

ANALYSIS OF THE RESISTANCE OF GRAIN PESTS TO PHOSPHINE. REVIEW

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KEY WORDS:

grain, insects, phosphine, resistance

ABSTRACT

Resistance of stored grain pests to phosphine is a problem that is being treated in many countries of the world. This is due to the fact that this fumigant is the most widely used in the world. The review shows the resistance of a number of major pests to phosphine from the initial to the high degree of resistance due to its importance for practical use in the protection of stored grain. The analysis of the search and use of alternative fumigants has been given, the reasons for their refusal to use them have been formulated. The causes of the emergence of resistant insect populations at high concentrations of phosphine are described and measures to overcome resistance are proposed. It is shown that this circumstance leads to inefficiency of the application of existing fumigation regulations by phosphine in warehouses and elevators, in metal silos, in wagons on the way, in the holds of small-ton and large-capacity vessels in the voyage. It is concluded that only a comprehensive approach to research to identify the causes of the emergence of resistance of stored product pests to phosphine will help to avoid the abandonment of the use of phosphine in Russia and other countries. This circumstance will avoid large losses in the grain industry.

1. Introduction

Since the development of the biological basis of the use of phosphine gas in Russia [1], it has been updated in the regulatory document for more than 20 years [2]. Phosphine is the only gas allowed in Russia [3, 4] to decontaminate grain in warehouses and elevators [5], in metal silos [6], in wagons on the way [7], in the holds of small-ton vessels in a voyage [8], in the holds of large-capacity vessels in a voyage [9], as well as the grain storages and grain processing plants [1, 2].

In recent years, according to experts of elevator companies and fumigation companies, often there are problems with phosphine fumigation of grain and the premises of processing plants. These failures were usually attributed to the uneven distribution of phosphine in the grain mound, possible violations of gas regulations or phosphine leaks due to insufficient air tightness of the premises. On the latter occasion we conducted special research and published data on the actual large leaks of phosphine in real fumigation of mills in Russia [10].

The publications [11, 12] described the problems of acquired resistance (further — resistance) of arthropods to various pesticides, identified resistance as an increased ability of pests to carry pesticides, and named the following three factors that cause resistance:

- 1) The use of pesticide in sublethal doses, especially systematic, for a number of generations, leads to the death of the most sensitive individuals and the survival of the most resistant to the poison. So the selection of resistant individuals is formed, which give resistant offspring;
- 2) In addition to selection, because of the effects of poison in insects can develop useful adaptations that allow to tolerate the destructive effects of poison and survive;
- 3) The genetic factor associated with the mutagenic effects of chemicals may also influence the increase in resistance in insects to pesticides. This has been a particular consideration in recent years [13].

The purpose of this review is to show the state with resistance to the phosphine of the pests of stored product pests in the world and the danger of this phenomenon for Russia.

2. Main part

2.1. Assessment of pest resistance to phosphine

In 1976, the UN FAO report on the Global Review of Resistance was published [14]. At that time, this phenomenon was observed in pests of stored products in 33 of the 82 countries surveyed. More resistance was to contact insecticides than to fumigants. So its first registration was made at *Tribolium castaneum* to malathion in Australia, in the state of Queensland on peanuts.

FAO has recommended a method for assessing insect resistance to pesticides [15] so that data from different laboratories can be compared. The technique includes three stages:

- 1) Assessment of dose-mortality dependence in a sensitive standard laboratory line of insects previously do not in contact with pesticides to establish LD-50, LD-99.9 (lethal doses causing the death of 50% and 99.9% of individuals in the population) and control (discriminatory) dose, which should slightly exceed LD-99.9;
- 2) Testing unknown insect lines for resistance to a discriminatory dose of pesticide to conclude their resistance compared to the standard line;
- 3) Establishing dose-mortality dependency by probit analysis in resistant lines and comparing it with data for the standard line.

The assessment of resistance has become widely popular in the world due to its importance for the practice of protecting grain from pests.

By 2000, 11 major stored product pest species had been found to be highly resistant [16]. By 2003, *Liposcelis bostrychophila* Badonnel (Psocoptera: Liposcelididae) had been found severely resistant to phosphine [17].

Over the past few decades, the situation in the world has deteriorated both in of frequency and terms resistance [18, 19, 20, 21, 22, 23, 24]. In most cases, the development of increased resistance is associated with inadequate fumigation, including poor sealing and repeated fumigation. Studies in the past decade have revealed strong phosphate resistance in a number of pests of stored products [22, 23, 24, 25].

Against these pests, the usual regimes of use of phosphine were ineffective and had to work out new regulations. For this reason, the traditional FAO methodology [15] for identifying severe resistance has not been fully adequate and has since been gradually adjusted [25,26]. A plenary report at a conference [27] stated that the key to successful management of increased phosphine resistance lies in its early diagnosis and proper characterization. It is noted that [28,29] Australia has adopted and successfully implemented a national resistance monitoring Programme since the 1980s, and the country is unique in this. At the same time, there is a steady annual increase in the incidence of resistance detection. That's why Australians are constantly following the trends and geography of resistance in the country [30, 31, 32].

Following the UN FAO review [14], the most comprehensive resistance survey has been undertaken in a number of Moroccan granaries. Its results were published in 2002 [33], which reported a strong and frequent increased resistance to phosphine in *T. castaneum*, *Rhyzopertha dominica* and *S. oryzae*. A smaller survey was conducted five years later in Brazil [24], where 14 of the 19 *Rh. dominica* populations studied had severe resistance to phosphine.

It is very important for countries that use phosphine to disinfect stored products to regularly monitor pesticide resistance in key pests. Late detection of severe resistance to phosphine will no longer help. Detection of the onset of increased resistance will provide an opportunity to eradicate this population, as well as give time to develop adjusted regulations for the use of phosphine and its alternatives.

2.2. Alternatives to phosphine

Experts know that the widespread use in the world phosphine took after the restriction by the famous Montreal Protocol of 1987 the use of methyl bromide for fumigation of stored products as a destructive substance ozone layer of the atmosphere [34].

After the discovery of the widespread resistance of insects to phosphine, various attempts were made to find new alternative fumigants. Among them, the most promising was fluoride sulfuril (SO_2F_2), which has a wide range of actions against pests. It has been registered in Australia for fumigation of grain processing and food processing plants, dried fruits and stored grains [27]. In addition, there is evidence that insect resistance to phosphine does not extend to their resistance to fluoride sulfuriles [35]. However, fluoride sulfuril has in some experiments shown a weak effect on the eggs of stored product pests [36, 37].

Another alternative fumigant, carbon dioxide (CO_2), has the prospect of rapid disinsection only at high pressure, but the high cost of high-pressure cameras limits its use [38].

The paper [39] reports on the effectiveness of carbonyl sulfide (SOS) against a number of pests of stored products. However, the later article [40] published about the weak effects of this gas on *S. oryzae*. Among its other limitations, it points to the oppression of the vitality of seeds and to the foreign smell acquired by the products after fumigation [41].

In experiments [42], it has been found that ethyl formate (NSO_2N_3) (ethyl ester of ant acid) can also produce a good disinfectant effect, but only in combination with carbon dioxide. When used independently, it is little effective against a number of pests. But the main danger lurks in its high capacity to ignite.

Good old-time cyanide (HCN) is highly toxic to insects [43, 44], but it is criticized for its strong grain sorbation [41].

Rather extensive publications are devoted to the cyanogen (CN)₂ [45, 46, 47, 49, 50, 51, 52, 53], which established the high efficiency of this gas in suppressing insects that harm grain. However, there

are indications of its phytotoxicity, which threatens the viability of the grain [41, 54].

The controlled modified atmosphere with an increased carbon dioxide content, almost supplanted by oxygen and high nitrogen content can be recognized as an alternative to other fumigants which is devoted to extensive scientific literature in our country. [55, 57, 58, 59, 60] and abroad, where specialized international conferences are held periodically every four years under the title «Controlled Atmosphere and Fumigation» (CAF) and proceedings of these conferences are published. A certain drawback here is too long time, which requires insects to suffocate in a controlled atmosphere [61].

2.3. Assessment of the future and recommendations

Due to the high and ever-expanding worldwide resistance of insects to phosphine [62], there is a serious problem of the possibility of its use in the foreseeable future. What steps are the scientific world considering in prolonging this future?

One of the key solutions is the correct use in the applicable regulations of the combination of phosphine concentration and fumigation exposure time [63]. Studies have also clearly demonstrated the effect of temperature on the effectiveness of phosphine [64, 65]. These factors should be directly taken into account when managing the effectiveness of phosphine against resistant pest populations. For example, in Australia, after the strong and extensive resistance of local pest populations to phosphine, new regulations on the use of phosphine have been developed and implemented to overcome the identified resistance [66, 67].

There are successes in understanding the molecular aspects of phosphine resistance [68, 69, 70].

It has been established that at least two main genes control a high level of phosphine resistance in *Rh. dominica* [71] and *T. castaneum* [72]. A detailed genetic and molecular analysis of *Rh. dominica* [73] found the presence of two loci (locations) *rph1* and *rph2* on the genetic map of the chromosome responsible for the resistance of this insect. *Rph1* controls the phenotype with «weak» resistance, providing moderate resistance to phosphine. *Rph2* itself determines only a very low level of resistance. *Rph2* was not detected until *rph1* became common, and until both locus were combined into the same individual and synergies produced a higher level of resistance, known as the «strong» phenotype of resistance.

This discovery led to a series of additional genetic experiments to determine whether the *Rh. dominica* populations, far apart geographically, form the same genes for the development of strong resistance [74, 75]. The results confirmed this hypothesis. At the same time, it has been shown [76] that if an insect flies over, a gene flies with it.

3. Conclusion

The results of the study showed that the following activities should be envisaged in our country:

1. To develop and implement a national Programme to monitor the resistance of key food pests to phosphine;
2. To identify the factors responsible for the development of resistance;
3. To reduce selection, i. e. to limit the number of fumigations by phosphine;
4. To eliminate detected resistant populations in enterprises by using alternative methods;
5. To develop plans to eradicate and follow these recommendations for the use of phosphine by all participants in the grain industry.

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Completely prepared the manuscript and is responsible for plagiarism.

The author declares no conflict of interest.

Received 18.02.2020 Accepted in revised 10.03.2020 Accepted for publication 20.03.2020