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The khapra beetle, *Trogoderma granarium* Everts, a serious pest of stored grains and other food products in India and elsewhere, has recently been found in 23 counties of California, Arizona, and New Mexico. It thrives on hot, dry conditions and has proved exceptionally difficult to control. The State Department of Agriculture is conducting an eradication program against it in California.

Studies have been conducted on factors affecting the development of this beetle and on its climatic adaptation, and tests have been carried out to find more effective control measures. The following are the principal results to date.

An increase in temperature from 70°F to 93°–95° decreased the average length of a generation from 220 days to 26 days; light conditions had little effect on it. At 90° egg viability averaged 94 per cent, and 93 eggs were laid per female. The length of a generation varied widely on different foods.

A few larvae survived exposures of 240 minutes to –6°F and of 51 days to temperatures fluctuating daily between 25° and 48°. Eggs and pupae were more susceptible. To obtain a 95 per cent kill (at 50 per cent relative humidity) required 960 minutes for larvae and 420 minutes for pupae at 118°, 8 minutes for both stages at 131°. These findings indicate that the species is capable of becoming a pest of grain stored in piles or sacks in the field in such climates as that of Imperial Valley, California.

Among ten fumigants tested (at 70°F and with 2-, 8-, and 24-hour exposures), hydrocyanic acid and acrylonitrile were the most toxic to khapra-beetle larvae and pupae. Eggs were more susceptible than the other immature stages to the majority of these fumigants. Hydrocyanic acid was the only one tested to which all three immature stages of the khapra beetle were more susceptible than granary-weevil adults. Fumigation for 12 hours with methyl bromide, hydrocyanic acid or acrylonitrile showed little evidence of reduced seed germination when moisture content of seed was less than 10 per cent.

Khapra-beetle larvae were more resistant to wheat treated with a piperonyl butoxide–pyrethrin dust mixture or with a malathion dust than were the adults of the granary weevil, rice weevil, and lesser grain borer.

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THE KHAPRA BEETLE, TROGODERMA GRANARIUM EVERTS[1]

DAVID L. LINDGREN, LLOYD E. VINCENT, and H. E. KROHNE[2]

INTRODUCTION

THE KHAPRA BEETLE, *Trogoderma granarium* Everts, was first identified in the United States in stored wheat and barley in two warehouses in Tulare County, California, in October, 1953 (Allen and Linsley, 1954). It is not known how this insect was introduced into the United States; however, according to Armitage (1954*a*), it is now known to have been present in California as early as 1946, at which time it was thought to be the black carpet beetle, *Attagenus piceus* (Oliver). United States Department of Agriculture entomologists surveyed grain warehouses in eleven western states in late 1954 and uncovered other infestations in Fresno, Imperial, Kern, Kings, Riverside, and San Diego counties in California; Maricopa, Mohave, Pima, Pinal, and Yuma counties in Arizona; and Curry and Roosevelt counties in New Mexico. In early 1955 a total of 151 infested premises had been found in the United States, 121 in 16 California counties, 27 in five Arizona counties, and 3 in two New Mexico counties. In addition 3 infestations in Mexicali, Baja California, Mexico, have been found.

Investigations on the biology and control of the khapra beetle were started at the University of California Citrus Experiment Station soon after it was definitely known that this insect was established in the United States. In view of the urgency of this problem and lack of published information on this insect in this country, it has been thought advisable to present the results of these investigations to date.

SYNONYMY

The khapra beetle was first described as *Trogoderma granarium* by Everts in 1898. According to Rahman, Sohi, and Sapra (1945) *Trogoderma granarium* Everts is a native of India. Harper (1955) states "The word Khapra is from an Indian word which means brick. This name described its habits in India of aestivating in the pores of the bricks used in the construction of storage warehouses."

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Barnes and Grove (1916) refer to this insect as *Attagenus undulatus* Motsch. Arrow (1917) states that *Trogoderma khapra* sp. n. had previously been figured and recorded under the name *Attagenus undulatus* Motsch.

Until 1923, this dermestid was either referred to as *Attagenus undulatus* Motsch. or *Trogoderma khapra* Arrow; then Champion (1923) pointed out that *Trogoderma khapra* Arrow is a synonym of *Trogoderma granarium* Everts, this name having been overlooked since Everts first described this insect in 1898.

REVIEW OF LITERATURE

The khapra beetle was first mentioned in Indian entomological literature as a pest by Cotes in 1894 (Barnes and Grove, 1916). He gave figures of the larva and the beetle and stated, "It is said sometimes to destroy as much as six or seven per cent of wheat stored in godowns."

One of the most comprehensive studies on this insect was conducted by Barnes and Grove and published in 1916. They state that although this insect is a serious pest of stored grain it has received little notice from scientific entomologists. They worked out the biology of this pest including descriptions of the egg, larva, pupa, and adult, length of life history, number of generations per year, effect on grain, and effects of asphyxiation. They found that this insect has four generations per year; the larvae are responsible for the damage caused since they are voracious feeders; these insects are generally found near the surface; are able to withstand adverse conditions; and cause heating in badly infested grain.

Arrow (1917) states that the khapra beetle was found in enormous profusion in cargoes of wheat from Karachi and Bombay, but had not occurred in grain imported from countries other than India, nor had it been known to perpetuate itself in Europe.

Dendy and Elkington (1918) found that the larvae of khapra beetle were destroyed in a small airspace by hermetical sealing for 6 days at 88° F, but the indications were that in a large airspace this species would be considerably less affected than *Calandra* spp.

Fletcher and Ghosh (1919), in Calcutta, found the khapra beetle in cereals and pulses. Fletcher (1920) found that this beetle revealed a long life cycle, from the end of June, 1919, to March and April, 1920, accounted for by the moist weather of the rainy season and cold winter weather, which retarded the development of the larvae.

Mason (1921) reports that in July, 1920, a serious case of insect depradation in stored malt in an English brewery was found to be due to the khapra beetle. On opening out bins in which malt was stored, they were found to be swarming with beetles and larvae intermingled with the empty husks. There does not appear to be any previous record of appreciable damage in Britain. There is little doubt that the presence of this beetle was due to shipments of Indian barley, which, prior to the First World War had been imported in large quantities for malting purposes. The only Indian barley ever used at the brewery concerned was introduced about four years previously, and the presence of numerous beetles became noticeable two years later. This species developed to such proportions as to become a serious economic pest. In experiments on control of this insect Mason found that fumigation with chlorine gas was very effective.

Parker and Long (1921) state that the khapra beetle is gradually spreading in England and can only be exterminated from malthouses by repeated fumigation. They found chloropicrin to be a more effective fumigant for killing the larvae than carbon tetrachloride, trichlorethylene, tetrachlorethane, or pentachlorethane.

Durrant (1921) states that the khapra beetle in the form of remains of the larval stage was found in wheat samples from Queensland, but whether the species was established there or only infesting the ship is doubtful.

In 1921 the Commonwealth of Australia issued a proclamation under the Quarantine Act 1908–1920 forbidding the introduction into Australia of *Attagenus undulatus* (khapra beetle) (Anonymous, 1921*b*).

Husain and Bhasine (1921) found that when the temperature in bins of wheat rose to 113° F the khapra beetle was unaffected. On exposure to various temperatures the larvae were killed in 5 hours at 122°.

Parker (1922), England, writes that malt stored in cold bins is never affected by the khapra beetle, infestations only appearing where the temperature approximates 90° to 110° F. Generally speaking the greatest infestation occurs around the walls adjoining the kiln or kiln shafts. The larvae migrate from one part of the building to another, but so far have not been observed on barley floors. Fumigation of the whole premises is the best remedy, according to Parker, though it is difficult to remove all the malt and leave the premises vacant for two or three weeks.

Zacher (1922) states that pests found in 1921 in grain from foreign sources stored in Germany included the khapra beetle. In a later paper (Zacher, 1926) he recommends carbon disulfide as the best fumigant for sacks infested with this pest.

Bhasine (1924) found that by hermetically sealing the khapra beetle in glass flasks the insects died in less than one month, but in further experiments under commercial conditions airtight storage was unsuccessful.

Mason (1924), working in England, gives a general account of the khapra beetle. He states that it will live for years without food, that larvae have been kept in petri dishes without change for three years. That it prefers high temperatures and can produce them by physiological processes in which the destruction of malt was involved was shown by the conditions of material in bins badly infested with this insect, for such bins always showed a grain temperature of 112° to 120° F, a fact that frequently led to the discovery of the pest.

Taylor (1924) states that, contrary to his previous view that the khapra beetle could not develop in malt or grain that had a moisture content of less than 2 per cent and that this moisture was communicated to the grain or malt by outside influences, it now appears as though they are themselves capable of producing moisture. It was found that in the most seriously infested bins the moisture content was as much as 7 to 7½ per cent higher than in uninfested ones, under circumstances such that it could not have been influenced by outside conditions.

According to Voelkel (1924) the khapra beetle was first reported in

Germany in 1921 and occurred in 1923 in numbers in the malt stores of a brewery in northwestern Germany. Unless otherwise stated the following data by Voelkel were obtained at a temperature of 77° F. The young adult remains for a period of from several hours to 10 days within the last larval skin that enclosed the pupa. The adult does not feed. Mating may begin immediately on emergence, but is greatly influenced by temperature. The observation of copulation at room temperature was at first quite difficult and he assumed that it occurred only at night. Oviposition begins 5 to 6 days after mating and continues until the female is 24 days old. The largest number of eggs laid on one day was 26 while the maximum laid by a female during her life and at 86° was 126. As a rule an average of 65 eggs are laid at the latter temperature. The young larva feeds on the floury debris resulting from the feeding of the older larvae, because it cannot attack entire grains. Malt and wheat are the preferred foods, but such products as rye, oats, rice, and maize are eaten also. Animal food is not refused. Pupation occurs on the forty-second day after hatching. The optimum temperature for the species lies between 89.6° and 96.8°. The number of sterile eggs increases rapidly below 77° and above 96.8°. At temperatures under 46.4° the larvae become torpid, but they can resist a temperature of 35.6° to 39.2° without any ill effect. A temperature of 14° was resisted for 72 hours by 89 per cent of the larvae. Repeated cooling to this temperature killed a larger percentage (73 per cent). As regards control, the best results were obtained with strong concentrations of Zyklon, tetrachlorethane, and chloropicrin used for a long time at temperatures over 77°.

Morison (1925), working in Edinburgh, discusses the biology of the khapra beetle. He also states that the larval hairs if swallowed in fair quantity by a human being would probably prove as harmful as powdered glass or powdered bamboo, since chitin cannot be digested and the hairs get entangled and stuck very easily in soft substances. They can be obtained in huge quantities in a case of bad infestation through the larval habit of molting the skin on top of the food.

Chopra (1928) states that larvae of the khapra beetle were controlled by fumigation with calcium cyanide at the rate of about 42 grams to 100 cubic feet for 18 hours.

Miles (1928) considers that calcium cyanide will give a satisfactory control of both adults and immature stages of the khapra beetle. He found the most successful results were obtained when repeated fumigations were carried out.

Bedwell (1931), England, states that the tendency to burrow into wood was not observed in the khapra beetle.

Nakayama (1932) found this beetle in Korea and Japan, where it was feeding on stored rice and wheat. Near Suigen it usually has one generation a year, the adults emerging in July and August. The egg, larval, and pupal stages last 6 to 12, 317 to 351, and 6 to 17 days respectively. In later papers (Nakayama, 1933*a*, *b*) he states that fumigation is the most satisfactory measure of control, all stages being killed by exposure for 25 hours to 3 to 4 pounds of carbon disulfide or for 48 hours to 8 to 16 ounces of chloropicrin per 1,000 cu. ft.

Mansbridge (1936) states that in England during the winter of 1935–36 cultures of the khapra beetle were exposed in an unheated building where conditions were comparable to those of a warehouse during an English winter. The temperature fell to 35° F on 11 days during 3 separate weeks including 2 days continuously below 32° on two occasions. The khapra-beetle cultures survived these exposures.

Madel (1939) reports that the khapra beetle developed in a drug preparation containing albumen.

Rahman and Sohi (1939), working in India, state that about 78 per cent of the one-day-old larvae were unaffected by light, but after the second day, the majority gave a negative response, the proportion doing so increasing with age until the fourth instar was reached. In subsequent instars, the proportion was slightly lower, but remained nearly constant. Many of the larvae did not react to light immediately before molting or pupating or on the day after they had molted. They state that this lack of reaction is due to the extreme toughness of the skin before and tenderness after molting, both of which restrict freedom of movement. More females reacted negatively during the oviposition than during the preoviposition or postoviposition period, but over 50 per cent reacted in this way in each period. A large majority of the males reacted negatively throughout life. A very small number reacted positively.

Chernuishex (1940) reports that of twenty-four species of insects that infest stored products in the U.S.S.R., the egg stage at 70° to 77° F is longest (12 to 17 days) in the khapra beetle and recommends that fumigation should be repeated after about a fortnight if infestation is not completely controlled by a first treatment.

Rahman (1942), India, has observed the khapra beetle feeding on wheat, maize, sorghum, rice, barley, gram, pulses, pistachio nuts, coconut, and walnut kernels, but it is really a serious pest of wheat. He also states that an unidentified mite of a pale color has been found to feed upon eggs of khapra.

Krishnamurti (1943), working in Bangalore, recommends spraying the interior of warehouses every evening with a petrol or kerosene extract of pyrethrum so as to produce a fine mist all over the interior of the warehouse.

Rahman, Sohi, and Sapra (1945) state that the khapra beetle is a serious pest of stored wheat and is distributed all over northern India. It is active from mid-March to October, but in the heavily infested godowns where the temperature rises due to insect activity it has been observed breeding even up to the end of November. They found that a female lays 4 to 89 eggs in 1 to 8 days at the rate of 1 to 55 eggs per day. Incubation period lasts for 3 to 10 days, larval stage occupies 16 to 53 days in case of male larvae and 20 to 63 days in case of female larvae, the pupal stage is completed in 3 to 8 days, and the adults live for 3 to 15 days depending upon the season. This insect passes through 4 to 5 generations in a year. Sex ratio and viability of different stages in different generations are given. They studied comparative development of the insect on different foods. Larval duration was found to be shorter on wheat, bajra, maize, sorghum, and rice, and the percentage of the viability of the larvae highest on rice and lowest on sorghum. The daily consumption of food by a female larva varies from 0.136 mg to 0.77 mg, which is double that of the male larva. Incidence of the pest at different depths in a heap is discussed. In a single storing season the extent of damage caused by this insect from the point of view of seedsmen and trade has been worked out at 5.9 to 32.5 per cent and 2.25 to 5.47 per cent, respectively.

Hinton (1945) gives the distribution of the khapra beetle as India, Ceylon, Malaya, Europe, U.S.S.R., China, Japan, Korea, Philippine Islands, Australia, and Madagascar, and concludes that it is now established in most of these countries. He states that unlike most other Dermestidae, this species prefers grain and cereal products to substances of animal origin, but will develop on dead mice, dried blood, dried insects, and similar material. He states that it will thrive on wheat, barley, oats, rye, maize, rice, and such cereal products as flour, malt, and noodles. He also notes that Munro (1940) recorded it in linseed imported into Britain from India.

Isaac (1946) writes that in 1944-45, DDT and benzene hexachloride diluted with chalk and mixed with the grain at 1:5,000 and 1:10,000 respectively, gave complete mortality of five pests in three days, but larvae of khapra were still alive after 17 days.

Parkin (1946) found that among seven species of insects likely to occur in empty sacks, the resistance of adults of *Calandra granaria* to a mixture of 3 parts (by volume) ethylene dichloride with 1 part tetrachlorethylene was exceeded only by that of larvae of the khapra beetle.

Rahman and Sohi (1946) report that exposure to the vapors of mercury kills the freshly deposited eggs of the khapra beetle but has no effect on older eggs; retards the growth of the larvae but does not kill them; has no effect on the pupae; and slightly reduces the egg-laying capacity of the adults.

According to Sohi (1947), light accelerates the development of all stages of the khapra beetle except the pupal stage but reduces oviposition; on an average a female lays 22.4 eggs under constant light against 40.8 eggs under constant darkness. Moreover, he continues, the amount of food consumed by a larva per day as well as throughout its larval period is greater under constant darkness than under constant light.

Oxley (1950) found that the khapra beetle was able to live in the Sudan under high temperatures and low humidities in large unprotected heaps of stored grain, where all other species of stored-product insects were unable to survive.

Pruthi and Singh (1950) state that, generally speaking, infestation by the khapra beetle occurs in superficial layers of grain as the pest is not able to penetrate beyond some depth into the grain. They point out that the damage to grain is done by the larvae while the adults are harmless. As a rule the larvae attack the embryo point, but in cases of heavy infestation other parts of the grain may also be attacked.

Freeman (1951) reports that the larvae are resistant to DDT and only slightly affected by gamma-BHC and are best controlled with pyrethrum sprays and dusts. The adults are susceptible to DDT and gamma-BHC so that measures designed to kill the adults before they oviposit should eradicate a population. He also states that methyl bromide is particularly effective owing to its powers of penetration.

The khapra beetle was first observed in Nigeria in 1948 on stored sorghum (Howe, 1952); it was subsequently found to be extremely abundant and widespread on stored groundnuts and evidence was obtained indicating that *it had been present on them in 1946 and probably in 1944. Howe found that* the adults cannot fly and that both adults and larvae can be dispersed by wind. The larvae feed on the groundnuts, powdering more than they consume, and also cause typical weakening of the sacks which ultimately tear. He believes that this insect is unlikely to became important in southern Nigeria owing to the less favorable climatic conditions, competition with *Tribolium,* and attack by a predacious anthocorid tentatively identified as *Lyctocoris.*

Armitage (1953) states that the khapra beetle was found in California in bulk barley in enormous populations and that this is the first recorded occurrence of this insect in the Western Hemisphere.

Parkin (1953) found that after an exposure of 50 days to a 5 per cent DDT dust, only 24 per cent of khapra larvae were killed.

Hewlett (1954*a*) found that the larvae of the khapra beetle are exceedingly resistant to the contact insecticides in general use and that even lethal doses of these are very slow to kill. Mixtures containing Valone (isovaleryl indandione) with pyrethrins or gamma-BHC were applied to larvae to discover whether the rapid action of Valone might be useful in their control. As sprays in refined kerosene, the lethal action on the larvae was rapid, but the synergism only moderate. However, as a dust on talc, a mixture of Valone with gamma-BHC showed both a rapid lethal effect and marked synergism.

Hayward (1954), in fumigating groundnuts for control of this pest in northern Nigeria, used 1 pound of methyl bromide per 5 tons of groundnuts; after a 20-hour exposure no living insects were found.

Beal (1954), working in California, states that there is no record of whether or not the khapra beetle will feed on its own exuviae.

DISTRIBUTION

Except for South America the khapra beetle is now found in all continents where grain and grain products are stored. In the United States it has become established in the states of California, Arizona, and New Mexico. It has also been reported from the U.S.S.R., England, Germany, Egypt, China, Japan, Korea, Philippine Islands, Australia, Ceylon, Malaya, Madagascar, Cyprus, Nigeria, Mexico, and is probably present in many other countries.

DESCRIPTION

Adult. When the adult khapra beetle (fig. 1) emerges from the pupa, it remains quiescent within the last larval skin for a period which varies from a few hours to ten days or more according to the temperature.

The adult is a small brownish-black beetle, oval in shape, the female measuring about ⅛ inch in length and being larger than the male. The female is lighter in color than the male. In the male, the head, thorax, and tip of the abdomen are of a dark brownish-black, the elytra and appendages are of a

Fig. 1. Khapra-beetle adults; the smaller ones are males, the larger, females.

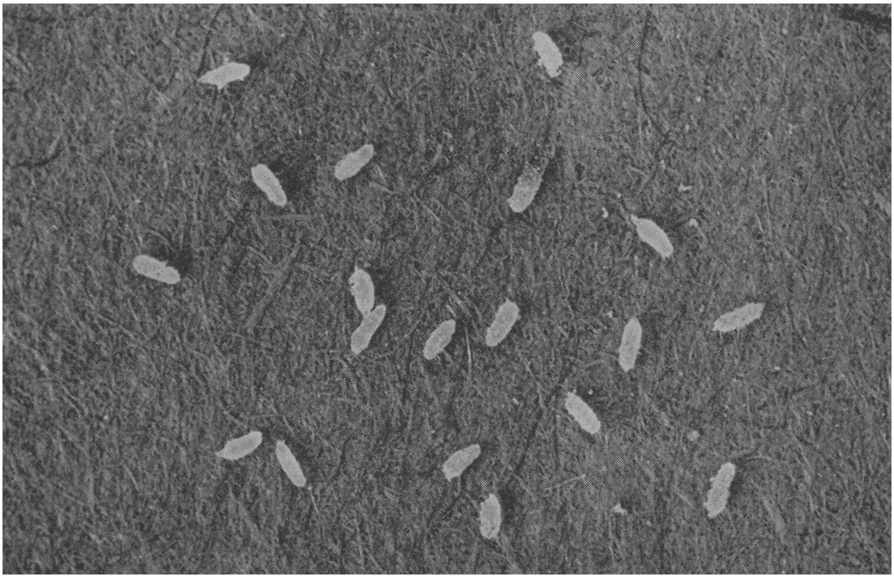


Fig. 2. Khapra-beetle eggs.

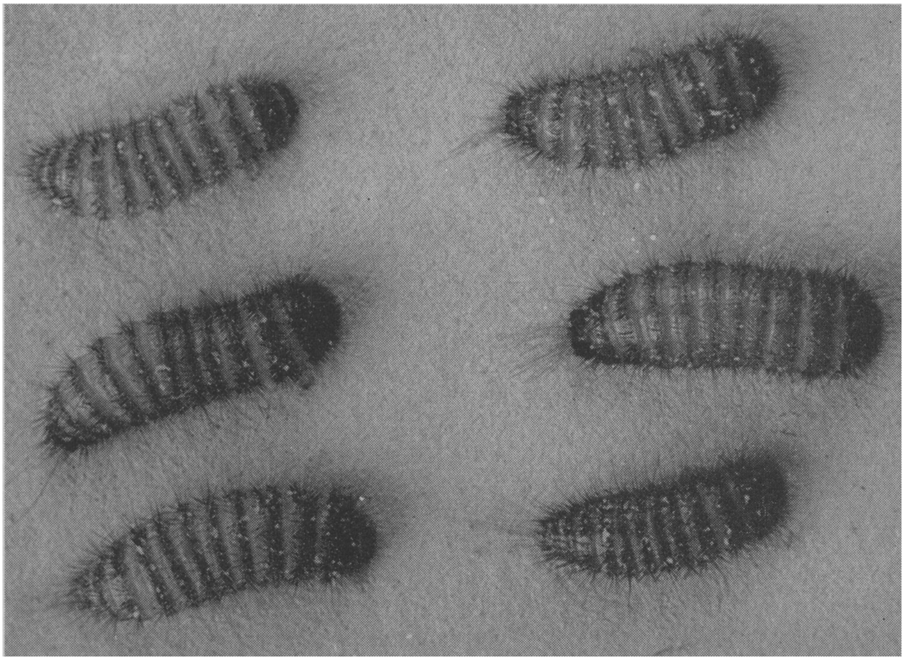


Fig. 3. Khapra-beetle fourth-instar larvae.

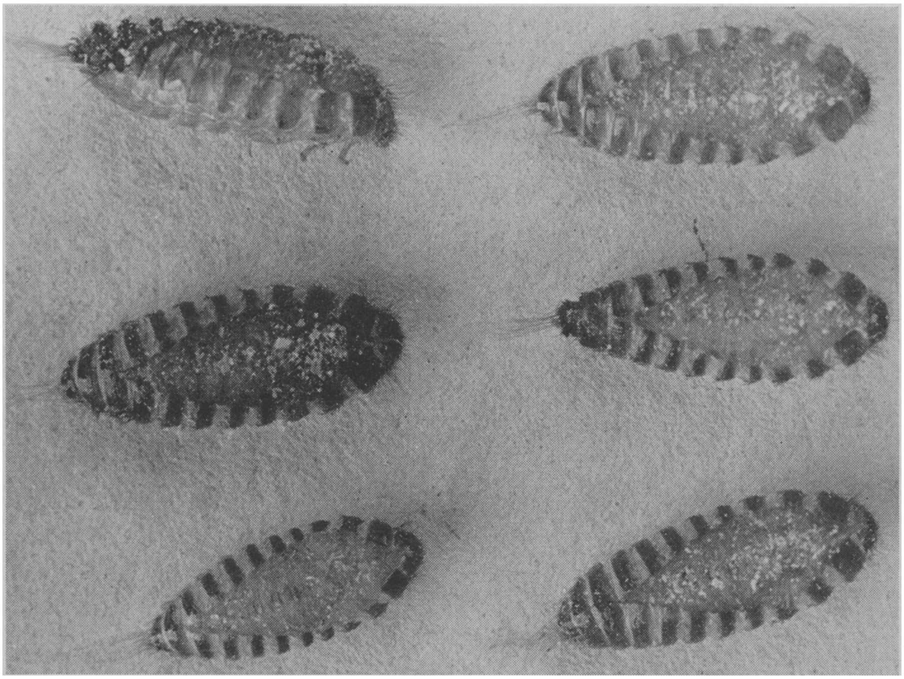


Fig. 4. Khapra-beetle pupae.

lighter color. In the female the difference in color between the head and thorax and the elytra is not so marked. The whole surface of the body and elytra is covered with fine hairs giving the body a velvety appearance, but as these hairs are rubbed off in the process of movement, the adult takes on a shiny appearance. A fringe of brown hairs covers the tip of the abdomen.

Egg. The eggs (fig. 2) are a little under $\frac{1}{64}$ inch in length, narrowly cylindrical, rounded at one end, somewhat pointed at the other, and are a translucent white when laid. The pointed end has a few hairs upon it. As development proceeds within the egg, reddish or yellowish-brown markings appear and the form of the developing larva can be distinguished.

Larva. The body of the newly hatched larva is yellowish-white and about 1/25 inch long. The head is brownish or yellowish-brown and the hairs on the segments are yellowish-brown. On development the larva assumes a reddish-brown appearance while the underside is a uniform cream color and when mature is approximately $\frac{1}{4}$ inch long.

The larva (fig. 3) is covered with two types of hairs—long simple hairs and short barbed ones. The posterior segments of the larva bear long movable erectile hairs that form somewhat of a tail projecting behind the insect.

Pupa. The female pupa (fig. 4) is approximately $\frac{1}{4}$ inch in length and is enclosed, with the exception of a portion of the dorsum, in the last cast larval skin. The pupa of the male is much smaller. The dorsal surface of the pupa is covered with hairs and the hairs along the median line form a distinct ridge. The color is a lighter brown than that of the larva. From the underside the parts of the beetle can be distinguished.

HABITS AND NATURE OF INJURY

A typical heavy khapra-beetle infestation is characterized by the presence of large numbers of larvae and their cast skins. As with most species of dermestids, feeding takes place in the larval stage. Young larvae feed on damaged kernels, while older larvae, fourth instar or more, attack whole

Fig. 5. (Left) Khapra-beetle larvae feeding on whole-kernel corn. Note larvae, abundance of shed skins, and hollow corn kernels. Fig. 6. (Right) Khapra-beetle larvae feeding on whole barley.

grain or seeds. The damage is caused by these actively feeding larvae, in which stage the insect spends the greatest part of its life cycle.

The larvae feed on a wide variety of stored products and by their continual gnawing reduce the material to a powdery mass. Unlike most other dermestids, this species prefers whole grain and cereal products to substances of animal origin but may feed on such materials as dried blood, dried milk, and fishmeal. It has been recorded from wheat, barley, oats, rye, corn, rice, groundnuts, flour, bran, malt, flaxseed, alfalfa seed, tomato seed, pinto beans, black-eyed cowpeas, sorghum seed, grain straw, alfalfa hay, various nut meats, spaghetti, noodles, cottonseed meal, dried fruits, and dried lima beans, but it prefers grains such as wheat, barley, and rice (figs. 5 through 13).

Grain under prolonged storage conditions is most favorable for khapra-beetle development and subsequent damage. Although reported losses vary from 2 to 73 per cent, an infested lot of grain if left undisturbed would eventually become a total loss.

The khapra beetle generally restricts its activity to the top 12 inches of grain, although it has occasionally been found to depths of 6 feet and may penetrate along the walls and in the corners of elevators and warehouses as deep as 12 feet or more. The presence of these larvae and their gregarious habit may cause heating of the grain which in turn creates a more favorable environment for larval development.

The larvae can feed on grain having as little as 2 per cent moisture content. They are able to live for long periods of time without food—as long as three years, according to reports in the literature.

The larvae, being relatively active, tend to wander in and out of sacked materials weakening and damaging the sacks, which ultimately may tear. They also tend to congregate in large numbers in cracks and crevices where they are very difficult to reach by ordinary sanitation practices.

Young larvae appear to be unaffected by light, but as they advance in age most of them become negatively phototropic, the number of such larvae be-

Fig. 7. (Left) Khapra-beetle larvae feeding on pinto beans. Note hollow beans. Fig. 8. (Right) Khapra-beetle larvae feeding on dried lima beans. Note hollow beans. The dark spots on whole beans indicate where larvae are about to chew out.

coming maximum in the fourth instar. Just prior to and after molting the larvae appear to be indifferent to light.

Contrary to Bedwell (1931), khapra-beetle larvae exhibit some tendency to burrow into wood especially surface gnawing.

Pupation generally occurs in the top layers of the food material.

Although the adults are seldom seen, they can usually be found in cracks and crevices and in the food material wherever the larvae occur. The adults normally do not feed, and food is unnecessary for the attainment of their full fecundity and longevity; but, contrary to Pruthi and Singh (1950), adults have been observed gnawing eroded wheat grains.

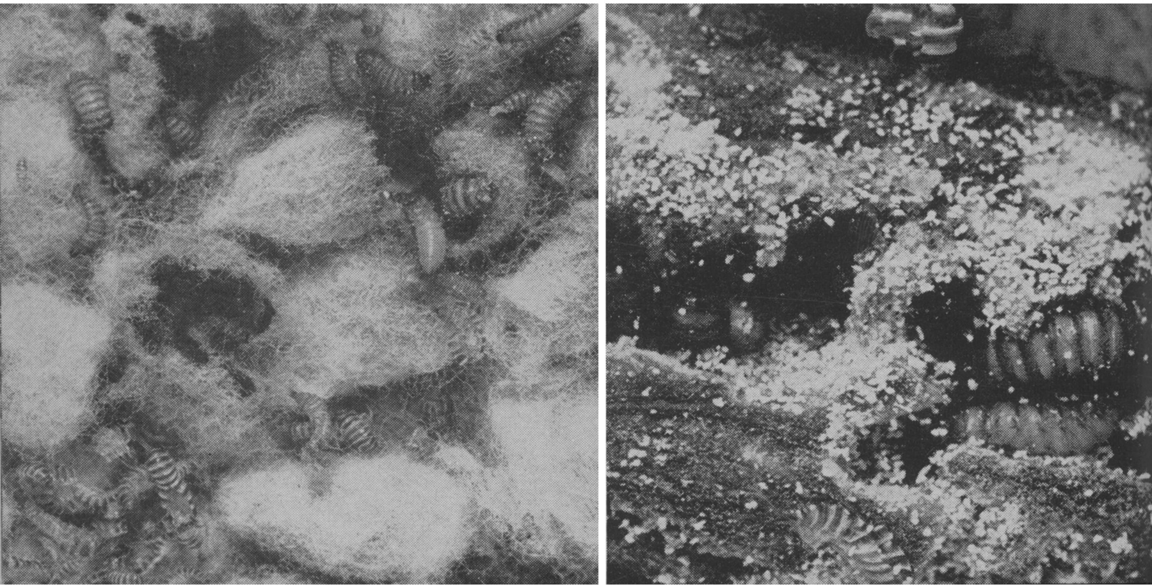
The adults usually mate immediately upon emergence and egg laying begins several days after, the interval depending on the temperature. Adults may live from a few days to several months, according to the temperature.

There is no record of the adults' being able to fly or of their occurrence as a pest in the field. Hence, infestations spread in nature for short distances are by actively crawling larvae, birds, other insects, and wind. Birds have been observed feeding on khapra-beetle larvae. Probably the most important means of spread, however, is by man and his modern methods of transporting commodities short or long distances. Any material or article stored on an infested premise is potentially capable of spreading this insect if moved from place to place. Infested trucks, railroad cars, shipholds, and so on, may harbor this insect for long periods of time since it is capable of living without food for several years. On reintroducing foods into these common carriers the larvae can move out and a new infestation is started.

EXPERIMENTS ON RESPONSES TO ENVIRONMENTAL CONDITIONS

Effects of Temperature on Development. Observations made by various authors indicate that the khapra beetle may have from 1 to 5 generations per year, depending on food, temperature, and moisture. Experiments were

Fig. 9. (Left) Khapra-beetle larvae feeding on fuzzy cottonseed. Note hollow cottonseed. Fig. 10. (Right) Khapra-beetle larvae feeding on almond meats. Note frass on the surface.



conducted to determine the length of time required for development of each stage of this insect at various temperatures. Individual eggs were placed in 1-ounce salve tins along with a supply of ground dog food and were maintained under conditions of complete darkness. Although no definite effort was made to segregate males from females, observations at 90° F indicated that males emerged from 1 to 10 days earlier than females.

Results of these experiments are shown in table 1. It will be noticed that

TABLE 1

LENGTH OF VARIOUS STAGES OF THE KHAPRA BEETLE AT VARIOUS TEMPERATURES UNDER CONDITIONS OF COMPLETE DARKNESS

Temperature, °F	Egg, days		Larva, days		Pupa, days		Adult, days		Total days, egg to adult	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
70	14	12–15	190	127–283	17	13–19	25	12–51	220	158–310
80	8	8–9	148	46–199	10	7–12	25	6–53	166	63–216
90	5	4–6	27	19–47	6	4–11	16	6–31	37	28–56
93–95	3	3–3	19	15–23	4	3–7	12	4–23	26	25–29

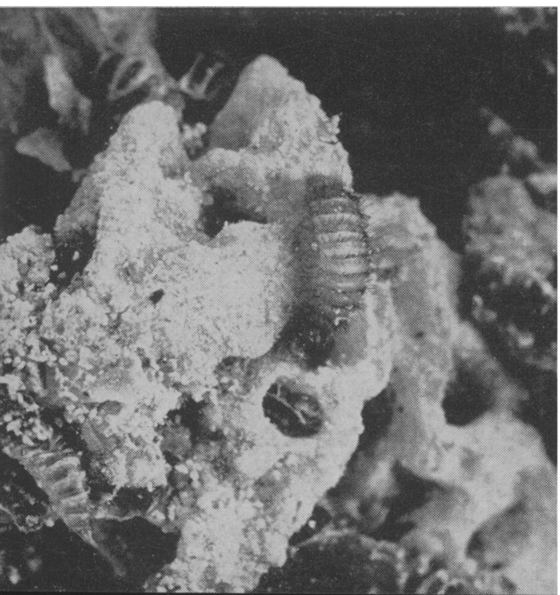
at 70° F it required an average of 14 days for the eggs to hatch, 190 days for larval development, 17 days for pupal development, and a total average of 220 days from egg to adult. The average adult longevity was 25 days.

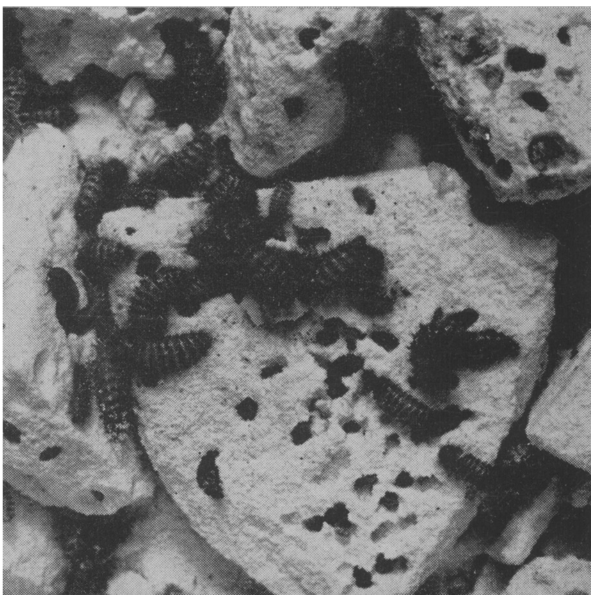
At 80° F it required an average of 8 days for the eggs to hatch, 148 days for larval development, 10 days for pupal development, and a total average of 166 days from egg to adult. The average adult longevity was 25 days.

At 90° F it required an average of 5 days for the eggs to hatch, 27 days for larval development, 6 days for pupal development, and a total average of 37 days from egg to adult. The average adult longevity was 16 days.

At 93°–95° F it required an average of 3 days for the eggs to hatch, 19 days

Fig. 11. (Left) Khapra-beetle larvae feeding on walnut meats. Fig. 12. (Right) Khapra-beetle larvae feeding on powdered skim milk. Note the numerous holes and the caking effect created by the larvae.





for larval development, 4 days for pupal development, and a total average of 26 days from egg to adult. The average adult longevity was 12 days.

Observations at these various temperatures indicated that there was very little or no mortality of eggs, larvae, or pupae of the khapra beetle at 80°, 90° or 93°–95° F. At 70° some mortality occurred in both the egg and larval stages, but none in the pupal stage.

TABLE 2

EFFECT OF LIGHT ON THE DEVELOPMENT OF THE VARIOUS STAGES OF KHAPRA BEETLE AND LONGEVITY OF ADULT

Temperature, °F	Light	Total days required for					Number of larval molts
		Egg	Larva	Pupa	Adult longevity	Egg to adult	
93–95	100% light	3	20	3	14	26	4
93–95	100% dark	3	19	4	12	26	4

Effect of Light on Development and Longevity. Table 2 gives the results of an experiment to determine the effect of light on the development of the various stages of khapra beetle and on the longevity of the adults. The temperature of the cabinet in which the insects were reared varied between 93° and 95° F. Ground dog food was used in these experiments. One group of insects was reared in petri dishes under 100 per cent light conditions, the light being furnished by a 50-watt electric light bulb about 2 feet from the

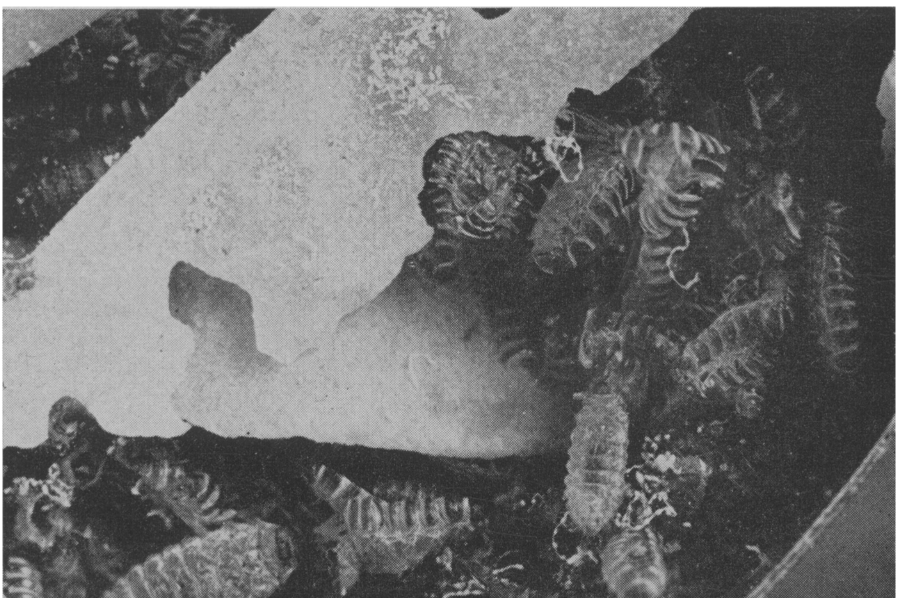


Fig. 13. Khapra-beetle larvae feeding on egg noodles. Note chewed-out portions.

insects; the other group of insects was reared in salve tins under complete darkness. Observations were made twice daily. There was little or no difference between the two groups in the rate of development of the egg, larval, or pupal stages or in the longevity of the adults.

Another series of experiments was conducted to determine the number of generations of khapra beetle under various light conditions. Light was furnished by a 50-watt bulb about 2 feet from the cultures. These insects were reared in pint Mason jars on ground dog food. Adult khapra beetles were placed in food and allowed to lay eggs for several days. Then the adults were removed and the time recorded when adults appeared in the culture. Observations were made twice weekly. Results are given in table 3. It

TABLE 3

EFFECT OF LIGHT ON THE LENGTH OF GENERATIONS OF KHAPRA BEETLE

Temperature, °F	Light	Date started, 1954	Date terminated, 1955	Number of generations	Average length of generation, days
90	100% dark	May 6	Feb. 13	9	31
90	50% dark, 50% light	May 6	Feb. 2	9	30
86–94	25% light, 75% dark	Nov. 2	Feb. 21	3	37
86–94	100% dark	Sept. 30	Feb. 25	4	37

appears that at any given temperature, there is very little difference in the number of generations among insects reared in complete darkness, in 75 per cent darkness and 25 per cent light, and in 50 per cent darkness and 50 per cent light.

Larvae from various infested warehouses in Imperial Valley were collected on November 11, 1954, January 3, 7, and 19, and February 14, 1955, to determine whether these larvae would pupate and emerge as adults when placed at a temperature of 93° to 95° F under laboratory conditions. These larvae developed, pupated, and emerged as adults in 2 to 3 weeks; but in infested warehouses adults did not appear until the middle of April. This would indicate that these insects do not hibernate because of light conditions, but are relatively inactive because of lower temperatures present in warehouses during the winter months.

An experiment was conducted to determine the viable-egg production and sex ratio of progeny of adult females and males held at various temperatures under conditions of complete darkness and fed ground dog food. From table 4 it will be observed that there appeared to be no difference in average viable-egg production at 70° and at 80° F. At 90° the viable-egg production increased to an average of 93 per female, with a range of 77 to 116. The viability of eggs at this temperature averaged 94 per cent. The sex ratio at all temperatures was approximately 1:1.

The number of khapra-beetle larval molts at various temperatures was determined under conditions of complete darkness. It will be noticed from table 5 that at 70° and 80° F the average number of molts was 7 to 8, while at 90° and 93°–95° it was only 4. It appears that a greater number of molts occurs under less favorable conditions of development.

Effects of Food on Development. Development of the khapra beetle was studied to determine whether it could complete its life cycle on various foods. Adult male and female beetles were placed on each food and allowed to lay eggs; the adults were then removed and the food material containing the eggs was held at 93° to 95° F. Table 6 shows the results of these experiments. There was a large variation in the length of development on the different foods, the time from egg to adults being shortest (29 to 30 days) on ground wheat, ground barley, and ground dog food. The larvae fed on whole corn for 8 months, fuzzy cottonseed for 5½ months, spaghetti and egg noodles for 5 months, and powdered skim milk, raisins, peaches, prunes, and dates for 3 months and none of these pupated, although the larvae fed actively up to the termination of the experiment. In the case of tapioca and ground flaxseed young larvae were observed but eventually died. Larvae were introduced into beef blood and survived to the termination of the experiment 6 months later.

TABLE 4

VIABLE-EGG PRODUCTION AND SEX RATIO OF THE KHAPRA BEETLE AT VARIOUS TEMPERATURES

Under conditions of complete darkness with food

Temperature, °F	Number of eggs per female			Sex ratio, males : females
	Min.	Max.	Av.	
70	54	76	65	1 : 1
80	46	71	53	1.2 : 1
90	77	116	93	1 : 1.2

Resistance to Low Temperatures. Experiments were conducted to determine the effects of low temperatures on eggs, larvae, and pupae of khapra beetle. In one series of experiments a conventional home refrigerator was used in which the temperature ranged from 25° to 48° F, as measured by a

TABLE 5

AVERAGE NUMBER AND RANGE OF MOLTS OF KHAPRA-BEETLE LARVAE AT VARIOUS TEMPERATURES

Under conditions of complete darkness

Temperature, °F	Number of molts	
	Average	Range
70	8	4–11
80	7	5–9
90	4	3–6
93–95	4	2–5

maximum-minimum thermometer observed daily. Another series was conducted using a deep-freeze unit in which the temperature remained at –6° ±2° during the exposure period.

Individual eggs not over two days old in plastic containers were exposed to a temperature of –6° F for periods of time ranging from 2 to 120 minutes. A total of 47 separate experiments was conducted using 5 to 20 eggs per test. Although the tests were replicated many times, using eggs laid by adults

TABLE 6

DEVELOPMENT OF KHAPRA BEETLE ON VARIOUS FOODS AT 93° TO 95° F

Food	Stage started	Developed to	Length of observation
Whole kernel wheat	Egg	Adult	....
Ground wheat	Egg	Adult	....
Whole kernel rice	Egg	Adult	....
Ground rice	Egg	Adult	....
Whole kernel corn	Egg	Larvae	8 months
Ground corn	Egg	Adult	....
Whole kernel barley	Egg	Adult	....
Ground barley	Egg	Adult	....
Ground dog food	Egg	Adult	....
Fuzzy cottonseed	Egg	Larvae	5.5 months
Lima beans	Egg	Adult	....
Pinto beans	Egg	Adult	....
Powdered skim milk	Egg	Larva	3 months
Whole kernel flax seed	Egg	Adult	....
Ground flax seed	Egg	Larva*	....
Walnut meats	Egg	Adult	....
Pecan meats	Egg	Adult	....
Almond meats	Egg	Adult	....
Spaghetti	Egg	Larva	5 months
Egg noodles	Egg	Larva	5 months
Pearl barley	Egg	Adult	....
Tapioca	Egg	Larva*	....
Beef blood	Larva	Larva	6 months
Raisins	Egg	Larva	3 months
Peaches	Egg	Larva	3 months
Prunes	Egg	Larva	3 months
Dates	Egg	Larva	3 months

* Larvae present on first few observations, but eventually died.

reared under similar conditions, the results were not consistent. In some experiments a kill of 100 per cent was obtained to 10-, 15-, and 18-minute exposure periods, whereas in others some eggs hatched at exposures of 40, 80, and 120 minutes. In a series of 36 parallel control experiments at 90° in which over 600 eggs were used, 94 per cent hatch was obtained.

Larvae and pupae in salve tins in the absence of food were exposed to a temperature of –6° ±2° F in a deep-freeze unit. The larvae were full-grown fourth-instar, and the pupae were less than 2 days old. These larvae and pupae were exposed for given lengths of time, removed, and held at 90° F, and mortality checks made at regular intervals over a period of several weeks. Results are given in table 7. The pupae were less able to survive at this temperature than were larvae, a 100 per cent mortality of the pupae being obtained with an exposure of 20 minutes or longer, whereas a few larvae survived an exposure of 240 minutes. Eighty per cent or more of the larvae were killed with an exposure of 30 minutes or longer.

Another series of experiments was conducted on fourth-instar larvae which were exposed to a daily fluctuating temperature of 25° to 48° F in a household refrigerator. These larvae were in salve tins containing a small amount of food. It may be observed from table 8 that more than 50 per cent of the larvae survived this fluctuating temperature for 28 days, and 2.5 per cent survived an exposure of 51 days. It would appear from these data that the larval stage is able to withstand relatively low fluctuating temperatures for long periods of time. This would indicate that larvae could withstand outdoor conditions in the southern sections of the United States.

TABLE 7

PER CENT MORTALITY OF KHAPRA-BEETLE LARVAE AND PUPAE AT –6° ± 2° F

Exposure, minutes	Per cent mortality	
	4th instar larvae*	Pupae
0	0	0
5	..	10
10	19	40
15	..	70
20	..	100
30	85	100
60	80	100
100	..	100
120	95	..
150	97.5	..
180	95	..
240	95	..

* No food present.

TABLE 8

PER CENT MORTALITY OF KHAPRA-BEETLE LARVAE UNDER A DAILY FLUCTUATING TEMPERATURE OF 25° TO 48° F

In the presence of food

Exposure, days	Per cent mortality of 4th instar larvae
8	0
12	2.5
16	2.5
20	10.0
24	15.0
28	47.0
30	67.5
51	97.5

Resistance to High Temperatures. Tests were conducted to determine the thermal death points of the larvae and pupae of the khapra beetle at various humidities. The methods used in these tests were similar to those used by Lindgren and Vincent (1953) on nitidulid larvae and adults.

From the results shown in table 9 it may be noted that the pupae are more susceptible than the larvae to high temperatures. In general, at each temperature tested, the survival of both larvae and pupae was slightly higher at 75 per cent relative humidity than at either 10 or 50 per cent.

In comparing the thermal death points of larvae of nitidulid beetles as given by Lindgren and Vincent (1953) with those of khapra-beetle larvae, under identical experimental conditions, it was found that the khapra-beetle larvae appeared to be much more resistant to high temperatures. At 120° F and 50 per cent relative humidity it required 10 minutes to kill 95 per cent of the nitidulid larvae, whereas at 124° and 50 per cent relative humidity it required 105 minutes to kill 95 per cent of the khapra-beetle larvae.

TABLE 9

TIME REQUIRED TO KILL 50 AND 95 PER CENT OF KHAPRA-BEETLE LARVAE AND PUPAE AT HIGH TEMPERATURES AND WITH VARIOUS RELATIVE HUMIDITIES

Temperature and stage of khapra beetle	Minutes required to kill					
	50 per cent			95 per cent		
	At 10 per cent rel. hum.	At 50 per cent rel. hum.	At 75 per cent rel. hum.	At 10 per cent rel. hum.	At 50 per cent rel. hum.	At 75 per cent rel. hum.
118° F						
4th-instar larvae	600	600	720	960	960	1,140
Pupae	210	220	240	420	420	720
124° F						
4th-instar larvae	45	45	60	105	105	135
Pupae	26	26	30	50	40	90
131° F						
4th-instar larvae	8	8	10	8	8	15
Pupae	8	8	8	8	8	8

Oosthuizen (1935) found that at 114° F it required approximately 90 minutes to kill 95 per cent of mature larvae of *Tribolium confusum* at all three relative humidities tested—0, 30, and 75 per cent. In table 9 it may be seen that at 118° and at 50 and 75 per cent relative humidity it required 960 and 1,140 minutes respectively to kill 95 per cent of fourth-instar khapra-beetle larvae. Oosthuizen also found that at 114° and 75 per cent relative humidity, it required 160 minutes to kill 95 per cent of *T. confusum* pupae, whereas, as can be seen from table 9, it required 720 minutes to kill 95 per cent of khapra-beetle pupae at 118° and 75 per cent relative humidity. These comparisons indicate that the larvae and pupae of the khapra beetle are more resistant to high temperatures than are those of the confused flour beetle.

These data indicate that the khapra beetle is probably able to withstand temperatures found in Imperial Valley, California, which frequently reach 120° F.

FUMIGATION EXPERIMENTS

Effect of Various Fumigants on Eggs, Larvae, and Pupae of Khapra Beetle. In the control of the khapra beetle, fumigation (fig. 15; see page 31) is one of the most frequently used and most effective methods of control. Experiments were conducted to determine the relative effectiveness of ten fumigants to the eggs, larvae, and pupae of the khapra beetle. All fumigations were conducted at a temperature of 70° F with a 2-hour exposure.

Eggs used were approximately 1 day old, the larvae were fourth instar, the pupae newly formed.

TABLE 10

LD_{95} OF VARIOUS FUMIGANTS FOR KHAPRA-BEETLE EGGS, LARVAE, AND PUPAE AND FOR GRANARY-WEEVIL ADULTS

At 70° F and with 2-hour exposure

Fumigant	Milligrams per liter to kill 95 per cent			
	Khapra beetle			Granary weevil
	Eggs	Larvae	Pupae	Adults
Acrylonitrile	<2.9	18.0	30.0	8.0
Carbon disulfide	220	220	214	149
Chloropicrin	>290	34	58	34.5
Ethylene chlorobromide	23.5	120	60	48
Ethylene dibromide	16	27	40	29
Ethylene dichloride	>271	>271	>271	>271
Ethylene oxide	13.5	54	70	31
Hydrocyanic acid	2.7	8.5	6.4	29
Methallyl chloride	>198	148	136	87
Methyl bromide	31	54	44	27

After fumigation the insects were held at a temperature of 82° F for a period of 10 to 15 days, at which time mortality counts were made. Controls were run simultaneously for all stages and a correction for natural mortality was made. Results are given in table 10. In comparing the toxicity of the fumigants at the LD_{95} to the various stages of the khapra beetle it was found that the eggs were more susceptible to acrylonitrile, ethylene chlorobromide, ethylene dibromide, ethylene oxide, hydrocyanic acid, and methyl bromide than the larval or pupal stages. It was found that larvae were more susceptible to chloropicrin than the egg or pupal stages. The pupae were more susceptible than the eggs or larvae to carbon disulfide and methallyl chloride, although in the case of carbon disulfide the amount per liter required to kill 95 per cent of the eggs, larvae, and pupae was approximately the same. Eggs were relatively resistant to chloropicrin and to methallyl chloride fumigation.

Granary-weevil adults were exposed to the same fumigants, and the results are also given in table 10. Hydrocyanic acid was the only fumigant to which all three of the immature stages of the khapra beetle were more susceptible than the granary-weevil adults.

Another series of fumigation tests was conducted similar to those discussed above, in which fourth-instar larvae and newly formed pupae of the khapra beetle were exposed for periods of 8 or 24 hours at 70° F. Results of these experiments are given in table 11, and for comparative purposes the results of the 2-hour tests are repeated. It will be observed from table 11 that at LD_{95} hydrocyanic acid and acrylonitrile were the most toxic fumigants tested against larvae and pupae of khapra beetle. Ethylene dichloride, carbon disulfide, and methallyl chloride were the least toxic, while ethylene dibromide, methyl bromide, chloropicrin, ethylene oxide, and ethylene chlorobromide fell somewhere between these two groups.

In table 11 it may also be noticed that in general larvae are more susceptible to acrylonitrile, chloropicrin, ethylene dibromide, and ethylene oxide than

TABLE 11

LD_{95} OF VARIOUS FUMIGANTS FOR KHAPRA-BEETLE LARVAE AND PUPAE AT 70° F AND WITH 2-, 8-, AND 24-HOUR EXPOSURES

Fumigant	Milligrams per liter to kill 95 per cent					
	Larvae			Pupae		
	2 hours	8 hours	24 hours	2 hours	8 hours	24 hours
Acrylonitrile	18	6.0	3.5	30	7.0	4.0
Carbon disulfide	220	87	38	214	54	20
Chloropicrin	34	12	8.0	58	24	11
Ethylene chlorobromide	120	32	18	60	19	8.0
Ethylene dibromide	27	10	7.0	40	12	8.0
Ethylene dichloride	>271	260	210	>271	105	47
Ethylene oxide	54	22	15	70	25	15
Hydrocyanic acid	8.5	3.3	1.8	6.4	2.7	1.8
Methallyl chloride	148	62	28	136	48	19
Methyl bromide	54	17	8.0	44	16	7.5

are the pupae, while the pupae are more susceptible to carbon disulfide, ethylene chlorobromide, ethylene dichloride, hydrocyanic acid, methallyl chloride, and methyl bromide.

An experimental fumigation was conducted with barley infested with khapra beetle. A granular calcium cyanide product (4 pounds equivalent to 1 pound of actual hydrocyanic acid) was used at the rate of 100 pounds per 100 tons, in a concrete bin 27.5 feet high and having a diameter of 16 feet. The granular calcium cyanide dust was introduced into the grain stream at a rate proportional to the rate of flow of grain. The bin, being normally open at the top, was sealed with a plastic tarp before the treated grain was introduced. Upon checking the fumigated barley several days after treatment, no live adults or immature stages were found.

Effect of Various Fumigants on Seed Germination. Experiments were conducted in coöperation with the State Department of Agriculture, Seed Laboratory, Sacramento, California, to determine the effect of fumigation on seed germination. These experiments were conducted in 100-cubic-foot chambers in which the temperature was controlled to ±1° F. Before fumigation moisture contents of all samples of seeds to be fumigated were determined. After fumigation the seeds were allowed to air for 24 hours and were then shipped to the State Department of Agriculture Seed Laboratory at Sacramento, California, where the germination tests were conducted.

TABLE 12

SEED GERMINATION AFTER FUMIGATION WITH METHYL BROMIDE, HYDROCYANIC ACID, AND ACRYLONITRILE

Fumigation for 12 hours at 70° F

Variety	Methyl bromide at 4 lbs./1,000 cu. ft.					Hydrocyanic acid at ½ lb./1,000 cu. ft.					Acrylonitrile at 1 lb./1,000 cu. ft.				
	Moisture content per cent	Control seed		Fumigated seed		Moisture content per cent	Control seed		Fumigated seed		Moisture content per cent	Control seed		Fumigated seed	
		Per cent germination	Per cent hard	Per cent germination	Per cent hard		Per cent germination	Per cent hard	Per cent germination	Per cent hard		Per cent germination	Per cent hard	Per cent germination	Per cent hard
Alfalfa, Red Seal, *Medicago sativa*	6.2	85	5	89	4	6.2	85	5	89	4	6.2	85	5	91	2
Beans, lima, Henderson, *Phaseolus lunatus*	8.3	89*	..	86	2	8.3	89*	..	88	..	8.3	89*	..	86	1
Beans, pole, *Phaseolus vulgaris*	7.3	87	8	90	7	7.3	87	8	76	21	7.3	87	8	79	16
Beet, Detroit Dark Red Short Top, *Beta vulgaris*	7.8	60	..	61	..	7.8	60	..	64	..	7.8	60	..	65	..
Bentgrass, Astoria, *Agrostis tenuis*	8.6	81	..	81	..	8.6	81	..	83	..	8.6	81	..	83	..
Bentgrass, highland, *Agrostis tenuis*	8.6	87	..	67	..	8.6	87	..	88	..	8.6	87	.	83	..
Bentgrass, seaside, *Agrostis palustris*	9.1	89	..	91	..	9.1	89	..	89	..	9.1	89	..	88	..
Bermuda, hulled, *Cynodon dactylon*	9.2	88	..	93	..	9.2	88	..	90	..	9.2	88	..	87	..
Bermuda, unhulled, *Cynodon dactylon*	8.8	96	..	93	..	8.8	96	..	91	..	8.8	96	..	93	..
Bluegrass, Fancy Kentucky, *Poa pratensis*	8.7	70	..	69	..	8.7	70	..	65	..	8.7	70	..	70	..
Bluegrass, Merion, *Poa pratensis*	8.1	74	..	68	..	8.1	74	..	79	..	8.1	74	..	77	..
Bromegrass, mountain, *Bromus marginatus*	9.1	35	..	53	..	9.1	35	..	49	..	9.1	35	..	48	..
Bromegrass, prairie, *Bromus catharticus*	8.3	89	..	95	..	8.3	89	..	93	..	8.3	89	..	95	..
Bromegrass, smooth, *Bromus inermis*	9.1	88	..	94	..	9.1	88	..	91	..	9.1	88	..	87	..
Burnet, *Sanguisorba minor*	7.0	90*	..	88	..	7.0	90*	..	76	..	7.0	90*	..	77	..
Cabbage, Premium Flat Dutch, *Brassica oleracea capitata*	5.2	91	..	90	..	5.2	91	..	89	..	5.2	91	..	89	..
Carrot, Long Chantenay, *Daucus carota*	6.2	92	..	95	..	6.2	92	..	95	..	6.2	92	..	91	..
Cauliflower, Early Snowball-A, *Brassica oleracea botrytis*	5.8	83	..	86	..	5.8	83	..	86	..	5.8	83	..	86	..
Celery, Utah 10-B, *Apium graveolens*	6.7	93	..	90	..	6.7	93	..	90	..	6.7	93	..	91	..
Clover, alsike, *Trifolium hybridum*	7.5	82	12	77	16	7.5	82	12	78	17	7.5	82	12	79	14
Clover, black medic, *Medicago lupulina*	8.5	65	2	65	1	8.5	65	2	63	2	8.5	65	2	60	3
Clover, bur, *Medicago hispida*	5.3	72	19	70	21	5.3	72	19	71	19	5.3	72	19	70	22
Clover, crimson, *Trifolium incarnatum*	7.9	74	2	75	3	7.9	74	2	69	2	7.9	74	2	76	2
Clover, hubam, *Melilotus* sp.	7.0	40	39	42	26	7.0	40	39	36	39	7.0	40	39	35	42
Clover, Ladino, *Trifolium repens*	6.7	90	8	90	9	6.7	90	8	91	8	6.7	90	8	92	5
Clover, Mammoth Red, *Trifolium pratense*	7.9	77	6	79	9	7.9	77	6	77	8	7.9	77	6	75	9
Clover, Mt. Barker subterranean, *Trifolium subterraneum*	6.6	87	5	77	4	6.6	87	5	81	11	6.6	87	5	82	9

* Company germination.

TABLE 12—*Continued*

Variety	Methyl bromide at 4 lbs./1,000 cu. ft.					Hydrocyanic acid at ½ lb./1,000 cu. ft.					Acrylonitrile at 1 lb./1,000 cu. ft.				
	Moisture content per cent	Control seed		Fumigated seed		Moisture content per cent	Control seed		Fumigated seed		Moisture content per cent	Control seed		Fumigated seed	
		Per cent germination	Per cent hard	Per cent germination	Per cent hard		Per cent germination	Per cent hard	Per cent germination	Per cent hard		Per cent germination	Per cent hard	Per cent germination	Per cent hard
Clover, red, *Trifolium pratense*	7.5	91	1	91	1	7.5	91	1	90	4	7.5	91	1	90	3
Clover, rose, *Trifolium hirtum*	5.4	48	47	36	58	5.4	48	47	45	51	5.4	48	47	41	55
Clover, strawberry, *Trifolium fragiferum*	6.2	44	47	50	43	6.2	44	47	52	42	6.2	44	47	46	48
Clover, sweet, *Melilotus* sp.	8.0	61.5	11	58	9	8.0	61.5	11	56	13	8.0	61.5	11	59	8
Clover, sweet yellow blossom, *Melilotus* sp.	7.1	74	13	71	16	7.1	74	13	68	18	7.1	74	13	68	15
Clover, Tallarook subterranean, *Trifolium subterraneum*	6.7	68	12	65	13	6.7	68	12	60	21	6.7	68	12	63	16
Clover, white, *Trifolium repens*	6.8	91	4	90	4	6.8	91	4	84	4	6.8	91	4	87	3
Corn, R-54 Strain Aristogold, *Zea mays*	6.5	22	..	15	..	6.5	22	..	15	..	6.5	22	..	15	..
Cucumber, Black Diamond, *Cucumis sativus*	5.7	86	..	81	..	5.7	86	..	85	..	5.7	86	..	85	..
Eggplant, Burpee's Black Beauty, *Solanum melongena*	6.1	70	..	60	..	6.1	70	..	66	..	6.1	70	..	70	..
Fescue, Alta, *Festuca arundinacea*	8.9	86	..	81	..	8.9	86	..	82	..	8.9	86	..	78	..
Fescue, Chewings, *Festuca* sp	9.2	92	..	93	..	9.2	92	..	89	..	9.2	92	..	89	..
Fescue, creeping red, *Festuca* sp.	8.8	96	..	94	..	8.8	96	..	95	..	8.8	96	..	95	..
Fescue, Illahee, *Festuca* sp.	8.5	93	..	93	..	8.5	93	..	95	..	8.5	93	..	95	..
Fescue, meadow, *Festuca elatior*	8.8	69	..	82	..	8.8	69	..	75	..	8.8	69	..	70	..
Fescue, Raineer, *Festuca* sp.	8.0	89	..	87	..	8.0	89	..	89	..	8.0	89	..	88	..
Grass, Dallis, *Paspalum dilatatum*	7.9	68	..	56	..	7.9	68	..	66	..	7.9	68	..	73	..
Grass, orchard, *Dactylis glomerata*	8.0	78	..	75	..	8.0	78	..	78	..	8.0	78	..	77	..
Grass, Rhodes, *Chloris gayana*	7.7	61	..	61	..	7.7	61	..	60	..	7.7	61	..	65	..
Lettuce, White Big Boston, *Lactuca sativa*	4.9	97	..	99	..	4.9	97	..	95	..	4.9	97	..	95	..
Melilotus indica	7.1	88	2	90	1	7.1	88	2	86	2	7.1	88	2	86	3
Muskmelon, Hearts of Gold, *Cucumis melo*	5.2	97	..	96	..	5.2	97	..	95	..	5.2	97	..	98	..
Mustard, California black, *Brassica kaber*	5.6	90	..	79	..	5.6	90	..	47	..	5.6	90	..	43	..
Oatgrass, tall meadow, *Arrhenatherum elatius*	7.9	84	..	87	..	7.9	84	..	83	..	7.9	84	..	83	..
Okra, Clemson Spineless, *Hibiscus esculentus*	7.4	88	4	93	3	7.4	88	4	93	5	7.4	88	4	90	5
Onion, Excell Bermuda, *Allium cepa*	7.2	89	..	87	..	7.2	89	..	93	..	7.2	89	..	92	..
Pea, Little Marvel, *Pisum sativum*	6.3	98	..	96	..	6.3	98	..	96	..	6.3	98	..	96	..
Peas, Canadian, *Pisum sativum arvense*	7.0	89*	..	97	..	7.0	89*	..	96	..	7.0	89*	..	97	..

* Company germination.

TABLE 12—*Concluded*

Variety	Methyl bromide at 4 lbs./1,000 cu. ft.					Hydrocyanic acid at ½ lb./1,000 cu. ft.					Acrylonitrile at 1 lb./1,000 cu. ft.				
	Moisture content per cent	Control seed		Fumigated seed		Moisture content per cent	Control seed		Fumigated seed		Moisture content per cent	Control seed		Fumigated seed	
		Per cent germination	Per cent hard	Per cent germination	Per cent hard		Per cent germination	Per cent hard	Per cent germination	Per cent hard		Per cent germination	Per cent hard	Per cent germination	Per cent hard
Pepper, California Wonder, *Capsicum frutescens*	6.0	96	..	98	..	6.0	96	..	95	..	6.0	96	..	95	..
Poa trivialis	8.8	86	..	94	..	8.8	86	..	87	..	8.8	86	..	87	..
Pumpkin, Small Sugar, *Cucurbita pepo*	5.5	94*	..	90	..	5.5	94*	..	94	..	5.5	94*	..	94	..
Radish, Crimson Giant Globe, *Raphanus sativus*	5.0	92	..	95	..	5.0	92	.	94	..	5.0	92	..	94	..
Redtop, fancy, *Agrostis alba*	8.1	82	..	82	..	8.1	82	..	84	..	8.1	82	..	82	..
Ryegrass, common, *Lolium* sp.	8.8	98	..	91	..	8.8	98	..	94	..	8.8	98	..	90	..
Ryegrass, perennial, *Lolium perenne*	9.0	93	..	94	..	9.0	93	..	95	..	9.0	93	..	93	..
Smilo, *Oryzopsis miliacea*	8.4	84	..	42	..	8.4	84	..	56	..	8.4	84	..	69	..
Spinach, Nobel, *Spinacea oleracea*	7.9	80	..	84	..	7.9	80	..	76	..	7.9	80	..	83	..
Squash, Zucchini Bush, *Cucurbita* sp.	5.7	90*	..	84	..	5.7	90*	..	85	..	5.7	90*	..	90	..
Timothy, *Phleum pratense*	9.0	86	..	88	..	9.0	86	..	88	..	9.0	86	..	89	..
Tomato, Burpee's Sunnybrook F_2 hybrid, *Lycopersicon esculentus*	6.2	93	..	92	..	6.2	93	..	93	..	6.2	93	..	92	..
Trefoil, birdsfoot broadleaf, *Lotus corniculatus*	8.0	75	9	65	16	8.0	75	9	77	12	8.0	75	9	73	14
Trefoil, birdsfoot narrowleaf, *Lotus corniculatus*	7.5	75	22	76	21	7.5	75	22	74	22	7.5	75	22	73	23
Turnip, Golden Ball, *Brassica rapa*	5.3	81*	..	82	..	5.3	81*	..	73	..	5.3	81*	..	74	..
Veldtgrass, perennial, *Ehrhartia calycina*	7.9	28*	..	39	..	7.9	28*	..	22	..	7.9	28*	..	19	..
Vetch, common, *Vicia sativa*	8.1	91*	..	91	4	8.1	91*	..	96	1	8.1	91*	..	92	2
Vetch, purple, *Vicia atropurpurea*	8.5	92*	..	95	2	8.5	92*	..	95	1	8.5	92*	..	92	1
Watermelon, Striped Klondike, *Citrullus vulgaris*	5.7	98*	..	96	..	5.7	98*	..	95	..	5.7	98*	..	95	..
Wheatgrass, crested, *Agropyron desertorum*	8.8	87*	..	93	..	8.8	87*	..	99	..	8.8	87*	..	90	..
Wheatgrass, tall, *Agropyron elongatum*	8.4	95*	..	98	..	8.4	95*	..	96	..	8.4	95*	..	96	..
Larkspur, Giant Imperial, mixed colors	6.2	80*	..	90	..	6.2	80*	..	85	..	6.2	80*	..	93	..
Marigold, tall double, African Sun Giants	6.8	97*	..	90	..	6.8	97*	..	64	..	6.8	97*	..	62	..
Petunia, Funny Face	5.9	94*	..	92	..	5.9	94*	..	89	..	5.9	94*	..	92	..
Snapdragons, Giant Ruffled Tetraploid	6.0	80*	..	62	..	6.0	80*	..	67	..	6.0	80*	..	60	..
Sweet peas, Giant Ruffled	8.2	90*	..	87	2	8.2	90*	..	83	4	8.2	90*	..	83	6
Zinnia, Burpee Giant Hybrid Sunny Boy	7.0	85*	..	97	..	7.0	85*	..	98	..	7.0	85*	..	97	..

* Company germination.

It will be observed from table 12 that of the more than 80 varieties of seeds tested, there was some indication that the germination was reduced in the case of highland bentgrass, Mt. Barker subterranean clover, rose clover, eggplant, Dallis grass, California black mustard, birdsfoot broadleaf trefoil, smilo, and snapdragon when fumigated with 4 pounds of methyl bromide per thousand cubic feet for 12 hours at 70° F. The reduction in germination was as high as 42 per cent in the case of smilo.

There was some indication that fumigation with ½ pound of hydrocyanic acid per thousand cubic feet reduced the germination of pole beans, burnet, California black mustard, smilo, marigold, and snapdragon (table 12). The reduction in germination was as high as 43 per cent in the case of California black mustard.

TABLE 13

SEED GERMINATION AFTER FUMIGATION WITH METHYL BROMIDE AT 70° AND 80° F

Moisture content of seeds less than 10 per cent; twelve hours' exposure

Variety	Control: per cent germination	Per cent germination at 70° F		Per cent germination at 80° F	
		With 3 lbs. methyl bromide per 1,000 cu. ft.	With 4 lbs. methyl bromide per 1,000 cu. ft.	With 3 lbs. methyl bromide per 1,000 cu. ft.	With 4 lbs. methyl bromide per 1,000 cu. ft.
Fuzzy cottonseed	72	68	62	66	53
Mechanical delinted ceresan-treated seed cotton	79	80	74	75	76
Mechanical delinted untreated seed cotton	75	73	70	79	70
Ceresan-treated seed flax	83	83	83	80	81
Ceresan-treated seed barley	97	97	95	94	96
Ceresan-treated seed wheat	81	83	80	79	77
Untreated N-46 soybean planting seed	67	71	67	68	66

There was some indication that fumigation with 1 pound of acrylonitrile per thousand cubic feet reduced germination of burnet, California black mustard, smilo, marigold, and snapdragon (table 12). The reduction in germination was as high as 47 per cent in the case of California black mustard.

From table 13 it will be noticed that of the seeds tested, the germination of fuzzy cottonseed was the only one affected when fumigated with 4 pounds of methyl bromide per thousand cubic feet for 12 hours at either 70° or 80° F.

Since all seeds used in the previous experiments (tables 12 and 13) had a moisture content of less than 10 per cent at the time of fumigation, an experiment was conducted to determine the effect of various moisture contents on two types of alfalfa, dwarf milo, sweet sudan, and giant sunflower seeds when fumigated with 3, 4, or 5 pounds of methyl bromide per thousand cubic feet for 12 hours at 70° F. From table 14 it can be seen that the germination of the two types of alfalfa seed was only slightly affected when the moisture content was increased from 6.2 per cent to 14.2 per cent. The germination of dwarf milo, sweet sudan, and giant sunflower seeds was greatly reduced by fumigation with methyl bromide for 12 hours at 70° F when the moisture content was above 12 per cent.

TABLE 14
THE EFFECT OF MOISTURE CONTENT OF SEED ON GERMINATION FOLLOWING FUMIGATION WITH METHYL BROMIDE
12-hour exposure at 70° F

Variety and per cent moisture content	Control: per cent germination	Per cent germination after fumigation with methyl bromide		
		At 3 lbs./ 1,000 cu. ft.	At 4 lbs./ 1,000 cu. ft.	At 5 lbs./ 1,000 cu. ft.
Chilean-type alfalfa				
6.2	92	90	95	92
8.8	94	91	88	91
11.8	90	87	91	82
14.2	91	88	85	75
Alfalfa seed #919				
7.2	95	92	94	92
10.3	90	87	91	89
12.2	93	90	85	87
14.0	89	89	85	85
Double Dwarf milo				
7.4	85	86	84	81
10.2	84	85	81	77
12.5	80	71	68	55
15.0	74	52	34	11
Sweet sudan				
6.8	95	90	93	94
9.8	96	89	91	86
12.2	93	87	79	66
14.6	91	73	48	14
Giant sunflower				
7.6	94	86	87	92
10.3	91	89	84	84
12.6	85	62	42	45
14.8	65	28	25	11

EXPERIMENTS WITH CONTACT INSECTICIDES

To determine the relative toxicity of several contact insecticides, fourth-instar khapra-beetle larvae were treated by the topical application method (fig. 14 and inset) similar to that used by March and Metcalf (1949). The method of holding the larvae by suction was adapted from Hewlett (1954*b*). Twenty-five fourth-instar larvae were used for each test, and the tests were replicated three times. Eight concentrations were used for each insecticide covering a range from 0.5 to 100 micrograms per larva. Most of the insecticides used were purified, but in some cases the technical material was used. The insecticides were dissolved in acetone and applied to the dorsal surface behind the head capsule. Parallel control experiments were conducted using acetone alone, and mortality in the controls was negligible. After treatment the test insects were held at 80° to 90° F for 20 days, then mortality counts were made. Results are shown in table 15.

In table 15 it may be noticed that of the materials tested by this method,

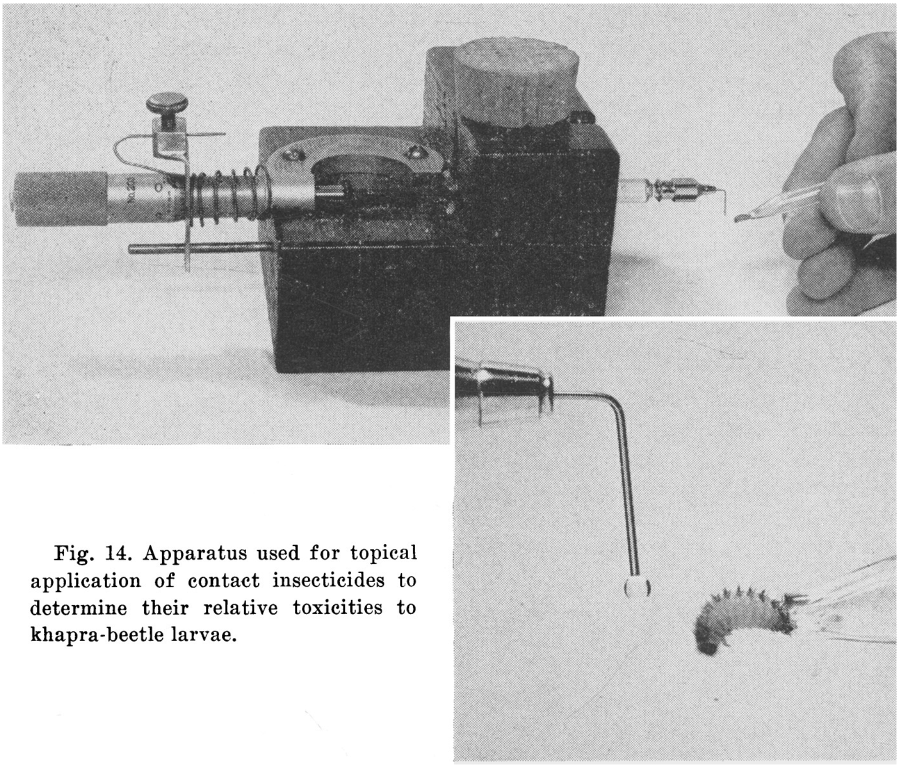


Fig. 14. Apparatus used for topical application of contact insecticides to determine their relative toxicities to khapra-beetle larvae.

TABLE 15

TOPICAL APPLICATION TESTS ON KHAPRA-BEETLE LARVAE

Compound	LD_{95}, µg per larva
Methyl analogue parathion	1.4
Compound 4124	2.2
Parathion	2.7
Malathion	3.6
Pyrocide 175 (20% pyrethrins)	4.2
Compound 12008	8.5
Chlorthion	8.8
Allethrin	29.0
Aldrin	30.0
Compound 1836	40.0
Lindane	50.0
Chlordane	>100
DDD	>100
DDT	>100
Dieldrin	>100
Dipterex	>100
Heptachlor	>100
Methoxychlor	>100
Nicotine (free)	>100
Piperonyl butoxide	>100
Strobane	>100
Toxaphene	>100

methyl analogue of parathion, compound 4124 [O,O-dimethyl O-(2-chloro-4-nitro phenyl) thiophosphate], parathion, malathion, Pyrocide 175 (20 per cent pyrethrins), compound 12008 (O,O-diethyl S-isopropyl mercaptomethyl dithiophosphate), and chlorthion were the most toxic to fourth-instar khapra-beetle larvae; all these required less than 10 micrograms per larva for LD_{95}. Allethrin, aldrin, compound 1836 (diethyl 2-chlorovinyl phosphate), and lindane are less toxic; they required from 29 to 50 micrograms per larva. Chlordane, heptachlor, toxaphene, DDT, DDD, methoxychlor, free nicotine, piperonyl butoxide, Strobane, Dipterex, and dieldrin require more than 100 micrograms per larva.

EXPERIMENTS WITH GRAIN PROTECTANTS

A series of experiments was set up in which whole-kernel wheat of 9 and 14.5 per cent moisture content was treated with malathion dust at the rate of 4, 8, 12, and 16 parts per million, or a dust consisting of 0.8 per cent piperonyl butoxide and 0.05 per cent pyrethrins. The diluent for malathion was apricot flour while that for the piperonyl butoxide–pyrethrin mixture was finely pulverized wheat. The treated wheat was held in tight gallon containers in the laboratory at room temperature. The effectiveness of these materials was tested by confining 100 adults each of the granary weevil, *Sitophilus granarius* (L.); the rice weevil, *S. oryza* (L.); and the lesser grain borer, *Rhyzopertha dominica* (F.); and 50 larvae of the khapra beetle, *Trogoderma granarium,* in 250-gram samples just after the grain was treated and 1 and 2 months later. All insects were exposed for a period of 10 days to the treated wheat with the exception of khapra-beetle larvae, which were exposed for a period of 20 days. After each exposure period the insects were removed and checked for mortality. The results are given in tables 16 and 17.

From these tables it may be observed that larvae of the khapra beetle are more resistant to wheat treated with the piperonyl butoxide–pyrethrin mixture or the malathion-treated wheat than are the adults of the granary weevil, rice weevil, and lesser grain borer.

The effect of the malathion treatment after storage for 1 or 2 months was much reduced when used with wheat of 14.5 per cent moisture content as compared with that of 9 per cent. This same effect, although not as pronounced, is also apparent in the wheat treated with piperonyl butoxide-pyrethrin.

SANITATION AND THE CURRENT ERADICATION PROGRAM

At the present time the California State Department of Agriculture is carrying out an eradication program against the khapra beetle, and no control measures for use by farmers or warehousemen are being recommended. Individuals will be well advised, however, to use special care in sanitation as a preventive practice; in fact, sanitation should have an important place in every insect-control program. The accumulation of food products in any part of buildings used for storage or processing provides ideal situations for the breeding of insects. These accumulations should be prevented by effective

TABLE 16

THE COMPARATIVE EFFECTIVENESS OF MALATHION-TREATED WHEAT ON THE CONTROL OF KHAPRA-BEETLE LARVAE AND THE ADULTS OF THREE OTHER STORED-FOOD PESTS

Malathion* ppm	Per cent mortality			
	Trogoderma granarium larvae	*Sitophilus granarius* adults	*Sitophilus oryza* adults	*Rhyzopertha dominica* adults
Wheat — 9 per cent moisture content				
Initial				
4	96.0	100	100	99.0
8	100	100	100	100
12	95.8	100	100	100
16	95.8	100	100	100
1 month				
4	8.3	100	100	95.0
8	48.1	100	100	100
12	96.2	100	100	100
16	84.0	100	100	100
2 months				
4	0	97.0	100	84.0
8	25.0	100	100	100
12	57.0	100	100	100
16	60.0	100	100	100
Wheat — 14.5 per cent moisture content				
Initial				
4	81.8	100	100	95.0
8	100	100	100	97.0
12	92.0	100	100	100
16	91.7	100	100	100
1 month				
4	0	3.0	2.0	5.0
8	0	6.0	3.0	8.0
12	0	60.0	89.0	51.0
16	8.3	92.0	94.0	66.0
2 months				
4	0	4.0	1.0	3.0
8	4.8	6.0	1.0	2.0
12	0	5.0	2.0	6.0
16	0	3.0	2.0	6.0

* 1 per cent malathion dust in apricot flour.

housekeeping practices. Construction should be such that ledges where food can accumulate and cracks and crevices where insects can congregate should be at a minimum.

The ability of the khapra beetle to live without food for long periods of time or survive on foods of low moisture content, its habit of crawling into tiny cracks and crevices and remaining there for long periods, and its relative resistance to many insecticides make this insect difficult to control once it has become established; therefore, all means possible should be taken to prevent the introduction of this pest into uninfested areas. Any host materials should be inspected for the presence of this insect prior to introduction into a clean

TABLE 17

THE COMPARATIVE EFFECTIVENESS OF PIPERONYL BUTOXIDE–PYRETHRINS* TREATED WHEAT ON CONTROL OF KHAPRA-BEETLE LARVAE AND THE ADULTS OF THREE OTHER STORED-FOOD PESTS

Piperonyl butoxide–pyrethrin, oz/bushel*	Per cent mortality			
	Trogoderma granarium larvae	*Sitophilus granarius* adults	*Sitophilus oryza* adults	*Rhyzopertha dominica* adults
Wheat—9 per cent moisture content				
Initial				
1	0	66.0	76.0	52.0
2	17.4	97.0	100	47.0
3	18.5	99.0	100	49.0
4	16.0	99.0	100	63.0
1 month				
1	4.5	18.0	12.0	70.0
2	4.2	93.0	65.0	93.0
3	4.5	100	97.0	96.0
4	0	100	100	96.0
2 months				
1	0	7.0	12.0	71.0
2	8.0	89.0	46.0	92.0
3	4.2	100	95.0	93.0
4	4.0	100	100	96.0
Wheat—14.5 per cent moisture content				
Initial				
1	8.3	42.0	26.0	63.0
2	8.3	88.0	85.0	74.0
3	24.0	100	100	59.0
4	16.7	100	99.0	57.0
1 month				
1	0	4.0	1.0	3.0
2	0	30.0	11.0	34.0
3	4.3	97.0	70.0	98.0
4	19.2	98.0	92.0	99.0
2 months				
1	0	10.0	1.0	6.0
2	0	16.0	4.0	26.0
3	0	85.0	11.0	79.0
4	0	98.0	53.0	93.0

* 0.8 per cent piperonyl butoxide and 0.05 per cent pyrethrins in a finely pulverized wheat carrier.

premise; and all used sacking materials, crating, or other materials which might harbor the insect should be vacuum-fumigated before acceptance for further use.

Since the khapra-beetle larvae are able to penetrate into almost inaccessible spots, repeated spray applications are necessary to effect even a partial clean-up. In an eradication program both fumigation and sprays are required. A week preceding the fumigation the surface area on all sides of the infested premise extending out to the property line or for 100 feet, whichever is nearest, is freed of all surface debris and thoroughly sprayed with 5 pounds of actual malathion in 50 gallons each of diesel oil and of water. The surface is again treated in a similar manner 24 hours before fumigation. In the same program, methyl bromide is used for fumigation; the rate is 5 pounds per thousand cubic feet for an exposure of 48 hours under gastight tarps (fig. 15) with the concentration maintained at no less than 2 pounds of methyl bromide per thousand cubic feet for an aggregate of 24 hours.

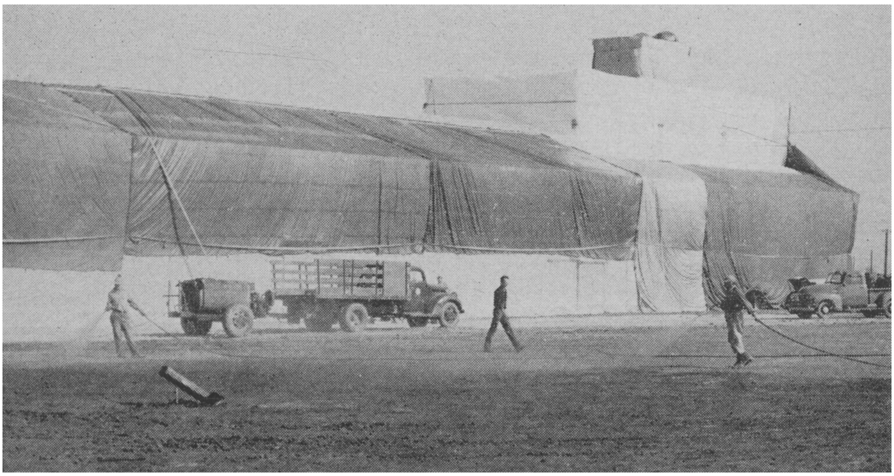


Fig. 15. A methyl bromide fumigation experiment conducted by the California State Department of Agriculture in the attempted eradication of the khapra beetle in an empty warehouse of approximately 1,000,000 cubic feet at Imperial, California. The entire structure was covered with gastight sheeting and was subsequently treated with methyl bromide at the rate of 5 pounds per 1,000 cubic feet for a 48-hour exposure period. The ground 100 feet out from the building was sprayed with a malathion–petroleum oil spray. (Courtesy of Dow Chemical Company.)

SUMMARY

The khapra beetle, *Trogoderma granarium* Everts (*Attagenus undulatus* Motsch.; *T. khapra* Arrow) was first found established in the United States in stored barley in two warehouses in Tulare County, California, October, 1953; however, it is now known to have been present in California as early as 1946. It has been reported from Asia, Europe, Africa, Australia, and now North America.

The adult is a small brownish-black beetle, oval in shape, the female measuring about 1/8 inch long, the male less. The female is lighter in color than the male. There is no record of the adults being able to fly.

The eggs are a little under 1/64 inch long, narrowly cylindrical, rounded at one end, somewhat pointed at the other, and translucent white when laid.

The body of the newly hatched larva is yellowish-white and on development assumes a reddish-brown appearance. The larva is covered with hairs and when mature is approximately 1/4 inch long. The posterior segments bear long movable erectile hairs that form somewhat of a tail. The larvae can live for long periods of time without food.

The pupa is approximately ¼ inch long and is enclosed with the exception of a portion of the dorsum in the last cast larval skin. The pupa of the male is much smaller than that of the female.

The damage is caused by the actively feeding larva, in which stage the insect spends the greatest part of its life cycle. The larvae feed on a wide variety of stored products and by their continual gnawing reduce the material to a powdery mass. This insect prefers whole grains and cereal products but may feed on such animal products as dried blood, dried milk, and fishmeal.

The time required for a generation (egg to adult) varied from an average of 220 days at 70° F to one of 26 days at 93° to 95°. The length of a generation appeared to be little affected by the amount of light to which the stages of the insect were exposed.

At 90° F egg viability averaged 94 per cent, and an average of 93 viable eggs were laid per female.

Exposure of eggs to –6° F gave erratic results, but some khapra-beetle eggs hatched at exposures of 40, 80, and 120 minutes. On exposure of larvae and pupae to –6°, a 100 per cent mortality of pupae was obtained at 20 minutes or longer, while a few larvae survived an exposure of 240 minutes to this temperature. A few larvae survived an exposure of 51 days to a daily fluctuating temperature of 25° to 48°.

In general it required a longer exposure to kill larvae at 118°, 124°, 131° F than it did to kill pupae at these same temperatures. To obtain a kill of 95 per cent at 50 per cent relative humidity and 118° required 960 minutes for larvae and 420 for pupae; while at 131° and 50 per cent relative humidity it required 8 minutes for both larvae and pupae.

In comparing the toxicity of various fumigants at LD_{95}, with a 2-hour exposure at 70° F, it was found that the eggs were more susceptible to acrylonitrile, ethylene chlorobromide, ethylene dibromide, ethylene oxide, hydrocyanic acid, and methyl bromide than the larval or pupal stages. Larvae were more susceptible to chloropicrin than the egg or pupal stages. The pupae were more susceptible than the eggs or larvae to methallyl chloride. With carbon disulfide the dosage required to kill 95 per cent of the eggs, larvae, and pupae was approximately the same. Eggs were relatively resistant to chloropicrin or methallyl chloride fumigation.

Hydrocyanic acid was the only fumigant among the ten tested to which all three immature stages of the khapra beetle were more susceptible than the granary-weevil adults.

In comparing the toxicity of various fumigants at LD_{95} with 2-, 8-, and 24-hour exposures at 70° F, it was found that hydrocyanic acid and acrylonitrile were the most toxic fumigants tested against larvae and pupae of khapra beetle.

Among 80 varieties of seeds tested, the number showing some evidence of reduced germination after fumigation was 9 with methyl bromide, 6 with hydrocyanic acid, and 5 with acrylonitrile.

In comparing the toxicity at LD_{95} of twenty-two contact insecticides on khapra-beetle larvae by the topical application method it was found that methyl analogue of parathion, compound 4124 [O,O-dimethyl O-(2-chloro-

4-nitro phenyl) thiophosphate], parathion, malathion, Pyrocide 175 (20 per cent pyrethrins), compound 12008 (O,O-diethyl S-isopropyl mercaptomethyl dithiophosphate), and chlorthion were the most toxic to fourth-instar khapra-beetle larvae; these required less than 10 micrograms per larva.

Khapra-beetle larvae were more resistant to wheat treated with a piperonyl butoxide-pyrethrin dust mixture or wheat treated with a malathion dust than were the adults of the granary weevil, rice weevil, and lesser grain borer.

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