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LIFE TABLE ANALYSIS OF THE PERFORMANCE OF APHID *SITOBION AVENAE* (HOMOPTERA: *APHIDIDAE*) NYMPHS EXPOSED TO A STATIC MAGNETIC FIELD

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Abstract - Using the age-stage two-sex life table, this work was undertaken in order to determine the effect of static magnetic fields (SMFs) at two flux densities (0.176T and 0.065T) applied at increasing times of duration (0.25, 0.5, 1 and 2 h) on the development, fecundity and reproduction of the aphid, *Sitobion avenae.* Exposed nymphs had a statistically significant shortened first instar period and adult longevity and prolonged fourth instar periods compared to controls. There were significant differences in the population parameters for two exposure combinations, 0.176T for 0.5 h and 0.065T for 1 h. The intrinsic rate of increase (*r*), net reproductive rate (R_0) and mean generation time (T) were 0.1165, 3.5 and 11.7 days, respectively, 0.176 T for 0.5 h and -0.0198, 0.7 and 11.8 days, respectively, 0.065T for 1 h. We therefore recommend using the age-stage, two-sex life table to study the effect of the static magnetic field on development and growth of the aphid, *Sitobion avenae*.

Key words: Life table, static magnetic field (SMF), *Sitobion avenae*

INTRODUCTION

The magnetic field (MF) has been studied for biomedical use for some time. Technological development has led to an overwhelming increase in the presence of electromagnetic fields (EMF), with many harmful effects increasingly observed in living systems.

Many authors have studied the effect of a magnetic field on living systems in laboratory conditions. There have been reports about the influence of a magnetic field on the behavior of unicellular organisms (Frankel, 1984), enzyme reactions (Nossol et al., 1993), replication and transcription mechanisms (Goodman et al., 1987), mutations (Giorgi et al., 1992) and higher systems (Gould, 1980). Fundamental processes (growth, development, orientation) were also studied in living systems, including mortality (Ramirez et al., 1983), wing development (Stamenković-Radak et al., 2001), behavior and metabolism (Pan et al., 2004) etc.

Life history has been used before in similar studies with other insects: the mortality of gametogenesis of *D. melanogaster* (Kale et al., 1980; Ramirez et al., 1983); the growth and development of old-house borer (*Hylotrupes bajulus*) (Rauš et al., 2009) and meal worm (*Tenebrio molitor*) (Prolić et al., 1995). Our work has expanded the knowledge of the influence of the magnetic field for a wider spectrum of electromagnetic radiation (He, 2012). In the present study, working with the wheat aphid *Sitobion avenae*, we used the age-stage, two-sex life table (Chi and Liu, 1985; Chi 1988) to reveal the biological effect of the magnetic field on insect growth and populations.

MATERIALS AND METHODS

Plant source and insects

The wheat used for feeding the aphids (*Triticum aestivum Linn*) was planted in a plastic pot (9×9×10 cm) filled with nutrient substrate (a mixture of soil, sand and soil-peat compound substrates) in a greenhouse at 15-18°C with, and exposed to a 16 h photoperiod, using artificial light of 800 lux. The host plant at stages 12 to 13 was used to rear the aphids (Zadoks et al., 1974). Ten wheat seeds were planted in each plastic pot (9×9×10 cm).

The organisms used in this study were obtained from a colony of *S. avenae* collected in the Insect Ecology and Integrated Pest Management Laboratory in Northwest A&F University, Yangling, Shaanxi, China, in April 2010, and maintained in the laboratory. One wingless adult aphid was reared on wheat plants for 4-5 consecutive generations at 21 ± 0.5°C temperature, 75 ± 5% RH (relative humidity), and a photoperiod of 16:8h (L: D) in a climate-controlled chamber. The adults began parthenogenetic reproduction and the population at that time was a monoclonal colony (Du et al., 2007).

Physical treatment

A moderate static magnetic field was used. The field gradient and exposure time were determined by a previous experiment with 0.176 T and 0.065 T for 0.25 h, 0.5 h, 1 h and 2 h (He et al., 2012). Glass Petri dishes with treated aphids were placed on the center of the magnet's surface. One 24-nymph cluster was taken from the monoclonal colony: 8 nymphs were exposed to control, 8 to 0.065 T and 8 to 0.17 T for 0.25 h. Another set of 24 nymphs from the monoclonal colony was similarly exposed but for 0.5 h, a third set of 24 nymphs was exposed for 1 h, and a fourth set of 24 nymphs similarly taken and exposed for 2 h. Each of the 8 treated nymphs were individually reared in one pot of the plant using a clip cage (0.6 cm in diameter and 0.3 cm in height). All the tested insects were placed at 21 ± 0.5°C temperature, 75 ± 5% RH, and a photoperiod of 16:8h (L: D) in a climate-controlled chamber. Parallel control experiments were performed with the samples not being exposed. The experiment was repeated three times with a new monoclonal colony under the same conditions.

Life history

It is known that four instars occurred in *S. avenae* ontogenesis. The newborn exposed nymphs were considered instar zero and the first time of *S. avenae* molting was recorded to first instar, followed by the second, third and fourth instar. Survivability of *S. avenae* and a time marker of development stage's onset were evaluated during exposure to an SMF for 24 h. The nymphs exposed to SMFs were observed daily. When the experimental nymphs were in adult age and parthenogenetic, all the newborn nymphs were removed and recorded daily from birth to death. Development times, total pre-oviposition period (TPOP), age-specific survival rate (l_x), and age-specific fecundity (m_x) were recorded daily until the death of all individuals. Development times for each nymphal instar and lifetime fecundity were calculated. All of the time-specific life table parameters of *Sitobion avenae* were also used to calculate the fecundity, development duration (T), net reproductive rate (R0), innate capacity of increase (r) and finite rate of increase (e) according to the data.

Statistical analysis

The variable developmental rate among individuals was taken into consideration, the age-stage and two-sex life table were used to analyze the life history data (Chi and Liu, 1985; Chi, 1988) by the computer program TWOSEXMSChart (Chi, 2008). The intrinsic rate of increase (*r*) was estimated by using the Euler-Lotka formula:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \text{ with age indexed from 0}$$

(Goodman, 1982). The mean generation time (*T*) is the time length that a population needs to increase to R_0-fold of its size (i.e., $e^{rt} = R_0$ or $I^T = R_0$) at a stable

age-stage distribution and is calculated as $T = (\ln R_0)/r$.

The data on nymphal development, life fecundity and adult longevity were compared by three-way analysis of variance (ANOVA) with SMF intensities, exposure times and replication as factors. Lifetime parameters were compared by two-way analysis of variance with SMF intensities and exposure times as factors. These data among treatments were compared by the Student-Newman-Keuls (SNK) method after one-way ANOVA, with either SMF intensities or exposure times as a factor. All the statistical analyses were processed with SPSS 11.5 statistical package (Lu, 2002).

RESULTS

Multi-way ANOVAs of SMF intensities and exposure time effects on S. avenae

The development periods and life fecundity were not affected by replication for any of the parameters. There were also no significant interactions between replication and SMF intensities or exposure times. Thus, these data were used in comparison among the SMF intensities and exposure times.

Development periods and fecundity

The effects of a magnetic field on the developmental periods and fecundity are shown in Table 1. As can be seen, there were no differences between the control and MF groups in the second instar, third instar and total pre-oviposition period (TPOP). There was a significant acceleration of *Sitobion avenae* development at the first instar ($p = 0.004$) while it exhibited shortened adult longevity ($p = 0.02$) compared with the control. In both the 0.176T for 0.5 h, and 0.065T for 1 h combinations, it was accelerated by 1.0 days and 0.9 days respectively, and shortened by 3.9 days and 3.1 days, respectively.

The prolonged periods of fourth instar and the negative life fecundities were also observed, comparing with the control group. However, statistical analysis of the data revealed the absence of significant differences (the fourth instars $p = 0.458$; life fecundity $p = 0.286$).

Population parameters

Table 2 shows that the variation of population parameters (the intrinsic rate of increase *r*, net reproductive rate R_0, mean generation time T and finite rate of increase e) were influenced by the SMFs. All these parameters were statistically different between the SMFs and control; but there were no significant differences between exposure times and between SMF intensities. In these cases, the intrinsic rates of increase were 0.1165±0.0424 in 0.176T SMF for 0.5 h and 0.0168±0.0485 in 0.065T SMF for 1 h, all of which were significantly lower than the control (0.2257±0.0112). The effect of the SMF on net reproductive rate also resulted in a significant decrease in 0.176T for 0.5 h (3.5±1.5) and 0.065T for 1 h (0.7±0.3) compared with the control group (19.8±3.1).

Interaction of SMF intensities and exposure times

The statistical analysis exhibited a significant difference of interaction between intensities and exposure times (Fig. 1). For the combination of 0.176T for 0.5 h and 0.065T for 1 h, the developmental periods of first instar and adult longevity were significant lower than those of the other combinations; meanwhile the population parameters of the intrinsic rate of increase (*r*) and net reproductive rate (R_0) of these two combinations were also significantly lower than those of the other combinations. The above data are in accordance with the effects established in the development periods and population parameters.

DISCUSSION

Static magnetic fields (SMFs) are capable of affecting a number of biological systems (Arthur, 2003). Static magnetic fields (0.05-0.2T) had an inhibitory effect and were dose-effect related to the intensity (Duan et al., 2004). Our previous study investigated the influence of SMFs on aphid survival ability; the present study shows the remarkable effects of SMFs on the

Table 1. Effect of 0.176 T and 0.065 T SMF exposure on the developmental periods of instar stages, total pre-oviposition period and life fecundity (mean±SE) of *S. avenae.*

Statistics	Treatments	0.25h	0.5h	1h	2h	df	f	p
The first instar	CK	4.0±0.2ay	4.0±0.2ay	4.0±0.2ax	4.0±0.2axy	6	3.26	0.004
	0. 176T	3.4±0.2by	3.0±0.1by	3.8±0.3bx	3.9±0.1bxy			
	0.065T	3.1±0.2by	3.8±0.2by	3.1±0.2bx	3.6±0.2bxy			
The second instar	CK	2.1±0.1ax	2.1±0.1ax	2.1±0.1ax	2.1±0.1ax	6	0.94	0.468
	0. 176T	2.1±0.2ax	1.8±0.1ax	2.1±0.2ax	2.3±0.1ax			
	0.065T	2.1±0.1ax	2.1±0.1ax	2.2±0.2ax	2.2±0.2ax			
The third instar	CK	1.2±0.1ax	1.2±0.1ax	1.2±0.1ax	1.2±0.1ax	6	0.94	0.468
	0. 176T	1.2±0.2ax	1.1±0.1ax	1.2±0.2ax	1.0±0.1ax			
	0.065T	1.2±0.1ax	1.2±0.1ax	1.2±0.2ax	1.2±0.2ax			
The fourth instar	CK	2.2±0.2bx	2.2±0.2bx	2.2±0.2bx	2.2±0.2bx	6	0.952	0.458
	0. 176T	2.5±0.2ax	3.6±0.1ax	3.7±0.3ax	2.5±0.2ax			
	0.065T	2.9±0.2ax	2.5±0.2ax	2.8±0.2ax	2.7±0.2ax			
TPOP	CK	10.1±0.3ax	10.1±0.3ax	10.1±0.ax	10.1±0.ax	6	0.25	0.959
	0. 176T	9.9±0.3ax	9.8±0.2ax	10.3±0.2ax	10.0±0.2ax			
	0.065T	9.9±0.3ax	9.9±0.3ax	9.8±0.5ax	9.7±0.3ax			
Adult longevity	CK	8.4±0.7ax	8.4±0.7ax	8.4±0.7ax	8.4±0.7ax	6	2.579	0.02
	0. 176T	8.3±1.0bx	4.5±0.7bx	7.3±0.6bx	6.5±0.5bx			
	0.065T	6.6±0.7bx	7.2±0.5bx	5.3±0.8bx	5.6±0.6bx			
Life fecundity	CK	19.9±6.1ax	19.9±6.1ax	19.9±6.1ax	19.9±6.1ax	6	1.24	0.286
	0. 176T	14.6±4bx	4.6±2.1bx	15.4±5.0bx	15.4±5.2bx			
	0.065T	11.5±3.5bx	18.8±6.0bx	0.9±0.4bx	9.7±3.3bx			

CK – control group; TPOP – Total pre-oviposition period of female counted from birth.
a,b means within a column sharing the same letter are not significantly different in magnetic field and x,y means within a line sharing the same letter are not significantly different in treatment time (a=0.05, Student-Newman-Keuls Test).

development time, reproduction and adult longevity of *S. avenae*.

Giorgi et al. (1992) deduced that the MF exposure of *D. melanogaster* led to an increase in body size and the number of wing hypodermal cells. They concluded that the MF, as a physical mutagenic agent, could affect some processes during the embryonic and larval development of insects. In our experiment, the first instar of *Sitobion avenae* was significantly shortened under the SMF exposures, indicating that the aphid's embryo was likely influenced by the static magnetic fields. Because the reproduction type of *S. avenae* is typically parthenogenesis and viviparous, the embryos had developed completely within the mothers' ovarioles before the offspring's gave birth (Zhao et al., 1992).

Sex ratio and occurrence of sex-linked recessive lethal mutations have been reported in *D. melanogaster* by Gotz (1977) in the presence of MF during insect development. Ramirez et al. (1983) recorded

Table 2. Effect of 0.176T and 0.065T SMF exposure on the intrinsic rate of increase (r), net reproductive rate (R0), mean generation time (T) and finite rate of increase (e) (mean±SE) of *S. avenae.*

Population parameters	Treatments	0.25h	0.5h	1h	2h
r	CK	0.2257±0.0112ax	0.2257±0.0112ax	0.2257±0.0112ay	0.2257±0.0112ax
	0.176T	0.2032±0.0161bx	0.1165±0.0424bx	0.196±0.0150by	0.2013±0.0565bx
	0.065T	0.1765±0.0199cx	0.2137±0.0650bx	0.0168±0.0485by	0.1808±0.0076bx
R_0	CK	19.8±3.1ax	19.8±3.1ax	19.8±3.1ax	19.8±3.1ax
	0.176T	14.6±3.0bx	3.5±1.5bx	12.9±2.3bx	12.9±2.0bx
	0.065T	9.7±2.4bx	15.8±2.5bx	0.7±0.3bx	8.5±1.9bx
T	CK	13.2±0.2ax	13.2±0.2ax	13.2±0.2ax	13.2±0.2ax
	0.176T	13.3±0.4bx	11.7±0.2bx	13.1±0.3bx	12.7±0.2bx
	0.065T	13.0±0.4bx	12.9±0.2bx	11.8±0.8bx	12.1±0.3bx
e	CK	1.2531±0.0150ax	1.2531±0.0150ax	1.2531±0.0150ay	1.2531±0.0150ax
	0.176T	1.2252±0.0198bx	1.1225±0.0467bx	1.2164±0.0180by	1.223±0.0138bx
	0.065T	1.1928±0.0237cx	1.2382±0.0161cx	0.9791±0.0463cy	1.1957±0.0242cx
	r	R_0	T	e	
Df	6	6	6	6	
F	9.171	4.529	2.906	9.5	
P	0.000	0.000	0.009	0.000	

a,b means within a column sharing the same letter are not significantly different in magnetic field and x,y means within a line sharing the same letter are not significantly different in treatment time (a=0.05, Student-Newman-Keuls Test).
CK – control group.

that the total viability of exposed *D. melanogaster* was lower than the control group. The developmental dynamics in the preadult of mealworm was significant in mortality and deformities (*Tenebrio molitor*) when exposed to a constant MF of 0.325 T. In our work, clear differences were observed in the last instar of the insects and adult longevity. Our results are in agreement with the data of the previously cited authors of Ma and Chu (1993), whose studies reliably confirmed the influence of ELF-EMF on the processes of *D. melanogaster* embryo development.

MF also contributed to stimulation of the neuroendocrine system. This means the influence of MF on an insect's neuroendocrine system was produced directly through the nervous system (Klimovskaya and Maslova, 1981) or indirectly through hormone regulatory pathways (Zagorskaya, 1981; Reiter and Richardson, 1992). Meanwhile, it can be assumed that a physical reaction can promote different dynamics in the insect of an inhibitory or stimulative character. The inhibitory level would be an irreversible disturbance of the internal equilibrium with the possibilities of biostructural damages, and this change could lead to permanent disturbances throughout the life span (Martin, 1988), even with a lethal outcome (Khalil and Qassem, 1991). However, the simulative level is reversible; the biosystem re-equilibrates without consequence after the MF is removed. Thus, an immediate neuroendocrine effect accelerated the first instar, returning to a normal physiological condition in the later instar period. Moreover, this change would demand some redistribution of resource and would be quickly

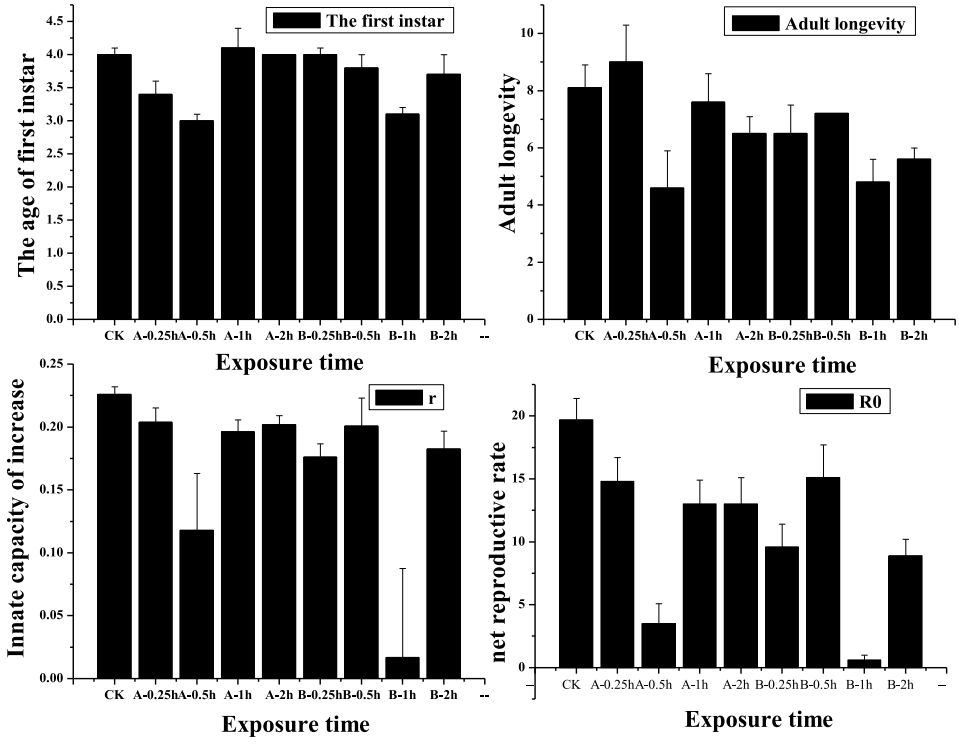

Fig. 1. The interaction of SMF exposure time and intensity on the developmental periods and population parameters of *S. avenae* ($p<0.01$).

The age of first instar ($p < 0.01$), adult longevity ($p < 0.05$), innate capacity ($p < 0.01$), net reproductive rate ($p < 0.01$). CK – control groups; A – 0.176T SMF intensity; B – 0.065 T SMF intensity; r – intrinsic rate of increase; R0 – net reproductive rate (R_0).

surpassed by the simulative SMF exposure. Such influences may finally lead to negative effects on the longevity of fourth instar nymphs and the female aphids.

In addition, the intrinsic rate of natural increase *r* is a key demographic parameter that has been used to summarize the qualities of an animal in relation to its capacity to increase (Andrewartha and Birch, 1954). In our study, the statistically significant difference of *r* and R_0, of *S. avenae* between treated groups and control group could indicate that an external MF changed the aphid's immature developmental time, progeny production and reproduction.

There is also a dose effect of a magnetic field on the biological system. It includes time thresholds that investigate in which field effects are observed only after a certain time of exposure (Wilson, 1981); transient responses that study in which field exposure induces a biological effect for only a short time after a change in the exposure (Byus, 1986); and field threshold effects that appear only when the field strength exceeds a certain threshold value (Liboff , 1984). The static magnetic fields (0.05-0.2T) had an inhibitory impact on the spinal cord neurons *in vitro* of rat and were also dose-effect related to the intensity. We obtained the remarkable effects of two SMF combinations (0.176T 0.5 h and 0.065 T 1 h) that

were in agreement with the time and field thresholds of MF.

Finally, many authors have already demonstrated that MF biological effects were related to the modulation of ion flow, DNA synthesis and RNA transcription, interaction of normal cells with the hormones, neurotransmitters, and growth factors (Liboff et al., 1984; Stuchly and Esselle, 1992; Frey, 1993; Yim and Jeong, 2006). Thus, more detailed examinations of the various molecular mechanisms and SMF-intensity are required to explain the mechanisms of static magnetic field on aphids.

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