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This book presents a detailed account of stored-grain pests and infestation of grain and grain products by these pests. It also gives methods for detecting the visible and hidden infestations of the grain, grain stores and grain-milling plants. Also mentioned are the measures including physico-mechanical and chemical methods for the control of these pests. The authors have studied the effect of pesticides and ionizing radiation on the quality of food and seed grains.

This book is meant for pest-control specialists working in grain stores and grain-milling plants.

Preface

The Directives of the XXIV Congress of the Communist Party of the Soviet Union on the Five-Year Plan for National Economic Development for 1971 – 75 specified a gross grain yield of not less than 195 million tonnes in the country. Implementation of measures to increase the quality of grain was also envisaged in the directives.

Preserving the harvested crop without loss or damage is a problem of national importance. In order to preserve the grain, it is necessary to wage a constant war with the stored-grain pests which inflict considerable damage on the cereals. These insects which lodge themselves within the grains cause a great loss of stored grain: they reduce weight, lower the quality, spontaneously heat the grain, soil the grain and its products, lower its germinating capacity, etc.

In recent years, science and technology in the Soviet Union and other countries have made marked progress in the study of stored-grain pests and in devising improved ways to control them. Many publications devoted to the study of the species composition of the pest fauna of grain mills have appeared, especially in the eastern regions of the USSR, Ukraine, Central Asian republics and Transcaucasia.

Better methods of identifying grain infestation have been evolved, especially to detect latent forms of infestation. These developments have been in two directions: 1) chemical detection by the use of special dyes and 2) the acoustic method based on receiving and amplifying the sounds produced by the insects during their life activities. The operational efficiency of these methods has been improved by inventing apparatus for quicker evaluation of the nature of the grain infestation.

The experts have also developed prophylactic measures to prevent the infestation of stored products. On one hand, seeds of highly resistant varieties which may serve as stock material are being studied. On the other hand, methods are being developed to create unfavorable conditions for the life activities of insects and mites during storage by using artificial cold or saturating the intergranular spaces with carbon dioxide.

Studies have been conducted on the disinfestation of grain by radiation and its effect on the grain. The growth of rocket technology in the Soviet Union has led to the invention of equipment for the radiation control of stored grain with an electronic beam.

At present, the use of DDT has been banned in the USSR because of its prolonged retention and accumulation in water and soil and in the human body through plant and animal products.

DDT and other dangerous or less effective chemicals like the 80% concentrate of green oil emulsion and caustic soda are being replaced by organo-phosphorus compounds which have high insecticidal and acaricidal potency and yet are less persistent and decompose comparatively faster into nontoxic metabolites.

In recent years, the country's chemical industry has started manufacturing large quantities of organo-phosphorus insecticides and acaricides, including Trichlorometaphos-3, Carbophos, Chlorophos and so on.

The production of organo-phosphorus pesticides which are less toxic to man has led to the discovery and introduction of disinfestation techniques and prophylactic treatment of grain by contact pesticides, particularly Carbophos. This involves spraying the grain with an aqueous spray of the pesticide. This is a new development in the country.

With the improved methods and varieties of chemicals used to control stored-grain pests, there is great need for hygiene in the disinfestation work and in the control of pesticide residues in the products after the treatment. Better methods of determining the pesticide content in the grain products and atmosphere have also been discovered.

The authors of this book have described and classified their research and field work.

The book also gives brief introductions to the bioecology of the pests and methods for their control through the latest scientific knowledge. Attention in this regard has been mainly concentrated on theoretical and practical prerequisites in the selection and use of any method of pest control to clearly understand its nature, significance and correct usage.

When selecting the chemical it is necessary to refer to the *Spisok Khimicheskikh i biologicheskikh sredstv bor'by s vreditelyami, boleznyami rastenii i sornyakami, rekommendorannykh dlya primeneniya v sel'skom khozyaistve na 1973 god* (Inventory for the Chemical and Biological Control of Pests, Plant Diseases and Weeds, Recommended for Agricultural Use, 1973).

Chapter II, "Methods to Detect Stored-grain Pests", Chapter III, "Control of Stored-grain Pests" and part of Chapter I, "Development and Infestation of Stored-grain Pests" were written by G.A. Zakladnoi, Candidate of Biological Sciences. Chapter I, "Characteristics of Stored-grain Pests", the Chapter III parts, "Fumigant Pesticides" and

"Selection of Method of Fumigation of Various Objects," Chapter IV, "Decontamination and Methods to Detect Pesticide Residues" and Chapter V, "Safety Measures while Using Chemicals to Combat Stored-grain Pests" were written by V.F. Ratanova, Candidate of Biological Sciences.

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Contents

CHAPTER I

Characteristics of Stored-grain Pests

1. DEVELOPMENT AND INFESTATION OF STORED-GRAIN PESTS

The fauna of stored-grain pests is large and varied.

Many species damaging agricultural products during storage, like species of the flour beetle, are widespread globally. Others, like mites, are more characteristic of the temperate zone.

There are several scores of species of insects and mites which are pests of grain, flour groat and other grain products. They are rare in tobacco and textile goods. Insect pests are not found in a few products like sugar and tea.

The living conditions of stored-grain pests are different from those of pests infesting agricultural plants since the grains which are the main habitat of these pests are always stored in closed areas. Fluctuations in temperature and moisture content are few in the grain due to its low heat and humidity conductivity. Usually the moisture content of grain products is lowered before storing. Grain is a bulk material which serves as food as well as habitat for these insects. The storage places for agricultural products are usually poorly illuminated. As a result of their life in such conditions insects and mites belonging to two widely differing taxonomic groups have developed a number of common characteristics that combine them into a single group called stored-grain pests.

Most representatives of this group have no diapause—a state of relative rest during which there is a steep fall in the metabolic rate. Diapause among insects and mites living in fields helps tide them over winter conditions.

Due to the absence of this phenomenon, insects and mites inhabiting stored products can, under favorable conditions, reproduce and infest all year round.

Most species of this group of pests have shorter developmental periods from egg to imago and thus have several generations a year.

Adult females and males of many species live for more than a year and have high fecundity. A female of many of these species can lay more than a thousand eggs during her lifetime.

The high fecundity and quick development of these pests can, under optimal conditions, result in a catastrophically fast increase in their population.

Many insects do not require humidity in their environment; some species of flour beetles can multiply in the flour with only about 1% humidity.

However, most pests, especially those of the class Insecta, cannot normally exist below 15°C.

Pests of stored grains have adapted themselves to life among the grain mass. The phenomenon of thanatosis or feigned death is characteristic of most. During mechanical disturbances, they withdraw their legs and antennae and feign death. This keeps away the insects and mites from mechanical injuries during the grain storage. All insects inhabiting the intergranular space have a tough chitinous integument. Soft bodied larvae of weevils, Anobiids and some moths develop within the grain and are thus protected from injury.

There are some species of stored-grain pests which can successfully live on the fields as well as in storage (for instance some species of grain beetles and moths). There are some others which start their development in the field and finish it in storage (pea weevil). A few species which infest the ripening grain crop in the field spend the rest of their lives in grain products storage areas (rice weevil, lesser grain borer and grain moth). Finally, there are species of stored-grains pests which live in stored products all the time. Typical representatives of such species are the granary weevils which cannot fly, having lost their second pair of wings during regressive evolution process.

Negative phototaxis is characteristic of the majority of these pests. Insects and pests of this group avoid bright light and hide in grain heaps and crevices of warehouses and other places.

Stored-grain pests are widespread over the globe and create much damage due to their high resistance to unfavorable habitat conditions, their high fecundity and fast development.

Potentially, these pests can infest various kinds of products, but their distribution in a country or a given region is usually determined by climatic factors.

Loss from these insects and mites is apparent in lower yields and the deterioration in quality of the stored products. This loss is different for different products in different countries. It is difficult to establish norms for such insect damage. The F.A.O. of the United Nations has estimated that every year, more than 5% of the world's stored grains, legumes and oil crops are destroyed by pests.

2. PLACE OF STORED-GRAIN PESTS IN THE ANIMAL KINGDOM

It is estimated that more than three hundred species of insects infest various animal and plant products in the world. They belong to widely varying classes of animals. The existing classification of the animal kingdom was established two hundred years ago and is expanded and improved with each discovery of new species.

The basic unit of taxonomy is the species. Species with related characteristics are combined into a genus. Genera in their turn constitute a family. Families are combined to form orders which are grouped together as classes. Finally, there is the phylum which is the highest taxonomic unit and unites the classes. Thus, every representative of the animal world is a species, under a genus, family, order, class and phylum. All taxonomic units are denoted by a common international terminology in Latin. For instance, in all countries the granary weevil is known by the Latin name *Sitophilus* (genus) *granarius* (species); it belongs to the family Curculionidae, order Coleoptera, class Insecta, and phylum Arthropoda.

Animals forming the complex of stored-grain pests belong to two phyla: Arthropoda and Chordata.

Arthropod pests are represented by two classes—Arachnida and Insecta.

The classification of the animal world is based on the peculiar external and internal structures of the organisms.

Arthropods are characterized by an absence of internal skeleton. Their bodies and appendages are divided into a number of segments covered by a tough chitinous layer which forms the exoskeleton. The chitinous covering does not stretch and the outer layer must be periodically cast off (molting).

The mouths of arthropods vary in structure. They may be biting and chewing, sucking, piercing and sucking or other types.

Arthropods have a single, large simple eye or compound eyes, but mites have no visual organs.

Olfactory and tactile organs are the feelers or antennae which in different species may be filiform, pectinate, fusiform, clavate or some other type.

Some arthropods are devoid of wings and cannot fly (mites). The majority of the insects have two pairs of wings and can fly considerable distances.

The legs of mites and insects are segmented. Insect legs may vary in structure, i.e., may be adapted for running, jumping, digging, etc.

All arthropods, including the mites and insects which are stored-grain pests, have no constant body temperature. Since they are poikilothermic animals, their temperature depends on that of their surroundings. Thus they are incapable of thermoregulation. This, to a large extent, determines the vital activities of arthropods throughout the year and permits their distribution in almost all climates of the world.

Some arthropods breathe by tracheal systems (predatory mites and most insects) and some through small openings on the surface of the body wall (integumentary respiration). The structure of the respiratory system of arthropods has special significance in the selection of agents and methods for pest control.

The blood-vascular system of arthropods is not closed and includes a tube with openings at the sides, in front and behind.

The nervous system is more developed in insects than in mites. In the majority of insects and mites reproduction is sexual, but some reproduce parthemogenetically.

The classes Mammalia and Aves belong to the phylum Chordata. Unlike arthropods, chordates or the so-called animals with backbone have endoskeletons and comparatively large bodies. They are warm blooded, which restricts their activity in relatively low temperatures.

Chordates are highly organized animals with well-developed blood-vascular and nervous systems and they breathe through lungs.

3. ARACHNIDA

Mites—*Acarina*

About 6,000 mite species are known but less than 30 species are stored-grain pests. Representatives of the following seven families of the class Arachnida, which sharply differ from one another in morphological, bioecological and physiological characteristics, are found in grains, grain products, grain stores and grain mills.

In the family of grain mites are included: flour mite, black-legged mite, forage mite, Rodionov's mite, root, onion or potato mite and slender mite.

In the family of hairy mites are included: smooth mite, common hairy mite, Michael's mite, cadaverous hairy mite, hairy house mite, ornate hairy mite and brown flour mite.

In the family of predatory mites are included: long-legged predatory mite, voracious predatory mite and common predatory mite.

In the family of grain itch mites are included: grain itch mite, *Acaro-*

phenax tribolii and grass and cereal mite.

The family of parasitic mites includes the manure mite.

The family of dust mites includes the dust mite.

The family of tydeid mites includes the field mite.

Representatives of only the first two families of mites are typical pests of grain and grain products; others, though found in granaries, do not cause any direct harm to stored grains.

All species of mites are oblong in shape and range from 0.2 to 1 mm. The body is divided into two parts: the cephalothorax and abdomen. On the cephalothoracic side are two pairs of mouth parts and two pairs of legs. On the abdominal side are two pairs of legs and genital and anal apertures. Legs are in six segments. The mouth parts of mites are grinding and piercing and sucking types. They have no antennae, but some (predacious) species have highly developed palps. The body is covered by a chitinous layer. The body is covered by setae, hairs or spines of various shapes and sizes. Respiration, digestion and reproduction vary in different groups of mites.

Mites are widely distributed geographically and ecologically. It is difficult to enumerate their ecohabitats. Besides granaries, grain-processing factories and feed mixing plants and their surrounding areas, the mites can live and develop in field conditions—in various plant residues in and around threshing floors, stacks of hay and straw, dead organic matter on the forest floor, rodent burrows, soil, stubble, etc. Plant residues retain optimal conditions for mites for a considerable time.

About 12 species of mites live in fields and the most common among these are flour mites and some species of Glycophagidae.

Grain mites—*Acaridae* (*Tyroglyphidae*).Body length ranges from 0.2 to 0.75 mm. The body is oval, white with a shiny surface covered sparsely or densely by hair. Mite hearts are short tubes open at both ends and situated along the dorsal side of the body. They pulsate and send blood (hemolymph) into the body cavity. Hemolymph is the only coelomic fluid carrying out metabolic functions. Respiration in grain mites is integumentary. Setae and hair are used for orientation. Reproduction, as a rule, is sexual, rarely parthenogenetic. In some species, the external features of males are quite different from those of females. The development process from egg to adult is an incomplete metamorphosis, which means that during growth and molting, one instar does not differ much from another in morphological characteristics.

Under favorable conditions, the development of mites follows the following pattern. A quite well developed larva hatches from the egg after a certain time (depending on conditions). The larval phase is morphologically different from the subsequent instars with smaller body dimensions and three pairs of legs. After the feeding stage the larva is transformed into nymph I, which, in its turn, becomes nymph II. These nymphs have four pairs of legs and are larger than the larva. After further molting nymph II metamorphoses into an adult mite.

Under conditions which are not favorable, arrested development has sometimes been seen in the life cycle of some species, followed by lowered oxidative processes, and retarded growth, feeding and reproduction. This state is known as diapause. In mites, diapause (under unfavorable conditions) sets in after the nymph I stage, when, instead of nymph II, the so-called hypopus emerges. Hypopus may be mobile or immobile. Both kinds of hypopus are known in flour mite. In Rodionov's mite the hypopus is mobile. In hairy mites the hypopus is immobile.

A mobile hypopus has a tough chitinous covering. On the ventral side there are strong suckers with which they attach themselves to insects, rodents, birds, human clothing, etc. (Fig. 1) and are thus transported to other habitats. A hypopus may live without food for several years and can endure with ease low humidity, high and low temperatures and pesticides.

When conditions become favorable, the hypopus molts and changes into nymph II. After that development is completed in the usual manner.

The duration of the development of generations depends on conditions in the habitat. Temperature and humidity are the main factors

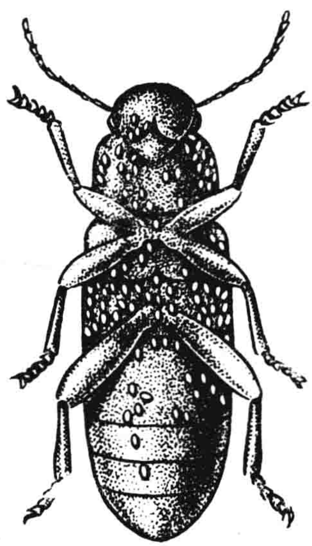

Fig. 1. Hypopus of mite (shown as white dots).

which determine mite population growth. In most species of grain mites the maximum tolerable temperature is 29–32°C and the optimum is 18–24°C. At 9–10°C or less mite development considerably slows down but does not stop and development takes longer. Table 1 shows the duration of development of flour mite, hairy mite and Rodionov's mite, depending on temperature.

Mites feed on any kind of plant or animal product. The most favorable humidity for mite development in grain is 15–16% and above; they do not develop in grain with humidity below 12%. They cannot infest whole grains of cereals with humidity below 14%. Grains with seed coats damaged over the embryo are most suitable for feeding.

After penetrating the seed coat of the grain, the mites enter a latent form of infestation.

The nature of mite infestation has not been sufficiently studied. However, as far as we know, they first infest the embryo. The grain shrivels, sometimes to a marked extent. Feeding upon the grain or its products, the mites soil them with their larval membranes and excrement, create conditions for the development of microorganisms, lower the quality of the grain and its products and transmit infectious diseases. However, the mite activity depends to some extent on the storage conditions for the grain and its products. The mites appear when storage regulations are not observed or when grain products are not carefully handled.

Under normal grain and grain product storage conditions, mite damage may be insignificant (Z.S. Rodionov, 1940). The nutritive value of mixed fodder decreases when highly infested with mites. Such fodder may cause sickness when fed to animals.

The following are descriptions of individual species of grain mites commonly found in grain and grain products storage areas in the Soviet Union.

Flour mite, *Acarus siro* (*Tyrogluphus farinae* L.). Distribution widespread.

Body of flour mite is oval, whitish; legs and mouth reddish-brown. Length of body up to 0.67 mm. Males differ from females in smaller size and structure of fore legs, which are spindle shaped with spiny outgrowths.

The flour mite is widely distributed, feeds on all possible products of plant and animal origin and is in fact a polyphage.

Reproduces sexually. Fertilized females lay 20 to 200 eggs, depending on environment. Duration of development of one generation from egg to adult also depends on the surrounding conditions and may last from 14 days to several months. Optimal temperature for development is 15 to