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THE TEORETICAL BASIS OF HOMEOSTASIS MAINTENANCE IN ARTIFICIAL INSECT POPULATIONS AND CONTROL OF THEIR CONDITION

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Theoretical basis of homeostasis maintenance in artificial insect populations and control of their condition. T. Yu. Markina – The principle of homeostasis as a general property of biological systems at various levels is fully peculiar for artificial insect populations. Features of technocenosis cause some changes in structural parameters of insect cultures. Viability index is suggested to use as the criterion of population condition. Correlation between viability of artificial insect populations and intensity of vital taxis has been proved. The role of taxis in maintaining of population homeostasis is analyzed.

Key words: homeostasis, artificial insect populations, structural parameters, viability, intensity of taxis.

Теоретичні основи підтримки гомеостазу в штучних популяціях комах і контроль їх стану. Маркіна Т.Ю. – Принцип гомеостазу, як загальна властивість біологічних систем різного рівня, в повній мірі характерний штучним популяціям комах. Особливості техноценозу обумовлюють деякі зміни структурних параметрів культур комах. Як критерій стану популяцій пропонується використовувати показник життєздатності. Показано зв'язок життєздатності штучних популяцій з інтенсивністю прояву життєво важливих для комах таксисів. Проаналізовано роль таксисів в підтриманні популяційного гомеостазу.

Ключові слова: гомеостаз, штучні популяції комах, структурні параметри, життєздатність, інтенсивність таксисів.

INTRODUCTION

In recent years, the interest to mass rearing of insects and their comprehensive use grows in the world [53]. By data of IOBC (International Organization for Biological Control; www.iobc-global.org) and FAO almost 2700 agents of biological control are known, and 170 species from them are entomophagous insects. About 30 large manufacturers deal with entomophagous insects production in the world, and 20 form them are located in Europe.

Breeding or rearing the rare and endangered insect species is also very important trend, especially for nature conservation activity [22, 38]. Insects are increasingly seen as valuable food resource for animals and humans [50, 55]. Programs of insect breeding as producers of raw materials and food (bees and silkworm) are still of current interest.

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Successful implementation of all programs of technical entomology is based on fundamental investigations of general biological lows for artificial insect populations. Effective insect production is possible only taking into account the mechanisms, which provide the population homeostasis, which is stable maintenance of viability and reproduction in certain groups of animals [11, 49, 52].

The aim of this study was to highlight the achievements in theoretical and practical problems of homeostasis maintenance in artificial insect populations and control of their condition in accordance with the objectives of breeding programs. Presented review is based on publications in scientific journals, including our own data on homeostasis manifestation in artificial insect populations and control of their condition.

RESULTS AND DISCUSSION

In modern biology homeostasis concept is among the main fundamental ones. Methodologically it is closely related to system-wide concepts of self-preservation, sustainability and integrity. Claude Bernard in 1878 was the first who expressed the idea of homeostasis. He understood it as stability of physical and chemical conditions of the internal environment of living organisms under the influence of environmental factors.

Subsequently, in 1929, the term "homeostasis" was introduced as the ability of the body as an integrated system to maintain a constant internal environment [5, 47]. Homeostasis is achieved as a result of the functioning of complex adaptive systems, which act on the basis of feedback. It is in this understanding the principle of homeostasis can be considered as the common property of biological systems at various levels [7, 42]. Homeostasis has its own characteristics and mechanisms of maintenance at every level of biosystems' organization. The principle of homeostasis of the population, as an integrated biological system, consists in the maintaining of dynamic equilibrium with the environment [42].

The forms of homeostasis maintaining in natural populations are very diverse, and their mechanisms are often common. Mechanisms of one group are stable and cause system adaptation to the most stable average characteristics of environment. Other mechanisms are labile (functional) that occur in response to a specific state of environment [43]. These mechanisms act together and provide the maximal adaptability of system and, as a consequence, the efficiency of its functioning in dynamic environment.

Stability of population systems depends on how the structure and internal properties of population retain their adaptive traits in changing conditions of existence [1, 7, 41, 42]. Due to heterogeneity, individuals and their groups are sources of unequal information. They react differently to the same conditions, and the total population response is not a simple sum of the responses of individuals. Therefore, unlike the organism as morphophysiologically structured system, population can be considered as information-structured system [27, 42]. From the point of view of information theory, the phenomenon of natural populations' structuring in the course of evolution is almost axiomatic, because it is connected with increase of its stability by reducing random errors [33, 39].

Relations between general diversity (and biological diversity in particular) and functioning of the systems have been widely discussed [3, 8, 35]. As a consequence of the Law of Requisite Variety, if the structural diversity of groups with different reactions to changes in the environment is high enough, then for a wide range of conditions there is for sure certain well-functioning group of individuals. Such examples are shown for vegetation in the study of the functional role of species diversity [33, 39].

Importance of population structures is the most manifested in extreme situations of experiment, when it is possible to see those possibilities of species that seldom occur in nature [34, 44].

The analysis of publications found, that the issues of homeostasis maintenance and stable functioning of population systems are studied quite full for vertebrates [1, 42]. The role of certain structural parameters is shown in the maintenance of optimal abundance of natural insect populations [9, 23, 37]. Knowledge of general principles and specific mechanisms of autoregulation in populations opens up new ways in development of approaches to directed action on population structure. It gives the possibility to use the natural mechanisms in insect population management [1, 43].

However, homeostatic properties of artificial insect populations are poorly understood yet. Artificial insect populations (or cultures) are man-made environmentally-isolated groups of individuals of one species. Artificial insect populations culture, which are reared for a long time (for example, silkworm *Bombyx mori* L. 1758), can be used for such investigations. They are adopted to long existence in technocenosis, have certain structural and functional organization. Such conditions are optimal for the species, but can be extreme for population survival, because population heterogeneity is considerably decreased [10, 13].

Due to the success of population ecology and genetics, some mechanisms to maintain stability at the population level in natural systems became clear *Drosophila* population systems have been established, and respective genetic processes were studied [1, 6].

The dynamics of ecological structure of artificial insect populations and mechanisms to maintain their homeostasis are poorly understood. This shows the necessity to study the features of homeostasis in artificial insect populations. Such knowledge can be the basis for development the effective ways to optimize artificial insect populations during breeding.

For a long time it was considered in technical entomology that artificial insect populations are not able to self-regulation even in the case of long-term maintenance [13]. It was explained by the fact, that technocenosis conditions assume breeding optimization, which is carried out by experimenter. Besides, artificial insect populations undergo substantial changes: allele pool depletes, viability decreases, and as consequence, stability and resistance decrease in changing environment [2, 11].

At the same time, investigation in population genetics shows sustaining the co-adaptive genetic systems from generation to generation as a manifestation of genetic homeostasis at population level, which is based on phenomenon of polymorphism.

Research of mutation and inversion polymorphism [48, 54, 56, 57], biochemical polymorphism, and polymorphism of genetic systems which affect behavior show respective stability of polymorphic allele frequency both in both populations, and in single lines [19, 46]. Thus, the populations are not just contain different allelic variants, but in most cases remain steady balance, form clinal variability and return to equilibrium soon after the breach [17, 46, 51].

Comprehensive experiments to studies on the structural and functional organization of artificial insect population can prove, that these systems have some ecological mechanisms for maintaining the integrity and sustainability.

Diversity is one of the most important properties, which ensure the population success and is the base of maintaining the homeostasis [27, 45]. Maintenance of homeostasis in artificial insect populations is provided by existence of certain structural and functional groups.

Every population is characterized by certain structure, which has adoptive meaning and forms in result of interaction of individuals with environmental conditions. In artificial insect populations ecological structure means existence of groups of individuals, which interact specifically with biotic and abiotic factors of environment [10, 11, 13].

Apart from ecological structure, clearly distinguishable age, sexual, spatial and ethological groups of individuals present in natural and artificial populations. These groups form certain population structure, which undergoes adaptive changes at environmental change

Our researches included comparative analysis of the main structural and functional parameters of natural and artificial insect populations.

Sexual structure of natural insect populations is determined by primary (zygote), secondary (neonate larvae) and tertiary (mature adults) sex ratio. The same features are characteristic for artificial insect populations. Sexual structure is evaluates as the ratio of males and females in different periods of insect development. Thus, primary sex ratio for silkworm is approximately 1:1. During cultivation survival of males and females differs during lifespan, but it does not reflect the primary sex ratio of the next generation [25]. Different adaptive abilities of males and females in technocenosis give the possibility to control rearing process with the aim to increase the effectiveness of breeding programs. On the other hand, sex ratio in population is the reliable performance of its condition. The methods of prediction for forest and agricultural pests take it into account [26].

Age structure of natural and artificial populations reflects the intensity of reproduction, mortality, the rate of generation change and gives the possibility to determine the prospects of further population dynamics. In technocenosis age structure often broken, especially for species after centuries of domestication (silkworm). It is explained by heterogeneity decrease in result of optimization for age-homogeneous artificial insect population. Nevertheless, all age groups present in artificial insect population, which provides their stability and promotes natural reproduction [31].

Spatial structure of population reflects the type of distribution of individuals within the range [29], and for artificial populations within the technocenosis. Spatial structure depends on mobility of individuals and their ability to form intrapopulation groups. Spatial structure changes in technocenosis: the possibility to maintain the spatial dissociation disappears because of high density of rearing; information and functional contacts become uncomfortable.

Despite this, high plasticity gives the possibility to maintain certain reasonable balance, which provides population existence (for example, in silkworm artificial population it expresses as uniform larvae distribution on foliage or uniform use the area for cocoons' formation) [10, 20]. As a consequence of changes in the spatial structure the changes occur also in ethological structure of artificial insect populations (reaction to the smell of food, sex pheromon, and ability to migration decrease). It influences on labile autoregulatory processes, providing population homeostasis. It brings to the changes of hormonal regulation, intensity of release the signal substances, and then to behavior change and synchronization of individual activity [23, 34]. Thus artificial insect populations maintain the structuring and, consequently the ability to maintain their homeostatic properties. In subsequent years we carried out the complex investigations on optimization of structural parameters of the artificial insect populations, depending on the purpose of breeding programs. The methods of optimizing the spatial, age, sex, ethological and ecological structures have been developed. Observations following cessation of directional selection show the possibility to return to the optimal structure of artificial population [20, 21, 24, 25], which was earlier shown for natural populations [27, 42].

An important point in determining of population condition is the choice of integral index, allowing to evaluate the structure of insect populations, to reveal the mechanisms for its changes and the role of intrapopulation groups of individuals in homeostasis maintaining.

Certain level of heterozygosity is one of conditions for maintaining the population homeostasis in a changing environment. Direct relationship between viability and the degree of heterozygosity of populations is experimentally demonstrated [11]. Therefore we consider, that the level of population viability may be used as criteria reflecting the ability to maintain the population homeostasis.

As is noted by M. Suley [36], viability is population survival in such status, which provides the maintenance of its vitality and the possibility to evolutionary adaptation. In the terms of technical entomology the viability of artificial populations means their possibility to survive and to produce the offspring in changing conditions of technocenosis [10]. Viability is associated with adaptive capacity of the species, it reflects its adaptation reserve and is controlled by genetic mechanisms. The mechanisms of maintenance an optimal level of viability in artificial insect populations remained uninvestigated before our research.

Study of artificial populations of silkworm and gypsy moth has shown the presence of individuals with different sensitivity to chemical substances. Chemical regulation is directly related to the information structure of community. Heterogeneity of groups of individuals by this feature has become the base for development the criteria for assessment the population condition to manage cultivation.

In the publications of A.Z. Zlotin et al. [13, 14] direct correlation between viability level of silkworm males and their reaction on female sex pheromone is experimentally proved for the first time. Later this relationship has been confirmed for other insect species [32, 40]. Further [30] a positive correlation was found between silkworm caterpillars viability and intensity of their chemotaxis (sensitivity to smell of mulberry leaf). Adult males, developed from such caterpillars, had higher sensitivity to sex pheromone of females [16]. The latter shows that high activity of sensory transduction in individuals with high vitality activity is maintained in all active phases of ontogenesis. In researches of K.V. Hayduk (2003) the existence of direct relationship between silkworm populations vitality and phototaxis intensity was proved for the first time. As a result of analysis of presented data and own research the existence of a direct relationship between the intensity of the main vital to insects taxis (chemotaxis and phototaxis) and viability level of population was proved [15].

Thus, more sensitive and therefore more viable individuals provide the success of population survival in stress conditions (at increased population density, lack of food etc.). Populations with greater intensity of taxis manifestation are more adapted to environmental conditions and have more and are more likely to survive. From practical point of view intensity of taxis manifestation can be consider as criterion of population viability and to use for prediction of dynamics in artificial insect populations.

CONCLUSIONS

The principle of homeostasis as a general property of biological systems at various levels is fully peculiar for artificial insect populations. They are characterized by all structural parameters, which are inherent to natural populations. It provides the possibility of autoregulation in artificial insect populations, which must be considered at insect rearing.

Mechanisms of maintenance the intrapopulation homeostasis have common features and some peculiarities for technocenosis conditions. Chemical regulation plays a special role in the maintenance of homeostatic properties in artificial populations, because it is based on vital for insect taxis.

On the basis of experimental data, dependence between taxis intensity and vitality level is proved. As a result of studies it was shown, that the index of viability for artificial insect populations and intensity of vital taxis can be used for assessment the condition of artificial insect populations.

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Теоретические основы поддержания гомеостаза в искусственных популяциях насекомых и контроль их состояния. Маркина Т.Ю. – Принцип гомеостаза, как общее свойство биологических систем различного уровня, в полной мере характерен искусственным популяциям насекомых. Особенности техноценоза обуславливают некоторые изменения структурных параметров культур насекомых. В качестве критерия состояния популяций предлагается использовать показатель жизнеспособности. Показана связь жизнеспособности искусственных популяций с интенсивностью проявления жизненно важных для насекомых таксисов. Проанализирована роль таксисов в поддержании популяционного гомеостаза.

Ключевые слова: гомеостаз, искусственные популяции насекомых, структурные параметры, жизнеспособность, интенсивность таксисов.