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Study on empoasca vitis gothe egg incubation by non-thermal effect model

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ABSTRACT

The classical Maxwell equation set, in combination with the quantum theory, is applied to establish an electromagnetic biologic non-thermal model, i.e. to define the relation between energy of photons coming into biological cells and applied weak electric field intensity. A broadband transverse electromagnetic (TEM) transmission cell is used to investigate the electromagnetic (EM) biologic non-thermal effect of applied weak electric field (WEF) intensity on incubation of empoasca vitis gothe eggs. The result has demonstrated that there is a threshold necessary for the applied electric field intensity during non-thermal effect on incubation of empoasca vitis gothe eggs; a positive effect occurs at the intensity below the threshold and a negative one takes place at the intensity above the threshold. So the model has proved correct and effective.

Keywords: Electromagnetic biologic non-thermal effect; Empoasca vitis gothe; Weak electric field intensity; Transverse electromagnetic transmission cell

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INTRODUCTION

Empoasca vitis gothe (EVG) belongs to cicadellidae, homoptera, which infests a number of crops such as tea trees, wheat, Arachis hypogaea and soybeans and is widely present in Hunan, Jiangsu, Guangdong, Zhejiang, the south of Shanxi, posing great harm to crops, and therefore must be seriously controlled and prevented [1]. EVG is No.1 pest to tea trees which is one of the most important economic crops in China and has been posing great hazard to tea trees. As EVG can be well-hidden from human vision due to small volume and reproduce at a very fast speed leading to significantly overlapped generations, its adult and nymph puncture tender tea leaves affecting tea quality and production.

At present, research on EVG's bio-ecologic properties and control &prevention technology has gained popularity. The results from study by Wang Yungang et al., [2] on impact of different plantation modes on EVG population dynamics have shown that there were significant difference between EVG populations in the tea farms at different plantation modes and EVG occurrence tends to come up in double peaks without obvious overwintering. Wang Qingsen et al., [3] after analyzing spatial distribution of EVG in an organic tea farm, concluded that there was no significant difference in quantities of EVG adults, nymphs and eggs at all horizontal orientations of tea trees. After investigating the impact of humidity and temperature on EVG population quantity and in-tip egg quantity, Li Huiling et. al., [4] drew a conclusion that quantities of EVG adult and nymph populations and in-tip eggs follow the rule in Yield Density model. Research by Li Lifang et al., [5] to investigate the difference in feeding behavior between EVGs in different breeds of tea trees using EPG has suggested that 7 basic puncturing and suction waveforms generated by leafhoppers are the same in 6 breeds of teas. Jin Shan et al., [6] has studied the resistance of different breeds of teas to EVGs and the result has demonstrated that the field population density, life cycles, nymph production per female nymph, nymph survival rate and feeding time can reflect the natural selection, adaptability and feeding preference in tea breeds, and there was significant difference in resistance to EVG between different breeds of teas. Zeng Mingsen et al, [7] has explored the effect of 48% Thiacloprid SC in prevention and control of EVG in tea and assessed its safety, and arrived at the conclusion that 48% Thiacloprid SC is safe to teas, appropriate to prevent and control EVGs in tea farms, and recommended to be applied during the peak of nymphs at the dose of preferably 45ga.i./hm^2. The above-mentioned researches have focused on EVG bio-ecological properties and how to prevent and control EVG. Building on these results, the thermal and non-thermal effect models for electromagnetic biological (EMB) effect is analyzed in this paper and applied to investigate the impact on EVG incubation percentages under the transient electromagnetic pulses so as to guide the research on EVG bio-ecologic characteristics and control &prevention technology.

ANALYSIS ON THEORETIACL MODEL FOR EMB NON-THERMAL EFFECT

General Concepts

EMB effect refers to the biological effect generated on living organisms under the action of EMW, including the thermal effect and the non-thermal effect. Here, the thermal effect relates to the fact that living organism's temperature rises under the action of EM field. In the environment of EM field present, the ion translation motion and dielectric relaxation of water and other molecules in the living organisms result in thermal effect such as changed gene expression including stress reaction genes and heat shock of biological tissues. The non-thermal effect means the process in which a system changes its own properties under the action of EM field and such change cannot be made through heating.

Damage to biologic tissues and cells due to thermal effect has been recognized internationally while non-thermal effect remains disputed. For instance, Guidelines For Limiting Exposure To Time-Varying Electric, Magnetic, And Electromagnetic Fields published by International Commission on Non-Ionizing Radiation Protection (ICNIRP) does not admit existence of the non-thermal effect. With more and more non-thermal effect-related phenomena found in the process of various experiments, research on non-thermal effect has become a hot issue. How the non-thermal effect takes place must be further explored.

Derivation of Theory Concerning Thermal Effect

It is known from the paper [8] that when a system reaches thermal balance, the temperature of biologic tissues is related to the radiation power following the equation below:

$$T=\eta\omega\{k\ln[1+\frac{d\eta f_0}{P[1-\exp(-\lambda\partial)]}]\}^{-1} \tag{1}$$

Where, ∂ is the absorbing coefficient of a biologic tissue; λ is the molecular scale; P is the radiation power on the surface of a biologic tissue, f_0 is the frequency of a EMW, ω is the mean vibrational frequency of biologic molecules and d is the dimensional number of molecular vibration. The corresponding mean quantity of photons inside a biologic tissue is:

$$<n>_d=\frac{d}{\exp(\frac{\omega\eta}{kT})-1} \tag{2}$$

Assuming $<n>_0$ is the mean photo quantity coming into a biologic tissue per unit time, and then we have:

$$\frac{<n>_d}{<n>_0}=1-\exp(-\lambda\partial) \tag{3}$$

In the EM field, the dielectric-absorbed microwave power P is in normal proportion to the frequency f_0, the square of the electric field intensity E, the dielectric constant ε_r and the tangential value of the dielectric loss $\tan\delta$, i.e.

$$P=2\pi f_0 gE^2\varepsilon_r V\tan\delta \tag{4}$$

Where, V is the available volume of dielectric medium aborting microwaves. Substitute Equation (4) in Equation (1) to obtain:

$$T=\eta\omega\{k\ln[1+\frac{d\eta}{[1-\exp(-\lambda\partial)]g2\pi E^2\varepsilon_r V\tan\delta}]\}^{-1} \quad (5)$$

Let $\zeta=\frac{d\eta}{[1-\exp(-\lambda\partial)]g2\pi E^2\varepsilon_r V\tan\delta}$, and convert Equation (5) to the one below:

$$T=\frac{\eta\omega}{k\ln(1+\zeta)} \quad (6)$$

Perform Tailor expansion to Equation (6) to get:

$$T=\frac{\eta\omega}{k\ln(1+\zeta)}=\frac{\eta\omega}{k(\zeta-\frac{1}{2}\zeta^2+\frac{1}{3}\zeta^3-\frac{1}{4}\zeta^4+\text{L})} \quad (7)$$

Retain the order-1 Tailor expansion. Let $x=-\frac{1}{2}\zeta$, and perform Tailor expansion to the result again and retain the order-1 Tailor expansion, to obtain:

$$T=\frac{\eta\omega}{kx}(1-x+x^2)=\frac{\eta\omega}{kx}(1+\frac{1}{2}\zeta+\frac{1}{4}\zeta^2) \quad (8)$$

Substitute ξ in Equation (8) and simplify it to obtain:

$$T=\frac{2\pi\omega\varepsilon_r\tan\delta}{kd}g[(1-\exp(-\lambda\partial))E^2V]\left\{\begin{array}{l}1+\frac{d\eta}{4\pi\varepsilon_r\tan\delta}g\frac{1}{(1-\exp(-\lambda\partial))E^2V}+\\ \frac{(d\eta)^2}{16(\pi\varepsilon_r\tan\delta)^2}g[\frac{1}{(1-\exp(-\lambda\partial))E^2V}]^2\end{array}\right\} \quad (9)$$

Let $M=\frac{2\pi\omega\varepsilon_r\tan\delta}{kd}[1-\exp(-\lambda\partial)]V$, $N=\frac{d\eta}{4\pi\omega\varepsilon_r\tan\delta}\frac{1}{[1-\exp(-\lambda\partial)]V}$

The above Equation (9) turns into:

$$T=ME^2+\frac{\eta\omega}{2k}\frac{N}{E^2}+\frac{\eta\omega}{2k} \quad (10)$$

When $ME^2=\frac{\eta\omega}{2k}\frac{N}{E^2}$ we will get:

$$E^2=\frac{d\eta}{4} \quad (11)$$

In this case, T has a minimum:

$$T_0=\frac{3\eta\omega}{2k} \quad (12)$$

Because biologic molecules vibrate at an inherent fixed frequency, T_0 has nothing to do with any external factors and can be considered as the temperature before a biologic tissue is exposed to irradiation. Let $T = T_0 + \text{V}T$, where △T is temperature rise of a biologic tissue after irradiation, then we have:

$$\text{V}T = T - T_0 = ME^2 + \frac{\eta\omega}{2k}\frac{N}{E^2} - \frac{\eta\omega}{k} \tag{13}$$

It can be derived from Equation (13) that: 1) the temperature rise △T due to thermal effect increases progressively with the EM field intensity E in a nonlinear way; 2) When the external EM field disappears (E=0), T_0 is not 0 representing the body temperature of the living organism.

Derivation of Non-thermal Effect Theory in the EM Environment

The EM working environment is created inside a rectangular resonant cavity in the dimensions of a×b×c in which the waveguide is distributed in symmetry along Axis Z: the resonant mode is TE_{10}; m, n and p are the intrinsic modes of the electric field in the resonant cavity, c is the wave speed in the free space and the resonant cavity's frequency is f_0, and therefore the equation is shown as below:

$$f_0 = \frac{c}{2}\sqrt{(\frac{m}{a})^2 + (\frac{n}{b})^2 + (\frac{p}{c})^2} \tag{14}$$

When the resonant cavity's dimensions a, b and c, and the resonant frequency f_0 are determined with the model of the waveguide BJ22, the intrinsic mode m, n, p of the electric field can be evaluated: Using the wave equation, we can get the multi-mode electric-field distribution satisfying the ideal conductor boundary conditions:

$$\begin{aligned}
&\text{E}_x = \frac{\pi n j\omega\mu}{bk_c^2} H_{mnp}\cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)\sin(\frac{p\pi}{l}z) \\
&\text{E}_y = -\frac{\pi m j\omega\mu}{ak_c^2} H_{mnp}\sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)\sin(\frac{p\pi}{l}z) \\
&\text{E}_z = 0 \\
&k_c^{\ 2} = (\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2
\end{aligned} \tag{15}$$

We can calculate the amplitude of the electric field:

$$E^2 = \text{E}_x^{\ 2} + \text{E}_y^{\ 2} + \text{E}_z^{\ 2} \tag{16}$$

It is understood from Equation (13): when the temperature rise △T = 0, the non-thermal effect takes place satisfying the Equation below:

$$T - T_0 = ME^2 + \frac{\eta\omega}{2k}\frac{N}{E^2} - \frac{\eta\omega}{k} = 0 \tag{17}$$

Now we obtain the conditions to be met for the non-thermal effect in the EM environment as shown in Equation (18):

$$\begin{aligned}
&2\pi\omega\varepsilon_r \tan\delta[1-\exp(-\lambda\partial)]V(\text{E}_x^{\ 2}+\text{E}_y^{\ 2}+\text{E}_z^{\ 2}) + \\
&\frac{\mathrm{d}^2\eta^2\omega^2}{8\pi\omega\varepsilon_r\tan\delta}\frac{1}{[1-\exp(-\lambda\partial)]V(\text{E}_x^{\ 2}+\text{E}_y^{\ 2}+\text{E}_z^{\ 2})} - d\eta\omega = 0
\end{aligned} \tag{18}$$

Let $x=[1-\exp(-\lambda\partial)]V(E_x^2+E_y^2+E_z^2)$, Equation (18) may be simplified into a quadratic equation with one unknown:

$$(2\pi\omega\varepsilon_r \tan\delta)x^2 - d\eta\omega x + \frac{d^2\eta^2\omega^2}{8\pi\omega\varepsilon_r \tan\delta} = 0 \tag{19}$$

Resolve it to obtain:

$$[1-\exp(-\lambda\partial)] = \frac{d\eta\omega}{4\pi\varepsilon_r V(E_x^2+E_y^2+E_z^2)\tan\delta} \tag{20}$$

Substitute Equations (2) and (3) in Equations (19) and (20) to obtain:

$$<n>_d = \frac{d}{2} \tag{21}$$

$$<n>_0 = \frac{2\pi\varepsilon_r V(E_x^2+E_y^2+E_z^2)\tan\delta}{\eta\omega} \tag{22}$$

Equations (21) and (22) indicate that: 1) when the incoming photon number per unit time is half of the dimensional number of molecular vibrations inside a biologic tissue, the temperature rise inside the biologic tissue is 0 generating the non-thermal effect; 2) the mean incoming photon number into biologic tissue per unit time is proportional to the square of the intensity of the external electric field. As long as the EM field's magnitude is controlled, the non-thermal effect is possible. This is importantly positive to study the pupa-to-adult conversion of EVG in the EM environment.

EXPERIMENT SECTION

Devices Used in the Experiment

In the experiment a transverse electromagnetic (TEM) wave transmission cell is used to transmit an isotropic quasi-plane-wave in the frequency range of DC ~ 10 GHZ, having a transmission coefficient higher than 0.85 and the number of resident waves less than 2.1, to simulate a free space. A signal generator is used to output quasi-rectangular pulse signals. In the experiment, the signal source has the following parameters: the pulse amplitude: 50V; the repeated frequency: 100 KHz; pulse width: 10 ns; rise time: 1.2 ns; the irradiation duration: 5, 15 or 25 mins. In the experiment a thermostat is used to maintain the temperature constantly at 22℃ so that both the test groups and the control group are exposed to irradiation at the same temperature.

a) Materials Used in the Experiment

Sufficient quantities of EVGs are obtained by collecting tea tips and peeling off its tender stem bark.

b) Grouping and Experimental Method

Select a certain quantity of eggs and divide into 5 groups, 1 as the control, 4 as test groups, to be exposed to radiation for 5, 15, and 25 mins, respectively. Every time, 100 eggs selected from each group receive 3 repeated irradiations and then are placed in culture dish for humid-keeping cultivation. EVG egg incubation rate is observed and recorded on daily basis.

Data Analysis

The data concerning incubation rate from eggs treated are processed using SPSS [9] and EXCEL [10-12].

RESULTS AND ANALYSIS

Table 1 Impact of TEM transmission cell on EVG egg incubation

	Electric field intensity（V/m）												
Treatment	255			310			365			550			CK
Treated duration /min	5	15	25	5	15	25	5	15	25	5	15	25	
Egg number in the culture dish	100	100	100	100	100	100	100	100	100	100	100	100	100
Measured incubated eggs	72	75	79	76	80	89	75	83	81	67	59	51	70
Incubation percentage /%	72	75	79	76	80	89	75	83	81	67	59	51	70

It is observed from Table 1 that TEM transmission cell has positive effect on EVG egg incubation. When the electric field intensity is 255 V/m, the exposure duration 25 mins results in the most significant effect and improves EVG egg incubation percentage; when the electric field intensity is 310 V/m, the exposure duration 25 mins produces the most significant effect on incubation; when the electric field intensity is 365 V/m, the exposure duration 15 min generates the best effect on incubation. When the electric field intensity is 550 V/m, the exposure duration 5 mins results in the most significant effect on incubation. It is known from comparing and analyzing the results from 4 test groups that TEM transmission cell's outcome versus time is in a nonlinear relation and there is no accumulative effect over time. 25 mins exposure at the electric field intensity of 310 V/m contributes significantly to incubation ($P<0.05$); the electric field intensity at 365 V/m has weaker contribution; and the electric field intensity at 550 V/m significantly suppresses incubation, and the longer the exposure is, the lower the incubation percentage is. By comparing data of both the test groups (except the group receiving exposure at the electric field intensity of 550 V/m) and the control group (CK) conclusion is arrived at that the test groups contributes significantly to the incubation percentage ($P<0.05$). However, by comparing the control group (CK) and the test group at the electric field intensity 550 V/m, it is understood that incubation is suppressed for the test group ($P>0.05$).

When the electric field is acting on EVG cell membrane, if the external electric field satisfies the inherent frequency of egg cells, it will assist the cell membrane to absorb EMW in the form of photons leading to resonance. Cell membranes absorb energy of photons $<n>_0$ through resonance resulting in increase in their surface charge density and changing pressure difference inside it. This will impact and change on/off status of ion passages inside the cell membranes and cells will respond to this by self-adaptation in an effort to maintain original condition (or living style). If the change in pressure difference is within the range of adaptation of cell membranes, the cell membrane can control the pressure difference due to changed surface charge density and as a result eggs incubate as usual. Where the pressure difference is beyond control of cell membranes and off its adaptive limit, it would mutate to subsist in different style resulting in EMB non-thermal effect. An extreme case in EMB non-thermal effect is that the excessive electric field intensity is so beyond the limit of cell membrane's self-adaptation as to destroy original structure of cell membrane and leave cells dead.

From analysis on the EM non-thermal effect theory it is known that the intensity of photons absorbed by egg cell membrane $<n>_0$ is proportional to the intensity of external electric field $(E_x{}^2+E_y{}^2+E_z{}^2)$ but having nothing to do with its frequency and the energy magnitude of photons absorbed is in normal proportion to the duration of exposure to the electric field. It is concluded from analyzing Table 1 that egg incubation percentage is the highest in the condition of the external electric field of 310 V/m and the exposure duration of 25 mins which provides good non-thermal effect on eggs. In this case cells show an obvious tendency to subsist in a new style helping incubation. Where the external electric field intensity is 550 V/m, the pressure difference due to excessive intensity is beyond the threshold that cells can withstand resulting in death of cells and thus suppressing egg incubation. This means there is an electric field intensity threshold for incubation.

CONCLUSION

It is concluded from the theoretic model on EMB non-thermal effect created by using the classic Maxwell Equation Set that EM non-thermal effect is proportional to the square of the intensity of the external electric field having no relation to the electric field frequency. With this theory, a TEM transmission cell is used to carry out a controlled test on 5 groups in the condition of weak electric field intensity to observe the weak electric field intensity's impact on EVG egg incubation. The result shows that the effect of the external weak electric field intensity on EVG egg incubation versus time is in a nonlinear relation having no accumulative effect and a positive effect exists at a certain range of electric field intensity. In the condition of the external electric field intensity of 310 V/m and 25 min exposure the EM non-thermal effect delivers significant outcome having better egg incubation percentage; The external electric field intensity of 550 V/m generates a pressure difference that is beyond the self-adaptation of cells and results in dead cells and so suppresses egg incubation; This indicates there is an electric field intensity threshold for incubation. Better EM non-thermal effect that contributes egg incubation will be obtained only when the external electric field intensity is below the threshold. In this way, the EMB non-thermal effect's theoretical model has proven correct.

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