Khapra Beetle (Trogoderma granarium Everts): Pest-Initiated Pest Risk Assessment

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PEST DATA SHEET
I. Introduction

A. General

This pest risk assessment was conducted by the United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (USDA, APHIS, PPQ). It was initiated in response to a need identified during an agency Program Review for khapra beetle (*Trogoderma granarium* Everts; Coleoptera: Dermestidae), which was requested during the November 1997 meeting of the Plant Protection and Quarantine Strategy Team (PPQST) and the National Plant Board Council. This assessment addresses the likelihood of khapra beetle becoming established in the United States, the economic consequences of khapra beetle infestation in the US, and available information regarding pathways, probability of detection, and marketing/export consequences of infestation in the US. This is a “pest initiated” pest risk assessment and is qualitative in nature. Although this pest risk assessment offers brief recommendations, it does not present APHIS’ decisions regarding risk management for khapra beetle.

International plant protection organizations such as the North American Plant Protection Organization (NAPPO), and the International Plant Protection Convention (IPPC) of the United Nations Food and Agriculture Organization (FAO) provide guidance for conducting pest risk analyses. The methods used to initiate, conduct, and report this pest risk assessment are consistent with guidelines provided by NAPPO, IPPC, and FAO. The biological and phytosanitary terms in this document conform with the *NAPPO Compendium of Phytosanitary Terms* (Hopper, 1996) and the *Definitions and Abbreviations* (Introduction Section) in *International Standards for Phytosanitary Measures, Section 1--Import Regulations: Guidelines for Pest Risk Analysis* (FAO, 1995). For example, “pest risk analysis” is defined as “pest risk assessment and pest risk management,” while “pest risk assessment” is defined as “determination of whether a pest is a quarantine pest and evaluation of its introduction potential.”

B. Historical Perspective

Khapra beetle feeds on dried plant and animal material with proteinaceous content, such as dried seeds, grains, fruits, spices, and gums (Hinton, 1945). It is a serious pest of stored grain and cereal in hot and dry climates of Eurasia and Africa (Burges, 1959; Banks, 1977). It 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). These khapra beetle infestations were eradicated from the United States by 1966 at a cost of over $11 million dollars (Armitage, 1958). 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 (PNKTO No. 30; Anonymous, 1978; FAO, 1981). These infestations were subsequently eradicated.

Most 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.

Methyl bromide, which has been used to fumigate many commodities containing regulated pests, is a known ozone depleter and is scheduled to be phased out by the Environmental Protection Agency (EPA). In accordance with the Clean Air Act, the EPA has prohibited production and importation of methyl bromide effective January 1, 2001. High concentrations of methyl bromide can also cause serious health effects in humans, including central nervous system and respiratory system failure, irritation of lungs, eyes, or skin, and sometimes even death (EXTOXNET, 1996). The impending loss of this treatment method necessitates reexamination of treatment options available to eradicate infestations of khapra beetle.

C. Previous Risk Assessments

Shannon (1989) wrote a chapter on khapra beetle that included information on quarantine significance, known pathways, treatment and regulatory options, and detection methods. However, the publication does not include a pest risk assessment that meets current guidelines as specified by NAPPO and FAO.

D. Current Status of Imports, Pertinent Interceptions

*T. granarium* has been intercepted at ports of entry in the United States through inspection activities of Plant Protection Officers and recorded in the automated Port Information Network (PIN) database. The PIN database was queried for interceptions of khapra beetle found beginning in 1985 through May 1998. A total of 407 interceptions was reported during the 13 ½ years. Almost all of the intercepted cargo containing khapra beetle during 1985-1998 arrived through airports (63%) and maritime ports (36%). Less than 1% arrived at land border crossings and Plant Inspection Stations. Interceptions at airports were found primarily in baggage, whereas interceptions at maritime ports were mostly in general cargo and stores (Table 1). By far, the most frequent port of entry for interceptions of khapra beetle was at Houston TX, which accounted for nearly half the khapra beetle finds (Table 2). At Houston, 78% and 22% of interceptions were found at the airport and maritime port, respectively. For airport interceptions at Houston, 88% were found in baggage.

Khapra beetle was intercepted on more than 75 hosts. Interceptions by commodity type are summarized in Table 3. The vast majority of khapra beetle interceptions were found in

Khapra beetle was intercepted infrequently for most species of seeds, with the exception of the *Curcubitaceae* (including *Citrus* sp., *C. lanatus*, *Cucumis* sp., *C. melo*, *Curcubita* sp., *C. maxima*, and *Momordica charantia*) and *Oryza* (including *Oryza* sp. and *O. sativa*). A total of 75 interceptions were reported from plant materials of species in the *Curcubitaceae*. All of these interceptions arrived by aircraft, mostly in passenger baggage (Note that commercial shipments of cucurbit seeds that would arrive through maritime ports receive mandatory treatment; and therefore, would not be inspected). For shipments of rice (*Oryza* spp.), a total of 55 khapra beetle interceptions were reported including those found in bagging and baggage. Half arrived by airport and half by maritime port. Most interceptions of khapra beetle in rice at airports were in baggage, whereas interceptions at maritime ports were mostly distributed in stores, general cargo, and permit cargo. These two plant groups (cucurbits and rice) accounted for 18% and 14%, respectively, of all interceptions of khapra beetle found from 1985 through May 1998.

**TABLE 1. LOCATIONS OF INTERCEPTIONS OF KHAPRA BEETLE, 1985-May 1998.**

<table>
<thead>
<tr>
<th>Where Intercepted</th>
<th>Number Intercepted</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Airport</td>
</tr>
<tr>
<td>Baggage</td>
<td>217</td>
</tr>
<tr>
<td>Mail</td>
<td>2</td>
</tr>
<tr>
<td>General Cargo</td>
<td>32</td>
</tr>
<tr>
<td>Permit Cargo</td>
<td>4</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
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<tr>
<td>Stores</td>
<td>0</td>
</tr>
<tr>
<td>Quarters</td>
<td>0</td>
</tr>
<tr>
<td>Holds</td>
<td>0</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Where Intercepted</th>
<th>Number Intercepted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>257</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Port</th>
<th>Number Intercepted</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston TX</td>
<td>196</td>
<td>48</td>
</tr>
<tr>
<td>Brooklyn NY</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td>New Orleans LA</td>
<td>25</td>
<td>6</td>
</tr>
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<td>San Francisco CA</td>
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<td>Atlanta GA</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Dallas TX</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Los Angeles CA</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Philadelphia PA</td>
<td>9</td>
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<tr>
<td>Seattle WA</td>
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<td>2</td>
</tr>
<tr>
<td>Elizabeth NJ</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Charleston SC</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Port Arthur TX</td>
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</tr>
<tr>
<td>Savannah GA</td>
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</tr>
<tr>
<td>Erlanger KY</td>
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<td>1</td>
</tr>
<tr>
<td>JFKIA NY</td>
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<td>&lt;1</td>
</tr>
<tr>
<td>Port Orlando FL</td>
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<tr>
<td>Boston MA</td>
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<td>Chicago IL</td>
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<td>&lt;1</td>
</tr>
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<td>&lt;1</td>
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<tr>
<td>Mobile AL</td>
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<td>&lt;1</td>
</tr>
<tr>
<td>Portland OR</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>San Pedro CA</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Tinker AFB OK</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Alabaster AL</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Baton Rouge LA</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Beltsville MD</td>
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<td>&lt;1</td>
</tr>
<tr>
<td>Blaine WA</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Corpus Christi TX</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Denver CO</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Detroit MI</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Dover DE</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Ft. Lauderdale FL</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Kansas City MO</td>
<td>1</td>
<td>&lt;1</td>
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<tr>
<td>Norfolk VA</td>
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<td>&lt;1</td>
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<tr>
<td>Raleigh NC</td>
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<td>&lt;1</td>
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<tr>
<td>San Diego CA</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>San Juan PR</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>St. Paul MN</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>West Palm Beach FL</td>
<td>1</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
Most interceptions of khapra beetle in bagging were also associated with plant species included in the list above for seeds. The exceptions were found in cargo containing foodstuffs (1), goatskins (2), gum (1), and spices (1). Interceptions from fruit included the following plant species: *Abelmoschus esclentus* (2), *Citrus aurantiifolia* (9), *Citrus limon* (3), *Citrus sinensis* (1), *Citrus sp.* (1), *Ficus sp.* (1), *Mangifera indica* (1), *Myristica fragrans* (1), *Phoenix dactylifera* (1), *Prunus domestica* (1), and *Prunus sp.* (2). Flowers found to contain khapra beetle included: *Citrus sp.* (1), *Hibiscus sp.* (1), and *Lathyrus sp.* (1). Other plant materials containing khapra beetle, but not already mentioned above included: *Berberis sp.* (1), *Cinnamomum sp.* (1), *Coriandrum sp.* (1), *Cuminum cyminum* (1), *Impatiens sp.* (1), *Mentha sp.* (1), *Origanum vulgare* (1), *Rhus sp.* (1), and *Saccharum officinarum* (1). Cargo associated with interceptions in crating included: artware (4), household goods (2), housewares (2), clothing (1), hardware (1), swords (1), and metal (1).

Interceptions differed dramatically from those reported by Shannon (1989) for the previous 14 year period of 1971 to 1984. Khapra beetle was intercepted relatively infrequently during 1985-1998 from the top 5 commodities reported for 1971-1984, namely gum, sheepskin, artware, capsicum, and cotton piece goods. The sixth most frequent commodity harboring khapra beetle in 1971-1984, i.e., cucurbit, has now become the top commodity for interception. Rice (*Oryza spp.*) was listed as the fifteenth most frequent commodity harboring khapra beetle in 1971-1984, along with peanut (*Arachis hypogaea*) and pistachio (*Pistacia vera*). Rice was the second most frequent commodity found to harbor khapra beetle during 1985-1998. Reported interceptions for 1985-1998 (407) were approximately one-third that of 1971-1984 (total of 1336; 801 with identified hosts). These differences may largely reflect changes in quarantine regulations.
effected in 1985 (i.e., prohibition of used jute and burlap bagging and mandatory fumigation of restricted articles), but other changes in safeguarding procedures and trade patterns may also have had some effect over the years studied.

Most interceptions during 1985-1998 were found in cargo originating from countries in southwestern Asia (Table 4). Four countries accounted for 79% of interceptions where the country of origin was designated: India, Saudi Arabia, Iran, and Pakistan. India accounted for 34% of interceptions in 1985-1998 versus 44% in 1971-1984 (Shannon, 1989), but remained in first place as the country of origin with the most shipments intercepted with khapra beetle (Table 5). Sudan dropped from second place to sixth, going from 24% of interceptions in 1971-1984 to 2% in 1985-1998. Pakistan also dropped from third place with 15% of interceptions in 1971-1984 to fourth place with 9% of interceptions in 1985-1998. Iran moved from fourth place in 1971-1984 with 5% of interceptions to third place in 1985-1998 with 14% of interceptions. Saudi Arabia, which accounted for less than 2% of interceptions in 1971-1998 moved into second place with 22% of interceptions in 1985-1998.

Countries considered to contain endemic populations of khapra beetle include: Afghanistan, Algeria, Bangladesh, Burkina Faso, Cyprus, Egypt, India, Iran, Iraq, Israel, Libya, Mali, Mauritania, Morocco, Myanmar, Niger, Nigeria, Pakistan, Saudi Arabia, Senegal, Sri Lanka, Sudan, Syria, Tunisia, and Turkey (USDA-APHIS, PPQ, Plant Import Manual (Nonpropagative), 05/96-01). No khapra beetles were reported intercepted from ten of the twenty-five infested countries between 1985 and 1998. This could be the result of low priority for inspection, low levels of trade in commodities that harbor khapra beetle, low numbers of airline passenger arrivals, or effective pre-certification of commodity shipments for these countries. A total of 46 interceptions (11%) were reported in items arriving from countries other than those considered to be infested with khapra beetle. Most of these countries, including those in Europe and the Americas, reported only one or two interceptions in the period of 1985 to 1998. The exceptions were from countries adjoining those considered to be infested: Kuwait (12), Jordan (9), United Arab Emirates (4), and China (3). A total of 11 interceptions (39%) from these four countries were found in shipments of cucurbits, with the remainder coming from Citrullus lanatus seed (5), foodstuffs (3), unidentified plant seed or material (2), bagging (1), Citrus limon fruit (1), crating (1), Cucumis sp. seed (1), dried flowers (1), spices (1), and Triticum sp. seed (1).

Instances of one or two interceptions from countries not known to have populations of khapra beetle may reflect cases where contamination from shipments to or from infested countries occurred prior to arrival in the United States, or where the origin of small quantities of infested material in passenger baggage may be uncertain.

Importation of restricted articles for khapra beetle require fumigation with methyl bromide at the port of entry according to specifications in 7 CFR 319.75-4. About 21% of interceptions reported in 1985-1998 were from items generally fitting the description of regulated articles (i.e., cucurbits and bagging from countries considered to contain populations of khapra beetle). Commercial shipments of these commodities and items would have undergone fumigation treatment prior to being moved into the United States from a port of entry. Therefore, these interceptions likely represent transport in host material in quantities smaller than that requiring
treatment (i.e., < 2 oz.). Conversely, about 79% of interceptions of khapra beetle came from articles that are unrestricted in any quantity.

**TABLE 4. INTERCEPTIONS BY COUNTRY OF ORIGIN, 1985-May 1998.**

<table>
<thead>
<tr>
<th>Country</th>
<th>Number Intercepted</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>130</td>
<td>34</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>84</td>
<td>22</td>
</tr>
<tr>
<td>Iran</td>
<td>53</td>
<td>14</td>
</tr>
<tr>
<td>Pakistan</td>
<td>36</td>
<td>9</td>
</tr>
<tr>
<td>Kuwait</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Sudan</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Jordan</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Syria</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Nigeria</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>China</td>
<td>3</td>
<td>&lt;1</td>
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<tr>
<td>Iraq</td>
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<td>&lt;1</td>
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<tr>
<td>Belgium</td>
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<td>&lt;1</td>
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<tr>
<td>Egypt</td>
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<td>&lt;1</td>
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<tr>
<td>Japan</td>
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<tr>
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<th></th>
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<tbody>
<tr>
<td>India</td>
<td>44 (1)</td>
<td>34 (1)</td>
</tr>
<tr>
<td>Sudan</td>
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<td>2 (6)</td>
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<tr>
<td>Pakistan</td>
<td>15 (3)</td>
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<td>Iran</td>
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</tr>
<tr>
<td>Saudi Arabia</td>
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<td>22 (2)</td>
</tr>
<tr>
<td>Kuwait</td>
<td>≤ 2 (Unreported)</td>
<td>3 (5)</td>
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</table>

* Data from Shannon (1989).

E. Regulatory Authority

Under the Federal Plant Pest Act, as amended 1957 (7 United States Code 150aa et seq.) and the Plant Quarantine Act of 1908, as amended 1967 (7 United States Code 150aa et seq.), USDA has broad authority to regulate the importation and interstate movement of organisms that may directly or indirectly injure, damage, or cause disease in plants. APHIS' authority to regulate these organisms is granted by Title 7 of the Code of Federal Regulations (CFR), Part 330 (i.e., 7 CFR § 330). Part 319 of Title 7 (7 CFR § 319) covers Nursery Stock, Plants, Roots, Bulbs, Seeds, and Other Plant Products.

Under 7 CFR § 319.75 (1-1-1997 edition) as amended March 5, 1985, restricted articles for khapra beetle include the following:

- “Seeds of the plant family Cucurbitaceae if in shipments greater than two ounces, if not for propagation, and if from a country listed” below,

- “Brassware and wooden screens from Bombay, India,”

- “Goatskins, lambskins, and sheepskins (excluding goatskins, lambskins, and sheepskins which are fully tanned, blue-chromed, pickled in mineral acid, or salted and moist) from Sudan or India,”

- “Plant gums shipped as bulk cargo (in an unpackaged state) if from a country listed” below,

- “Used jute or burlap bagging not containing cargo if a country listed” below,

- “Used jute or burlap bagging from a country listed” below “that is used as a packing material (such as filler, wrapping, ties, lining, matting, moisture retention material, or
protection material), and the cargo for which the used jute or burlap bagging is used as a packing material,” and

“Whole chilies (Capsicum spp.), whole red peppers (Capsicum spp.), and cumin seeds (Cuminum cyminum) in new jute or burlap bags from Pakistan.”

Countries for which these definitions apply include: Afghanistan, Algeria, Bangladesh, Burkina Faso, Cyprus, Egypt, India, Iran, Iraq, Israel, Libya, Mali, Mauritania, Morocco, Myanmar, Niger, Nigeria, Pakistan, Saudi Arabia, Senegal, Sri Lanka, Sudan, Syria, Tunisia, and Turkey.

Importation of a restricted article for khapra beetle requires an import permit and treatment under the supervision of an inspector by methyl bromide fumigation according to schedules specified in 7 CFR 319.75-4 (1-1-1997 edition). Regulated articles for khapra beetle may be imported only at ports of entry that have nongovernmental fumigators available as specified on an import permit.

A phytosanitary certificate of inspection is required for restricted articles grown in countries that maintain an official system of inspection for the purpose of determining whether such articles are free of injurious pests. For countries that do not issue phytosanitary certificates of inspection, the cargo must be inspected at the port of entry into the United States.

II. Summary of Risk Assessment Methods

A. General

Stage 1 of a pest risk analysis identifies a pest or pathway for which a risk assessment is needed. Since this is a “pest-initiated” pest risk assessment, the focus is on T. granarium. Stage 2 examines whether the criteria for quarantine pest status are satisfied. In so doing, the pest risk assessment considers all aspects of the pest, and in particular actual information about its geographical distribution, biology and economic importance. Available scientific data and expert judgment are then used to assess the establishment, spread and economic importance potential in the Pest Risk Analysis (PRA) area. Finally, the potential for introduction into the PRA area is characterized. The PRA area for the purposes of this PRA is considered to be the entire United States.

B. Qualitative Assessment

The risk assessment methodology and rating criteria for the qualitative assessment are not included; these can be found in the document: Guideline for Plant Pest Risk Analysis of Imported Commodities, Version 1.6 (USDA/APHIS, 1997). This document is available from USDA Animal and Plant Health Inspection Service, Biotechnology and Biological Analysis, 4700 River Road, Unit 133, Riverdale, MD 20737-1236.
III. Pest Risk Potential

Plant pest risk is composed of two general elements: the consequences of introduction of a particular pest, and the probability that the pest will be introduced.

A. Economic Importance: Consequences of Introduction

The consequences of introduction were considered for *T. granarium*. These risks were estimated by rating the pest with respect to five risk elements. A full description of these elements and rating criteria can be found in USDA/APHIS (1997). Table 6 shows the risk ratings for these risk elements.

| TABLE 6. RISK RATING - CONSEQUENCES OF INTRODUCTION |
|---------------------------------|--------------|-----------------|-----------------|-----------------|---------|
| Climate/Host Interaction   | Host Range  | Dispersal Potential | Economic Impact | Environmental Impact | Risk Rating |
| High                   | High        | High             | Medium          | Medium           | High    |

The Consequences of Introduction Risk Rating for *T. granarium* is **High**. A discussion of the scientific basis corresponding to each rating criterion follows.

**Climate/Host Interaction:** 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). However, 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).

**Host Range:** 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). Even those native species of *Trogoderma* [e.g., *T. glabrum* (Herbst), *T. grassmani* Beal, *T. ornatum* (Say), *T. parabile* Beal, *T. simplex* Jayne, and *T. sternale* subspecies] that apparently can develop solely on grains are more commonly found in insect or spider nests than is *T. granarium*, and never to infrequently build population levels to economic significance in granaries (Beal, 1956; Strong *et al.*, 1959).
Dispersal Potential: 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 (Banks, 1977). The diapause characteristics of khapra beetle larvae make it extremely persistent, and its cryptic nature enables it to be transported undetected (Burges, 1962).

Khapra beetle also 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).

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 (Banks, 1987; Desmarchelier, 1984; 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).

Economic Impact: 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. Eradication efforts for khapra beetle likely would require use of higher doses and/or longer exposure times than may be commonly used to mitigate populations of domestic species of stored grain pests. Treatments of stored grains for domestic species of stored grain pests may allow infestation by khapra beetle to develop a competitive edge due to its relatively greater resistance to control treatments.

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 health hazard if swallowed. Cast skins may cause dermatitis in people handling heavily infested grains (Pruthi and Singh, 1950).

The mere presence of khapra beetle in the US 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.

Availability of effective treatments for eradication are limited and may become scarcer as methyl bromide is phased out and khapra beetle populations develop increasing resistance to malathion and phosalone. Although some alternative treatments show promise, additional development is required prior to adoption.

Environmental Impact: 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. However, use of methyl bromide or other fumigants to eradicate or control khapra beetle will likely produce adverse effects to the environment and human health. Methyl bromide is an ozone-depleting substance. About 80-95% of methyl bromide used to treat commodities and over 90% used to treat structures reaches the atmosphere (EPA, Methyl Bromide Phaseout Web Site). Human exposure to high concentrations of methyl bromide can result in failure of the central nervous system and respiratory system (EXTOXNET, 1996). 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.

B. Likelihood of Introduction

The pest is rated with respect to introduction potential (i.e., entry and establishment). The likelihood of introduction is rated relative to six factors. A full description of these factors and rating criteria can be found in USDA/APHIS (1997). Table 7 shows the risk ratings for these factors.
The Likelihood of Introduction Risk Rating for *T. granarium* is **High**. A discussion of the scientific basis corresponding to each rating criterion follows.

**Quantity of Commodity Imported:** Commercial shipments of rice from India, Pakistan, and Saudia Arabia in fiscal years 1994-1996 averaged over 26,000 metric tons per year (*Foreign Agricultural Trade of the United States*), which translates to about 623 40’ shipping containers per year. In 1997, India, Pakistan, and Saudi Arabia were ranked second, fifth, and twenty-fourth, respectively, in quantity of rice supplied to the US (data obtained from USDA Foreign Agricultural Service). This commodity alone represents a high level (>100 containers) of host material imported annually. Commercial shipments of cucurbit seeds require mandatory treatment; therefore, these should not be sources of khapra beetle entering the United States. However, khapra beetle may frequently arrive in small quantities of untreated cucurbit seeds and other host materials carried in passenger baggage. Information on the quantity of such material is unavailable. There is currently no commercial trade with Iran, so interceptions of khapra beetle from that country may be assumed to be arriving on small quantities of host material, largely carried in aircraft passenger baggage.

**Likelihood of Surviving Postharvest Treatment:** Treatment with methyl bromide fumigation is very effective at destroying khapra beetle. However, many potential hosts of khapra beetle can be imported without mandatory fumigation. Also, commodities and associated products or packaging often become infested following harvest while stored in grain facilities or warehouses or during transit in infested containers or vessels. Treatment may become more difficult or less effective with the loss of methyl bromide as an option.

**Likelihood of Surviving Shipment:** Khapra beetle is highly likely to survive shipment. It thrives in stored grains, especially in hot, dry conditions. It does especially well in grain that is cracked or broken, which is common in seed that has been harvested or jostled in containers. It can remain dormant for several years under less than ideal conditions (Burges, 1962), and can live through temperatures below 35°F for at least short periods (Mansbridge, 1936; Voelkel, 1924).

**Likelihood of Not Being Detected at Port of Entry:** Current methods of detecting khapra beetle rely almost entirely on visual inspection (USDA-APHIS, 1981). Detection of khapra beetle can be difficult. Adult beetles are about 1.8 to 3.0 mm long and about half as wide. In stable populations, adults comprise less than 2% of all stages present (Atwal and Dhaliwal, 1981).
Larvae range from 1.6 to 6.0 mm, depending on instar and sex. Eggs and early instars may be nearly imperceptible. Eggs and active larvae are scattered through host material, such as grain, while adults and diapausing larvae tend to hide in cracks and crevices and other dark places. Besides host commodities, such as grain and seeds, all stages can be transported in a variety of materials such as bagging (especially those made of burlap and cotton), clothing, household goods, and vehicles, making it difficult to determine where to inspect for this pest. Vacuum cleaners may be used to draw cast skins or dead adults out of cracks and crevices, or pick up debris for subsequent inspection.

Even when khapra beetles are detected, most likely as larvae, they can be difficult to identify with certainty. Khapra beetle can be mistaken for other species of *Trogoderma*, including those native to the US. Small larvae of the various *Trogoderma* species are nearly impossible to differentiate morphologically. An enzyme-linked immunosorbant assay (ELISA) has shown promise for identifying larvae, pupae, and adults of *T. granarium* at a high level of accuracy (although some false positives occur) even when specimens are in poor condition (Stuart *et al.*, 1994), but needs further refinement for field use, licensing, and commercializing.

Detection traps using a combination of pheromone lure, food attractant, and dark places to hide have been developed for use in grain storage facilities and warehouses. Barak (1989) improved on earlier designs by developing a vertical wall mount trap (US Patent No. 4,866,877) that virtually eliminated losses of insects due to escape from the trap or loss of the trap itself. Unfortunately, the licensed supplier of the Agrisense Vertical Wall Mount Trap for khapra beetle went out of business, so a new supplier is currently being sought (Al Barak, personal communication). Since the pheromone lure is cross-attractive to several species of *Trogoderma* (Greenblatt *et al.*, 1977), it is recommended that aerial traps be used to capture flying species of *Trogoderma*, thereby reducing the number of non-khapra beetle catches in wall-mount traps (Faustini *et al.*, 1991).

**Likelihood of Moving to Suitable Habitat:** Khapra beetle arriving in shipments of agricultural commodities would likely find suitable habitat upon arrival at grain or food storage facilities and processing plants, which are primarily controlled environments (i.e., heated). Khapra beetle arriving in noncommercial quantities, such as that carried in passenger baggage, also would likely find suitable environments for survival in people’s homes. Khapra beetle arriving as contaminants in non-host materials could be moved to warehouses or other buildings, which may provide protected environments for survival.

**Likelihood of Finding Suitable Hosts:** Khapra beetle arriving in commercial shipments of agricultural commodities would find ample grain or other plant hosts available in grain and food storage facilities or processing plants. Khapra beetle arriving in passenger baggage or stores would be less likely to find suitable hosts upon arrival, but could become established if placed with other foods in pantries or kitchens. Likelihood of khapra beetle finding suitable hosts in general warehouses could be low, but will vary with the contents of those facilities. Khapra beetle larvae can survive for several years without food until conditions become suitable for further development (Mason, 1924). This ability to remain dormant (in diapause) for long
periods of time increases the likelihood that new introductions of khapra beetle will encounter suitable host material before perishing.

IV. Conclusion: Pest Risk Potential and Phytosanitary Measures

The Pest Risk Potential (PRP) for *T. granarium* is High. For pests receiving a high PRP rating, specific phytosanitary measures are strongly recommended. Port-of-entry inspection is not considered sufficient to provide phytosanitary security. Detailed examination and choice of appropriate sanitary and phytosanitary measures to mitigate pest risk is undertaken as part of the pest risk management phase (Stage 3) and is not discussed in this document. Availability of technologies for population reduction or treatment and appropriateness of potential regulatory actions need to be considered during development of management alternatives during Stage 3.

Some recommendations for possible actions that could be considered during Stage 3 (i.e., the development and selection of management alternatives) based upon information collected for this PRA include the following:

- Direct safeguarding efforts (inspection, treatment, pre-certification, etc.) especially toward imports of cucurbits and rice coming from countries known to be infested with khapra beetle;

- Develop technology to better detect infested seeds in passenger baggage;

- Investigate adding Kuwait, Jordan, United Arab Emirates, and China to the list of countries harboring populations of khapra beetle;

- Conduct an intensive, pre-fumigation survey (blitz) of brassware and screens arriving from Bombay, India to determine whether they are still high risk commodities for khapra beetle, given the lack of interception information available in the PIN database for these items due to existing mandatory treatment regulations that preclude routine inspection;

- Locate a manufacturer willing to take over the patent (No. 4,866,877) for the vertical wall mount insect trap designed for khapra beetle detection in grain storage facilities, warehouses and other likely introduction locations;

- Establish survey protocols (trap density, placement, intensity, check frequency, etc.) for area-wide detection of khapra beetle and certification of pest-free areas;

- Conduct methods development to improve tools for identification of khapra beetle, such as use of an enzyme-linked immunosorbant assay (ELISA) kit (Stuart *et al*., 1994), which would be sensitive enough to identify a part of a larva;

- Conduct research and methods development on alternative methods of eradication and control to replace methyl bromide fumigation (for example, carbonyl sulfide, heat treatment, irradiation, neem additives);
Investigate higher efficacy alternatives to surface treatment with malathion (such as deltamethrin, fluvalinate, methoprene, fenvelerate, cypermethrin);

Revise Khapra Beetle Program Manual to incorporate recent changes in trapping and eradication methodologies, as developed.

V. Preparation, Consultation and Review

This pest risk assessment was prepared by staff at the Raleigh Plant Protection Center, Center for Plant Health Science and Technology, within USDA-APHIS, Plant Protection and Quarantine:

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PEST DATA SHEET

TROGODERMA GRANARIUM EVERTS

IDENTITY

Name: Trogoderma granarium Everts
Synonyms: Trogoderma affrum Priesner
Trogoderma khapra Arrow
Taxonomic position: Insecta: Coleoptera
Common Names: khapra beetle (English), Trogoderma (dermeste) du grain (French), khaprakäfer (German), Escarabajo khapra (Spanish)

MAIN DAMAGE

Khapra beetle is primarily a pest of stored grains. Larvae typically attack the embryo point or a weak place in the pericarp of grain or seed, but will attack other parts during heavy infestations (Pruthi and Singh, 1950). Young larvae feed on damaged seed, while older larvae are able to feed on whole grains. Larvae wander in and out of sacked material, weakening the sacks, which may ultimately tear (Howe, 1952).

HOST RANGE

Khapra beetle will feed on most any dried plant or animal matter, but prefers grain and cereal products, particularly wheat, barley, oats, rye, maize, rice, flour, malt, and noodles (Hinton, 1945). It can feed in products with as little as 2% moisture content (Taylor, 1924). It can develop on animal matter such as dead mice, dried blood, and dried insects.

Primary seed and cereal grain hosts include: Avena sativa (oat), Cicer arrietinum (garbanzo), Glycine max (soybean), Hordeum vulgare (barley), Lens culinaris (lentil), Oryza sativa (rice), Pisum sativum (garden pea), Sorghum bicolor (grain sorghums), Triticum aestivum (wheat), Vigna unguiculata (cowpea), and Zea mays subsp. mays (corn). Preferred animal feeds and concentrates include: rolled and ground barley, ground corn, ground dog food, rolled oats, dried orange pulp, ground rice, and cracked and ground wheat bran. Nuts that may serve as primary hosts include: Arachis hypogaea (peanut), Carya illinoensis (pecan), Juglans sp. (walnut), and Prunus dulcis (almond). Grocery commodities that sometimes serve as hosts include: bread, dried coconuts, cornmeal, crackers, white and whole wheat flour, hominy grits, baby cereals, pearl barley, and wheat germ. Larvae can feed, but not fully develop on seeds of Medicago sativa subsp. sativa (alfalfa), noodles, Phaseolus lunatus (lima bean), and raisins (Strong et al., 1959).
GEOGRAPHIC DISTRIBUTION

Khapra beetle is apparently native to India (Rahman et al., 1945). Hinton (1945) reported that it was distributed in India, Ceylon, Malaya, Europe, (former) U.S.S.R., China, Japan, Korea, Philippines, Australia, and Madagascar, and had become established in most of those countries. It was discovered in stored guinea corn in Nigeria in 1948, and may have been present in stored groundnuts as early as 1944 (Howe, 1952). Current quarantine regulations for the US recognize 25 countries as harboring endemic populations of khapra beetle: Afghanistan, Algeria, Bangladesh, Burkina Faso, Cyprus, Egypt, India, Iran, Iraq, Israel, Libya, Mali, Mauritania, Morocco, Myanmar, Niger, Nigeria, Pakistan, Saudi Arabia, Senegal, Sri Lanka, Sudan, Syria, Tunisia, and Turkey (USDA-APHIS, PPQ, Plant Import Manual (Nonpropagative), 05/96-01).

CABI and EPPO (1997) listed countries where khapra beetle is established, has been found in the past, or where interceptions of infested exports occurred:

European and Mediterranean region: Established in Algeria, Austria, Cyprus, Egypt, Germany (found in past in protected environments, but not established), Israel, Lebanon, Libya, Morocco, Spain, Switzerland, Syria, Tunisia, Turkey (southeastern), United Kingdom (protected environments only). Found in past but not established in Belgium, Denmark, Ireland, Luxembourg, Netherlands, Russia. Intercepted only in Hungary and Italy.

Asia: Afghanistan, Bangladesh, India, Indonesia (found but not established), Iran, Iraq, Israel, Japan (restricted distribution), Korea Republic, Lebanon, Myanmar, Pakistan, Saudi Arabia, Sri Lanka, Syria, Taiwan, Turkey, Yemen.

Africa: Algeria, Burkina Faso, Egypt, Kenya (found but not established), Libya, Mali, Mauritania, Morocco, Niger, Nigeria (mainly in north), Senegal, Sierra Leone (intercepted only), Somalia, South Africa (found but not established), Sudan, Tanzania (found but not established), Tunisia, Zambia, Zimbabwe.

North America: Mexico (found in past but not established), United States (found in past but eradicated in Arizona, California, New Mexico, Texas).

South America: Venezuela.

Oceania: Intercepted only in Australia (Bailey, 1957) and New Zealand.

BIOLOGY

Development rates and survival vary considerably depending upon temperature, light, moisture, season, and host species (Lindgren et al., 1955; Rahman et al., 1945). 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 (Burges, 1959; Mason, 1924; Rahman et al., 1945), which may help maintain suitable living conditions, but may increase mortality of larvae when temperatures become too high (Bains et al., 1974).

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, somewhat 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.

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).

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 food, 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).

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).

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).

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).

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).

DETECTION AND IDENTIFICATION

Symptoms

Infested matter turns to a powdery dust. The most obvious signs of infestation are the presence of larvae and cast skins. Infestation by khapra beetle most often occurs in the superficial layers of stored grain (Bains et al., 1974; Pruthi and Singh, 1950). 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 depth) and bottom layers (10.9-19.2 m 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.

Morphology

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.

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).

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).
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 surface 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).

Barak (1995b) 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.

**Detection and inspection methods**

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.

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. Development of a vertical wall mount trap (US Patent No. 4,866,877) improved upon earlier designs by virtually eliminating losses of insects due to escape from the trap or loss of the trap itself (Barak, 1989). Additionally, this design was found to attract more of the small larvae than previous designs. Use of ground wheat germ rather than oil baits allows captured larvae to grow to a size that can be detected and then identified by a specialist (Barak, 1995a). A trapping protocol for facilities and trapping instructions are described in the National Agricultural Pest Information System (NAPIS) website (http://ceris.purdue.edu/napis/pests/khb/index.html). The licensed supplier of the Agrisense Vertical Wall Mount Trap for khapra beetle went out of business, so the trap is currently unavailable commercially, but efforts are underway to locate a new supplier (Al Barak, personal communication). *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).

**MEANS OF MOVEMENT AND DISPERAL**

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.

PEST SIGNIFICANCE

Economic impact

Larvae reportedly can destroy up to 30% or more of stored grain (Rahman, et al., 1945). In India, khapra beetle infests about 5% of stored grains, but can affect a whole lot under heavy infestation (Anonymous, 1967; Pruthi and Singh, 1950). Infestation affects grain quality as well as quantity.

Environmental impact

Direct and indirect effects on the environment due to establishment of khapra beetle are expected to be minimal. However, use of fumigants, such as methyl bromide, to eradicate or control khapra beetle may have significant adverse environmental effects. Methyl bromide is a known ozone-depleting substance (EPA, Methyl Bromide Phaseout Web Site). In high concentrations, it can also cause failure of the central nervous system and respiratory functioning in humans (EXTOXNET, 1996).

Control

Fumigation with methyl bromide provides good control in a variety of commodities and currently is the only treatment method approved for restricted articles being imported into the US. However, methyl bromide is an ozone depleting substance and its production and importation into the US is prohibited beginning January 1, 2001 in accordance with the Clean Air Act. Effective treatment of storage facilities and ships requires use of high concentrations, which has raised concerns among the public.

Potential alternatives to the use of methyl bromide may need to be tested for effectiveness against khapra beetle prior to implementation. Research trials of fumigation with carbonyl sulfide or phosphine/carbon dioxide combinations have shown promise for controlling domestic species of stored grain pests, but these treatments may need further testing for efficacy against khapra beetle (EPA, 1997a, b). Addition of 75% and 100% carbon dioxide to phosphine gas at 30°C increased larval mortality of khapra beetle at exposures of 48-72 hours, but decreased larval mortality at shorter exposure times compared to phosphine alone (El-Lakwah et al., 1989). At 19°C and 70% RH, eggs (the most resistant stage) required exposures to phosphine/carbon dioxide mixtures of up to 140 hours to kill 99% of the population (Desmarchelier, 1984). Khapra beetle larvae were effectively eradicated with exposure to CO₂ rich atmospheres (80%), but required lengthy exposures of 23 days or more (Krishnamurthy et al., 1993). Neem kernel powder and neem oil at
1% and 2% (w/w) in sorghum grains completely prevented damage by larvae of khapra beetle (Jood et al., 1996).

Khapra beetle shows signs of resistance to some common chemicals such as phosphine alone and malathion. Larval mortality in a resistant strain averaged 5-12% compared to 84-94% in a susceptible strain in India when treated with phosphine fumigant (Borah and Chahal, 1979). Populations of khapra beetle were able to multiply following fumigation with phosphine even when a higher than normal dose of 60g/tonne was used (Chahal and Ramzan, 1991). Phosphine resistance can be easily selected in mature larvae, resulting in a four-fold increase in resistance after two generations (Udeaan, 1991). Evaluations of resistance to phosphine in populations from seven localities in Punjab, India during 1984-1985 found resistance ratios ranging from 10 to 47.9 (Udeaan, 1990). Khapra beetle reportedly developed resistance to malathion in Tunisia (Yana, 1967).

Facilities that can not be fumigated may be sanitized and treated with a surface application of insecticide. Malathion applied repeatedly is currently approved for control of khapra beetle infestations in structures and surrounding surface areas (USDA-APHIS, 1981). Control of khapra beetle may not reach 100% for pesticides that require ingestion because adults do not feed and diapausing larvae may not ingest high enough concentrations to be affected. A dose of 12.8 mg a.i./kg of the insect growth regulator, diflubenzuron, failed to provide complete control of larvae or suppression of productivity in survivors (Rajendran and Shivaramaiah, 1983). Laboratory tests conducted in India showed that khapra beetle is highly susceptible to the pyrethroids deltamethrin and fluvalinate, and less so to the organophosphates chlorpyrifos-methyl, etrimfos, and malathion (Singh and Yadav, 1994). The insect growth regulator, methoprene, also shows promise for control of khapra beetle based upon laboratory tests (Sharma, 1994). At 100 ppm in diet, larvae eventually died or did not complete normal development. Eggs failed to hatch after laboratory exposure of 4-6 days for high concentrations of the pyrethroids, fenvelerate (0.25, 0.5, and 1.0%) and cypermethrin (0.25, 0.5, and 1.0%), and the organophosphates, chlorpyriphos (0.5, 1.0%) and monocrotophos (1.0%) (Dwivedi and Kumar, 1997).

Eradication of khapra beetle can be difficult due to its habit of hiding in cracks and crevices, and its ability to enter diapause, which may reduce its susceptibility to some control methods (Burges, 1962). Control methods designed to eradicate new infestations must be able to penetrate throughout the infested material or facilities.

Heat treatment appears to be very effective; a 30-minute exposure at 60°C (140°F) gave 100% kill of all stages of T. granarium (Ismail et al., 1988). Mortality of larvae began at 42.5°C (108.5°F); complete mortality of larvae required 8 days exposure at that temperature (Battu et al., 1975). Diapausing larvae are more resistant to high temperatures than non-diapausing larvae. Some natural mortality of larvae may occur in stores due to warming caused by activities of khapra beetle itself.

Treatment with fast electrons, using a linear accelerator, could provide an efficient method of controlling khapra beetle in stored grain. No adults emerged within two weeks from pupae
irradiated with 600 Gy, no F₁ progeny developed when pupae were irradiated with 5 Gy, all eggs were nonviable for females irradiated with 21.6 Gy, and most larvae died within 10 weeks of exposure at doses of 50 Gy and higher (Szendak and Davis, 1989). A dose of 0.3 kGy killed all stages of khapra beetle. Fast electrons were more efficient than gamma rays in sterilizing khapra beetle adults. Ignatowicz (1996) found that diapausing and non-diapausing larvae were equally susceptible to gamma irradiation, and that a dose of more than 0.5 kGy was needed to cause 100% mortality within 60 days of treatment. Rate of mortality increased with increasing dose, such that larvae died within one day at a dose of 3.0 kGy.

**Phytosanitary Risk**

*T. granarium* is of quarantine concern for CPPC, COSAVE, EPPO, JUNAC, NAPPO, and OIRSA. Many countries take severe action against this pest, which could significantly constrain exports from infested areas. The high potential for spread of *T. granarium* through international trade makes this species a continued threat.

**PHYTOSANITARY MEASURES**

Potential hosts and products that may harbor khapra beetle should be subject to inspection. A permit should be required for those articles that are defined as restricted from entry to the US. Restricted articles should receive appropriate treatment at the port of entry prior to movement into the US. A phytosanitary certificate should be issued for restricted articles from those countries that maintain official inspection programs.

**REFERENCES**


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