A differential mathematical model for experiments to determine the efficacy of treatments against the bean weevil

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Abstract: - The article presents a mathematical model for experiments evaluating the effectiveness of diatomaceous earth treatments against the bean weevil, *Acanthoscelides obtectus*. The proposed mathematical model is of the differential type, inspired by the category of prey-predator models. The system of equations is nonlinear and is solved numerically. A systemic characterization of the bean weevil treatment process is used to describe the model, which uses three functions of time: the number of beans, the pest population, and the amount of diatomaceous earth. The three functions offer users four applications: forecasting, control, formulation of treatment efficacy estimators, and simulation of different types of pest control. The model is built for closed (isolated) experiments typical of laboratories, but this feature makes it extensible to other treatments to combat bean weevils in closed spaces characteristic of the storage of beans in silos.

Key-Words: -mathematical model, bean weevil, treatments, experiences, efficacy, control

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1 Introduction

The mathematical modelling of experiences in biological processes is a broad field that has received attention in the literature.Numerous articles deal with the general theory of models and (mathematical) modelling of biological systems [8], [9], [10], [11], [12], and [38]. These are just a few titles from a large number of papers on the subject. The computer simulation of the integrated management of spruce worms was already used in 1982 [26].

Many concerns similar to the ones described in this paper are also found in the literature. In [13], the authors mathematically model the control of harmful insects by interrupting mating and capturing them, also using a system of differential equations.

Concerns in the field of strategy for the development of mathematical modelling and experimentation in the field of biology are found in [14], some of them resulting from our work.

A broad differential model (with fifteen differential equations), which, as in our case, uses the calibration operation, is dedicated to a deadly tropical disease for humans[17]. Differential models for mosquitoes carrying Wolbachia bacteria and dengue disease are reviewed in [18]. A new differential model is presented in [19] for the study of the dynamics of vector-borne disease transmission (a new mathematical model for the transmission dynamics of vector-borne diseases with vertical transmission and cure is developed). Differential models of prey-predator types with applications in agricultural crop protection are exposed in [21]. The authors [22], [39] used simple mathematical models to describe the dynamics of interaction between sterile and wild insect populations in the insect control technique by launching the sterile male Sterile Insect Technique (SIT). Similar problems are studied by the same authors in [23], [25].

Differential models and mixed differential and partial derivative models for the description and understanding of malaria spread are presented in [20]. Another category of mathematical models is those that combine statistical models with differential ones, possibly using statistically modelled functions in the dynamic, differential model [15]. Statistical models have long been used in the study of insect populations [24]. The use of even more complex, semi-discrete mathematical

models is part of a class of hybrid models, which are often described by continuous dynamics but repeatedly experience discrete changes at certain times [16].
Concerns at a higher-level aim at an optimal design of the dynamic models of the pest populations [27]. Works dedicated to determining the efficacy of alternative treatments, even for stored beans and, among others, diatomaceous earth, using statistical processing of experimental data can be found in [28], [30], and [32]. Statistical mathematical modelling of experimental data on the efficacy of diatomic soils against insects can be found in [32], [33], [34], [35], and [36]. A mathematical model for describing the kinetics of diatomic soil adhesion on the body of the bruchids *Callosobruchus maculatus* (F.) or *Acanthoscelidesobtectus* (Coleoptera: Bruchidae) is proposed by the authors [29], [31]. In [37], the authors also consider the influence of ambient temperature and humidity on the bean weevil population.At the level of descriptive statistics, the results can be used to extend mathematical models to the two variables, which in the present research are considered constants.
Mathematical models are constructed to explain the phenomena of the physical world better than purely descriptive models. A more important role of mathematical models is to make predictions about the values of the parameters of the modelled phenomenon. A higher level for a mathematical model is reached when it can demonstrate the existence of optimal values for the parameters of the phenomenon and, in addition, calculate these values. Based on mathematical models, the authors [40] optimize the control of mosquito populations. Several mathematical models with which heuristic optimizations are performed are reviewed by the authors [41]. Mathematical modelling with control and optimization also exposes the authors [42] to sugar beet pests. The articles of the authors [43], [44], [45], [46], [47], and many others are inscribed on the same coordinates.

2 Material and method

The subject of the research described in this article is the mathematical modelling of the behaviour of a population of bean weevils in a closed or isolated system. The purpose of the model is to estimate the effectiveness of the treatment.

2.1 Material of the study

The physical support of the study consists of the closed system made in a cylindrical container with transparent walls, in which there are three main components: beans, adult bean weevils, and diatomaceous earth as a treatment against them.

2.2 Material of the study

The method of mathematical modelling of the biological process that constitutes the study material is the description of the system as a dynamic system of the prey-predator type with three components.
The differential mathematical model that is presented in this paper, tries to describe the behaviour of a closed system, consisting of three components: a prey and two predators. Prey (stored beans) is the food for the first predator (the bean weevil), and the substance with which the treatment is performed against the bean weevil is considered to be the second predator. The closed system consisting of bean grains, bean weevils, and bean weevil control substance (in this case, diatomaceous earth) is enclosed in glass jars with transparent walls and a perforated lid to allow ventilation (jars with a special locking system; see Figs. 1 and 2) [1] and [2].

Fig. 1 Isolated systems: the beans, the beans weevil, and the fighting substance.

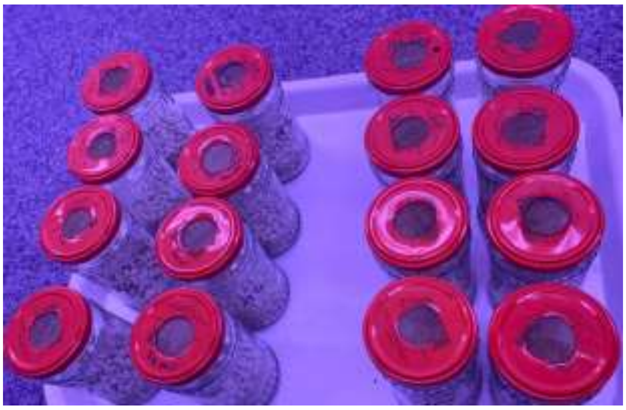

Fig. 2 Isolated systems: prey, primary predators, and secondary predators.

The exchange of air and humidity between the insulated system and the room in which the system is stored will be neglected.

The behaviour of the components of the closed or isolated system described above allowed us to formulate the following hypotheses, which were used in the mathematical modelling of the system:
i1) The prey (beans) interacts only with the primary predator (bean weevil);
i2) The prey does not record its growth or reproduction;
i3) The primary predator (bean gargoyles) interacts for its own feeding with prey and negatively, for combat, with the secondary predator (combating substance);
i4) The study period is limited to exactly one reproduction cycle, so natural growth and mortality exist but are hidden by the action of the control substance (a secondary predator);
i5) The growth rate of the secondary predator (control substance) is zero (it does not reproduce), and its "mortality" is its consumption rate in the control action.

2.3 The system of differential equations

The system of differential equations that models the isolated process of fighting the bean weevil, in hypotheses i1)-i5), is given in (1).

$$\begin{aligned} \frac{dx(t)}{dt} &= -\beta y(t), \\ \frac{dy(t)}{dt} &= \delta x(t)y(t) - \mu_N(t)y(t) - \theta\big(z(t)\big)y(t)z(t), \\ \frac{dz}{dt} &= -\mu\big(z(t)\big)y(t) + Z(t) \end{aligned} \tag{1}$$

with the initial conditions:

$$x(t_0) = x_0, y(t_0) = y, z(t_0) = z_0. \tag{2}$$

The definition, significance, and units of measurement of the variables and parameters of the model (1)-(2) are given in Table 1.
The natural mortality function of bean weevils is modelled after [3], with the expression (3).

$$\mu_N(t) = \frac{\pi}{2T}\sin\left(\frac{\pi t}{T}\right). \tag{3}$$

For the consumption function of the diatomaceous earth in the control process, the hypothesis is (4).

$$\mu(u) = \begin{cases} \mu_0, u > 0 \\ 0, u \le 0 \end{cases} \tag{4}$$

and for the function of the interaction between the bean weevil population and the diatomaceous earth, hypothesis (5) is used.

$$\theta(u) = \begin{cases} \theta_0, u > 0 \\ 0, u \le 0 \end{cases} \tag{5}$$

Table 1 Mathematical model parameters (1)-(2), meaning, notation, and units.

Definition	Notation	Units
The mass of uninfected beans at the current time	x	kg
The mass of the bean weevils at the current time	y	kg
The mass of diatomaceous earth available at present	z	kg
Bean mass at the initial time	x_0	kg
The mass of bean weevils at the initial time	y_0	kg
Diatomaceous earth mass at the initial time	z_0	kg
The initial time	t_0	days
Parameter of the bean damage consumed by the bean weevil population	β	days^{-1}
Parameter of interaction between the bean, and the bean weevil population	δ	days^{-1}kg^{-1}
The natural mortality function of the bean weevil	$\mu_N(t)$	days^{-1}
The interaction function between the bean weevil population and the diatomaceous earth	$\theta(t)$	days^{-1} kg^{-1}
Diatomaceous earth consumption rate in the control process	$\mu(t)$	days^{-1}
Diatomaceous earth supply rate during the process	$Z(t)$	kg days^{-1}
The period of the bean weevil reproduction cycle	T	days
The consumption ratio of diatomaceous earth during the process	μ_0	days^{-1}
The constant interaction between the bean weevil population and the diatomaceous earth	θ_0	days^{-1} kg^{-1}
The average mass of the beans	m_b	kg
The number of beans placed in each glass jar	n_b	-
The average mass of a bean weevil	m_g	kg
The number of bean weevils placed in each glass jar	n_g	-
Dose of diatomaceous earth administered	c	-
Mortality function of the pest population	$\gamma(t)$	%
The function of the percentage of infested grains	$\psi(t)$	%
Percentage function of diatomite available	$d(t)$	%
Percentage mortality function of the pest population at the *c* dose of diatomite	$\gamma_c(t)$	%

2.4 Estimation of the constant parameters involved in the model

The mass of the beans with which the experiments described in [1] were carried out was calculated by averaging 1000 grains, which together weighed 145-450 g. Therefore, we work with the average mass of a bean having the value m_b = 0.0002975 kg. For each cylindrical container (glass jar) that isolates the experiment (control process), a number n_b (200 - 700 beans/ glass jar). As a result, the average initial mass of beans in each experiment is approximately x_0 = 0.02975 kg. The bean weevils were weighed, and it was found that 50 adult weevils weigh an average of 0.1176 g, therefore, the mass of a bean weevil is m_g= 0.000002352 kg. As for each experiment, 50 weevils were introduced into containers; the result is the initial mass of bean weevils, which is y_0 = 0.0001176 kg. The initial dose of diatomaceous earth was limited between 100 and 900 ppm (by mass ratio to the initial mass of beans). As a result, the initial mass of diatomite, z_0, is between 0.0000001 and 0.0000009 kg, calculated according to the formula: $z_0 = c \cdot x_0$.
The value of the β parameter is inspired by [4], assuming that during the experiment, about 23% of the bean mass is infested. It took β = 17 days^{-1} to achieve a percentage of approximately 77% beans remaining uninfected. For the period of the bean weevil reproduction cycle, the value T = 14 days was taken, in the conditions in which the temperature in the experiment container is kept constant. For the first tests, it will be assumed that the pest control operation is done only by the initial dose of diatomite and that no additional amounts are added during the 14 days of the experiment. Therefore, the function $Z(t)$ is identical to zero. The parameter μ_0, which describes the consumption of diatomaceous earth, is used only to control the amount of diatomite consumed in the control operation.
Only three model constants remain to be identified: the constants that define the functions δ, θ_0 , and μ_0. We currently lack special experiences of direct or indirect determination to set the values of these parameters. For this reason, a calibration process is used using the data from the experiments described in [1]. The experimental data we rely on are the mortality rates achieved by the treatments with doses of 100, 300, 500, and 900 ppm at observation times of 3 and 7 days. Let the experimental mortality m_{3i} and m_{7i}, i = 1, ..., 4, correspond to the four doses of diatomite applied, at times of 3 and 7 days, respectively. The system of differential equations (1), with the initial conditions (2), is solved numerically starting from randomly established starting values (by tests that tend to approach the experimental values at times of 3 and 7 days). For each pair of values (δ_k, θ_{0k}), corresponding to the coordinate network taken into account in the calibration, the sum is calculated using the equations (6) and (7),

$$S_k = \sum_{i=1}^{4} \sqrt{(m_{3i} - \lambda_{3k})^2 + (m_{7i} - \lambda_{7k})^2} \quad (6)$$

where:

$$\lambda_{\tau i} = 100 - \frac{100y(\tau)}{y_0}, \tau = 3, 7, i = 1, \dots, 4 \quad (7)$$

data obtained for each run k = 1,2,..., m (number of calibrations runs required; we use 20). The optimal torque will be that for which the sum S_k is minimal, after k = 1, 2,..., m. Using this model calibration procedure, based on a heuristic optimization procedure [5], the following values are obtained: δ = 0.045 days^{-1}kg^{-1} and θ_0 = 4925 days^{-1}kg^{-1}.
In the same calibration process, the μ_0 constant was calibrated by heuristic optimization so that at the diatomite concentration of 900 ppm, the bean weevil population disappeared. Initially, each jar contained 50 bean weevils; the value 0.00005 was chosen for μ_0 because the percentage mortality is greater than 98%.

3 Results

Using the values of the parameters of the model (1)-(2), chosen in 2.4, one can find the behaviour of the system: beans-weevils-diatomaceous earth. The system is isolated in containers such as those in Figs. 1 and 2.

3.1 Validation of the model in the experimental case

The time dependence of the percentage mortality of the bean population is shown in Fig. 3 for the values of system parameters experimentally determined and specified in 2.4.
The percentage mortality function, represented graphically in Fig. 3, is calculated starting from the population $y(t)$, resulting from solving the differential problem (1)-(2) and is given in (8).

$$\gamma(t) = 100 - \frac{100y(t)}{y_0} \quad (8)$$

The percentage of infested grain is calculated from the solution of problem (1)-(2), according to the formula (9).

$$\psi(t) = 100 - \frac{100x(t)}{x_0} \quad (9)$$

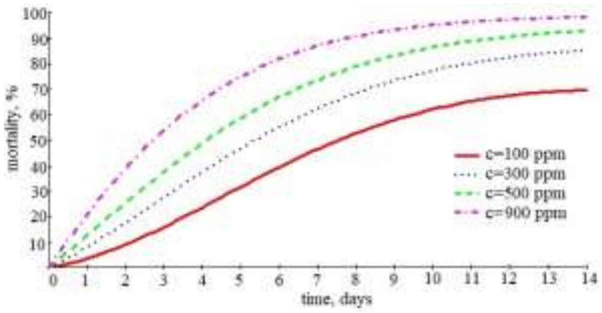

Fig. 3 Dependence of mortality percentage on time for four doses used experimentally.

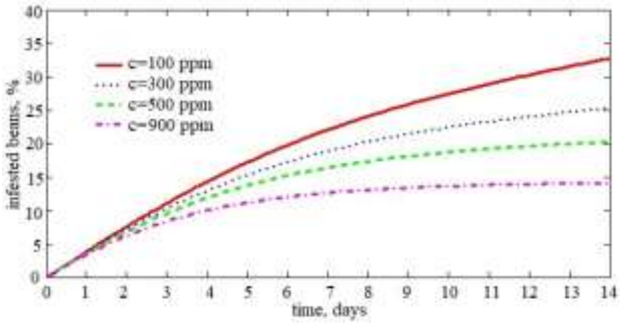

Fig. 4 The percentage of infested beans varies with time for four experimental doses.

The available diatomite function is calculated using the solution to the problem (1)-(2), according to the formula (10).

$$d(t) = \frac{100z(t)}{z_0} \quad (10)$$

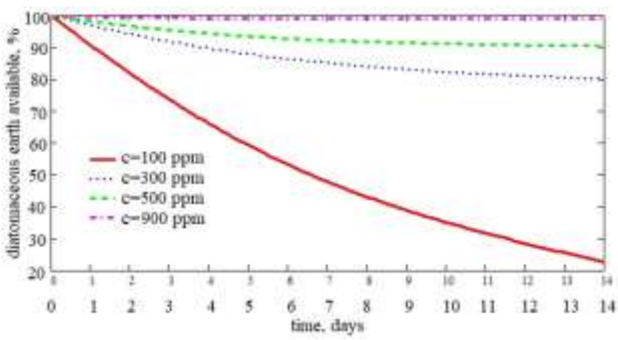

Fig. 5 The time dependence of the percentage of available diatomaceous earth for four experimental doses.

3.2 Applications

3.2.1 Process prediction and control

The simplest application of model (1)-(2) is the prediction of the results of the experiment for treatment doses different from those used in the physical experiments and in the calibration of the model. The principles of interpolation recommend that we do not use doses outside the experimental range. If, however, we use a dose outside the experimental working range ([100,900] ppm), quite far from the maximum limit (for example, 2000 ppm), the response of the model is that of Fig. 6.

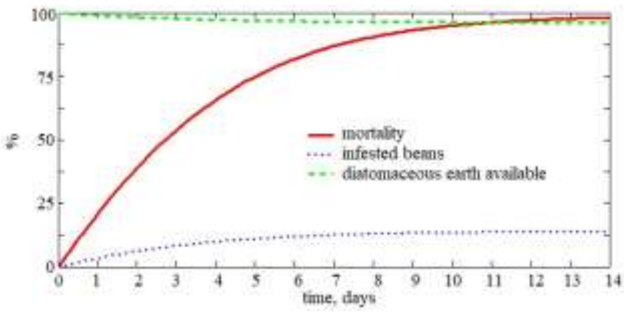

Fig. 6 The time dependence of the three characteristic functions of the control process carried out in an isolated environment at a dose of diatomite with a value of 2000 ppm.

This result is subject to a possible validation of the model. The forecast shows how many days are needed for the pest population mortality rate to reach the conventional critical value (for example, 99%), depending on the treatment dose chosen. In other words, we can select a dose that shortens the time required to achieve the desired mortality or, implicitly, a dose that reduces the damage to stored grains (curve of the quantity of infested grains). The model also allows control of the amount of diatomaceous earth still available for action against pests.

3.2.2 Efficacy of treatment

Using the results of the mathematical model (1)-(2), several functions can be defined that measure the efficacy of the treatment. These are defined using the functions provided by the solution to problem (1)-(2).The two efficiency indices that will be defined in this chapter are based on the percentage mortality index (Fig. 7).

Repellence index
The repellence index function is defined by [6] according to the formula (11).

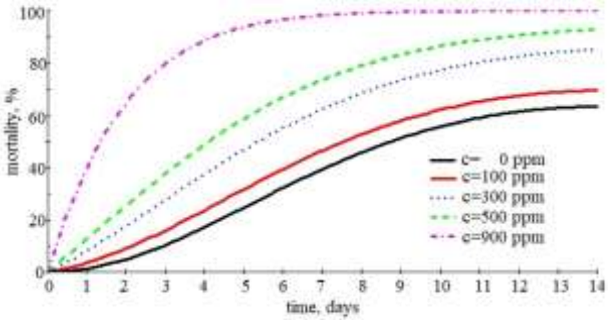

Fig. 7 The dependence of the mortality rate on time, for five doses of treatment, and the zero-dose corresponding to the control experiment.

$$ri(t,c) = \frac{2\gamma_c(t)}{\gamma_c(t) + \gamma_0(t)}, t \in (0,T] \quad (11)$$

An average repellence index can be defined according to the formula (12).

$$RI(c) = \frac{1}{T-\varepsilon}\int_{\varepsilon}^{T} ri(t,c)\,dt \quad (12)$$

where ε is a very small number, for example, 1% of T added to the initial moment in formula (12), so that the repellence index function makes sense on the whole mediation range. The repellence index (12) is a dose-dependent number c, see Fig. 8. The mortality function is a function of two variables, t and c, but its consideration in the model will change the model in the future into one with a partial differential equation.

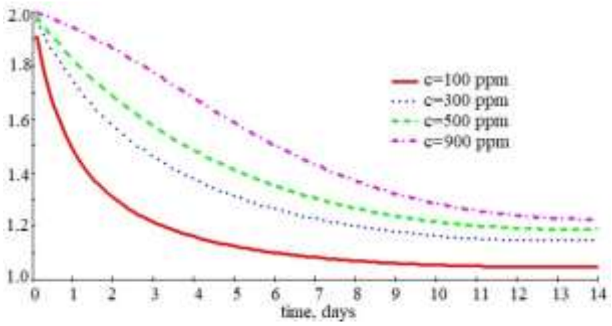

Fig. 8 Time dependence of repellence indices (11) for the four doses of diatomaceous earth used in the experiments.

The Abbott indexes

A measure of efficacy can be defined starting with Abbott's formula [7]. The efficacy function inspired by the source [7] is defined by the formula (13).

$$e_A(t,c) = \frac{\gamma_c(t)-\gamma_0(t)}{\gamma_0(t)}, t \in (0,T]. \quad (13)$$

As with the repellence index, an average Abbott-type efficacy can be defined, which is a number that depends on the dose of the treatment substance (14). The dependence of the Abbott index on time can be seen in Fig. 9.

$$E_A(c) = \frac{1}{T-\varepsilon}\int_{\varepsilon}^{T} e_A(t,c)\,dt. \quad (14)$$

Similarly, other measures of the efficacy of pest treatment can be introduced.
The average values of the repellence indices, according to the formula (12), are: $RI(1) = 1.155, RI(3) = 1.315, RI(5) = 1.389$ and $RI(9) = 1.501$, taking $\varepsilon = 0.1$ days.

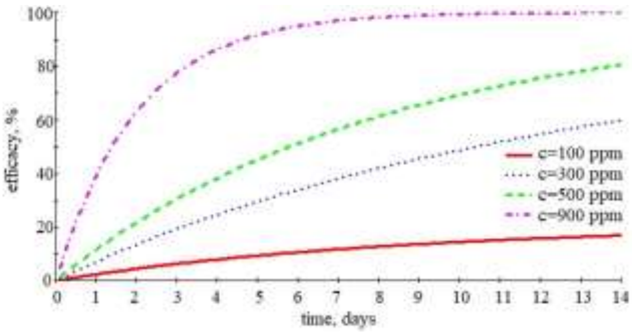

Fig. 9 Time dependence of Abbott-type efficacy for the four experimental treatment doses.

The average values of the corresponding Abbott efficacies, according to formula (14), are: $E_A(1) = 0.83, E_A(3) = 2.071, E_A(5) = 2.964, E_A(9) = 4.182$, taking $\varepsilon = 1$ day.

3.2.3 Additional loads with treatment substance
Sometimes, the initial amount of substance with which the treatment is done may not be enough to achieve the desired efficacy within the time limit. To increase the efficacy of the treatment, an additional loading of the pest control substance (diatomite, in this case) can be performed, an operation that model (1)-(2) can simulate through a $Z(t)$ function that has positive values. The simulated load in this example has the expression from the equation (15).

$$Z(t) = \begin{cases} 0, t \in [0,t_1) \cup (t_2,T] \\ \frac{7cx_0}{t_2-t_1+1}, t \in [t_1,t_2] \end{cases}. \quad (15)$$

The numerical analysis used the following data: $t_2 = 3, t_1 = 2, c = 100$ ppm, $x_0 = 0.1$ kg, which corresponds to a uniform load on the third day of the experiment with a loading speed of 70 ppm/day.
The function of loading the pest with the attack substance is shown in Fig. 9. For this method of combat, the response of the mathematical model of the system described above is graphically presented in Fig. 10.

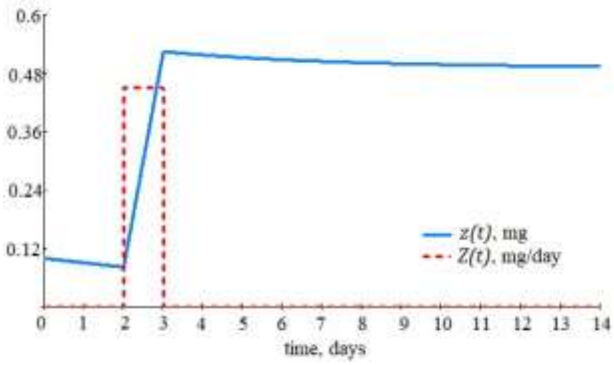

Fig. 10 Time-dependence of the amount of diatomaceous earth and the loading speed during the process.

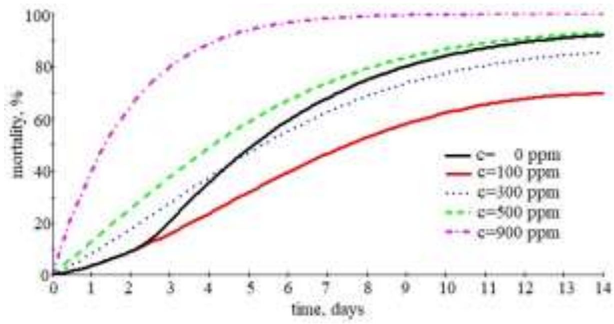

Fig. 11Time-dependence of percentage mortality for initial loading experiments with doses of 100, 300, 500, and 900 ppm, compared to the percentage mortality in the control sample with zero initial loadings and loaded on the second and third days, as shown by the curve $Z(t)$ of Fig. 10.

4 Comments

The mathematical model proposed in this article manages to simulate the main aspects of the process of experimental estimation of the efficacy of treatments against pests.
The shape of the mortality curves is in agreement with the experimental data, at least in the area of intermediate control times. Differences occur at low doses of pest control substances in the final part of the time interval, where mortality does not reach 100% (see Fig. 3). This behaviour can be further studied, possibly altering the natural mortality of the bean weevil population, possibly aided by a greater number of experiments, with a much better resolution over time, in particular.
The percentage mortality curves are ordered by the doses of substance used and are directly correlated (see Figs. 3, and 7). The curves of the infested bean percent are also ordered by the doses of pest control substance used, but the correlation is negative, i.e., the percent of infested beans increases as the dose of diatomite decreases (see Fig. 4). The curves of the percentage amount of diatomaceous earth available in the process appear in Fig. 5. They are ordered in reverse order of the dose of substance applied. The graphs in Fig. 5 must be read carefully because the curves included are of a percentage nature, but the quantities of diatomaceous earth from which they start (the initial load) are different for each concentration. These statements are validating elements of the model (i.e., (1)-(2)) at the current level of the mathematical model.
Several applications present the capabilities of the mathematical model presented in Chapter 3.2. The prognosis and control of the process are presented in Chapter 3.2.1. This application shows the predictive role of function y (mass of the pest population) and the control role of functions x (mass of uninfected beans) and z (mass of diatomaceous earth available). On a single graph, the variation in time of the three functions in a pest control process with the initial loading of diatomaceous earth can be seen in Fig. 6. The applications in chapter 3.2.2 provide examples of measures of the efficacy of some treatments. There are current efficiencies (time-dependent functions), but there are also global efficiencies, which are numbers. Both efficacy types depend on the dose of substance used for the treatment of bean weevils. To understand the behaviour of efficacy functions, the time dependence of mortality functions for four doses of diatomite is represented in Fig. 7, together with the natural mortality curve (control or zero treatment doses). Starting from these results and applying formulas (11)-(14), the efficacy of the treatments is obtained: the repellent efficacy function and the Abbott type efficacy function, respectively, and the average repellence and Abbott type indices. All indications show the same ranking of treatments with the same control substance, with the place occupied by each treatment being proportional to the dose administered.
A third application, presented in Chapter 3.2.3, demonstrates the ability of the mathematical model to describe treatments with additional loading of the treatment substance. The system response in this

case of loading in terms of pest mortality is given in Fig. 11, and the evolution in time of the additional load and the loading speed is given in Fig. 10. It is observed that starting treatment at a lower dose and supplementing with the active substance along the way may increase the efficacy of treatment at a higher initial dose. In [29], interpolation curves similar to those of Figs. 7, 9, and 11 appear in connection with the accumulation of diatomic soils per individual bean weevil, separately for males and females. These similarities show that there are strong links between the individual accumulation of diatomaceous earth and the percentage mortality, which a possible development of the model could highlight. Substance use for treatment would thus be more deeply embedded in the mathematical model, describing the phenomenon and interpreting the results.

The mathematical model of experiments to estimate the efficacy of substances for controlling bean weevils can be extended to common storage spaces, such as silos. In this case, it must be taken into account that during the storage time there may be fluctuations in the loading with stored material, and the loading with substances to control pests varies over time. Application 3.2.3 demonstrates that the proposed mathematical model can simulate such phenomena. To obtain a minimal model of the silo treatment processes, a loading (or unloading) term with stored material must be added to the right member of the first equation in (1), similar to the term $Z(t)$ in the third equation of the same system. Also, both due to the real climatic conditions and potential treatments with thermal or humidity shocks, we will look in the future for an extension of the mathematical model proposed in this paper, which will contain the two variables, as some authors have conceived already [37] and [55].

The mathematical model proposed in this paper goes through the three stages indicated in a reference paper [8]: "conceptualization of the biological system into a model mathematical formalization of the previous conceptual model and optimization and system management derived from the analysis of the mathematical model." Because the answer of the model proposed in this paper has main elements of similarity with the real isolated system of experiments to estimate the efficacy of treatments against pests (the shape and values of mortality curves), it is considered that the model is at least partially correct and relevant. These conclusions are important in connection with Manfred Eigen's statement in The Origins of Biological Information: "A theory has only the alternative of being right or wrong. A model has a third possibility: it may be right, but irrelevant."

Percentage mortality curves, similar in shape to those provided by the model proposed in this paper, are frequently present in the results in the literature [48] and [49]. The experimental curves exposed in [1] and [2] are often found as forms in the literature [50], [51], and [52]. Especially regarding the bean weevil, such mortality curves are found in [53], [54], and [55].

5 Conclusion

The mathematical model presented in the article satisfactorily simulates the treatment of beans attacked by bean weevils using diatomaceous earth. The effects highlighted are generally consistent with the experimental results in the literature. A system of three differential equations inspired by mathematical models of predator-prey types describes the process of treating beans against bean weevil.

The main applications of the model consist of the prediction and control of the treatment, the formulation of some measures of the treatment's efficacy, and the simulation of some processes with intermediate loads in time. The last application opens a wide field of applications related to treatments against pests that act on the storage spaces of agricultural materials (e.g., silos), spaces considered as isolated systems, but with inputs and outputs in time of the stored material and substances for pest treatment.

As an important direction of model development, it is proposed to introduce the influence of temperature (if it proves effective, including humidity), because there are treatments against bean weevils that involve lowering the ambient temperature to a certain value for some time.

All directions of model development can be done only to the extent that we have sufficient experimental data (as many direct ones as possible), at a temporal resolution of at least one day, and at a longer range of values for concentrations, which is also valid for temperature (a continuous or very high-resolution monitoring action would be desirable).

The utility of the model results mainly from the possibility of predicting the achievement of the desired mortality at a certain time and the dose of substance to control pests so that the desired mortality occurs at a certain time. Another application of the proposed mathematical model refers to the optimal character of the desired mortality at the prescribed time. This is to be obtained through the precise selection of the combating substance dose so that there is no waste or risk to not achieving the prescribed time or pest mortality. The measures of the efficacy of the elaborated treatments are also useful and start from the answer of the model, which allows reaching the main purpose of the modelling: the simulation of the experiences in an isolated system for estimating the efficacy of the treatments. The indications and clarifications resulting from solving the model regarding the intensive and extensive development of experiences required to deepen the problem of simulation and sorting treatments against pests are also useful for future work.

A specification of principle for the possible continuation of the study refers to the natural approach to the pest control phenomenon described in this article. We believe that a new approach to the problem of the efficacy of treatments against pests must begin with modelling the normal life of the pest and increasing and decreasing the insect population in the absence of treatments. After this model is close enough to the experimental reality, functions can be developed in the basic model to describe the reduction of the reproductive capacity or the unnatural increase in mortality, functions with different arguments (concentrations of treatment substances, temperature, etc.).

Finally, a general observation refers to the ethical aspect of such research. The human species has acquired, over time, an increasingly aggressive character. Man tends to exterminate any species that endangers his existence or affects his comfort. The man decided to fight and destroy his opponent, instead of learning to live with him. To the same extent, other species have developed responses corresponding to human actions. In this context, the moral aspect of such research, in which living beings are killed, is debatable. Creation has its laws, and predator-prey behaviour seems to be one that cannot be changed by man. Even though man tries to tame this law, our species only manages to simulate this action in reality, even in interpersonal relationships, the prey-predator behaviour is the real one.

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