An efficiency increase in the field of beekeeping is impossible without development and implementation of progressive resource-saving technologies and means of their implementation aimed at ensuring proper veterinary and sanitary conditions for maintenance, breeding and use of bee colonies. This fully applies to the development of means for prevention and treatment of bee diseases in active and passive periods of their life. Creation of the new beekeeping implements, which are capable of meeting the requirements of biosafety technologies, is an urgent problem for the design of technical means to control bee varroatosis with a use of UV irradiation. A promising development in mentioned area is creation of unified protective devices located outside nursing sockets. The devices are hive entrance attachment equipped with a module of UV radiation capable of performing several preventive and therapeutic functions simultaneously. In particular, it is formation of conditions for reduction of non-technological losses of the biopotential of a bee colony, preservation of its feeding stocks and possession of highly specialized characteristics, which ensure the reliable operation of a hive entrance attachment in the struggle with bee varroatosis [1, 2].

2. Literature review and problem statement

Varroatosis is an invasive disease of bee colonies, which causes significant material damage in the field of beekeeping and plant growing. It affects a level of food security of a country negatively. There are several types of known technologies to struggle with the disease: chemical, zootechnical, physical and combined. The aim of them all is inhibition or

1. Introduction

An efficiency increase in the field of beekeeping is impossible without development and implementation of progressive resource-saving technologies and means of their implementation aimed at ensuring proper veterinary and sanitary conditions for maintenance, breeding and use of bee colonies. This fully applies to the development of means for prevention and treatment of bee diseases in active and passive periods of their life. Creation of the new beekeeping implements, which are capable of meeting the requirements of biosafety technologies, is an urgent problem for the design of technical means to control bee varroatosis with a use of UV irradiation. A promising development in mentioned area is creation of unified protective devices located outside nursing sockets. The devices are hive entrance attachment equipped with a module of UV radiation capable of performing several preventive and therapeutic functions simultaneously. In particular, it is formation of conditions for reduction of non-technological losses of the biopotential of a bee colony, preservation of its feeding stocks and possession of highly specialized characteristics, which ensure the reliable operation of a hive entrance attachment in the struggle with bee varroatosis [1, 2].
destruction of a causative agent of bee varroatosis – a Varroa destructor mite. Chemical technologies imply processing of bees directly in a hive using artificially synthesized substances based on heavy (amitraz, fluvaniline) or lighter (thymol) acaricides. A significant disadvantage of the use of acaricides is contamination of honey, perg, propolis and sotoramo by remnants of synthetic substances. They also do not promote preservation of the bio-potential of bee colonies and protection of their feeding stocks. In addition, mentioned technologies and means of their implementation complicate or make impossible to obtain environmentally friendly bee products [3, 4].

There are technologies based on the application of physical non-medicamentous methods to struggle with varroatosis. One of them involves processing bees in a heat chamber located outside a hive. In this case, there is a temperature of 46–48 °C in the operation volume of a heat chamber. Electric heaters and fans maintain the temperature throughout a period of bees staying in it. The technologies have greater effectiveness for controlling varroatosis due to the effect of high temperature on mites – most of them fall from bees and die. At the same time there is a risk associated with the emergence of a negative effect on future life of bees and bee queens due to overheating. This is the disadvantage of the heat treatment technology of bee colonies. In addition, to maintain a predetermined temperature in a heat chamber, there is a need in precise measurement equipment as a temperature comes near to critical acceptable temperature for bees. Increased energy consumption and labor intensity characterizes a process of heat processing of bee colonies. In addition, the technologies, despite the fact that a heat treatment process takes place outside a hive, cannot ensure preservation of feeding stocks and protection against non-technical losses of bees during their life.

There are also works devoted to the study of an influence of optical irradiation of living organisms, including mites, which is a kind of non-medicamentous physical technology. They prove that irradiation with short-wavelength visible light kills eggs, larvae, pupae and adult Drosophila. Studies conducted in this direction showed that high-toxic wavelengths of visible light have different degrees of toxicity for certain types of insects [5].

There is a separate group of studies devoted to benefits of ultraviolet short-wave irradiation, which affects biopolymers destructively, including proteins and nucleic acids at the cellular level [6, 7]. Studies confirm the fact of death of spider mites from irradiation by electromagnetic radiation of UVB ultraviolet spectrum (280–315 nm) [8]. Thus, in paper [9], there is information on the practical application of intermittent ultraviolet irradiation of UVB spectrum of lower leaves of strawberry bushes at low temperatures at night for the treatment of Tetramychus urticae Koch mite in greenhouses. The data of scientific and technical literature indicate that peristalsis of intestines of mite females becomes sharply more activated under the influence of ultraviolet rays. One can observe mengeous movements of a Varroa mite in this installation. LEDs are powered by photocells. The module for UV irradiation of bees and Varroa mites includes a hive entrance attachment, LEDs, a power supply for LEDs, a protective grid, a switching and control system. Fig. 1 shows the general view of the hive entrance attachment (HEA-1) equipped with UV irradiation module.

We solve the following tasks to achieve the objective:
- determination of the effect of UV radiation on life processes of a Varroa mite and a bee;
- substantiation of geometrical parameters of a hive entrance attachment equipped with a module of UV irradiation of bees and mites;
- determination of the efficiency of the use of a hive entrance attachment equipped with a module of UV irradiation for the struggle with the varroatosis of bees.

4. Materials and methods of research

UV radiation causes specific reactions of a body of a bee and a Varroa mite. Nerve endings and humoral mechanisms transform the reactions by transferring generated active substances to hemolymph from a place of its formation into other insect organs. Such a property of UV radiation has large practical importance, as it shows the effectiveness of application and feasibility of not only general but also local irradiation.

We propose a modular installation of UV irradiation to implement the assumption of effective control of bee varroatosis and preservation of bee potential. Electromagnetic radiation of UV spectrum of light emitting diodes affects a Varroa mite in this installation. LEDs are powered by photocells. The module for UV irradiation of bees and Varroa mites includes a hive entrance attachment, LEDs, a power supply for LEDs, a protective grid, a switching and control system. Fig. 1 shows the general view of the hive entrance attachment (HEA-1) equipped with UV irradiation module.

We consider the Varroa mite as a specific radiative receiver in the study. It has a relative spectral sensitivity. A ratio of the minimum amount of irradiation at λ=297 nm to the intensity of irradiation with a given wavelength κ(λ), which provides the same erythematous action, determines the sensitivity. Given this, the erythematous flow is defined as radiation. Such radiation is assessed by the ability of harmful effects on a Varroa mite (1).

\[ P = \int_{\lambda_{1}}^{\lambda_{2}} \phi(\lambda)\kappa(\lambda)d\lambda, \]  

(1)
where \( k(\lambda) \) is the relative erythematous efficiency of radiation; \( \phi(\lambda) \) is the magnitude of spectral intensity of the radiation flow,

\[
\phi(\lambda) = \frac{dP}{d\lambda} \quad \text{W}\cdot\text{nm}^{-1}.
\]

\[ F_{\text{min}}(\lambda) = \frac{k_{\text{ef}}}{k_{\text{ef}} \int_{\lambda_{\min}}^{\lambda_{\max}} \frac{A}{2} \cdot \frac{r^2}{h^2} \cdot \Phi \cdot \tau \cdot h^2 \, d\lambda, \quad (5) \]

where \( k_{\text{ef}} \) is a coefficient of biological efficiency, which depends on a wavelength; \( k_{\text{ef}} \) is a coefficient, which takes into account reflection, absorption, external conditions, a level of natural light; \( b \) is the width of the hive entrance attachment, cm; \( A \) is the dose of irradiation, a. u.; \( h \) is the height of the hive entrance attachment, cm; \( \Phi \) is the threshold value of a light flow for one bio dose, meas \( \text{s}\cdot\text{cm}^{-2} \); \( h_0 \) is the normalized height of the installation of UV source for one bio dose, cm; \( \tau \) is the operating time of the installation, s; \( S_0 \) is the estimated area of a surface of a bee and a Varroa mite, cm².

We can estimate the adequacy of the mathematical model taking into account the following:

\( a \) a bee and a mite located on it passes into a hive through the entrance attachment as a bio-object;

\( b \) a length and a height of the hive entrance attachment affect a level of irradiation of a bio-object;

\( c \) a time of irradiation of a bio object depends on a rate of passing a tunnel of the hive entrance attachment by a bee;

\( d \) a dose of irradiation of a bee and a Varroa mite depends on an amount and power of UV radiation of the light emitting diodes;

\( e \) we can consider irradiation as effective if a bio dosage, which affects a bee, does not exceed a threshold dose;

\( g \) we can consider irradiation as effective if a bio dosage, which affects a Varroa mite, exceeds the threshold dose.

We consider a bee and a Varroa mite in a shape of a cylinder with average values of sizes. Such assumptions make possible to simplify a practical application of the model.

We use the following input values to calculate parameters that create a process of interaction of a Varroa mite and electromagnetic UV radiation using the given mathematical model:

- a wavelength range of UV radiation 265–315 nm with a change step \( \Delta\lambda = 5 \) nm;
- a range of a change of a length of the hive entrance attachment 20–2 cm with a change step \( \Delta l = 2 \) cm;
- a range of a period of stay of bees and mites in an erythematous dose 2.5–25 s with a step \( \Delta t = 2.5 \) s;
- a range of a change in a height of the hive entrance attachment 1–3 cm with a step \( \Delta h = 1 \) cm;
- a range of an irradiation dose 0.2–0.6 with a step \( \Delta\lambda = 0.1 \), a.u.;
- an estimated average surface area of a bee \( S_b = 1.1 \text{ cm}^2 \), and a mite \( S_m = 0.02 \text{ cm}^2 \).

We obtained data according to formula (5). We constructed dependences of irradiation of installation \( F_{\text{inst}} \) to a length of the hive entrance attachment at a wavelength \( \lambda = 297 \) nm based on the obtained data. Fig. 2 shows the dependences.

Analysis of the dependences (Fig. 2) shows that the value of the irradiation of the installation should be increased at the increase in the length of the hive entrance attachment. At a length of the console tunnel \( l = 8 \) cm and its height \( h = 1 \) cm, the power consumed by the sources of the UV installation – \( 2.7\cdot10^6 \cdot 9.1\cdot10^7 \) W at a change in the dose of radiation from 0.6 to 0.2.

Irradiation of the module depending on wavelength (6):

\[
F_{\text{min}}(\lambda) = 0.5 \cdot \frac{k_{\text{ef}} \cdot l \cdot A \cdot h^2 \cdot h_0^2 \cdot \Phi \cdot \tau}{k_{\text{ef}} \int_{\lambda_{\min}}^{\lambda_{\max}} \frac{A}{2} \cdot \frac{r^2}{h^2} \cdot \Phi \cdot \tau \cdot h^2 \, d\lambda, \quad (6)\]
length of irradiation with A dose, which varies in the range from 0.2 to 0.6 threshold value. Table 1 shows calculation data for the hive entrance attachment with a length of the tunnel l=8 cm and a height h=1 cm and t=5 s. The obtained values of bio doses do not act on bees destructively.

We used the results of the determination of the irradiation of the installation depending on a wavelength with the dose A=0.6 from a threshold value of a bio dose and parameters of the hive entrance attachment: a length of a tunnel of the hive entrance attachment l=8 cm, its height h=1 cm and a width b=20 cm, to construct dependence in Fig. 3.

![Fig. 2. Dependences of irradiation of the installation \( F_{\text{inst}} \), on the length of the hive entrance attachment \( A \), of irradiation \( A=0.2 \); \( A=0.4 \); \( A=0.6 \) from a threshold value at a wavelength \( \lambda = 297 \) nm and a height of the hive entrance attachment \( h = 1 \) cm.](image)

We analyzed graphical dependence in Fig. 3 and can state that the total erythematos flow of the installation reaches a maximum at a wavelength of 265 nm and 295 nm and is 109.59\( \times 10^{-5} \) units. We need four light emitting diodes of irradiation \( F_{\text{inst}} \), at a dose change \( A=0.6 \) on a threshold value of bio doses.

![Fig. 3. Dependence of irradiation of the installation \( F_{\text{inst}} \), on wavelength \( \lambda \), at a dose change \( A=0.6 \) on a threshold value of bio doses.](image)

According to formula (6), we obtained a total power of UV irradiation, which affects the area of the hive entrance attachment, at a wavelength of irradiation from 265 nm to 315 nm with a dose \( A=0.2 \) from a threshold value of a bio dose. We calculated a bio dose of a bee and a mite for a time they pass through the hive entrance attachment by the formula (7). We took into account parameters of the hive entrance attachment \( h=1 \) cm, \( l=8 \) cm, \( b=20 \) cm. Table 2 gives results of calculations.

![Table 1: Bio doses, which act on a bee at doses \( A=0.6 \), \( A=0.5 \); \( A=0.4 \); \( A=0.3 \); \( A=0.2 \) of a threshold value and irradiation wavelength](table)

According to formula (6), we obtained a total power of UV irradiation, which affects the area of the hive entrance attachment, at a wavelength of irradiation from 265 nm to 315 nm with a dose \( A=0.2 \) from a threshold value of a bio dose. We calculated a bio dose of a bee and a mite for a time they pass through the hive entrance attachment by the formula (7). We took into account parameters of the hive entrance attachment \( h=1 \) cm, \( l=8 \) cm, \( b=20 \) cm. Table 2 gives results of calculations.

![Table 2: Value of a total power of the UV irradiation with a dose \( A=0.2 \) from a threshold value and a number of LEDs](table)

The obtained values (Table 2) make it possible to conclude that a bio dose, which a mite and bee receives, depends on irradiation of the installation \( F_{\text{inst}} \). A mite gets a maximum value of a bio dose at a wavelength of 265 nm and 297 nm. A magnitude of such a bio dose is fatal to a mite. Mites and bees are exposed at the same time, but the levels of bio doses are different.
5. Results of study into existence of mites on bees using a hive entrance attachment

We carried out experiment from April 15, 2014 to September 30, 2016 in the beekeeping sector of “Charunka” Scientific and Technical Center, Pervukhinka settlement, Bogodukhivsky region of Kharkiv oblast (Ukraine) to study effectiveness of the proposed hive entrance attachment as a measure against mites. We conducted the experiment under field conditions, objects of the experiment were Carpathian bee kinds affected by Varroa destructive mites.

We found that the experimental bee colonies number 2 and number 3 had the same – high – level of mite presence. The degree of mite presence of the bee colony number 2 was 5–7%, the degree of mite presence of the bee colony number 3 was 6%. The mentioned bee colonies could be used as control and test bee colonies, respectively, for the further stages of field experiment on using the proposed HEA-1 hive entrance attachment to struggle with varroatosis directly on an apiary when LEDs were powered by a solar cell. In the experiment, we used UV radiation sources with the following technical characteristics: a wavelength interval of 305-265 nm, an interval of erythematous flow 35-10^-5-110·10^-5 units, voltage of power supply was 4 V, supply current was 20–30 mA. Table 3 gives the type and specifications of power supply.

The next stage of the experiment was control weighing of hives of 20 breeding frames with control and experimental bee colonies. The total weight of the control hive with a bee colony was 43 kg on April 15, 2014, the test one – 45 kg. We left both the test and the control hives on scales until the end of the experiment (September 30, 2016).

Next, we equipped an entrance of the test hive with the attachment with a module of sources of UV irradiation with a photocell attached (the total weight of the connected structure was 950 grams). Fig. 4 shows the setup.

We determined effectiveness of the use of a hive entrance attachment by formula (8): 

\[ E_{\text{sh}} = \frac{(P_{\text{BA}} - (P_{\text{BA}} - K_{\text{e}}))100}{P_{\text{BB}}}, \]  

where \( P_{\text{BB}} \) is a degree of presence of mites in a bee colony before the use of a hive entrance attachment, %; \( P_{\text{BA}} \) is a degree of presence of mites in a bee colony after the use of a hive entrance attachment, %; \( K_{\text{e}} \) are the mites exterminated by auxiliary means against varroatosis, %.

Table 4 gives results of the determination of effectiveness of the hive entrance attachment with an irradiated module of the UV spectrum, as a tool to fight against varroatosis.

6. Discussion of results of the productivity improvement of bee colonies

A number of external and internal factors affects productivity of a bee colony as a single bio organism. If we assume
that external factors influence on biology and physiology of any bee colony equally, a scale of an influence of internal factors on the production of bee products will correlate. Diseases belong to internal factors for which we determine a number of bee products. One of the major invasive diseases is the varroa. Therefore, nominal productivity of a bee colony depends on the effectiveness of counteraction to distribution of diseases and effectiveness of devices, which struggle with varroa. Creation of a new beekeeper equipment based on bio-safe electrotechnology to control varroa of bees using UV irradiation, as shown by analytical experimental and calculation data, can significantly increase productivity of bee colonies. At the same time, promising development in this area is creation of unified protective devices located outside a nursing socket and thus do not violate a natural rhythm of operation of bee colonies. It has a positive effect on improvement of their productivity. Such protective devices are the developed hive entrance attachments, which are additionally equipped with a LED module of UV radiation capable of simultaneously performing several functions (therapeutic and prophylactic).

The advantage of the proposed solutions is possibility to create conditions for reduce in non-technological losses of the biopotential of a bee colony, preserving its feeding stocks during a production cycle, and ensuring the sustained operation of a hive entrance attachment in fighting varroa.

Justification of geometrical parameters of a hive entrance attachment and UV characteristics of UV radiation provide its effective work to increase productivity of a bee colony.

The disadvantage of studies includes difficulties caused by the cost of indicators of UV radiation and their shortage in the retail network.

The development of the study can be continued in terms of determination of an effect of UV radiation on pathogenic microflora and fauna, as pathogens of infectious disease of bees (mould, mycoses, etc.).

7. Conclusions

1. We established that a bio dose obtained by a bee and a Varroa mite depends on the power of UV installation. A mite and a bee get the maximum value of a bio dose at a wavelength of 265 nm and 297 nm with a power of 36.53·10⁻⁵ units. This value corresponds to 1.98 a.u. for a mite and 0.03 a.u. for a bee. Such parameters of a bio dose can heal bees from varroa.

2. Analytical studies made possible to substantiate approaches to determination of characteristic geometric parameters of a hive entrance attachment. A recommended length of a tunnel is \( l = 8\pm0.1 \text{ cm} \), height \( h = 1\pm0.1 \text{ cm} \), the number of LEDs – 1–4 pieces with a power of 0.08 W and a voltage of 4–7 V taking into account an irradiation dose and a wavelength.

3. We established that effectiveness of the use of a hive entrance attachment equipped with a UV radiation module when fighting bee varroa was 83.86 % in 2014, 67.2 % in 2015, 76.33 % in 2016.

References

1. Klochko R. T., Voronkov I. M. Measures to combat varroa of bees // Beekeeping. 2009. Issue 2. P. 28–30.
2. Investigation of the disinfectant effect of UV in maintaining the biopotential of bee colonies / Romanchenko N., Masly I., Kundayko N., Sanin Y., Tsekhmeister O. // Scientific Bulletin of the National University of Bioresources and Natural Resources of Ukraine. Series: Tekhnikahny production and processing of livestock products. 2015. Issue 223. P. 162–167.
3. Priyamak G. M., Palivoda V. O., Metryuk Yu. Yu. Varro’s Prayer, the Way of the Struggle // Passion. 2013. Issue 4. P. 17–19.
4. Makarov S. Increasing the resistance of bee colonies to varroa // Veterinary of farm animals. 2013. Issue 12. P. 30–35.
5. Lethal effects of short-wavelength visible light on insects / Hori M., Shibuya K., Sato M., Saito Y. // Scientific Reports. 2014. Vol. 4. Issue 1. doi: 10.1038/srep07383
6. Salnik V. V., Skomorokhina D. P., Reushev M. Yu. Effect of pulsed ultraviolet laser radiation on the functional activity of macroorganisms // Siberian Medical Education. 2014. Issue 4. P. 39–44.
7. Pfeifer G. P., Besaratinia A. UV wavelength-dependent DNA damage and human non-melanoma and melanoma skin cancer // Photochem. Photobiol. Sci. 2012. Vol. 11. Issue 1. P. 90–97. doi: 10.1039/c1pp05144j
8. Ohsuka K., Osakabe M. Deleterious Effects of Uv-B Radiation on Herbivorous Spider Mites: They Can Avoid It by Remaining on Lower Leaf Surfaces // Environmental Entomology. 2009. Vol. 38. Issue 3. P. 920–929. doi: 10.1603/022.038.0346
9. Nakai K., Murata Y., Osakabe M. Effects of Low Temperature on Spider Mite Control by Intermittent Ultraviolet-B Irradiation for Practical Use in Greenhouse Strawberries // Environmental Entomology. 2017. doi: 10.1093/ee/nvx179
10. Chernovskiy L. S., Radko I. P. A new approach to the quantitative assessment of the effect of ultraviolet radiation on irradiation of animals // Motorization and power industry in agriculture, MOTROL. 2011. Vol. 13D. P. 296–301.
11. A beehive with a device for controlling varato-zooms of bees by physical method: Pat. No. 82214. MPK: A01K 47/00 / Romanchenko M. A., Nikitina O. S., Sanin Yu. K., Romanchenko V. M., Nikitin S. P., Chervinskyi L. S.; zaiavnyk i patentoobladach Kharkiv. No. u201301608; declareted: 11.02.2013; published: 25.07.2013, Bul. No. 14.
12. Effects of UV-A exposures on longevity and reproduction in Helicoverpa armigera, and on the development of its F1 generation / Zhang C.-Y., Meng J.-Y., Wang X.-P., Zhu F., Lei C.-L. // Insect Science. 2011. Vol. 18. Issue 6. P. 697–702. doi: 10.1111/j.1744-7917.2010.01393.x