Drosophila melanogaster* was examined.

Materials and Methods

The organism and environmental conditions

In this study, the wild type Oregon strain of *Drosophila melanogaster* was used. The flies were kept in a *Drosophila* culture room (Hacettepe University, Ankara / Turkey) at 25 ± 1 ºC and relative humidity of 50-60% and in 8 hrs light, 16 hrs dark periods on a standard *Drosophila* medium described by Bozcuk (10).

EMF exposures

EMF exposures were done by using an electromagnetic radiation source (antenna) at 25 ± 1 ºC temperature in Hacettepe University, Microwave and Aerial Laboratory of Electricity and Electronic Engineering Department (Ankara / Turkey). The intensity of radiation used was determined taking into account previous publications and our pilot experiments. The Oregon strain (w.t.) females of *D. melanogaster* were exposed to a 10 GHz EMF for 3 h, 4 h and 5 h continuously and 3h + 3h discontinuously with a 30-min interval in between. It was a single exposure. The groups were organized according to the dose levels to which they were exposed.

The EMF source was a horn type antenna (Figure) which produced a pulsed (modulated) square wave (1 kHz), approximately 5 mW (lowered power). This had an X-band frequency range 8.2-12.4 GHz with a gain of 16 dB. The frequency was fixed at 10 GHz. The power density of the antenna was 0,0156 Watt/m^2, electric field intensity was 3,42 V/m and SAR (Specific Absorption Rate) was approximately 9,8 mW/kg (11, 12, 13).

During the EMF exposure, *Drosophila* females were placed in empty glass tubes (2,5 × 7,5 cm). The experimental tubes were kept just opposite the antenna at a distance of 1 m, and stabilized by a rectangular holder. In the 3 + 3 h exposed group, the flies were transfered in vials containing fresh meal during the 30 minutes resting period. The females in the control group were kept away from the EMF source in the same laboratory conditions during the exposure period.

Determination of the mean fecundity

In order to determine the effects of the 10 GHz EMF on the mean fecundity, exposed virgin females were used. An exposed female and 3 non-exposed males of same age (3 days old) were crossed in empty glass culture bottles. Then spoons, containing standard medium, were placed in these culture bottles immediatelly. These spoons were changed for every 24 h and the eggs were counted for a period of 10 days. It was stated that the egg production in the first 10 days of adult life was a good reference for the whole adult life egg production of this organism (14, 15, 16).

Statistical methods

The statistical analysis of the results was carried out using the SPSS 10.0 programme. The daily mean egg production in each group was calculated with the ANOVA test.

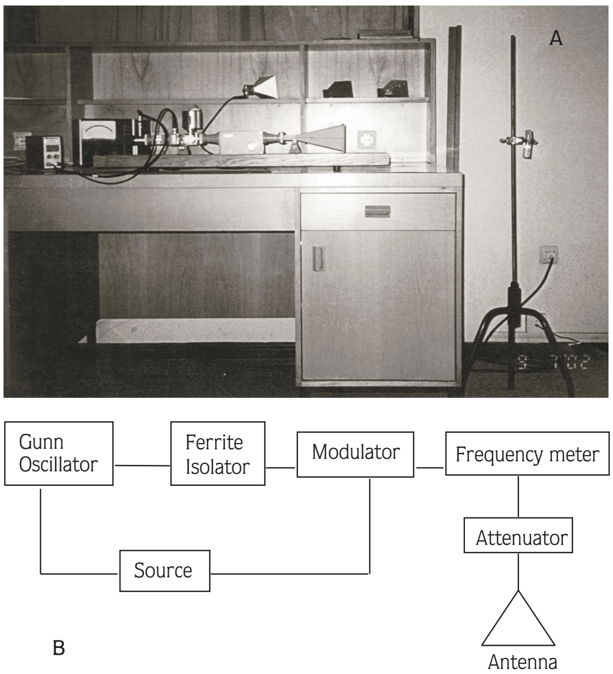

Figure. Picture (A) and diagram (B) of horn type antenna used for EMF exposure of *Drosophila melanogaster* females (11-13).

Results

Table shows the effect of different EMF-exposure periods on fecundity. The daily mean egg-production per female during the first 10 days of adult life was 12.6 for non-exposed control group. However, the daily mean egg production was 11.56, 10.22, 10.88 and 11.54 in the 3 h (E3), 4 h (E4), 5 h (E5) and 3 + 3 h (E3 + 3) exposure group, respectively.

As seen in Table, there was a statistically significant reduction in the daily mean egg production in the E4 and E5 ($P < 0.05$) compared to the control group. The other reductions, observed in the other groups, were not significant statistically ($P > 0.05$).

Discussion

In this study, the effects of the 10 GHz EMF on the fecundity of *Drosophila melanogaster* were investigated. Under the experimental conditions, the factors that might have affected the egg production were kept stable. The heat increase in the system during exposure was calculated and found to be too small to cause a significant heating effect. Thus, the differences in the results were interpreted as being caused by the EMF used.

In our experiments, it was determined that there was a general reduction in the egg production of all exposed groups compared to control group. Although this reduction was statistically insignificant in the 3 h (E3) and 3 + 3 h (E3 + 3) exposed groups ($P > 0.05$), it was statistically significant in the 4 h (E4) and 5 h (E5) exposed groups ($P < 0.05$) (Table). In the E3 (11.56) and E3 + 3 (11.54), the mean egg production was almost the same with each other. The reason of this similarity may be half-hour nutrition and relaxation period, in the middle of 3 + 3 h exposure. During this period, EMF exposure was interrupted and the flies were taken into vials containing *Drosophila* medium. In this relaxation period, repairing reactions might have appeared and there might have not been any difference between E3 and E3 + 3.

Many external (temperature, humidity, nutrition, population density etc.) and internal factors (genetic structure, age etc.) affect fecundity of *Drosophila melanogaster*. (14, 17, 18, 19, 20). It was reported that there was considerable changes in the *Drosophila* reproductive functions under external stress factors and that ecdysteroid hormones (ecdysone and 20-hydroxyecdysone) was involved these events. Both males and females have a certain base level of ecdysone, which is known to be a prohormone convertible into a hormone, 20-hydroxyecdysone, in the target tissues. As 20-hydroxyecdysone controls the ovary development it is found in females higher than males. It was reported that there is negative feedback mechanism between 20-hydroxyecdysone quantity and egg production. Therefore, any effect for increasing the quantity of 20-hydroxyecdysone will reduce the egg production. For instance, it was shown that 1-day-old females exposed to 38 ºC showed a one-day delay in egg laying and a reduced fertility during 6 days. This situation was attributed to increasing concentration of 20-hydroxyecdysone. Likewise, there was increase at 20-hydroxyecdysone level among the females, left hungry (21).

Table. The effect of EMF exposure on daily mean egg production of *Drosophila melanogaster*.

Group No.	Group	Number of female	Number of egg	Daily mean egg production per female ± S.E.	S.D.	Significant differences of the means
1	Control	24	3024	12.60 ± 0.50	7.71	
2	E3	24	2774	11.56 ± 0.48	7.47	
3	E4	24	2452	10.22 ± 0.41	6.30	1-3*
4	E5	21	2282	10.88 ± 0.30	4.66	1-4*
5	E3 + 3	24	2770	11.54 ± 0.42	6.47	

E: Exposed group (3 h, 4 h, 5 h, 3 + 3 h), S.E.: Standard error, S.D.: Standard deviation.
* : $P < 0.05$.

EMF are external factors and cause stress in the cells. It was found that EMF affected *Drosophila* fecundity (5). In our study, 4 h and 5 h EMF exposure caused a statitically significant reduction in the egg production of *Drosophila melanogaster.* The reason of this reduction may be the increased proportion of ecdysteroid hormones because of stress conditions caused by EMF.

The effects of EMF on *Drosophila* fecundity have been examined in many studies. In a study done to determine the effects of EMF on the reproduction of *Drosophila melanogaster,* application of long term 2450 MHz EMF reduced the egg production of *Drosophila* females compared with control (5). In another work, Panagopoulos et al. (6) reported that pulsed radiofrequency EMF from common GSM with a carrier frequency at 900 MHz, "modulated" by human voice, (speaking emission) was decreased the reproductive capacity of *Drosophila melanogaster* by 50-60%, whereas the corresponding "nonmodulated" field (nonspeaking emission) was decreased the reproductive capacity by 15-20%. Similarly, It was found that pulsated (100 Hz, 1.76 mT) and sinusosidal fields (50 Hz, 1 mT) decreased oviposition of *Drosophila* (7). In these publications, the fecundity of *Drosophila melanogaster* was decreased by EMF exposure. So it was clear that EMF exposure affected the fecundity of *Drosophila melanogaster.*

In general, it is clear that 10 GHz EMF exposure has effects upon fecundity of *Drosophila melanogaster*. Based on the present report we conclude that 10 GHz microwave frequency EMF can cause decrease the egg production. However, relatively little is known with any certainty about possible effects of non-ionizing EMF on fecundity. Therefore, this issue should be examined in detail at the biochemical and molecular level to clarify the effect mechanisms.

Acknowledgements

The authors would like to thank TUBITAK (The Scientific&Technological Researh Council of Turkey) (Project Number: TBAG-1976) for their financial support.

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