ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Study of Biological Efficacy of Drugs and Resistance of Acridoidea in Semi-Arid Areas.

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ABSTRACT

In terms of occurrence and injuriousness in the semi-arid area of the West-Kazakhstan region, the most hazardous species are the migratory locust (Locusta migratoria L.) and the Italian locust (Calliptamus italicus L.). The study undertaken in the semi-arid area is intended for agri-environmental monitoring of species composition, phenology, occurrence and injuriousness of acridoids, and the selection of optimal insecticides to control the Acridoidea.The studies result in data on biological efficacy of state-of-the-art insecticides to control the Acridoidea in the semi-arid area of the West-Kazakhstan region (Zhangalinskiy and Syrymskiy regions). The highest biological efficacy is observed when using Gerold (97.8-98.4%) and Tanrek (97.0-97.8%) drugs. When applying Detsis-Extra, the lethal count varied from 94.8% to 95.4%.Furthermore, the article contains the results of studying the resistance of Acridoidea in the semi-arid area of the West-Kazakhstan region. The insecticides investigated showed the following toxicity towards Italian locust larvae (in descending order): Gerold – Tanrek – Detsis-Extra.

Keywords: Forage lands, Acridoidea, migratory locust, Italian locust, monitoring, insecticides, biological efficacy, resistance.

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INTRODUCTION

Among many insect species harmful for agricultural crops, the Acridoidea hold a special place because of their notoriety since ancient times when they wreaked havoc in many countries of Africa and Asia with their swarm attacks that condemned millions of people to famine and death (Louveaux, 1986; Liebhold *et al.*, 1996).

Mass reproduction of Acridoidea that has been underway in the West Kazakhstan for the last 10 years drew the attention to the migratory locust (Locusta migratoria L.), the Italian locust (Calliptamus italicus L.) and some species of non-gregarious Acridoidea being serious crop pests. In the West Kazakhstan region, the pest control was provided within the area of dozens of thousands of hectares during the previous five years. This area showed an intensive growth of regions occupied by gregarious Acridoidea, along with their proliferation from initial habitats predominantly located in southern semi-arid areas to virtually the whole West Kazakhstan region.

Whereas general trends in the dynamics of Acridoidea population have been studied by many scientists, the features of the current outbreak of propagation deserve special attention. The search for ways and methods to restrict the population and injuriousness of Acridoidea, which is an important and urgent task, is impossible without analyzing the modern environmental profile in the region and the impact of man-made impacts on the Acridoidea, including large-scale direct control measures.

In this connection, the peculiar features of the Acridoidea biology and ecology were studied in the West Kazakhstan semi-arid areas, along with the efficacy of several methods and ways to restore their population, some aspects of insecticides resistance and ways to overcome it, and the impact of weather conditions on the population dynamics.

The existing primary areas of Acridoidea propagation in the West Kazakhstan region include Zhangalinskiy, Syrymskiy and other semi-arid areas.

Most studies on the Acridoidea in this region were undertaken before the first half of the 20th century. Currently, the habitation and development conditions of the Acridoidea have changed, which is related to the climate dynamics and structure of cultivated lands that are largely affected by man-made impacts. This caused a substantially increased number of agricultural lands inhabited by the Acridoidea and significantly increased injuriousness towards agricultural crops.

Currently, due to its high performance and efficiency, the chemical control method is widely used to control the Acridoidea over the area of hundreds of thousands of hectares; however, no environmental consequences are taken into account for this type of control. For this reason, the studies aimed at minimizing the environmental damage through selecting an efficient range of drugs, their combinations, optimal rates and application techniques, are of immediate interest. Continuously expanding range of insecticides widely used to control the Acridoidea makes it vitally important to define their efficacy in various soil and climatic areas, including the West Kazakhstan semi-arid areas (Nasiyev *et al.*, 2015).

The prevailing use of protecting chemicals to control the Acridoidea has gradually resulted in depauperization of useful entomofauna, environmental pollution and formation of resistant populations. The resistance has become a factor destabilizing the phytosanitary situation, so studying this phenomenon is rather urgent, since it has become most intensive for harmful Acridoidea in the West Kazakhstan semi-arid areas.

Making realistic forecasts of mass propagation of gregarious Acridoidea requires getting familiar with biological peculiarities of certain species, weather conditions in the region and regular observations, which conditions the need to determine specific air temperatures and amounts of precipitation that give rise to propagation of these species and its decline in the West Kazakhstan semi-arid area, and the need to monitor the behavior of the Italian locust and the migratory locust in the areas of their normal abundance.

Justification of research trends.

The long-term experience shows that the efficient protection of agricultural crops and pastures against the Acridoidea is possible through the complex use of agronomic and chemical methods taking due consideration to the action of entomophages and entomopathogenes.

The most famous method of Acridoidea control that has been applied both in Russia and abroad since the second half of the 20th century is chemical control. In foreign countries, for the purposes of cost-efficiency and environmental protection, chemicals are predominantly used by means of ultralow-volume spraying, usually in the form of strip-like treatment (Lachininskiy *et al.*, 1999; Lockwood *et al.*, 2000; Stolyarov, 2000). This method is used to treat with organophosphorous drugs, Karbofos and Fufanon (malation), and Kabril (Sevin) belonging to the group of carbamates. The following drugs have shown high results in treating gregarious Acridoidea with pyrethroids: Deltametrion, Dekametrion and others, as well as growth regulators Diflourbenzuron and Flufenoxuron affecting larvae only. In Kazakhstan, the following pyrethroids were applied against the Italian locust: Detsis, Karate, Fury, etc. In various countries nowadays a new drug belonging to the group of phenylpyrazoles (fipronil as an active substance), Adonis, has been widely applied (Duranton & Yaunois-Yuong, 1996; Stolyarov, 2000). It has been successfully tested in various Russia regions (Lachininskiy & Sergeyev, 1999; Dolzhenko & Burkova, 1999; Lachininskiy, 2000; Sergeyev *et al.*, 2002; Dolzhenko, 2001; Dolzhenko, 2002).

The list of pesticides and agrochemicals approved for use in the Republic of Kazakhstan includes more than 65 drugs belonging to various groups of chemical compounds intended to control injurious Acridoidea. New insecticides, such as Mospilan, Konfidor, Adonis, Dimilin, are characterized by high biological efficacy when applied at small rates against the Acridoidea, which promotes lower toxic load, since these drugs belong to the group of medium and low-hazard compounds.

In the time of increased Acridoidea population, the primary control method appears to be chemical treatment. Protective measures taken in certain framing units and regions are based on the results of surveys undertaken and the dynamics forecast for the population of gregarious Acridoidea.

Recently, the areas subjected to chemical treatment against Acridoidea in the West Kazakhstan region have substantially expanded. Currently, the range of anti-Acridoidea insecticides is rather wide. In recent years, both organophosphorous and pyrethroid insecticides were used to control Acridoidea. Pyrethroids include such drugs as Arrivo, Detsis, Karate, Mavrick, Fury, etc. Organophosphorous drugs include Karbofos, Rogor-S, Fufanon, etc. In recent years, Detsis-Extra, Gerold and Tanrek have become widely known. However, no studies to determine the biological efficacy of new drugs have been undertaken in the West Kazakhstan.

Thus, the analysis of the above materials shows that in modern environmental conditions the following requirements are implied: all direct control measures shall be taken in accordance with the environmental impact; the control strategy and tactics shall be based on population monitoring for gregarious Acridoidea, their phase versatility, and analysis of the region's climatic conditions; regular check of insecticide biological efficiency in production conditions, revealing the most efficient way of applicants and studying the resistance phenomenon.

METHODOLOGY

The studies were performed in the Zhangir khan West Kazakhstan Agrarian-Technical University in the period between 2012 and 2015 (Uralsk, RoK).

The phenology and injuriousness of Acridoidea were studied in the Syrymskiy and Zhangalinskiy regions of the West Kazakhstan semi-arid area. The region selection within the study area was not accidental. The selected regions are the areas of normal habitation of the Italian locust and injurious non-gregarious Acridoidea and their active long-term and vast control. The Acridoidea sampling points will be selected so as to cover the maximum diversity of landscapes and biotopes of the area under investigations.

In the area under study, the examinations were performed for crops, pastures that have been previously cultivated but not any more, as well as fallow lands with xerophilous wild grasses.

During the studies, the following modern insecticides used for control were investigated: detsis-extra, gerold, tanrek.

The biological efficacy of insecticides was determined by means of comparing the number of larvae prior and after treatment and by calculating under the formula:

$$E = a\text{-}b \times 100\%,$$

where E – efficacy, %;
a – number of Acridoidea before treatment;
b – number of Acridoidea after treatment;

The stability levels for pest populations were established by performing special experiments. When determining the stability levels, larvae are placed in entomologic test tubes, 20-30 specimens in each. Prior to insecticide treatment, insects are immobilized by cold to prevent their through-freezing, the refrigerator floor is covered with PE mat, and expositions are cooled down for 1.5-2 minutes. Frozen, but still viable larvae are dumped out of tubes into Petri dishes covered with filtering paper and are sprayed with insecticide emulsions by a manual sprayer in a series of dosages. Forage plants are placed into dishes, and dishes are covered with gauze swabs with rubber rings. Control insects are sprayed with water. The test is performed three times. In 24 h, the number of perished and perished insects is counted. A dependency chart for their mortality from toxicant dosages is then plotted, and the average lethal concentrations are determined that cause the death of 50% and 95% of specimen.

In our opinion, to obtain the most distinctive difference in pest sensitivity to the applied drugs, the insects must have been taken for analysis from two regions showing different range size and chemical impact. The obtained data revealed the most sensitive population which toxicity criteria (SCso and SC95) are further used as a benchmark to calculate the resistance indicator (RI) of pests from other regions of the range to track the toxicity dynamics of Acridoidea insecticides under study.

Furthermore, this methodology was used to calculate the toxicity index (TI) showing the extent to which the sublethal concentration (SC95) is less or more than the production concentration of the drug (Dolzhenko *et al.*, 2001). The latter is measured in % of the active substance with due consideration to the highest amount of the drug per hectare among the recommended values and the treatment solution flow rate in l/h. The sensitive population TI shows the resistance level when the drug loses its efficacy (SC95). The higher is the TI, the more guaranteed is the action of the drug in field conditions; the closer is the IT to 1, the less is the reliability of the drug. The IT amounting to 1 or less shows the non-toxicity of the drug caused by the resistance developed in the pest race. Diagnostic concentrations of drugs were selected to ensure 100% death of specimens (Kovalenko & Turina, 2002).

RESULTS AND DISCUSSION

Biological efficacy of state-of-the-art insecticides

Until now, nowhere in world have been developed and implemented any measures to prevent mass propagation of gregarious Acridoidea. In the Republic of Kazakhstan, as well as in other countries, the Acridoidea control is provided only during the periods of mass propagation, mainly by means of treating contaminated areas with insecticides, which requires substantial material expenses and causes severe environmental damage. Agronomic methods appear to be more environmentally friendly; however, their application over wide areas is not always appropriate (or even possible) from a commercial point of view.

There are a lot of examples of successfully operated systems of preventive measures in the global practice that allow substantially reducing the amount of insecticide anti-Acridoidea treatments without detriment to efficacy (Lachininskiy, 2000). In Argentina, Africa and Asia, these systems of preventive cloud treatment have proved high efficacy in the spots of constant propagation. This strategy allows preventing swarm fly-out and damage to farming ecosystems, and it substantially decreases the amount of insecticide treatments. If applied in our conditions, this strategy can be implemented into practice to control the migratory locust that shows restricted nesting, usually in reed beds. For the Italian locust whose habitats are quite diverse in environmental and climatic conditions and are spread over a vast area, this strategy will be perhaps less effective. Nonetheless, even in this case, preventive treatments of clouds in constant areas of normal abundance will be undoubtedly more fruitful and economically beneficial than large-scale control of swarms at the peak of mass propagation.

In the time of increased Acridoidea population, the primary control method appears to be the chemical treatment. Protective measures taken in certain farming units and regions are based on the results of surveys undertaken and the dynamics forecast for the population of gregarious Acridoidea.

Recently, the areas subjected to chemical treatment against Acridoidea in the West Kazakhstan region have substantially expanded.

Currently, the range of anti-Acridoidea insecticides is rather wide. In recent years, both organophosphorous and pyrethroid insecticides were used to control Acridoidea. Pyrethroids include such drugs as Arrivo, Detsis, Karate, Mavrick, Fury, etc. Organophosphorous drugs include Karbofos, Rogor-S, Fufanon, etc.

In recent years, Detsis-Extra, Gerold and Tanrek are widely known. Their biological efficacy was studied when applying them in the West Kazakhstan semi-arid area.

In 2015, our studies of the biological efficacy of insecticides were performed in the Syrymskiy and Zhangalinskiy regions. The total plot area is 1 hectare, with tests performed three times.

The ultralow-volume sprayer Analog 2 was used.

The studies were performed on natural pastures. During chemical treatments against the Italian locust, the pest was represented basically by 2nd age larvae.

As shown by calculations, the biological efficacy of insecticides under study varied from 96.5 to 98.4%. The highest efficacy was shown by such drugs as Gerold and Tanrek. The highest rate of mortality was observed when applying Gerold (98.4%) and Tanrek (97.8%). When applying Detsis-Extra, the larva mortality was 95.4% (Table 1).

Table 1 Biological efficacy of insecticides in production tests in the Syrymskiy region

Drug	Larva mortality, %
Detsis-Extra	95.4
Gerold	98.4
Tanrek	97.8

As shown by calculations for the Zhangalinskiy region, the biological efficacy of insecticides under study varied from 94.8 to 97.8%. The highest efficacy was shown by such drugs as Gerold and Tanrek. The highest rate of mortality was observed when applying Gerold (97.8%) and Tanrek (97.0%). Detsis-Extra showed the minimal efficacy with larva mortality of 94.8% (Table 2).

Table 2 Biological efficacy of insecticides in production tests in the Zhangalinskiy region

Drug	Larva mortality, %
Detsis-Extra	94.8
Gerold	97.8
Tanrek	97.0

The studies showed that the maximum efficacy of insecticides was observed on Day 9 after their application when up to 92% of pest's larvae perished.

A comparably high effect was achieved when applying Gerold and Tanrek. In this case, the mortality on Day 9 after treatment was 91.5-92.0%. However, on Day 15 after treatment, the efficacy of the preparation dropped to 90%.

When selecting an insecticide, the primary indicators of toxicity and drug properties shall be taken into account, along with the phytosanitary situation in pest spots.

Insecticides showing high rate of toxic activity ensure rapid decline of Acridoidea population, preventing their migration to farming ecosystems and possible crop harvest losses. This is especially important for treatments during the periods of massive propagation.

Gerold proved to be the most effective in the Syrymskiy region in terms of duration of action during general treatment against 2nd age Italian locust larvae. Its high efficacy was preserved for 21-28 days after application. Thus, on Day 21, the biological efficacy of the drug was 96%, on Day 28, it reduced to 80%, but still was on a relatively high level.

The Tanrek biological activity was high within 10 days. On Day 7, the Tanrek biological activity was 92%, and on Day 10, it decreased to 91%. In the following days, its biological activity kept going down, and on Day 28, it was 56%.

The Detsis-Extra biological activity, similar to that of Tanrek, was high – 85%. In the following days, the efficacy of the drug was rapidly decreasing, amounting to 78% on Day 7, 62% on Day 10, 38% on Day 14.

On Day 21 after application, Detsis-Extra completely lost its toxicity in relation to 2nd age Italian locust larvae.

In the Zhangalinskiy region, Gerold showed the highest duration of action against 2nd age Italian locust larvae, with the lowest efficacy shown by Detsis-Extra. Tarnak shows the intermediate efficacy.

Currently, general aerial and ground treatments and regional (around crops), local (for high concentrations of pests (clouds and swarms) and barrier treatments (on the path of larvae migration) (Dolzhenko *et al.*, 2003).

Chemical treatments are optimal in the years with high number of Acridoidea. When the number is rising and mass propagation is underway, it is appropriate to have local treatments. In these conditions, barrier treatments by drugs showing long-term protective effect (Gerold, Tanrek) are efficient. General treatments are reasonable for limited areas where Acridoidea larvae are accumulated and there is a real threat for harvests. In the period with peak number of Acridoidea, general treatments are also permitted apart from the above control methods, but predominantly in farming ecosystems and adjacent sites.

The studies conducted in 2015 in the Syrymskiy region show that Gerold was basically effective for barrier treatments, and Tanrek for general treatments (Table 3).

Table 3 Biological efficacy of insecticides for various application methods against 2nd age Italian locust larvae

Drug	Treatment method	Larva mortality, %
Detsis-Extra	barrier	90.5
Detsis-Extra	general	90.0
Gerold	barrier	95.0
Gerold	general	96.0
Tanrek	barrier	92.1
Tanrek	general	92.0
SMD_{05}		1.61

Thus, at this stage we worked to establish and specify comparative efficacy of insecticides applied in the semi-arid area of the West-Kazakhstan region to control injurious Acridoidea and their application methods.

This task is solved, but in the future, when the number of commercially available insecticides and their application methods will grow, it is necessary to continue these studies.

The results of our studies have shown that in the conditions of the West-Kazakhstan semi-arid areas, Gerold and Tanrek are the most efficient to control Acridoidea; the efficacy of Gerold is high for 28 days, that of Tanrek – for 10-14 days; Gerold barrier treatments cause 95% of 2nd age Italian locust larvae to perish, with 96% for general treatments.

Resistance of Acridoidea to insecticides

In the conditions of mass propagation of Acridoidea, high efficacy and opportunity to treat vast areas proves that chemical control methods are of high priority. However, in these conditions, drug efficacy varied (Detsis, Karate, Fastak, Sumution) in various farming units and West-Kazakhstan regions, which made it possible to suggest the loss of natural sensitivity of locust to insecticides. This made us evaluate the toxicity of recommended drugs towards pests.

The need to study the locust response to control chemicals was resulted from the general principle previously revealed when analyzing dominant pests of crops against which insecticides are applied. In particular, a serious phytosanitary problem is shown by high populations of pentatomid bugs, Colorado beetles, big greenbugs, cotton budworms, pear slow-worms, gooseberry red spiders, hothouse whiteflies and many other plant feeders showing group, cross and multiple resistance to organophosphorous and pyrethroid compounds, growth and development regulators (Kovalenko *et al.*, 1998; Stolyarov, 2000; Sukhoruchenko, 2001; Kovalenko & Tyurina, 2003).

Almost all farming ecosystems and uncultivated land plots are somewhat subjected to the action of pesticides of several chemical classes and purposes for many years, which promotes high mutation with various resistance mechanisms in pest populations. It was unreasonable to claim that the Italian locust shows a different response to pesticides.

According to scientific data, currently, forty-six species of pests have developed resistant populations. However, there are no Acridoidea among them. Only laboratory conditions allowed showing an opportunity to develop species and age resistance to Karbofos in the Siberian grasshopper and the Italian locust (Kurdyukov, 1980).

In 2015, we monitored the sensitivity of Italian locust populations in the Zhangalinsiy and Syrymskiy regions towards three insecticides under study. The most sensitive populations were found in the Syrymskiy region where the minimal toxicological parameters (SC_{50} and SC_{95}) were taken as the locust species sensitivity included in methodological recommendations [60] and were used to calculate the resistance levels in other populations.

Because of regular treatments performed for many years in the Zhangalinskiy region, a significantly increased locust resistance to drugs is observed.

In the Zhangalinsiy region, the differentiation of locust populations was highly regional; the resistance increased from the south to the north reaching its maximum in the area bounding with the Akzhainskiy region.

Prevalence of various-resistance clouds in the same region was repeatedly observed. This was explained by active migration from the areas of moderate prevalence with limited treatments to the areas of intensive control, and vice versa.

The studies conducted in the Syrymskiy region prove that insecticides applied against the Italian locust have different toxicity and various effects towards larvae of various ages (Table 4).

Table 4 Insecticide toxicity for the Italian locust, Syrymskiy region

Drug and formulation	2nd age larvae		5th age larvae	
	SC_{50}, % a/i	SC_{95}, % a/i	SC_{50}, % a/i	SC_{95}, % a/i
Detsis-Extra	0.053000	0.21000	0.004100	0.01320
Gerold	0.000154	0.00061	0.001440	0.00550
Tanrek	0.008900	0.02700	0.002000	0.00740

Gerold showed the highest toxicity for 2nd age larvae in our experiments – 50% of larvae perished from this drug with percentage in relation to active ingredient of 0.000154. 95% of larvae perished from this drug with percentage in relation to active ingredient of 0.00061.

The lowest toxicity for 2nd age larvae wash shown by Detsis-Extra. When applying this drug to reach 50% lethal outcome for larvae, the percentage in relation to active ingredient was 0.05300. 95% lethal outcome for 2nd larvae was achieved when applying this drug with the percentage in relation to active ingredient of 0.2100.

The intermediate toxicity towards 2nd age larvae among the above drugs was shown by Tanrek.

The highest toxicity for 5th age larvae of Italian locusts was shown by Gerold. 95% lethal outcome for larvae was achieved at the percentage in relation to active ingredient of 0.00550.

The lowest toxicity for 5th age larvae wash shown by Detsis-Extra. Almost 100% lethal outcome for 5th age larvae was observed for the percentage in relation to active ingredient of 0.01320.

The intermediate toxicity among the above drugs for 5th age larvae was shown by Tanrek.

CONCLUSION

The insecticides investigated showed the following toxicity towards Italian locust larvae (in descending order): Gerold – Tanrek – Detsis-Extra.

The data showing that the Italian locust has developed resistance to insecticides prove the urgency of this issue.

In order to overcome the resistance of plant feeders to insecticides and restrictions of their negative environmental impact, the following measures seem reasonable: regular monitoring, alternate use of drugs of various chemical classes, action mechanisms and activity spectrum, according to the recommendations developed for the semi-arid area of the West-Kazakhstan region, as well as studying and implementing agronomic and biological control methods.

ACKNOWLEDGMENTS

The work was completed within the grant-funding program of the Committee of Science of the RoK Department of Education and Science within the project titled *Acridoidea: Fauna and Ecology in Relation to Climate Changes, Improving the Population Forecast, Planning of Control Activities*.

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