DETERMINATION OF TECHNICAL AND ECONOMIC EFFICIENCY OF EQUIPMENT FOR MASS BREEDING OF ENTOMOPHAGES

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Abstract. The existing practice of creating the equipment for industrial production of entomophages is usually based on the development of the working design documentation for already tested mock-ups and experimental samples of the laboratory equipment obtained as a result of the research work on introduction of insects into culture and their breeding. However, such an approach is rather expensive. This study is aimed at a methodological provision of the stage of the engineering design of technological complexes for industrial production of entomophages, the main characteristics of which are determined by the design of the cages for insects. The proposed scientifically based scaling methodology substantiates a possibility and conditions to ensure pre-set values of the abiotic and the biotic factors of the cage models when their areas are changed. Criteria are justified for a complex assessment of various technical solutions by way of minimising the relative technological prime cost of manufacturing the cages and boxes in which they are implemented. Analytical dependences were obtained and investigated of the technological cost of a set of cages and boxes for the cultivation of lacewings on their areas. It has been established that increasing the area of the cage for lacewings from 0.0625 to 0.125 m^2 reduces its cost from 1.43 to 1.06 UAH·$(insect)^{-1}$, and increasing the area of the box for cages from 0.3 to 0.6 m2 reduces its cost from 0.55 to 0.04 UAH·$(insect)^{-1}$. In order to minimise the prime cost, it is necessary to increase the horizontal cross-sectional areas of cages and boxes to values limited by the ease of use or the structural strength. The developed methodologies were tested during the design of a technological complex for the production of the gold-eye entomophagy, including the prototype cages. In comparison with the existing equipment, a 50-60 % improvement in the economic indicators has been achieved.

Keywords: production, entomophages, equipment, simulation.

Introduction

The production and use of entomophages for the biological protection of plants from pests is one of the main mechanisms for the ecologisation of agriculture [1]. This production is based on appropriate technological equipment, which is designed for several dozen insects and ticks [2], including for the well-known entomophage of lacewing [3], an example of which is being studied according to the developed new technique.

The existing practice of creating equipment for the industrial production of entomophages is usually based on the development of working design documentation for already tested mock-ups and experimental samples of laboratory equipment, which were obtained as a result of research work on introducing insects into the culture and breeding.

However, when the production volumes increase to an industrial level, this approach becomes economically inefficient. Analysis of the existing equipment [5-7] shows that each stage of the development of an insect occurs in a certain cage, in the closed space of which the necessary living conditions for insects are created. Obviously, the design of the cages created during the development of the breeding technologies in the research laboratory will not be optimal at the factory for the production of entomophages.

There a need arises for a system engineering (engineering) designing [8], which allows implementation of specified biotechnological requirements for breeding insects in various variants of the equipment with the choice of the most efficient of them. One of the methods for solving this problem is mathematical simulation of the technical and economic efficiency of the main equipment for breeding entomophages.

The purpose of simulation is to determine the dependence of economic characteristics on the structural technical parameters of the technological equipment. This will allow to find the values of the design parameters that provide maximum economic efficiency of the equipment.

Materials and methods

When designing the production on the basis of the existing laboratory technology for the mass breeding of specific insects, the technological process is predetermined and unchanged. But its technological (regulatory) indicators can be implemented in various design solutions of the equipment. As a result of our research, we developed a technique for scaling cages, which allows to change their sizes in compliance with the basic biotechnological requirements. It was substantiated that the determining condition for scaling is the invariance of the height of the insect layer with the food substrate, which sets the height of the cage, as well as the surface or bulk density of insects. Other abiotic parameters that must be preserved when scaling include temperature and the air humidity. This condition is met by ensuring the constancy of the ratio of the area of the ventilation openings to the area of the cage in the base and scalable versions [9].

The analysis of the industrial equipment for the production of common entomophages [9; 10] shows that each stage (or several stages) of insect ontogenesis proceeds in a cage, which is usually parallelepiped of the height h_c and area S_c. Cages in the amount of n_c are placed in the technological box, the number of boxes is n_a. The totality of the indicated quantities of cages and boxes makes up a set of equipment at this stage of ontogenesis. The capacity of the set per a breeding cycle is determined by the expression:

$$Q = n_c \cdot n_a \cdot Q_c = d \cdot S , \tag{1}$$

where Q – assigned efficiency of the set for the insects;
   S – total area for keeping insects, m^2;
   d – surface density of insects in the cage, pcs m^{-2}.

The geometric characteristics of the cage and box can be determined from such expressions:

$$V_o = S_c \cdot h_c , \quad V_a = S_a \cdot h_a = \frac{n_o \cdot S_c \cdot h_c}{\eta} , \tag{2}$$

where V_o, V_a – volume of the cage and box, respectively;
   $\eta = h_v \cdot V_o \cdot (V_a)^{-1}$ – coefficient of filling the box with cages;
   h_a – height of the box;
   S_a – cross-sectional area of the box (the shelf area).

From expressions (1) and (2) is determined:

$$n_a = \frac{S \cdot h_c}{\eta \cdot S_a \cdot h_a} . \tag{3}$$

When updating the equipment, determination of the economic efficiency is most often carried out through the technological cost of manufacturing the equipment K, which consists of the cost of the materials – M, salary – T, the energy carriers – E.

Therefore, a need arises to develop such a new mathematical model that could be successfully used not to calculate specific economic indicators, but to determine the possibility and direction of optimisation of the equipment for systems engineering in the field of biotechnology, in particular, for efficient cultivation of entomophages.

The energy costs at the designing stage can be determined only through the coefficients of communication with other cost items. From the experience we have accepted:

$$E = k_e \cdot T , \tag{4}$$

from where:

$$K = M + k \cdot T , \tag{5}$$

where K – technological cost of manufacturing a unit of equipment;
   $k = 1 + k_e$ – cost conversion factor, which we will consider constant in each variant of the equipment.

The technological cost of manufacturing a set of the equipment, which consists of cages and boxes:

$$K = K_c + K_a \ , \tag{6}$$

$$K_c = n_c \cdot n_a \left(M_c + k_c \cdot T_c \right) , \tag{7}$$

$$K_a = n_a \left(M_a + k_a \cdot T_a \right) , \tag{8}$$

where n_c, n_a – number of cages and boxes, respectively.

For the analysis costs are usually used which are given in the conventional unit of production:

$$K' = \frac{K}{Q} = \frac{K}{d \cdot S}, \tag{9}$$

where K' – reduced cost of manufacturing the equipment.

From expressions (3) – (8) we obtain:

$$K'_c = \frac{M_c + k_c \cdot T_c}{d \cdot S_c} \ , \tag{10}$$

$$K'_a = \frac{\left(M_a + k_a \cdot T_a \right) \cdot h_c}{d \cdot \eta \cdot S_a \cdot h_a} \ . \tag{11}$$

Further we will use only the reduced cost, let us omit the bar in designation K'.

When simulating, an assumption was made that the monetary costs of manufacturing the apparatus or its parts are described by linear functions of the determining geometric parameter:

$$M = m \cdot S , \tag{12}$$

$$T = v \cdot S , \tag{13}$$

$$T = u \cdot L , \tag{14}$$

where M, T – costs for manufacturing of the part, UAH;
m, v – conversion factors, UAH·m^{-2};
u – conversion factor, UAH·m^{-2};
S – specific surface area, m^2;
L – conditional linear size of the part, m.

This assumption has sufficient accuracy when comparing variants of the same part or apparatus, which have the same shape and materials, but differ in size.

Results and discussion

The parameter to be optimized (minimised) was the reduced technological cost of manufacturing a set of cages and boxes (10, 11). We define the main dependencies between the economic and design parameters of the equipment that were the basis of the models. From the given set of parameters in (10, 11) we choose as independent S_c, S_a can be changed for optimisation.

During the design, the following biological and technical requirements were specified [9-10]: h_c – the cage height, m; h_a – the height of the box, d – the surface density of insects, individuals m^{-2}; from the technical task Q – the productivity of the set, insects per cycle.

The model of the cost for making the cage. The cage is a closed volume, which contains insects at different stages of ontogenesis. It is made of plastic, consists of a shell, a bottom, a removable cover. The body is parallelepiped of the height h_c. Its bottom area is S_c, which is further considered to be square with the side length, to simplify the formulas $l_c = \sqrt{S_c}$.

The costs of the cage materials according to (12) are calculated in proportion to the area of its side surface and are averaged in the case of various materials:

$$M_c = m_c \left(2S_c + 4h_c \sqrt{S_c} \right).$$
(15)

The labour costs (14) are calculated in proportion to the doubled sum of the lengths of all the edges of the body blanks on which the blanks are cut, glued (welded) or bent and mechanically fixed:

$$T_c = 2 \cdot u_c \cdot \left(8\sqrt{S_c} + 4h_c \right).$$
(16)

We substitute the obtained in (10):

$$K_c = \frac{2m_c}{d} + \frac{1}{d \cdot \sqrt{S_c}} \left(4h_c \cdot m_c + 16u_c \cdot k_c \right) + \frac{8h_c \cdot u_c \cdot k_c}{d \cdot S_c}.$$
(17)

The model of the production cost of the box. The box has a parallelepiped shape with a conditionally square base and consists of two parts: a shell and a shelving structure made of shelves for placing cages.

The costs of the shell materials M_S, according to (12), are calculated in proportion to the area of its lateral surface and averaged in the case of various materials:

$$M_S = m_S \left(2S_a + 4h_a \cdot \sqrt{S_a} \right).$$
(18)

The labour costs (14) are calculated in proportion to twice the sum of the lengths of all the edges of the shell blanks:

$$T_S = 2u_S \left(8 \cdot \sqrt{S_a} + 4h_a \right).$$
(19)

The costs of the material of the rack structure (12) from the shelves are calculated in proportion to the area of the shelves:

$$M_h = m_h \cdot n_h \cdot S_a,$$
(20)

where n_h – number of shelves in the box (12).

The labour costs for the rack structure (13) are calculated in proportion to the area of the shelves:

$$T_h = v_h \cdot n_h \cdot S_a.$$
(21)

We substitute everything in (11) for the box:

$$K_a = \left[M_S + M_h + k_a \left(T_S + T_h \right) \right] \cdot \frac{h_c}{d \cdot \eta \cdot S_a \cdot h_a} = \frac{h_c \cdot \overline{K}_a}{d \cdot \eta \cdot h_a},$$
(22)

where

$$\overline{K}_a = \left(2m_S + m_h \cdot n_h + k_a \cdot v_h \cdot n_h \right) +$$
$$+ \frac{1}{\sqrt{S_a}} \left(4m_S \cdot h_a + 16k_a \cdot u_S \right) + \frac{1}{S_a} \left(8k_a \cdot u_S \cdot h_a \right).$$
(23)

The developed model of the reduced technological cost for manufacturing cages and boxes was used in the system design of a new technological complex for the production of ordinary lacewing. Earlier, we carried out the scientific and research work on the development of a technology and the equipment [8] for lacewing, which was chosen as the basic option when comparing the technical and economic efficiency.

As an example, let us consider simulation of a cage for the lacewing imago. Fig.1 shows the mock-up options for cages with different S_C area, which were made to study the impact of S_C on the economic efficiency. Cages 4 are made of acrylic and are shown without covers. The lid 5 of the cage is shown in the background, from the inside the lid is glued with a black cloth on which the imago of the lacewing lay their eggs. Cages 1 and 2 were used for laboratory dilution of the lacewing.
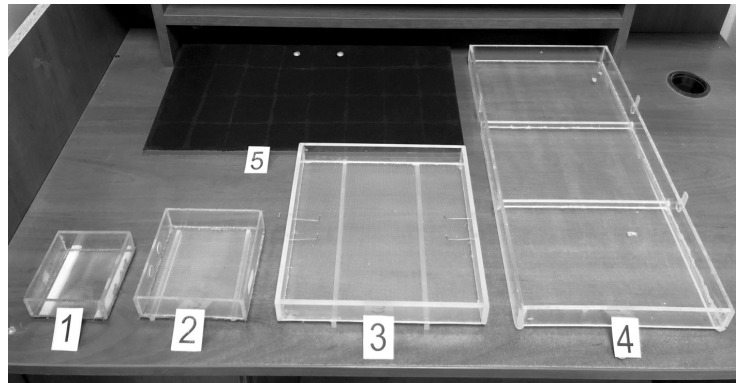
Fig. 1. **Variants of the cages for the imago lacewing for the research of the economic efficiency of their manufacture**

Cage 3 with the dimensions 25–25 cm was used in the basic industrial set. For it by the well-known direct calculation method the costs K, M, T, E were calculated which allowed using formulas (4, 15-21) to calculate the average values of the coefficients k, m, u, v. In a similar manner the conversion factors were calculated for the box of a standard design. The following are the values of the model parameter:

- of the cage: $h_c = 0.03$ m, $d = 11200$ insects m^{-2}, $m_c = 1199$ UAH·m^{-2}, $u_c = 186.3$ UAH·m^{-1}, $k_c = 1.03$;
- of the box: $h_a = 1.95$ m, $n_h = 5$, $\eta = 0.26$, $m_S = 65.9$ UAH·m^{-2}, $m_h = 220$ UAH·m^{-2}, $u_S = 72.6$ UAH·m^{-1}, $v_h = 440$ UAH·m^{-2}.

Figures 2 and 3 show the dependences of the technological cost of the cages and boxes on their areas, which are calculated on a PC using formulas (17, 22, 23).
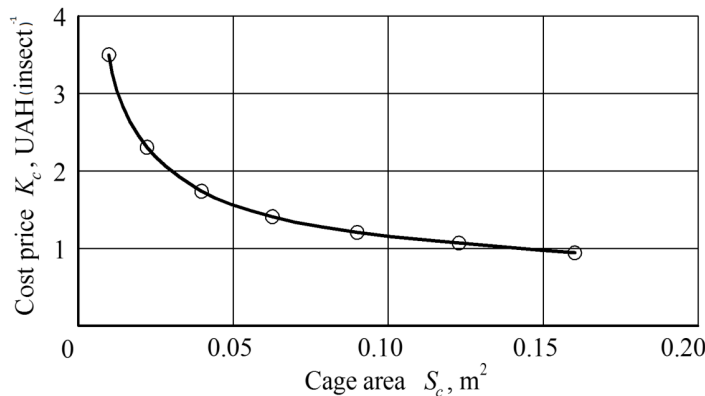
Fig. 2. **Dependence of the technological cost of a set of cages of the imago lacewings on the area of the cage**
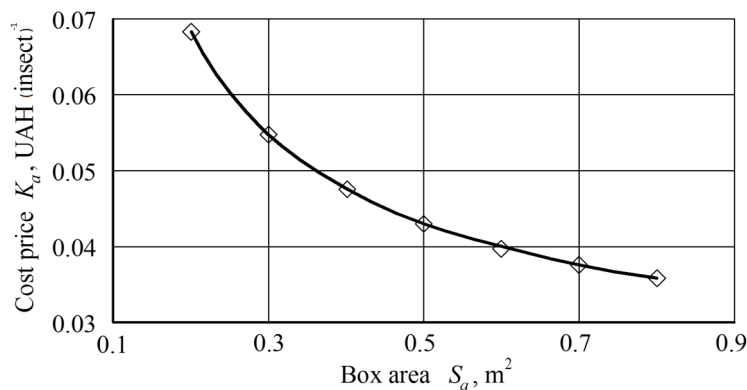
Fig. 3. **Dependence of the technological cost of a set of boxes for cages of the imago lacewings on the area of the box**

Analysis of the mathematical formulas and graphs shows that the reduced technological cost of manufacturing a set of cages and boxes monotonously decreases with an increase in their area. This proves the economic expediency of increasing the area of the cage and the box to their maximum possible dimensions, which are determined by the ergonomic requirements for comfortable work of the staff. Therefore, an imago cage (Fig. 1, Cages 4) was chosen with dimensions of 25×50 cm and an area of 0.125 m^2, with a prime cost of K_c = 1.06 UAH·(insect)$^{-1}$ (see Fig. 2). Compared with the base cage of the old complex 25×25 cm, area 0.0625 m^2, the prime cost 1.43 UAH·(insect)$^{-1}$, a reduction of the reduced technological cost by 25.9 % was achieved. Comparison of the numerical values of K_c, K_a in Figs. 2, 3 shows that K_a is approximately 4 % of K_c, i.e. the impact of the component K_a upon the total cost of the set K (5) is sufficiently small. This regularity is explained by the fact that the number of cages significantly exceeds the number of boxes, and indicates that it is the design of the cage that determines the technical and economic efficiency of the entire set.

Conclusions

1. Approbation of the model during the system-and-technical designing of the technological complex for the production of an entomophage – the ordinary lacewing allowed to reduce by 26 % the technological cost of manufacturing a set of cages and boxes.
2. By means of this model there is first substantiated the economic purposefulness of maximal increase of the area of individual cages and boxes for a given area of their set.
3. As a result of the research, it was found that increasing the area of the cage for the cultivation of lacewings from 0.0625 to 0.125 m^2 reduces its cost from 1.43 to 1.06 UAH · (insect)$^{-1}$, and increasing the area of the box for cages from 0.3 to 0.6 m^2.

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