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APPLICATION OF NONMEDICAMENTOUS BIOLOGICALLY HARMLESS ELECTROTECHNOLOGIES AND THEIR IMPLEMENTATION FOR VARROOSIS CONTROL IN HONEY BEES

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Summary. The aim of the work was to study the development of biologically harmless methods for controlling bee varroosis and optimization of geometric parameters of their means of implementation in order to increase the efficiency of honey bee product manufacturing. This work shows the results of analytical studies of the influence of electromagnetic radiation of the optical spectrum on bioobjects in the UV range (UVB, UVC) and in particular on the pathogenic microflora, the agents of various invasive and infectious diseases in honey bees, including varroosis. For the first time, we obtained mathematical expressions that simulate the dependencies of the electric power and design characteristics of protective devices that realize the operation of the entrance block equipped with LED modules of UV radiation when powered from solar cells. The manufacture of protective devices with scientifically grounded parameters allows optimizing of the power and quantity of UV-radiation LEDs, their placement in the tunnel of entrance block, to determine the wavelength, exposure, as well as the geometric parameters of LPRS-1 entrance block, which provides the detrimental effect of UV radiation on the physiological functions of the *Varroa* mites. In addition, the application of entrance block for beehive provides sanitation of bees from varroosis without disrupting their natural rhythm of life, preventing the premature first cleansing flight of bee colony at unfavorable temperature conditions. This is due to the elongation of the path of bees from the hive's hole to the exit from the tunnel of the entrance block formed by the upper and lower grids and the effect of ascending airflows, which enables the bees to adapt to the meteorological conditions and feel the low temperature of the outside air and return to the hive. In addition, the study of the proposed entrance block showed its functional ability to prevent the penetration of robber bees, wasps, hornets, and rodents to the hive due to the presence of a tunnel with calibrated inner air spaces. This creates conditions for restricting their direct access to the entrance of the hive, from where they smell the appealing odor of honey. The created device allows to prevent the infection of healthy bee colonies by due to the exclusion of the possibility of penetration into the entrance block of the hive of infected robber bees due to the presence of lattice tunnel, the inner surface of which is irradiated by sources of electromagnetic radiation of the optical range of the ultraviolet spectrum (LEDs). In this case, we observed the decreasing of bee colony biopotential as a result of the impossibility of attacking by its enemies (tits, jays, woodpeckers, etc.) due to the presence of limited space, formed around the entrance of the hive by a tunnel, bottom board and protective shield, that avoids direct contact of bees with their pests and enemies. The practical application of the entrance block provides protection against the take-off of bee colony and uncontrolled leave of swarm due to the presence of calibrated exit from the tunnel, which makes it impossible to leave of queen-bee with swarm or while taking-off by bee colony. Thus, the installation of the protective mean — multifunctional device (the entrance box is equipped with UV module powered by light-emitting diodes from photocells) allows to: (1) increase the efficiency of environmentally safe production technologies of beekeeping products by preserving the biopotential of bee colony and its honey products; (2) introduce more widely non-medicated biologically harmless technologies for the prevention and treatment of varroosis through the application of innovative solutions and means of their implementation of integrated protection of bee colonies during the production cycle, promoting the development of organic beekeeping, subject to increased profitability of honey farms and improvement of the production culture in the industry.

Keywords: bees, bio-safe electrotechnologies, dose of irradiation, energy and resource-saving technologies, erythematous flux, irradiation of bioobjects, photocells, radiation source, *Varroa destructor*, mites, ultraviolet radiation (UV range), wavelength of the ultraviolet spectrum

Introduction. The basic condition for harmonious combination of solving problems of economy and environment, faced by agricultural producers, can be the introduction of progressive bio-safe electrotechnologies that enable to increase the efficiency of production processes and the production culture in the industry. For instance, in beekeeping, the effective direction of increasing the effectiveness of combating such parasitic diseases as varroosis, according to the experts, is the development of combined means, which, for example, by combining measures of resource-saving and the function of treating bees with ultraviolet irradiation will contribute to increasing the profitability of honey bee farms and production culture in the industry (Kuryshev and Kuryshev, 2008; Romanchenko et al., 2015).

On the basis of the analysis of known means and methods for controlling varroosis and critical analysis of their advantages and disadvantages, we can generalize that the existing approaches to the treatment of such a disease of bees as varroosis are not fully satisfy the current zooveterinary and sanitary requirements for the breeding, keeping and use of honey bees for the production of bee products. The problem of physical (zootechnical) means and methods of fighting against invasion of *Varroa destructor* mites are considered in a number of studies of Ukrainian and foreign scientists (Romanchenko et al., 2013; Romanchenko and Nikitina, 2013; Ohtsuka and Osakabe, 2009; Zhang et al., 2011). The analysis of well-known scientific research showed the lack of generalized methodology of physical methods and means of fighting varroosis, as well as the lack of integrated approach to the creation of biologically harmless electrotechnological devices based on high-performance sources of optical radiation (UV) range. It was revealed that under the influence of ultraviolet rays in female mites the peristalsis of intestines is acutely activated, mengeous movements, phosphorescence of chitinous cover are observed. At irradiation under Q-400 lamp at a distance from the working surface of 34.0–16.0 cm and exposure of 10 minutes in 17 hours, 100% of *Varroa* mites died (Romanchenko et al., 2013; Romanchenko and Nikitina, 2013).

Systematic analysis of scientific and technical literature showed, for example, that Japanese scientists Ohtsuka and Osakabe (2009) made findings of fact of the death of spider mites from irradiation by electromagnetic radiation of UVB ultraviolet spectrum (280–315 nm). However, the scientific literature has lack of systematic data on the level of lethal effects on insects under electromagnetic irradiation of UVA and UVB ultraviolet spectrum (315–400 nm).

In addition, there is also no information on the design of protective devices, their geometric parameters, and exposure for effective control of varroosis in works devoted to research on the use of the spectrum of electromagnetic radiation in the field of short-wave range for the control of pathogenic microflora and fauna.

In view of the foregoing, it can be stated that the actual scientific and applied task, that would contribute to the further development of the beekeeping industry, is the scientific substantiation of the parameters and regimes of the treatment of bees by the UV spectrum of optical radiation and the development of constructions of special means for the implementation of the specified process.

The aim of the work was to study the development of biologically harmless methods for controlling bee varroosis and optimization of geometric parameters of their means of implementation in order to increase the efficiency of honey bee product manufacturing.

Materials and methods. *Hypothesis.* The ability of UV to cause through nerve endings, as well as through humoral mechanisms by transferring produced active substances by hemolymph flow from the place of production into other organs, causing specific reactions of the body, has great practical importance, as evidenced by the effective application and effectiveness of not only general, but also local irradiation (Romanchenko et al., 2013; Romanchenko and Nikitina, 2013).

For the implementation of the working hypothesis of increase in the effectiveness of the fight against the varroosis of bees and the preservation of their potential we provided multifunctional design of the device, in which the effect on *Varroa* mite will be carried out by electromagnetic radiation of the ultraviolet spectrum of light emitting diodes powered from photocells. The device for UV irradiation of bees and mites includes entrance block, LEDs, power supply of LEDs, protective grid, switching and control system. Structural-technological scheme of one of the LPRS-1 type provided with UV irradiation module is shown in Fig. 1.

Figure 1. Entrance block of LPRS-1

For the correctness of the study of bioobjects we will consider the *Varroa* mites as the specific receiver of radiation energy.

It could be characterized by relative spectral sensitivity, which is determined by the ratio of the minimum amount of irradiation with $\lambda = 297$ nm to the intensity of irradiation with a given wavelength, which provides the same erythemal action. In this case, the erythemous flux is defined as radiation, which is estimated by its ability to harm the mite, using mathematical model (1):

$$F = \int_{\lambda_{min}}^{\lambda_{max}} \varphi(\lambda)\kappa(\lambda)d\lambda, \qquad (1)$$

where: $\kappa(\lambda)$ — relative erythemic radiation efficiency;

$\varphi(\lambda)$ — value of the spectral intensity of the radiation flux, $\varphi(\lambda) = \frac{dF}{d\lambda}$, $W \times mn^{-1}$.

We used the mathematical model as initial objective function that allows the modeling of the parameters for entrance block and determine the power of the LEDs and their quantity. The implementation of the indicated model is the solution of the system of inequalities according to the vector criteria (2):

$$H^{б}_{min} \le H^{б}_{j}(\lambda, a, t, h) \le H^{б}_{max} \qquad (2)$$
$$H^{б}_{i}(\lambda, a, t, h) \ge H^{б}_{max}$$

As the circumstances require finding the best value vector of variables that are calculated with following restrictions:

$$\lambda_{min} \le \lambda \le \lambda_{max}$$
$$a_{min} \le a \le a_{max} \qquad (3)$$
$$t_1 \le t \le t_2$$
$$h_1 \le h \le h_2$$

$H^{б}_{min}$, $H^{б}_{max}$ — the limit values of the interval of the dose of the erythemal flux beyond which the bee and the mite do not survive (0.125; 0.667).

The vector of criteria $H^{б}_{j}(\lambda, a, t, h)$ and $H^{б}_{i}(\lambda, a, t, h)$ covers the space of the erythematous dose for the bee (*j*) and the mite (*i*) when irradiated in UV-B with different wavelength λ, which mathematical representation has the form (4):

– dose of erythemal flux that effects on the bee and the mite, Mer×s×cm^{-2}

$$H^{б}_{ji}(\lambda, a, h) = \int_{t_1}^{t_2} S_{ji} \frac{F_y(\lambda, a, h)}{t} dt, \qquad (4)$$

– total capacity of UV device effecting on the area of the entrance block is determined by (5):

$$F_y(\lambda, a, h) = k_1 \cdot k_2 \cdot k_3 \cdot k_{від.} \cdot k_{пог.} \cdot$$
$$\cdot \int_{\lambda_{min}}^{\lambda_{max}} \int_{a_{min}}^{a_{max}} \int_{h_1}^{h_2} a \cdot b \frac{A \cdot k_{еф}(\lambda) \cdot h^2 \cdot \Phi(\lambda)}{\tau \cdot h^2_{н}} d\lambda \cdot da \cdot dh, \qquad (5)$$

where: $k_{еф}$ — coefficient of biological efficiency, depending on the wavelength;

h — height of the entrance block, cm;

Φ — threshold value of the light flux at one biodose, Mer·s·cm^{-2};

$h_н$ — normalized height of the installation of UV source for one biodose, cm;

t — time of stay of the bee and the mite in the erythema zone, s;

S_{ji} — calculated area of the bee and mite surface, cm^2.

The adequacy of the mathematical model is estimated on the basis that:

(a) the bee and the mite located on it pass into the hive through the tunnel of the entrance block;

(b) the level of irradiation of the bee and the mite depends on the geometric dimensions of the entrance block (length, height);

(c) the period of irradiation of the bee and the mite depends on the speed of the bee on the tunnel of the entrance block;

(d) the radiation dose of bioobject depends on the amount and power of UV radiation source;

(e) if the biodose effecting on the bee does not exceed the threshold dose, the irradiation is effective on the bee;

(f) if the biodose effecting on the mite exceeds the threshold dose, the mite dies, and the level of irradiation is considered effective.

To simplify the practical application of the mathematical model, the following assumptions are used:

(1) the coefficient of biological absorption of the bee and the mite is not taken into account;

(2) the average value of the size of the bee and the mite is taken into account;

(3) the bee is considered in the form of a cylinder.

Results. As a result of calculations by the equations of the mathematical model, the values of the biodoses effecting on the mite at a given wavelength of radiation with doses A from the threshold value in the range from 0.2 to 0.6 are derived and summarized in Table 1 for *h* = 1 cm, *a* = 8 cm, t_1 = 5 s.

Table 1 — Biodoses effecting on the mite at doses A = 0.6, A = 0.5, A = 0.4, A = 0.3, A = 0.2 from the threshold value and wavelength of radiation

***h* = 1 cm, *a* = 8 cm, t_1 = 5 s**									
A = 0.2		**A = 0.3**		**A = 0.4**		**A = 0.5**		**A = 0.6**	
λ, nm	**$D_к$, e.i.**	**λ, nm**	**$D_к$, e.i.**	**λ, nm**	**$D_к$, e.i.**	**λ, nm**	**$D_к$, e.i.**	**λ, nm**	**$D_к$, e.i.**
270	1.741	270	2.610	270	3.482	270	4.350	270	5.223
275	1.684	275	2.530	275	3.368	275	4.210	275	5.052
280	1.628	280	2.442	280	3.256	280	4.070	280	4.884
285	1.556	285	2.340	285	3.119	285	3.900	285	4.680
290	1.413	290	2.120	290	2.825	290	3.530	290	4.238
297	1.960	297	2.940	297	3.920	297	4.900	297	5.880
300	1.899	300	2.850	300	3.798	300	4.750	300	5.700
305	0.622	305	0.935	305	1.243	305	1.550	305	1.870
310	0.102	310	0.160	310	0.203	310	0.250	310	0.310
315	0.023	315	0.035	315	0.045	315	0.057	315	0.070

Analyzing the values of the Table 1 it can be concluded that in the entrance block with tunnel length $a = 8$ cm, height $h = 1$ cm and exposure $t_1 = 5$ s at given wavelength of 297–300 nm and irradiation with doses A from the threshold value in the range from 0.2 to 0.6 we obtain the highest values of biodose that have a detrimental effect on the mite.

Equation (5) using demonstrated, that the values of the total capacity of the UV device, that effects on the area of the entrance block with parameters $h = 1$ cm, $a = 8$ cm, $b = 20$ cm at different wavelengths of radiation and doses, are obtained.

The results of calculations are presented in Table 2.

Table 2 — Values of total capacity of UV device and quantity of LEDs with dose A = 0.6 from the threshold value

A = 0.6 e.i., h = 1 cm, a = 8 cm, t_1 = 5 s						
λ, nm	**F_{yc}, Mer**	**n, psc.**	**$H_п$, Mer×s/cm²**	**$H_к$, Mer×s/cm²**	**$D_п$, e.i.**	**$D_к$, e.i.**
265	109.59×10^{-5}	3.60	15.68×10^{-4}	1,014.60×10^{-4}	0.0900	5.880
270	97.56×10^{-5}	3.30	13.95×10^{-4}	903.30×10^{-4}	0.0807	5.223
275	94.41×10^{-5}	3.20	13.50×10^{-4}	874.17×10^{-4}	0.0780	5.052
280	91.23×10^{-5}	3.10	13.05×10^{-4}	844.71×10^{-4}	0.0753	4.884
285	87.44×10^{-5}	2.97	12.50×10^{-4}	809.61×10^{-4}	0.0723	4.680
290	79.20×10^{-5}	2.70	11.33×10^{-4}	733.20×10^{-4}	0.0655	4.238
297	109.59×10^{-5}	3.60	15.68×10^{-4}	1,014.60×10^{-4}	0.0900	5.880
300	106.44×10^{-5}	3.63	15.22×10^{-4}	985.56×10^{-4}	0.0880	5.700
305	34.85×10^{-6}	1.20	4.98×10^{-4}	322.70×10^{-4}	0.0290	1.870
310	5.70×10^{-5}	0.20	0.82×10^{-4}	52.77×10^{-4}	0.0047	0.310
315	1.27×10^{-5}	0.10	0.18×10^{-4}	11.73×10^{-4}	0.0011	0.070

The determined parameters (Table 2) allow us to conclude that the biodose obtained by the mite and the bee depends on the irradiation of the device F_{yc}. The mite and the bee are exposed at the same time, but the level of biodoses is different. As a result of numerical simulation, we obtained data on the basis of which the dependencies of irradiation of the device $F_{yc.}$ were based on. Fig. 2 shows the dependence of the irradiation of the device $F_{yc.}$ on the wavelength λ at dose change from 0.2 to 0.6 from the threshold value of biodose that can affect animals.

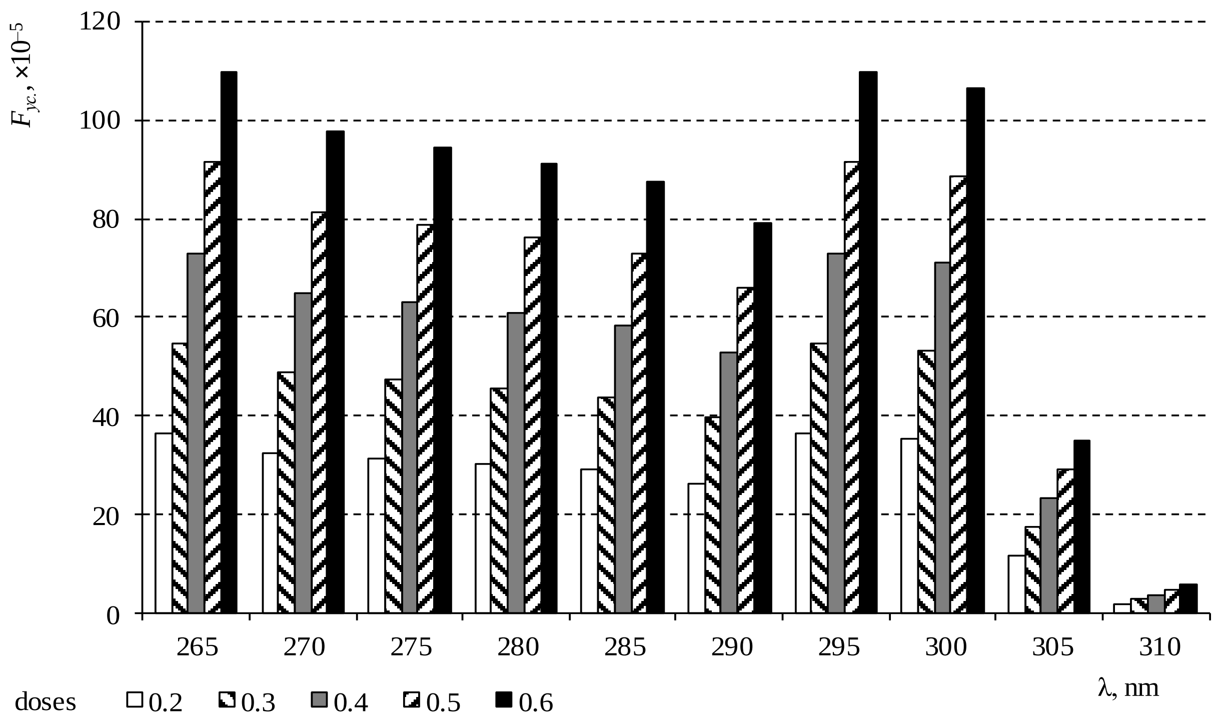

Figure 2. The dependence of the irradiation of the device ($F_{yc.}$) on the wavelength (λ) at dose change from 0.2 to 0.6 of the threshold value of the biodosis

The graphic dependence analysis demonstrated, that the total erythemal flux of the device reaches its maximum at wavelength of 265 nm and 297 nm and dose $A = 0.6$ of the threshold value of biodose and is 109.59×10^{-5} Mer. In order to provide this radiation, it is necessary to have LEDs in the amount of four pieces with a power of 0.08 Watts. The minimum value of the total erythemal flux of the device at the same dose and wavelengths of 310 nm and 315 nm is 5.7×10^{-5} Mer and 1.27×10^{-5} Mer. It is necessary to have one LED with a power of 0.016 Watts to provide such irradiation.

At a minimum dose of 0.2 of the threshold value, the total erythematous flux of the device at a wavelength of 265 nm and 297 nm is 36.53×10^{-5} Mer, and at wavelengths from 305 nm to 315 nm, the total erythematous flux varies in the range of $11.61–0.42\times10^{-5}$ Mer.

Conclusions. 1. The analysis of scientific and technical literature aimed to the issues of the development and application of biologically harmless technologies and their implementation means of varroosis control revealed the lack of methodology regarding comprehensive approach for the creation of modern light technical electrical devices effecting on biological objects with improved energy and biological characteristics with the use of special sources of optical UV radiation (LEDs).

2. Analytical studies provide the opportunity to optimize the parameters and operating modes of the entrance block equipped with LED module of UV irradiation with UVB light-emitting diodes.

3. We recommended the optimal energy and resource-saving parameters of the LPRS-1 entrance block: the length of the tunnel $a = 8\pm0.1$ cm, the height of the tunnel of the entrance block $h = 1\pm0.1$ cm, quantity of LEDs is 6–8 pcs with current of 20 mA, voltage of 4 V, taking into account the dose of the irradiation of the device and the wavelength of the UV spectrum.

References

Kuryshev, V. and Kuryshev, R. (2008) 'Bactericidal lamps in beekeeping' [Bakteritsidnye lampy v pchelovodstve], *Honeybees Plus [Pchely plyus]*, 5, pp. 54–55. Available at: http://rnsp.su/files/pdf/m5.pdf. [in Russian].

Ohtsuka, K. and Osakabe, M. (2009) 'Deleterious effects of UV-B radiation on herbivorous spider mites: they can avoid it by remaining on lower leaf surfaces', *Environmental Entomology*, 38(3), pp. 920–929. doi: 10.1603/022.038.0346.

Romanchenko, M. A., Chervinskyi, L. S., Sanin, Yu. K., Nikitina, O. S., Nikitin, S. P., Romanchenko, V. M. (2013) *Beehive with a unit to control bee varroatosis by physical method [Vulyk z prystroiem dlia borotby z varoatozom bdzhil fizychnym metodom]*. Patent no. UA 82214. Available at: http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=189725. [in Ukrainian].

Romanchenko, M. A., Maslii, I. H., Kundenko, M. P., Sanin, Yu. K. and Tsekhmeister, O. S. (2015) 'Research disinfecting effect of UV in the conservation action potential of bee colonies' [Doslidzhennia dezinfikuiuchoi dii UF u zabezpechenni zberezhennia biopotentsialu bdzholosimei], *Scientific Herald of the National University of Life and Environmental Sciences of Ukraine [Naukovyi visnyk Natsionalnoho universytetu bioresursiv i pryrodokorystuvannia Ukrainy]*, 223, pp. 162–167. Available at: http://nbuv.gov.ua/UJRN/nvnau_tevppt_2015_223_27. [in Ukrainian].

Romanchenko, M. A. and Nikitina, O. S. (2013) 'The substantiation of the parameters of the device to study the effect of ultraviolet radiation on biological objects in beekeeping' [Obosnovanie parametrov ustroystva dlya issledovaniya vliyaniya ul'trafioletovogo oblucheniya na bioob"ekty v pchelovodstve], *Bulletin of the Kharkiv Petro Vasylenko National Technical University of Agriculture [Visnyk Kharkivskoho natsionalnoho tekhnichnoho universytetu silskoho hospodarstva imeni Petra Vasylenka]*, 141, pp. 122–123. Available at: http://nbuv.gov.ua/UJRN/Vkhdtusg_2013_141_46. [in Russian].

Zhang, C.-Y., Meng, J.-Y., Wang, X.-P., Zhu, F. and Lei, C.-L. (2011) 'Effects of UV-A exposures on longevity and reproduction in *Helicoverpa armigera*, and on the development of its F_1 generation: effects of UV-A exposures in *Helicoverpa armigera*', *Insect Science*, 18(6), pp. 697–702. doi: 10.1111/j.1744-7917.2010.01393.x.