Mini Risk Assessment
Khapra Beetle, *Trogoderma granarium* (Everts)
[Coleoptera: Dermestidae]

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Figure 1. *Trogoderma granarium*: line drawings of adult and larvae (left); and larvae and adults feeding on stored grain (right).
[Images from http://www.biopuglia.iamb.it/erbacee/images/trogoderma_granarium.JPG (left); http://www.eppo.org/QUARANTINE/insects/Trogoderma_granarium/TROGGA_images.htm (right)]

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Introduction

Khapra beetle, *Trogoderma granarium*, is a serious pest of stored grain products in Africa, the Middle East, the Near East, and pockets of Europe and eastern Asia (USDA 1983, CABI/EPPO 1997, CAB 2004, EPPO 2005). It has been nominated as one of the 100 worst invasive species worldwide (Lowe et al. 2000). This insect is not known to occur in the United States, but the potential introduction of this insect into the US has been a serious concern for a number of years. In 1998, USDA sponsored a comprehensive pest risk assessment for *T. granarium* (Pasek 1998). The assessment evaluated the likelihood that the beetle might become established in the US and the economic and environmental consequences if it would establish. Pasek (1998) considered both the likelihood and consequences of establishment to be high; however, economic and environmental impacts were predicted to be moderate and high, respectively. We utilize the original document as the foundation for our mini-pest risk assessment. The purpose of the mini-risk assessment is to further evaluate several factors that contribute to pest risk and where appropriate to re-evaluate risk ratings based on current research. This information can then be applied to the refinement of survey and detection programs.

1. **Ecological Suitability. Rating: High.** The range of *T granarium* extends from the northern half of Africa through the middle East into India (EPPO 2005). Small geographic pockets of the insect occur in Europe and northeast Asia. Appendix A provides a detailed list of the reported worldwide distribution of this insect. In general, *T. granarium* occurs in dry, tropical, and temperate climates. The currently reported distribution of *T. granarium* suggests that the pest may be most closely associated with biomes characterized as: desert and xeric shrublands; tropical and subtropical grasslands, savannas, and shrublands; tropical and subtropical moist broadleaf forests; and temperate broadleaf and mixed forests. All of these biomes occur in the US. Consequently, we estimate that approximately 67% of the continental US would have a suitable climate for *T. granarium* (Fig. 2). See Appendix A for a more complete description of this analysis.

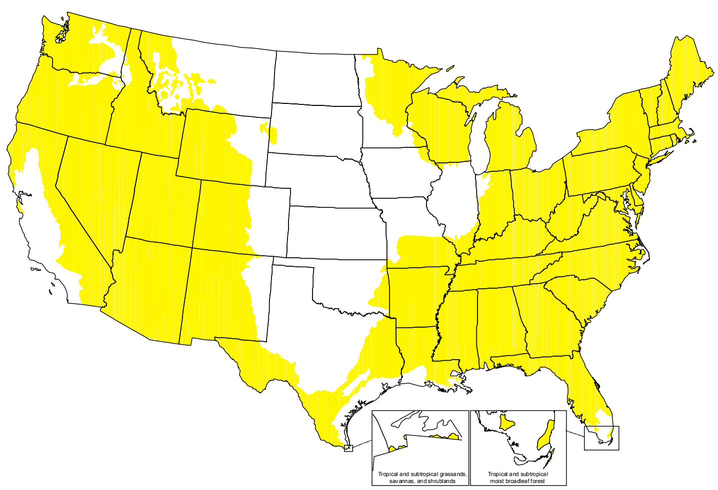

Figure 2. Predicted distribution (shaded yellow) of *Trogoderma granarium* in the contiguous US.

"[Khapra beetle] was initially described as a pest in India by Cotes in 1894. Khapra beetle was first identified in the United States in October 1953 in samples collected from two warehouses containing stored wheat and barley located in Tulare County, California (Jensen 1954), apparently carried there in used sacks from Fresno, California, where the pest may have been introduced as early as 1946 but was mistaken for other species of Dermestidae (Armitage 1954). Surveys in grain warehouses in 1954 and early 1955 revealed infestations at 151 sites in 23 counties in the three states of California, Arizona, and New Mexico (Lindgren et al. 1955)" (Pasek 1998).

Figure 2 illustrates where *T. granarium* is most likely to encounter a suitable climate for establishment within the continental US. This prediction is based only on the known geographic distribution of the species. Because this forecast is based on coarse information, areas that are not highlighted on the map may have some chance of supporting populations of this exotic species. However, establishment in these areas is less likely than in those areas that are highlighted. Initial surveys should be concentrated in the higher risk areas and gradually expanded as needed.

"Khapra beetle may survive best in areas with mean monthly temperatures above 20°C (68°F) and mean relative humidity of less than 50% for at least four consecutive months (Banks 1977). In the United States, parts of California, Arizona, Nevada, New Mexico, Texas, Oklahoma, and Kansas may best match these conditions (Howe and Lindgren 1957). [Our updated analysis (Fig 2) generally supports this conclusion.] [The] controlled environment of heated warehouses, grain storage facilities, and other structures that provide protection from freezing likely will allow khapra beetle to become established in such facilities anywhere in the United States. Additionally, khapra beetle has the ability to become dormant for at least six years until suitable conditions for development occur (Burges 1962)" (Pasek 1998).

2. **Host Specificity/ Host Availability. Rating: Low/High.** *Trogoderma granarium* is a non-selective feeder that can utilize a number of food products that are commonly available (Table 1). "Khapra beetle infests a wide variety of dried plant and animal materials, especially seeds of most any plant family (Hinton 1945). In addition to seeds, it also infests spices, dried gums, dried fruits and other dried proteinaceous materials. It is capable of completing development solely on grains, unlike many species of *Trogoderma* native to the United States that require animal matter, insects or spiders as food to sustain populations (Beal 1954, 1956)" (Pasek 1998).

Table 1. Hosts of *Trogoderma granarium* (organized by common name).

Hosts	**References**
alfalfa (*Medicago sativa*)[2]	(Lindgren et al. 1955, Pasek 1998)
almond (*Prunus dulcis*)	(Pasek 1998)
barley (*Hordeum* sp. 'Brenda') [1]	(Poplawska et al. 2001, Niegowska et al. 2002)
barley (*Hordeum* sp. 'Krona') [1]	(Poplawska et al. 2001, Niegowska et al. 2002)
barley (*Hordeum* sp. 'Maresi') [1]	(Poplawska et al. 2001, Niegowska et al. 2002)
barley (*Hordeum* sp. 'Rasbet') [1]	(Poplawska et al. 2001, Niegowska et al. 2002)
barley (*Hordeum* sp.)	(Lindgren et al. 1955, Hadaway 1956, Shutova 1978)
barley, common (*Hordeum vulgare*)	(Pasek 1998, CAB 2004)
bean (*Phaseolus* sp.)	(Hadaway 1956)
bean, broad (*Vicia faba*)	(CAB 2004)
bean, pinto (*Phaseolus vulgaris*)	(Lindgren et al. 1955)
beans, lima (*Phaseolus lunatus*) [2]	(Lindgren et al. 1955, Pasek 1998)
buckwheat (*Fagopyrum esculentum* 'Emka') [1]	(Ciepielewska et al. 2000, Poplawska et al. 2001)
buckwheat (*Fagopyrum esculentum* 'Hruszoska') [1]	(Ciepielewska et al. 2000, Poplawska et al. 2001)
buckwheat (*Fagopyrum esculentum* 'Kora') [1]	(Ciepielewska et al. 2000, Poplawska et al. 2001)
cereal grains	(Ahmed et al. 2002)
chickpea (*Cicer arietinum*)	(Pasek 1998, CAB 2004)
coconut (*Cocos nucifera*)	(Lindgren et al. 1955, Pasek 1998)
corn (*Zea mays* 'Amber popcorn') [1]	(Paudel et al. 2004)
corn (Zea mays 'Basi local') [1]	(Paudel et al. 2004)
corn (*Zea mays* 'Dhawal') [1]	(Paudel et al. 2004)
corn (*Zea mays* 'Kisan') [1]	(Paudel et al. 2004)
corn (*Zea mays* 'Pusa composite-1') [1]	(Paudel et al. 2004)
corn (*Zea mays* 'Surya') [1]	(Paudel et al. 2004)
corn (Zea mays var. mays)	(Pasek 1998)
corn (*Zea mays* 'Win popcorn') [1]	(Paudel et al. 2004)
corn (*Zea mays*)	(Lindgren et al. 1955, Shutova 1978, Ciepielewska et al. 2000, Niegowska et al. 2002, CAB 2004)
cotton (*Gossypium* sp.)	(Shutova 1978, CAB 2004)
cowpea (*Vigna* sp.)	(Ahmed et al. 2002)
flax (*Linum usitatissimum*)	(Lindgren et al. 1955, Shutova 1978)
gram	(Lindgren et al. 1955)

Hosts	References
ground nut (*Arachis hypogaea*)	(Lindgren et al. 1955, Hadaway 1956, Shutova 1978, CAB 2004)
lentil (*Lens culinaris*)	(Pasek 1998)
millet, broomcorn (*Panicum miliaceum*)	(CAB 2004)
millet, pearl (*Pennisetum glaucum*)	(CAB 2004)
oat (*Avena sativa*)	(Rahman et al. 1945, Lindgren et al. 1955, Shutova 1978, Pasek 1998)
pea, blackeyed (*Vigna unguiculata*)	(Lindgren et al. 1955, Pasek 1998, CAB 2004)
pea, garden (*Pisum sativum*)	(Pasek 1998)
peanut (*Arachis hypogaea*)	(Pasek 1998, Ahmed et al. 2002)
peas	(Hadaway 1956)
pecan (*Carya illinoinensis* (= *illinoensis*)	(Pasek 1998)
pistachio (*Pistacia vera*)	(Lindgren et al. 1955)
pulse	(Rahman et al. 1945, Lindgren et al. 1955, Ahmed et al. 2002)
rice (*Oryza sativa*)	(Lindgren et al. 1955, Hadaway 1956, Shutova 1978, Pasek 1998, CAB 2004)
rice, Basmati (*Oryza sativa*)	(Zimmerman and Barron 1998)
rye (*Secale cereale*)	(Rahman et al. 1945, Lindgren et al. 1955, Shutova 1978)
sesame (*Sesamum indicum*)	(CAB 2004)
sorghum (*Sorghum* sp.)	(Lindgren et al. 1955, Niegowska et al. 2002)
sorghum, common (*Sorghum bicolor*)	(Dwivedi and Kumar 1998, Pasek 1998, CAB 2004)
soybean (*Glycine max*)	(Pasek 1998)
sunflower, common (*Helianthus annuus*)	(Obretenchev et al. 2001, CAB 2004)
tomato seed (*Lycopersicon esculentum*)	(Lindgren et al. 1955)
walnut (*Juglans* sp.)	(Lindgren et al. 1955, Pasek 1998)
wheat (*Triticum* sp. 'Almari')	(Niegowska et al. 2002)
wheat (*Triticum* sp.)	(Rahman et al. 1945, Lindgren et al. 1955, Shutova 1978, Mahmood et al. 1996, Ciepielewska et al. 2000, Chaudhary and Mahla 2001, Ahmed et al. 2002, Niegowska et al. 2002, Jha 2003, CAB 2004)
wheat, common (*Triticum aestivum*)	(Pasek 1998, El Nadi et al. 2001, CAB 2004)
wheat, durum (*Triticum durum*)	(Jha 2003)
wheat, triticale (×*Triticosecale rimpaui* [*Triticum aestivum* × *Secale cereale*])	(Jha 2003)

1. Laboratory experiment (Poplawska et al. 2001, Niegowska et al. 2002, Paudel et al. 2004);
2. Pasek (1998) reports that larvae will feed on but cannot develop on this host.

3. **Survey Methodology. Rating: High.** Visual inspections and pheromone baited traps are useful for the detection of *T. granarium*. During visual inspections of grain storage areas (e.g., silos and warehouses), it may difficult to locate live adults. "Khapra beetle prefers dark, dry locations in host and packing materials. Adults are rarely seen and tend to seek out cracks and crevices in packing materials, conveyances, and storage facilities. The most obvious signs of infestation by Dermestidae are the hairy larvae and cast skins. Larvae are difficult to distinguish morphologically from other species of *Trogoderma*, including those native to the US (Beal 1956). Examination of specimens by specially trained identifiers is necessary to confirm presence of khapra beetle" (Pasek 1998).

   During inspection of silos, "[i]nfestation by khapra beetle most often occurs in the superficial layers of stored grain (Pruthi and Singh 1950, Bains et al. 1974). Most damage occurs in the top 12 inches of grain, but khapra beetle was observed as deep as six feet and penetrating up to 12 feet along walls and in corners of grain storage facilities by Lindgren et al. (1955). When fresh malt was added to a silo, larvae were found initially near the walls, nearest to hiding places for diapausing larvae, but migrated to the surface within 22 weeks (Burges 1959). In large vertical grain silos in Pakistan, khapra beetle primarily infested the top (to 3.6 m [~12 ft] depth) and bottom layers (10.9-19.2 m [~32-63 ft] depth near aeration ducts) during July and August but could be found at all depths from October through December (Mahmood et al. 1996). The downward movement of insects in October was theorized to have resulted from surface treatment with phosphine gas" (Pasek 1998).

   "Most trap designs for detection in grain storage facilities and warehouses have relied on use of a pheromone in combination with a food attractant and a dark place to hide, that will attract both adult and larval stages of khapra beetle. ... A [detailed] trapping protocol for facilities and trapping instructions are described in the National Agricultural Pest Information System (NAPIS) website [http://www.ceris.purdue.edu/napis/pests/khb/topics/trap-instruct.html; accessed on 27 Sept 2005]. ... *T. granarium* shares a common pheromone component, attractive to adult males, with several species of *Trogoderma* native to the US (Greenblatt et al. 1977). Trapping in grain storage facilities and warehouses using a pheromone lure made up of this component likely would attract a large number of native *Trogoderma*, making it difficult to detect *T. granarium*. Therefore, it is recommended that aerial traps be used to capture *Trogoderma* species that are capable of flight, thereby reducing the number of non-khapra beetle catches in wall-mounted traps (Faustini et al. 1991)" (Pasek 1998).

4. **Taxonomic Recognition. Rating: Low.** Infestations of *T. granarium* are not easily recognized in the field. Several *Trogoderma* species occur in the US. Species are incredibly difficult to identify when specimens are intercepted as pupae or larvae (Karnowski 2002). Species that might be confused with *T. granarium* include: *T. glabrum* (Herbst), *T. grassmani* Beal, *T. ornatum* (Say), *T. parabile* Beal, *T. simplex* Jayne, and *T. sternale*.

Suspect specimens must be confirmed by a qualified taxonomist. Karnowski (2002) provides a detailed guide for the identification of *T. granarium* and other dermestids.

For more details about the morphology of *Trogoderma granarium*, see Appendix B.

5. **Entry Potential. Rating: Medium.** *Trogoderma granarium* has been intercepted at least 470 times at US ports of entry between 1985 and 2004 (incomplete records complicate the accuracy of this count); unspecified "*Trogoderma* sp." were reported an additional 16 times over the same period (USDA 2005). On average, *T. granarium* or "*Trogoderma* sp." have been intercepted 20 (±4 standard error of the mean) times annually, although interceptions after 1998 have been consistently lower than average (USDA 2005). The majority of interceptions have been associated with international airline baggage (54%), general cargo (24%) and ship stores (10%). Most interceptions were reported from Houston, TX (42%), Brooklyn, NY (9%), San Francisco, CA (8%), Atlanta, GA (6%) and JFK International airport, NY (4%). These ports are the first points of entry for infested material coming into the U.S. and do not necessarily represent the final destination of infested material. Movement of potentially infested material is more fully characterized in the next section.

   Interceptions of *T. granarium* were strongly associated with seed (>35% of all interceptions). Seeds of various cucurbitaceae accounted for 13.8% of all interceptions and rice for an additional 12.8%. Records from APHIS do not clarify whether rice was intended for propagation or consumption.

   Pasek (1998) provides a detailed analysis of interception records from 1985-May 1998.

6. **Destination of Infested Material. Rating: High.** When an actionable pest is intercepted, officers ask for the intended final destination of the conveyance. Between 1985 and 2004, materials infested with *T. granarium* or "*Trogoderma* sp." were destined for 27 states, including the District of Columbia, within the contiguous US. The most commonly reported destinations were Texas (44%), California (13%), New York (10%), Florida (4%), and Georgia (4%) (USDA 2005). We note that some portion of each of state identified as the intended final destination has a climate and hosts that would be suitable for establishment by *T. granarium*.

   "From 1978 to 1983, khapra beetle infestations were detected in food processing facilities, bagging, wooden crates, and other protected facilities in isolated locations in California, Maryland, Michigan, New Jersey, New York, Pennsylvania, and Texas (Anon. 1978, FAO 1981, USDA 1983). These infestations were subsequently eradicated. [More] recently, a khapra beetle infestation was detected in 1997 in a spice processing warehouse in Owings Mills, Maryland. Actions taken to contain and eliminate the infestation included: fumigating all shipments leaving the facility, surface spraying the facility with malathion, vacuuming all surfaces to remove dust and insects, sealing surfaces with several coats of thick latex paint, and decontaminating and replacing spice processing equipment. The methods used likely are not economically feasible for most commodity handlers and were chosen, in part, in this instance because the plant intended to remodel the facility anyway. The facility itself was not fumigated due to citizen opposition" (Pasek 1998).

7. **Potential Economic Impact. Rating: High.** Establishment by *T. granarium* would have a severe economic impact by lowering the volume of affected products, lowering the quality of infested goods, and adversely impacting international trade. Collectively, these impacts warrant a high rating. The only mitigating factor may be that treatments currently used for other stored product pests may control this insect. Therefore, while unmitigated populations of the insect would likely have a high economic impact, available treatments might lower the overall impact to medium (a result of remaining impacts on trade).

   "Feeding by khapra beetle larvae reduces the weight and grade of grain. In India, average damage levels ranged from 6% to 33% of grain in a single storage season, with maximum damage at 73% (Rahman et al. 1945). Loss of weight in wheat ranged from 2.2% to 5.5%. At optimal conditions of 36°C (97°F) and 15% infestation level, wheat lost 2.6% of its weight and 24% of its viability (Prasad et al. 1977). The loss of grain or costs of necessary treatment may result in less profit for wholesalers. However, routine treatments of stored grains for domestic species of stored grain pests may control khapra beetle as well, and sufficiently avert significant economic losses of the commodity itself" (Pasek 1998).

   "Severe infestations of grain by khapra beetle may make it unpalatable or unmarketable. Grain quality may decrease due to depletion of specific nutrients. Infestation levels of 75% in wheat, maize, and sorghum grains resulted in significant decreases in crude fat, total carbohydrates, sugars, protein nitrogen, and true protein contents and increases in moisture, crude fiber, and total protein (Jood and Kapoor 1993, Jood et al. 1993, 1996a). Starch content was significantly reduced at the 50% infestation level (Jood et al. 1993). Substantial losses of the vitamins thiamin, riboflavin, and niacin occurred at infestation levels of 25% and above (Jood and Kapoor 1994). Significant increases were found at infestation levels of 25% and higher for non- protein nitrogen, total nitrogen, total protein, and uric acid (Jood and Kapoor 1993). Levels of uric acid were above acceptable limits for food consumption at 50% and 75% infestation levels. Total lipids, phospholipids, galactolipids, and polar and nonpolar lipids all declined significantly at infestation levels of 50% and 75% (Jood et al. 1996b). The antinutrient polyphenol increased significantly at the 75% infestation level, while the antinutrient phytic acid increased slightly only in wheat (Jood et al. 1995). Morison (1925) suggested that barbed hairs of larvae that rub off and remain in the grain may present a serious heath hazard if swallowed. Cast skins may cause dermatitis in people handling heavily infested grains (Pruthi and Singh 1950)" (Pasek 1998).

"The mere presence of khapra beetle in the US, however, could have significant economic effects as a result of the restrictions other countries would place on imports of grain, seed, or cereal products originating from the US. Exports from the US of coarse grains, wheat, rice, and peanuts to countries other than those in the Middle East and North Africa had average values of 5.818, 3.744, 0.746, and 0.218 billion dollars per year, respectively, in 1993-1997, for a total value of over 10 billion dollars per year (data obtained from the USDA Foreign Agricultural Service). The comparable value of exports of wheat flour averaged 0.137 billion dollars per year, while breakfast cereals and pancake mixes averaged 0.283 billion dollars per year. Although khapra beetle could impact other commodities as well, the commodities summarized here represent approximately 18% of the value of the principal US agricultural exports. ... *T. granarium* is of quarantine concern for [many international phytosanitary organizations, for example] CPPC, COSAVE, EPPO, JUNAC, NAPPO, and OIRSA. Many countries take severe action against this pest, which could significantly constrain exports from infested areas" (Pasek 1998).

8. **Potential Environmental Impact. Rating: Medium.** *Trogoderma granarium* is predicted to have little effect on the natural environment directly. Indirect effects on the environment may result from chemical treatments used to control the pest. Pasek (1998) concluded that environmental impacts would be high due to the likely use of methyl bromide, a known ozone depleting gas. Since 1998, methyl bromide has been phased out as a general use fumigant (United Nations Environment Programme 2000). Although proposed alternatives are not always as effective as methyl bromide in controlling pests, these chemical fumigants do not adversely affect ozone.

   "Since infestations of khapra beetle would most likely be confined to grain storage facilities, food processing plants, warehouses, or other buildings containing suitable host material, establishment of this pest is not expected to have significant direct or indirect impacts upon natural environments or endangered, threatened, or candidate species. ... Adoption of alternative methods of eradication or control that use chemical toxicants also has potential for adverse impacts to the environment, but likely to a lesser degree than that of methyl bromide" (Pasek 1998).

9. **Establishment Potential. Rating: High.** Our review of the literature and analysis of the geographic distribution of *T. granarium* continues to support the conclusion that the probability of pest establishment is high. A substantial portion of the country has a climate that should be suitable for this insect. Stored product facilities are also common throughout the United States. The high rating is tempered a bit by a moderate rate of arrival.

Historical evidence supports the high probability of establishment. As discussed under 'Climatic Suitability,' established populations of the beetle were once found in California, Arizona, and New Mexico but were subsequently eradicated. In the absence of intervention, these populations presumably would have persisted.

See Appendix C for additional details on the biology of *Trogoderma granarium.*

References

Aggarwal, V. P., D. M. Saxena, and H. C. Agarwal. 1981. Effect of larval age on induction of diapause in a stored grain pest *Trogoderma granarium* Everts. Indian journal of experimental biology 19: 83-85.

Ahmed, Z. A., O. H. Gareeb, S. A. Hassan, and M. S. Abd-Alla. 2002. Genetic studies on DNA and cleavage enzyme in active larvae, diapause larvae and pupae of *Trogoderma granarium*, Everts (Dermestiidae - Coleoptera). Journal of the Egyptian German Society of Zoology 37E: 59-83.

Anon. 1978. Khapra beetle (*Trogoderma granarium*). USDA Cooperative Plant Pest Report, Abstracted in: CAB Abstracts 1976-1978.

Armitage, D. M., and D. A. Cook. 1997. Laboratory experiments to compare the development of populations of five species of insect during dormancy break and subsequent cool storage of malting barley. Journal of the Institute of Brewing 103: 245-249.

Armitage, H., M. 1954. Current insect notes. Calif. Dept. Agric. Bull. 43: 41-43.

Atwal, A. S., and G. S. Dhaliwal. 1971. The rate of increase in numbers of *Trogoderma granarium* Everts on different varieties of wheat. Indian Journal of Entomology 33: 172-175.

Bains, S. S., G. S. Battu, and A. S. Atwal. 1974. Population dynamics of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) in rural wheat stores in the Punjab. Indian Journal of Ecology 1: 38-47.

Banks, H. J. 1977. Distribution and establishment of *Trogoderma granarium* Everts (Coleoptera: Dermestidae): climatic and other influences. Journal of Stored Product Research 13: 183-202.

Banks, H. J. 1987. Disinfection of durable foodstuffs in ISO containers using carbon dioxide. Australian Centre for International Agricultural Research (ACIAR) Proceedings Series 23: 45-54.

Barak, A. 1995. Identification of common dermestids, pp. 187-196. *In* V. Krischik, G. Cuperus and D. Galliart [eds.], Stored Product Management, Cooperative Extension Service Circular No. E-912 (revised). Oklahoma State University.

Beal, R. S. 1954. Biology and Taxonomy of the Nearctic Species of *Trogoderma* (Coleoptera: Dermestidae). University of California Press, Berkeley.

Beal, R. S. 1956. Synopsis of the economic species of *Trogoderma* occurring in the United States with description of a new species (Coleoptera: Dermestidae). Annals of the Entomological Society of America 49: 559-566.

Burges, D. H. 1959. Studies on the dermestid beetle *Trogoderma granarium* Everts. III. Ecology in malt stores. An. Appl. Biol. 47: 445-462.

Burges, D. H. 1962. Diapause, pest status and control of the khapra beetle, *Trogoderma granarium* Everts. An. Appl. Biol. 50: 614-617.

CAB. 2004. Crop Protection Compendium. CAB International. Available on-line at http://www.cabicompendium.org/cpc. Accessed 5 July 2005.

CABI/EPPO. 1997. Quarantine Pests for Europe, 2nd Ed. CAB International, Wallingford, UK.

Chaudhary, S. D., and J. C. Mahla. 2001. Insect-pests infesting stored wheat in different climatic regions of Haryana. Crop Research 21: 384-386.

Ciepielewska, D., L. Fornal, and M. Poplawska. 2000. Infestation of buckwheat grain and its products by pests in storage facilities. Journal of Plant Protection Research 40: 30-34.

Desmarchelier, J. M. 1984. Effect of carbon dioxide on the efficacy of phosphine against different stored product insects. Mitteilungen aus der Biologischen Bundesanstalt für Land- und Forstwirtschaft, Berlin-Dahlem 220: 57 p.

Dwivedi, S. C., and R. Kumar. 1998. Evaluation of *Cassia occidentalis* leaf extract on development and damage caused by *Trogoderma granarium*, khapra beetle. Journal of Ecotoxicology & Environmental Monitoring 8: 55-58.

El Nadi, A. H., E. A. Elhag, A. A. Zaitoon, and M. A. Al-Doghairi. 2001. Toxicity of three plants extracts to *Trogoderma granarium* Everts (Coleoptera: Dermestidae). Pakistan Journal of Biological Sciences 4: 1503-1505.

EPPO. 2005. *Trogoderma granarium.* Distribution Maps of Quarantine Pests for Europe. EPPO. Available on-line at http://www.eppo.org/QUARANTINE/insects/Trogoderma_granarium/TROGGA_map.htm. Accessed 20 May 2005.

FAO. 1981. United States - khapra beetle infestations reported. FAO Plant Protection Bulletin 29: 30.

Faustini, D. L., A. V. Barak, W. E. Burkholder, and J. Leos-Martinez. 1991. Combination-type trapping for monitoring stored-product insects - a review. Journal of the Kansas Entomological Society 63: 539-547.

Greenblatt, R. E., W. E. Burkholder, J. H. Cross, R. F. Cassidy Jr., R. M. Silverstein, A. R. Levinson, and H. Z. Levinson. 1977. Chemical basis for interspecific responses to sex pheromones of *Trogoderma* species (Coleoptea: Dermestidae). Journal of Chemical Ecology 3: 337-347.

Hadaway, A. B. 1956. The biology of the Dermestid beetles, *Trogoderma granarium* Everts and *Trogoderma versicolor* (Creutz). Bull. Entomol. Res. 40: 781-796.

Hava, J. 2000. New interesting Dermestidae (Coleoptera) from the world with descriptions of ten new species. Veröffentlichungen Naturkundemuseum Erfurt 19: 161-171.

Hinton, H. E. 1945. A Monograph of the Beetles Associated with Stored Products. British Museum, London.

Howe, R. W. 1952. Entomological problems of food storage in northern Nigeria. Bull. Entomol. Res. 43: 111-144.

Howe, R. W., and D. L. Lindgren. 1957. How much can the khapra beetle spread in the U.S.A.? J. Econ. Entomol. 50: 374-375.

Howe, R. W. 1963. The prediction of the status of a pest by means of laboratory experiments. World Review of Pest Control 2: 30-40.

Husain, M. A., and H. D. Bhasin. 1921. Preliminary observations on lethal temperatures for the larvae of *Trogoderma khapra*, a pest of stored wheat. Proc. Entomol. Mtgs Pusa 4: 240-248.

Ismail, I. I., T. S. Mostafa, and B. B. El-Keridees. 1988/89. Effect of food and light on reproductive capacity and rate of infestation of *Trogoderma granarium* Everts. Bulletin of the Society of Entomology Egypte 68: 159-168.

Jensen, D. D. 1954. Proceedings of the Pacific Coast Entomological Society. Pan-Pacific Entomology 30: 77-91.

Jha, A. N. 2003. Feeding propensity of *Ephestia cautella* and *Trogoderma granarium* to eighteen cultivars of wheat. Indian Journal of Entomology 65: 228-232.

Jood, S., and A. C. Kapoor. 1993. Protein and uric acid contents of cereal grains as affected by insect infestation. Food Chemistry 46: 143-146.

Jood, S., A. C. Kapoor, and R. Singh. 1993. Available carbohydrates of cereal grains as affected by storage and insect infestation. Plant Foods for Human Nutrition 43: 45-54.

Jood, S., and A. C. Kapoor. 1994. Vitamin contents of cereal grains as affected by storage and insect infestation. Plant Foods for Human Nutrition 46: 237-243.

Jood, S., A. C. Kapoor, and R. Singh. 1995. Polyphenol and phytic acid contents of cereal grains as affected by insect infestation. Journal of Agricultural and Food Chemistry 43: 435-438.

Jood, S., A. C. Kapoor, and R. Singh. 1996a. Chemical composition of cereal grains as affected by storage and insect infestation. Tropical Agriculture 73: 161-164.

Jood, S., A. C. Kapoor, and R. Singh. 1996b. Effect of insect infestation and storage on lipids of cereal grains. Journal of Agricultural and Food Chemistry 44: 1502-1506.

Karnavar, G. K. 1973. Prolonged starvation on survival and fecundity in *Trogoderma granarium*. Current Science 42: 609-610.

Karnowski, W. 2002. *Trogoderma granarium*, diagnostic protocols for regulated pests. Bulletin OEPP/EPPO Bulletin 32: 299-301.

Krishnamurthy, T. S., N. Muralidharan, and M. K. Krishnakumari. 1993. Disinfecting food commodities in small storages using carbon dioxide rich atmospheres. International Pest Control 35: 153-156.

Lindgren, D. L., L. E. Vincent, and H. E. Krohne. 1955. The khapra beetle, *Trogoderma granarium* Everts. Hilgardia 24: 1-36.

Lowe, S., M. Browne, S. Boudjelas, and M. DePoorter. 2000. 100 of the World's Worst Invasive Alien Species: A Selection from the Global Invasive Species Database. Invasive Species Specialist Group, World Conservation Union (IUCN). Available on-line at http://www.issg.org/booklet.pdf. Accessed 27 September 2005.

Mahmood, T., M. S. Ahmad, and H. Ahmad. 1996. Dispersion of stored grain insect pests in a wheat-filled silo. International Journal of Pest Management 42: 321-324.

Mason, F. A. 1924. The khapra beetle in British maltings. Bulletin Bur. Bio-Technology, Leeds 2: 118-123.

Morison, G. D. 1925. The khapra beetle (*Trogoderma granarium* Everts). Proceedings of the Royal Physical Society of Edinburgh. 21: 10-13.

Nair, K. S. S., and A. K. Desai. 1972. Some new findings on factors inducing diapause in *Trogoderma granarium* Everts (Coleoptera, Dermestidae). Journal of Stored Product Research 8: 27-54.

Nair, K. S. S., and A. K. Desai. 1973. The termination of diapause in *Trogoderma granarium* Everts (Coleoptera, Dermestidae). Journal of Stored Product Research 8: 275-290.

Niegowska, M., D. Ciepielewska, and L. Fornal. 2002. Development of the khapra beetle (*Trogoderma granarium* Ev.) on the kernels of malting barley and on malt. Polish Journal of Food and Nutrition Sciences 11/52: 61-64.

Obretenchev, A., D. Pilarska, and V. Golemansky. 2001. Entomopathogens (Protozoa: Apicomplexa) infecting the khapra beetle *Trogoderma granarium* Everts and the larger cabinet beetle *Trogoderma versicolor* Creutz. (Coleoptera: Dermestidae). Acta Entomological Bulgarica 7: 76-79.

Okumura, G. T. 1966. A supplemental character for separating adult *Trogoderma granarium* Everts, khapra beetle, from other Nearctic *Trogoderma* species. California Department of Agriculture, Bureau of Entomology, Sacramento, CA.

Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, I. Itoua, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, T. H. Ricketts, Y. Kura, J. F. Lamoreux, W. W. Wettengel, P. Hedao, and K. R. Kassem. 2001. Terrestrial ecoregions of the world: a new map of life on earth. BioScience 51: 933-938.

Pasek, J. E. 1998. Khapra beetle (*Trogoderma granarium* Everts): pest-initiated pest risk assessment, pp. 32. USDA APHIS, Raleigh, NC.

Paudel, L. R., R. K. Sharma, and K. Sharma. 2004. Varietal influence on the biology of khapra beetle, *Trogoderma granarium* Everts in stored maize. Annals of Plant Protection Science 12: 67-70.

Poplawska, M., D. Ciepielewska, and L. Fornal. 2001. Feeding of the khapra beetle on barley, malt and buckwheat nutlets. Journal of Plant Protection Research 41: 216-222.

Prasad, H., P. Bhatia, and G. R. Sethi. 1977. Estimation of feeding losses by *Trogoderma granarium* Everts in wheat. Indian Journal of Entomology 39: 377-378.

Pruthi, H. S., and M. Singh. 1950. Pests of stored grain and their control, Third revised edition.

Rahman, K. A., and G. S. Sohi. 1939. Observations on the reactions of the dermestid beetle *Trogoderma khapra* Arr. to light. Journal of Indian Entomology 1: 57-63.

Rahman, K. A., G. S. Sohi, and A. N. Sapra. 1945. Studies on stroed grain pests in the Punjab VI. Biology of *Trogoderma granarium* Everts. The Indian Journal of Agricultural Science 15: 85-92.

Ramzan, M., and B. S. Chahal. 1986. Effect of interspecific competition on the population build-up of some storage insects. Indian Journal of Ecology 13: 313-317.

Ramzan, M., and B. S. Chahal. 1989. Effect of initial infestation levels of three common species of stored grain pests on their population build-up at constant laboratory conditions. Journal of Research, Punjab Agricultural University 26.

Saxena, B. P., P. R. Sharma, R. K. Thappa, and K. Tikku. 1992. Temperature induced sterilization for control of three stored grain beetles. Journal of Stored Product Research 28: 67-70.

Saxena, D. M., V. P. Aggarwal, and H. C. Agarwal. 1981. Reproductive potential of *Trogoderma granarium* Everts during diapause. Current Science 50: 424-425.

Seifelnasr, Y. E. 1991. Stored grain insects found in sorghum stored in the central production belt of Sudan and losses caused. Tropical Science 32: 223-230.

Shutova, N. N. [ed.] 1978. A Handbook of Pests, Diseases, and Weeds of Quarantine Significance. Published for the Agricultural Research Service, U.S. Dept. of Agriculture and the National Science Foundation, Washington D.C. by Amerind Publishing Co., New Delhi.

Sohi, G. S. 1947. Studies on stored grain pests in the Punjab. VIII. Effect of constant light and darkness on the development and reproduction of and amount on food consumed by *Trogoderma granarium* Everts. Indian Journal of Entomology 9: 143-147.

Sohi, G. S. 1986. Influence of food on the phototactic response of the larvae of *Trogoderma granarium* Everts (Dermestidae: Coleoptera). Indian Journal of Ecology 13: 179-182.

United Nations Environment Programme. 2000. The Montreal protocol on substances that deplete the ozone layer as either adjusted and/or amended in London 1990, Copenhagen 1992, Vienna 1995, Montreal 1997, Beijing 1999. Secretariat for the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme. Available on-line at www.unep.org/ozone/pdf/Montreal-Protocol2000.pdf. Accessed 2003.

USDA. 1983. Pests not known to occur in the United States or of limited distribution, No. 30: Khapra Beetle, pp. 1-11. APHIS, PPQ, Hyattsville, MD.

USDA. 2005. Port Information Network (PIN-309): quarantine status database. US Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Riverdale, MD.

Voelkel, H. 1924. Zur biologie ind bek'mpfung des khaprak'fers, *Trogoderma granarium* Everts. Arb. Bio. Reichsanst 13: 129-171.

Zimmerman, M. L., and J. A. Barron. 1998. Recent interception of live khapra beetle, *Trogoderma granarium* (Coleoptera: Dermestidae), at the port of Baltimore, Maryland. Entomological News 109: 20, 46.

Appendix A. Geographic distribution and comparison of climate zones. To determine the potential distribution of a quarantine pest in the US, we first collected information about the worldwide geographic distribution of the species (Table A1). Using a geographic information system (e.g., ArcView 3.2), we then identified which biomes (i.e., habitat types), as defined by the World Wildlife Fund (Olson et al. 2001) occurred within each country or municipality reported An Excel spreadsheet summarizing the occurrence of biomes in each nation or municipality was prepared. The list was sorted based on the total number of biomes that occurred in each country/municipality. The list was then analyzed to determine the minimum number of biomes that could account for the reported worldwide distribution of the species. Countries/municipalities with only one biome were first selected. We then examined each country/municipality with multiple biomes to determine if at least one of its biomes had been selected. If not, an additional biome was selected that occurred in the greatest number of countries or municipalities that had not yet been accounted for. In the event of a tie, the biome that was reported more frequently from the entire species' distribution was selected. The process of selecting additional biomes continued until at least one biome was selected for each country. Finally, the set of selected biomes was compared to only those that occur in the US.

Table A1. Reported geographic distribution of *Trogoderma granarium*.

Locations	**References**
Afganistan	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Africa (central)	(CAB 2004)
Africa (east)	(CAB 2004)
Africa (north)	(CAB 2004)
Algeria	(Pasek 1998, CAB 2004, EPPO 2005)
Angola[1]	(CAB 2004, EPPO 2005)
Argentina	(Shutova 1978)
Australia[3]	(Lindgren et al. 1955, Pasek 1998, CAB 2004, EPPO 2005)
Austria[4]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Bangladesh	(Pasek 1998, CAB 2004, EPPO 2005)
Belgium[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Bolivia	(Shutova 1978)
Bulgaria (Boijchinovci)	(Obretenchev et al. 2001)
Bulgaria[3]	(CAB 2004, EPPO 2005)
Burkina Faso	(Pasek 1998, CAB 2004, EPPO 2005)
Canada	(Shutova 1978)
China[1]	(Lindgren et al. 1955, Shutova 1978, CAB 2004, EPPO 2005)
Côte d'Ivorie[1]	(Shutova 1978, CAB 2004, EPPO 2005)
Croatia[3]	(CAB 2004, EPPO 2005)
Cyprus	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Czech Republic[3]	(CAB 2004, EPPO 2005)
Denmark[4]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Egypt	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)

Locations	References
England (Kent)	(Hadaway 1956)
England[4]	(Rahman et al. 1945, Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Europe	(Lindgren et al. 1955)
Finland	(Shutova 1978)
France	(Shutova 1978)
Gambia[1]	(CAB 2004, EPPO 2005)
Germany[2]	(Rahman et al. 1945, Lindgren et al. 1955, Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Ghana	(Shutova 1978)
Guinea[1]	(Shutova 1978, CAB 2004, EPPO 2005)
Hungary[2]	(Pasek 1998, CAB 2004, EPPO 2005)
India	(Lindgren et al. 1955, Hadaway 1956, Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
India (Haryana)	(Chaudhary and Mahla 2001)
India (Uttar Pradesh, Central Provinces, Berar, Gwaliar, Punjab)	(Rahman et al. 1945)
Indonesia[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Iran	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Iraq	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Ireland[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Israel	(Pasek 1998, CAB 2004, EPPO 2005)
Italy (Sicily) [1]	(CAB 2004, EPPO 2005)
Italy[3]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Jamaica	(Shutova 1978)
Japan[2]	(Rahman et al. 1945, Lindgren et al. 1955, Hadaway 1956, Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Kenya[4]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Korea	(Rahman et al. 1945, Lindgren et al. 1955, Shutova 1978)
Korea, Republic of	(Pasek 1998, CAB 2004, EPPO 2005)
Lebanon	(Pasek 1998, CAB 2004, EPPO 2005)
Liberia	(Shutova 1978, Hava 2000)
Libya	(Pasek 1998, CAB 2004, EPPO 2005)
Luxembourg[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Madagascar (formerly Malagasy Republic)	(Lindgren et al. 1955, Shutova 1978)
Malaya	(Lindgren et al. 1955)
Malaysia (peninsular) [1]	(CAB 2004, EPPO 2005)
Malaysia[2]	(Shutova 1978, CAB 2004, EPPO 2005)
Mali	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Mauritania	(Pasek 1998, CAB 2004, EPPO 2005)
Mexico[4]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Morocco	(Pasek 1998, CAB 2004, EPPO 2005)
Mozambique[1]	(CAB 2004, EPPO 2005)

Locations	References
Myanmar (formerly Burma)	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Netherlands[4]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Netterlands (Rotterdam)	(Rahman et al. 1945)
New Zealand[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Niger	(Pasek 1998, CAB 2004, EPPO 2005)
Nigeria	(Lindgren et al. 1955, Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
North America	(Rahman et al. 1945)
Pakistan	(Pasek 1998, Zimmerman and Barron 1998, CAB 2004, EPPO 2005)
Pakistan (North West Frontier Province, Sind)	(Rahman et al. 1945)
Philippines[1]	(Lindgren et al. 1955, Shutova 1978, CAB 2004, EPPO 2005)
Poland[3]	(CAB 2004, EPPO 2005)
Portugal[3]	(Shutova 1978, CAB 2004, EPPO 2005)
Réunion[1]	(CAB 2004, EPPO 2005)
Russia[4]	(Lindgren et al. 1955, Pasek 1998, CAB 2004, EPPO 2005)
Saudi Arabia	(Pasek 1998, CAB 2004, EPPO 2005)
Senegal	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Serbia and Montenegro[1]	(CAB 2004, EPPO 2005)
Sierra Leone[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Slovakia[3]	(CAB 2004, EPPO 2005)
Somalia	(Pasek 1998, CAB 2004, EPPO 2005)
South Africa[2]	(Pasek 1998, CAB 2004, EPPO 2005)
Spain	(Pasek 1998, CAB 2004, EPPO 2005)
Sri Lanka (formerly Ceylon)	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Sudan	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Sweden[4]	(CAB 2004, EPPO 2005)
Switzerland	(Pasek 1998, CAB 2004, EPPO 2005)
Syria	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Taiwan	(Pasek 1998, CAB 2004, EPPO 2005)
Tanzania (Zanzibar Island)	(CAB 2004)
Tanzania[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Thailand[1]	(Shutova 1978, CAB 2004, EPPO 2005)
Tunisia	(Pasek 1998, EPPO 2005)
Turkey	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
Turkey (southeastern)	(Pasek 1998)
Ukraine (Odessa)	(Rahman et al. 1945)
United States of America (Arizona)[2]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
United States of America (California)[2]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)

Locations	References
United States of America (New Mexico) [2]	(Shutova 1978, Pasek 1998, CAB 2004, EPPO 2005)
United States of America (Texas) [2]	(Pasek 1998, CAB 2004, EPPO 2005)
Venezuela[4]	(Pasek 1998, CAB 2004, EPPO 2005)
Vietnam	(Shutova 1978)
Yemen	(Pasek 1998, CAB 2004, EPPO 2005)
Yugoslavia	(Shutova 1978)
Zambia	(Pasek 1998, EPPO 2005)
Zimbabwe (formerly Rhodesia)	(Pasek 1998, CAB 2004, EPPO 2005)
Zimbabwe (southern)	(Shutova 1978)

1. Absent, doubtful record (CAB 2004);
2. Absent, eradicated (CAB 2004);
3. Absent, intercepted only (CAB 2004);
4. Absent, fomerly present (CAB 2004).

Appendix B. Morphology of *Trogoderma granarium*

“The tiny (0.7 mm long), translucent, white egg is generally cylindrical with one end pointed and the other rounded (Lindgren et al. 1955).   The pointed end contains a few hairs. Eggs develop reddish or yellowish brown markings as they mature” (Pasek 1998).

Young larvae are yellowish-brown, but become reddish-brown as they mature, and are covered with long hairs. The posterior abdominal segments have long, erectile hairs that resemble a tail. Larvae and pupae have a distinctly segmented appearance. Larvae range in length from about 1.6 mm for first instars to 6 mm for final instars.   Characters that distinguish *T. granarium* larvae from nearctic species of *Trogoderma* are described in a key by Beal (1956)” (Pasek 1998).

“The exarate pupa remains inside the split skin of the last larval instar (Hinton 1945). The dorsal surface is covered by a medial ridge of hairs (Lindgren et al. 1955)” (Pasek 1998).

“The adult is a small, oval, pubescent, yellowish to reddish brown beetle, about 1.8-3.0 mm long (Hinton 1945). The female is about 1.4 times longer than the male and lighter in coloration (Hinton 1945, Lindgren et al. 1955). Hairs on the dorsal sur face are easily rubbed off, giving the beetle a shiny appearance (Hinton 1945). Okumura (1966) described an additional characteristic useful for distinguishing the adult from related species. A key to distinguish *T. granarium* adults from nearctic species of *Trogoderma* is presented by Beal (1956)” (Pasek 1998).

“Barak (1995) detailed larval and adult characteristics needed to distinguish *T. granarium* from other species of Dermestidae that occur in the US using dichotomous keys and figures” (Pasek 1998).

Appendix C. Biology of *Trogoderma granarium*

Spread

"Natural spread is limited to short distances (Lindgren et al. 1955). Adults can not fly; however, both adults and larvae may be dispersed by wind (Voelkel 1924, Howe 1952). The primary means of dispersal over both short and long distances is by transport of infested materials by humans or technology (Lindgren et al. 1955). Adults and inactive larvae seek out cracks and crevices and may remain in trucks, rail cars, ship holds, and packing materials, such as bagging and crates, for many years (Pruthi and Singh 1950). The rapid spread of khapra beetle in this century to countries in nearly every continent in the world is an indication of the capacity of this pest to be moved about through artificial means. ... The diapause characteristics of khapra beetle larvae make it extremely persistent, and its cryptic nature enables it to be transported undetected (Burges 1962)" (Pasek 1998).

Population dynamics

"Khapra beetle has a high capacity for population increase. It has a fairly high reproductive potential, low mortality rate, and may produce many generations per year under favorable temperature conditions (Lindgren et al. 1955). At 30-33°C (86-92°F), populations were able to multiply 19 to 44 times per generation on several varieties of wheat (Atwal and Dhaliwal 1971). This resulted in infestation increases of 1.7 to 2.4 times per week. Female adults resulting from termination of larval diapause on introduction of food following prolonged starvation were still able to produce 41% of the normal complement of eggs (Karnavar 1973)" (Pasek 1998).

"Khapra beetle may have a competitive advantage for population buildup under conditions of low relative humidity compared to other major stored grain pests (Howe 1963, Ramzan and Chahal 1989). It was consistently the most frequent of ten stored grain insect species found in grain storage facilities in Sudan (Seifelnasr 1991). Its prevalence relative to other species of stored grain pests may also be related to its greater tolerance to prolonged high temperatures (Howe 1952, 1963, Saxena et al. 1992) and its generally greater resistance to control measures (Desmarchelier 1984, Banks 1987, Krishnamurthy et al. 1993). Khapra beetle was by far the most abundant pest species found in a Pakistan silo in the three months following phosphine fumigation, despite its lower starting population level prior to treatment relative to the lesser grain borer, *Rhyzopertha dominica* Fabricius, and the red flour beetle, *Tribolium castaneum* (Herbst) (Mahmood et al. 1996)" (Pasek 1998).

"Development rates and survival vary considerably depending upon temperature, light, moisture, season, and host species (Rahman et al. 1945, Lindgren et al. 1955). Khapra beetle may have one to nine or more generations per year as a result. High humidity has a depressing effect on population buildup (Ramzan and Chahal 1986, 1989). At favorable temperatures, eggs, pupae, and adults each last about a week, whereas the larval stage may last a month to several years (if it enters diapause) (Burges 1959). The average time to complete development from egg to adult on ground dog food in complete darkness was 220, 166, 37, and 26 days, respectively, at 70°F, 80°F, 90°F, and 93-95°F

(Lindgren et al. 1955). At 70-80°F, larvae had an average of 7-8 instars , whereas at 90-95°F, larvae molted only 4 times. Under adverse conditions, larvae may molt up to 15 times (Voelkel 1924). Infestations of khapra beetle generate heat (Mason 1924, Rahman et al. 1945, Burges 1959), which may help maintain suitable living conditions, but may increase mortality of larvae when temperatures become too high (Bains et al. 1974)" (Pasek 1998).

"Little or no mortality of eggs, larvae, and pupae reared on ground dog food occurred at temperatures above 70°F (21°C) (Lindgren et al. 1955). Voelkel (1924) did not find khapra beetle living in environments of more than 44.2°C (112°F). Husain and Bhasin (1921) reported that all stages of khapra beetle died within five hours at 50°C (122°F). Bains et al. (1974) noted a lethal effect at 41.5°C (107°F). Larvae are also extremely cold tolerant (Lindgren et al. 1955). Only 52% of fourth instar larvae died when exposed for 25 hours to -10°C (14°F) (Voelkel 1924)" (Pasek 1998). Larval development stops at 40°C (104°F), but 35°C is still suitable (Armitage and Cook 1997)" (Pasek 1998).

"Most larvae more than a day old and adults are negatively phototropic through the majority of their lives, but adults become positively phototropic shortly before dying (Rahman and Sohi 1939). Prolonged starvation results in an indifference to light by affected larvae (Sohi 1986). Mating occurs only at night, and between temperatures of 10-42°C (50-108°F) (Voelkel 1924)" (Pasek 1998).

"Populations of parasites and predators were found to remain low in rural wheat stores in Punjab, India, and played only a minor role in regulating populations of khapra beetle (Bains et al. 1974)" (Pasek 1998).

Larvae

"Development times at 90-93°F for a variety of host materials tested varied from 29 days to eight months (Lindgren et al. 1955). Larval survival varied significantly depending upon type of food; 89-91% of larvae completed development to the adult stage when reared on crushed wheat or whole wheat flour at 30°C (86°F) compared to 56% survival when reared on Hindy rice grains (Ismail et al. 1988/89). Rahman et al. (1945) found that larvae developed fastest on wheat, bajra, maize, jowar, and rice, somewh at slower on barley and gram, and slowest on pista and walnut, while survival was greatest on rice and lowest on jowar. Larvae consumed an average of 3-12 mg of food during their development, with females eating about double the amount as compared to males" (Pasek 1998).

"More food was consumed in constant darkness; however, constant light accelerated development but reduced oviposition (Sohi 1947). Larval survival was 81% in constant darkness versus 51% in constant light for khapra beetle reared on white rice at 28.5°C (83°F) (Ismail et al. 1988/89)" (Pasek 1998).

"Larvae can prolong development time by entering a facultative diapause, whereby they are capable of surviving without food for several years (Mason 1924, Burges 1962, Karnavar 1973). Diapause is induced by accumulation of larval fecal pellets in f ood, crowding, or low temperature (Burges 1959, 1962, Nair and Desai 1972). However, diapause can not be induced after the 16th day following hatch, apparently a critical time for onset of pupation (Aggarwal et al. 1981). Diapausing larvae remain mobile (Burges 1962). Where some food is available, some larvae can live in diapause for 6 years (Burges 1962). Diapause is broken by a substantial rise in temperature or provision of fresh food and reduction in crowding (Burges 1959, 1962, Nair and Desai 1973). Some larvae also break diapause spontaneously after a period of time (Nair and Desai 1973)" (Pasek 1998).

Adults

"Sex ratio of emerging adults was 1:1 (Lindgren et al. 1955). Adult longevity varied from 25 days at 70°F to 12 days at 93-95°F. Under darkness and reared on ground dog food, fecundity increased with increasing temperature and females laid averages of 65 and 93 eggs at 70°F and 90°F, respectively. Adults derived from diapausing larvae tended to lay more eggs than those from non-diapausing larvae, although adults of diapausing larvae that had been starved produced fewer eggs than those of non-starved diapausing larvae (Saxena et al. 1981). Eggs are usually laid singly amongst host material (Voelkel 1924). Adults feed very little during their short lives and do not fly (Voelkel 1924)" (Pasek 1998).