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TROGODERMA GRANARIUM (EVERTS) (COLEOPTERA: DERMESTIDAE), AN ALARMING THREAT TO RICE SUPPLY CHAIN IN PAKISTAN

[a]Sabyan F. Honey*, [a]Babar Bajwa, [a]Muhammad S. Mazhar, [b]Waqas Wakil
[a] *Centre for Agriculture and Biosciences International, (CABI), Regional Centre for Central and West Asia, Rawalpindi., Pakistan.*
[b] *Department of Entomology, University of Agriculture, Faisalabad, Pakistan.*

A B S T R A C T

Khapra beetle (*Trogoderma granarium*) is designated as a quarantine insect pest worldwide due to its voracious feeding on stored grains. Development of insecticidal resistance and its ability to withstand starvation for longer time makes it one of the most destructive arthropod for stored products. It is primarily known as pest of stored wheat, where it can cause up to 30% postharvest losses. During recent years (2010-2014), the reports of occurrence of Khapra beetle in rice supply chains of Pakistan and stiff competition in world rice market resulted in decline of rice exports from 42 million tons to 37 million tons to partner countries and caused 1000 million dollars value loss to rice industry. This review briefly describes the current status and economic impact of Khapra beetle under storage conditions with special focus on its effects on rice supply chain in Pakistan. Potential management practices to regulate population of this arthropod under storage conditions are also given.

Keywords: Khapra beetle, monitoring, Pakistan, rice, severity, storage.

INTRODUCTION

Rice is one of the cash crops of Pakistan. It contributes about 0.7 percent to Gross Domestic Products and is considered as 3rd export earning source for the country. Pakistan exports more than 50 percent of its produced rice and is the 3rd largest exporter of Basmati and IRRI varieties in the world (Ministry of commerce, 2016). In Pakistan, storage of grains and cereal products is a very common practice. But low standards of storage facilities and poor sanitation promote the infestation of different stored grains insect pests in bins, godowns, granaries, silos as well as in farm houses throughout the country. In recent years between 2010-2014, export share of Pakistan suffered a rapid decline in global market highlighting the constraints in rice supply chain of the country. During this period share of Pakistan in global rice market declined from 2.2 billion dollars in 2010 to 2.1 billion dollars in 2014. Numbers of factors were considered as driving force in this decline including stiff competition and production constraints in the country. But, detection of a notorious stored grain pest commonly known as Khapra beetle in rice consignments exported from Pakistan to other countries opened a new area for researchers to monitor the activity of this pest in stored rice. In 2011, Khapra beetle larvae were detected twice in USA under rice consignments shipped from Pakistan and later in 2014, this pest was again detected at US border and 43000 pounds of rice was returned to Pakistan. In the meanwhile during 2013, rejection of a rice consignment at Mexico border exported from Pakistan weighing 3000 metric tons infested with Khapra beetle was also returned. Continuous rejection of rice consignments between 2011-2014 estimating 1000 million dollars loss by trading partners has opened a new discussion for Pakistani exporters to eliminate this pest from rice supply chain of the country (Green, 2011).

Khapra beetle (*Trogoderma granarium* Everts) (Coleoptera: Dermestidae) is one of the most destructive insect pests of stored grains worldwide. It usually causes qualitative and quantitative losses to stored grains. However, its unique ability to withstand starvation for four years and survival on food even with very low moisture content makes it most destructive arthropod

* Corresponding Author:
Email: s.honey@cabi.org

pest of stored grains (Dale, 1966). Moreover, its ability to overcome adverse environmental conditions as a diapausing larvae and resistance development against certain insecticides maintains its dispersal among various stored products (Myers, 2012). This pest got much attention after its consideration as A2 quarantine organism and included among 100 worst invasive species worldwide (EPPO, 2011). *T. granarium* was reported for the first time from India in 1894 by Cortes and now has been reported from more than 40 countries in Asia, Africa, Europe and Middle East. It is associated mainly with regions having hot and dry environment. In terms of its host range, more than 96 commodities have been found to be infested with this pest preferring grains and cereals (Pasek, 1998; Lowe *et al*., 2000; CPC, 2005). It can cause up to 30% losses during one season and the infested grain losses both its weight and viability (Ahmedani *et al*., 2011). The World Trade Organization committee on Sanitary and Phytosanitary has also prohibited import of cereals, oil seed commodities and similar grains, seeds, flours and meals, consigned from Europe, Africa, Oceania and particularly the following Asian countries like Afghanistan, Bangladesh, Chinese Taipei, Cyprus, India, Iran, Iraq, Israel, Korea, Lebanon, Myanmar, Pakistan, Saudi Arabia, Sri Lanka, Syria, Turkey and Yemen and all other countries in which the Khapra beetle has been reported. Such restrictions are supported by the facts that feeding by Khapra beetle larvae reduces the weight and quality of grain (Pasek, 2004). There are about 134 nominal species reported from the world within the genus *Trogoderma*. However, only 12 species have been reported from stored products (Table 1). But Khapra beetle is known to be associated with stored grains infestation because other species are only scavengers feeding on dead bodies and do not pose considerable losses to stored products (Hava, 2011). Presence of 12 species under storage conditions demands very careful identification of species especially Khapra beetle among others. Usually identification is made on the basis of different morphological characters of larvae and adult beetle. For this purpose, careful identification and knowledge about its biology and other life parameters is required to combat this issue.

Biology: Khapra beetle completes its life cycle in about 4-5 weeks on 35^0C but depending on the temperature it may get prolong up to 6 months. Under very low temperature, they may enter into diapause but can survive at temperature below -8^0C. If adverse environmental conditions persist, they may undergo diapause for long period of time. During their development, Khapra beetle undergoes three life stages like egg, larva and adult stage.

Eggs: Adult female lays translucent white eggs singly in the host material (grains or cereals). Later, eggs become yellowish brown (Pasek, 1988). Mostly they are cylindrical (0.7mm long and 0.25mm broad). Presence of spine like projections at one end of egg makes their eggs visible under stored product (Lingren *et al*., 1955; EPPO, 1981). Under optimum condition comprising 28-32 C^0 temperature and 75 % relative humidity, female usually lays 50-90 eggs loosely in host material. Eggs hatch in about 3-14 days depending on the temperature.

Larvae: Khapra beetle undergoes five larval instars (Morschel, 1972). 1^{st} instar larva is about 1 mm long, yellowish white in color consisting of a long tail bearing number of hairs on abdominal segment. Larva is also known for bearing simple and barbed hairs on its body. Simple hairs are distributed on dorsal surface of the body while barbed hairs are confined to abdominal tergites. With developmental stages, larval color changes to reddish brown with increase in density of hairs on body. During 4^{th} larval instars, hairs become short in length and give an impression of four dark transverse bands. Mature larvae becomes approximately 6mm in length (EPPO, 1981). Under adverse environmental conditions larvae may enter into diapuse, where it can molt but does not feed and remain inactive. They are considered as secondary pest of stored grains, so damaged food products are mostly vulnerable to their attack (Hinton, 1945; Howe, 1952; Karnavar, 1972; Nair and Desai, 1972). The developmental period between 1^{st} and 5^{th} instar larvae may range between 30-50 days depending on the temperature and relative humidity of the storage conditions. During extremes of temperature and relative humidity imposing adverse environmental conditions on physiology of the developing larvae, the larvae may undergo 8-10 molts and larval duration may get prolonged for a period of four month to four years unless environmental conditions become favorable for optimum larval development.

Pupa: Khapra beetle exhibits exarate type of pupa in which pupa remains within the shell or skin during ecdysis (Hinton, 1945; EPPO, 1981). Dorsal surface of pupa is covered by ridges of hairs (Lindgren *et al*., 1955). The female pupa is larger in size with respect to male pupa and can be distinguished easily. The pupal duration is approximately of five days at 27± 5C^0 and may vary depending on the temperature (Kulkarni *et al*., 2015).

Adult: Males are brown to black with reddish brown marking on the wing while females are lighter in color. Adults are short lived and mated females live for one week while unmated females can live upto one month. Males live for only one to two weeks. Usually adults mate after 4-5 days of emergence from pupal case. Female may undergo many mating process and usually after first mating, female lays up to 60 eggs while this number goes up to 500 eggs per female after her second mating. Temperature greatly influences the pre-oviposition and oviposition period of the female but below 20^{o}C female does not lay any egg (Eliopoulos, 2013). Usually adult longevity ranges between 7-10 days and it may produce 8 generations per year.

Table 1. Species in the genus Trogoderma found under storage conditions.

Order	Family	Species
Coleoptera	Dermestidae	*Trogoderma granarium* (Everts)
		Trogoderma variable (Ballion)
		Trogoderma glabrum (Herbst)
		Trogoderma grassmani (Beal)
		Trogoderma ornatum (Say)
		Trogoderma parabile (Beal)
		Trogoderma simplex (Jayne)
		Trogoderma sternale sternale (Jayne)
		Trogoderma sternale maderae (Beal)
		Trogoderma sternale plagifer (Casey)
		Trogoderma inclusum (Le Cont)
		Trogoderma versicolor (Creutzer)

Economic Importance: Khapra beetle is known as one of the most notorious pest of stored grains under hot and dry conditions. It has the ability to induce huge losses to stored grains and cereals in very short time. It may causes huge losses up to 70 % to stored grains through voracious feeding and heating of grains. Its ability to withstand starvation up to 3 years makes it more destructive for prolonged period. While feeding, it moves in and out, this induces qualitative losses to grains and reduces seed germination. Larvae starts feeding from embryo and consumes whole seed leaving behind only shell. Larvae can be seen on edges of bags and their cast skin makes it unsuitable for consumer. Moreover, they are responsible for human health problem like dermatitis and asthma caused by cast skin of this pest (Morison, 1925; Pasek, 1988; Parashar, 2006). Khpara beetle has been reported to cause 6-33% damage to grains extending up to 73% in a single season (Rahman *et al*., 1945). Wheat grains have been reported to lose 24% of its viability and 2.6% of its weight under optimum conditions (Prasad *et al*., 1977). Under heavy infestation, grains become unmarketable and unpalatable by consumers. In grain products like wheat, sorghum and maize the association between infestation level and loss in grain quality was determined. High infestation level (75%) by Khpara beetle greatly reduces sugar contents, crude fats, carbohydrates and protein profile of the grain along with high level of uric acid (Jood *et al*., 1993). Medium level infestation (50%) caused reduction in starch contents while at 25% infestation level, losses in vitamin profile of the grains were observed (Jood and Kapoor, 1993). Moreover, very little is known about Khapra beetle effect on environment. Indirect effects may include the use of chemicals for control of this pest especially in case of fumigants where phosphine and methyl bromide has extensively been used.

Detection: Usually hairy larvae are seen during inspection of the infested product and cast larval skin of Khapra beetle is considered as sign of its presence within the commodity. For proper management of Khapra beetle, timely detection and exact identification is the key component to achieve successful management against this pest. Detection of this pest can be made by visual inspection, product sampling and some sort of pheromone traps and food attractants. Sometimes, it becomes difficult to identify adults in a sample because they tend to move inside the cracks and crevices of storage facility. But larval movement, especially cast skin over product gives a very useful clue about the activity of this pest in storage conditions (Barak, 1989). After confirmation of this pest in sample, different management tactics may be applied to reduce its infestation.

Management: Very comprehensive studies on the possible management tactics against stored grains insect pests have been conducted worldwide. But the ability of many species in the family Dermestidae to withstand adverse environmental conditions through resistance development and undergoing facultative diapause lowers the effectiveness of management tactic. However, combination of different management practices deployed on proper stage of insect pests and its optimum exposure time can give better results to reduce their population under storage conditions.

Fumigation: Use of fumigants like methyl bromide and phosphine against Khpara beetle is the most primarily control method being used since many decades under storage conditions (Fields and White, 2002; Ahmedani *et al*., 2007; Rajendren *et al*., 2008). Methyl bromide proved itself most promising fumigant against Khapra beetle. It acts as suffocating agents and kills insect by blockage of its spiracle. Recent studies have revealed that methyl bromide is involved in ozone depletion phenomenon and is designated as major ozone depleting agent. This phenomenon has directed many countries to minimize its usage under storage conditions (MBTOC, 2010). Phosphine is also very common fumigant being used a long time ago but it gives moderate to poor control against *T. granarium*. But different experiments have shown that *T. granarium* has evolved resistance against this fumigant (Bell *et al*., 1984; Rajendran, 2002). Moreover, the exposure time, concentration and storage structure plays an important role in determining the effectiveness of phosphine. The application of increased rate of CO2 in combination with phosphine may provide a significant mortality rate High rate of CO2 increases insect breathing rate which facilitates the inhalation of phosphine by insect. It gives promising results in controlling *T. granarium* (Desmarchelier and Wohlgemuth, 1984; El-Lakwah *et al*., 1989).

Insecticidal Control: The applications of different contact insecticides like malathion, pyrethrins and chlorpyriphos has been extensively used as surface treatment on stored products (Khosla *et al*., 2005; Eliopoulos, 2013). But their effectiveness is also not reliable due to the fact that *T. granarium* has the ability to withstand adverse environmental conditions and they can hide in small cracks and crevices thus avoiding their exposure to insecticide. Moreover, decreased persistence of some insecticides also lowers their effect after certain period of time. Especially the main concern with the contact insecticide has been their residual effects on stored commodities that can harm stored product and humans involved with their handlings (Arthur, 2012). These concerns have led researchers to find out some alternate methods for management of Khapra beetle (Traynier *et al*., 1994; Abdelghany *et al*., 2015).

Modified Temperature Extremes: Temperature plays a very crucial role in optimum development of all stored grains insect pests including *T. granarium* and they require 25-35 C^o for proper development. But any extreme variation both in terms of heat or cold may adversely affect all biochemical rates and different physiological processes of the insect. Moreover, no study has reported resistance development in *T. granarium* against temperature extremes or any negative effect on stored product (Fields *et al*., 2012). It has been studied that at low extremes (-10 to -40 C^o) and high extremes (5h at 50 to 60 C^o) can cause mortality in insect (Evans, 1987; Strang, 1992; Fields, 2001; Fields *et al*., 2012; Philips and Throne, 2010). The larval stage of *T. granarium* appears to be most cold tolerant, so keeping temperature at -10C ^{0} for 30 days can give >90% mortality (Mathlein, 1961). Even longer time is needed in low temperature to get the desired mortality in *T. granarium* but they are more reliable than high temperatures because low temperature does not harm stored product while high temperature for longer period can alter physio-chemical properties of the product (Linnie, 1999). So, use of extreme low and high temperature at proper exposure time may provide a considerable control of *T. granarium*.

Physical Control: As discussed above that CO2 in combination with fumigants and heat can give very promising control against *T. granarium*. Low oxygen atomosphere has also appeared to be effective for eliminating eggs and diapausing larvae of khapra beetle (Verma and Wadhi, 1978). The use of different gamma radiations has also proved their effectiveness in this instance. Different studies have revealed that use of Cobalt 60 along with a beam of electron can be effectively used to disinfect the product from Khapra beetle and this method is very useful for quarantine purposes. Exposure of larvae in a Co-60 to gamma radiations at rate of 20 Gy/min can greatly affect the midgut epithelial morphology of the feeding larvae. The changes in the midgut may include swelling and abnormal growth of the epithelial cell, loss of nuclei and thickening of the muscles with vacuolization of the mid gut cells. These can abruptly cease the feeding behavior of the larvae and cause mortality. However, due to low acceptance of these radiations by the consumer, this control method has not been applied on large scale. But in some countries like France, Indonesia and South Africa stored products are commercially irradiated to disinfect the product (Stibick, 2007; Arthur and Silva, 2007; Abdel-Kawy, 1999; Gao *et al*., 2004). These treatments can give better management of khapra beetle with increased exposure time but cost of this treatment may limit the scope of this strategy under small storage facilities.

Plant Extracts: Growing awareness among public for their health and environmental related issues raised due to application of non-judicial use of synthetic pesticides, efforts are being made to find some alternate management tactics for stored grains pests. In this instance, exploration and evaluation of natural chemicals can provide a safer management approach to deal with insects associated with eatable food commodities. Plant extracts have been found very effective in managing insects under storage conditions (Verma and Dubey, 1999). These are plants derived extracts usually in oil form that show broad spectrum activity against different insect pests. They may act as insecticidal agent, antifeedant, deterrent and growth inhabitation compounds ultimately regulating an insect growth (Dale, 1996). Apparently, use of plant extracts has mostly been associated with management of stored grains insects under specified controlled conditions. Moreover, compounds available in plant extracts have been identified as non-toxic to mammals and meet the criteria of reduced risk pesticides (Isman and Machial, 2006). During the last decade, many studies on evaluation of insecticidal activity of plants have been carried out for khapra beetle. The use of neem (*Azadirachta indica*) essential oil has proved to be the most promising plant extract in controlling *T. granarium*. They act as suffocating agents and kill the insect by blockage of their spiracles (Arivudainambi and Singh, 2003; Egwurube *et al*., 2010; Odeyemi *et al*., 2005). The comparison of Neem oils has also been documented with other plant oils to evaluate its efficacy in regulating khapra beetle. Jakhar and Jat (2010) evaluated 14 different plant oils against khapra beetle as grain protectant and suggested that sunflower oil can be effectively used in reducing khapra beetle in combination of neem oil. They proposed that these oils can greatly influence the larval duration, emergence of adults and fecundity of female, ultimately reducing their infestation on the grains. Mansoor *et al*. (2006) evaluated the efficacy of essential oil extracted from rhizomes of *Acorus calamus* against Khapra beetle and found 27.77% mortality with exposure of 70µl for period of seven days and suggested that increasing exposure time with high dose can greatly reduce the population build up of khapra beetle under storage conditions. Ibrahim and Sahar (2011) found that application of garlic oil against Khapra beetle can cause high percent mortality, reduced generation developmental time and can greatly reduce percent infestation to grains. Fumigant toxicity has been of prime importance to regulate stored grains insect pests. In this instance, (Tayoub *et al*., 2012a) determined the chemical composition of essential oil extracted from *Juniperus foetidissima* and evaluated its fumigant toxicity against larval stage of khapra beetle. They found that *J. foetidissima* showed high mortality against this pest because of the presence of components like monoterpenes (51.4%) and citronellol (22.3%) in the oil. Citronellol has been documented to cause 100% mortality against sawtoothed grain beetle after 14 hours exposure time (Lee *et al*., 2003). In the same year, Tayoub *et al*. (2012b) also determined the fumigant activity of *Eucalyptus globulus* and *Origanum syriacum* and found that these oils can cause 95% mortality to larval stage of Khapra beetle at concentration of 312µl and 187.5 µl respectively. Later in 2013, Ghanem *et al*. also analyzed the chemical composition of oil extracts obtained from fruits of *Foeniculum vulgare* and found that it contain anethole (61.1%), fenchone (27.3%) and estragol (3.9%) as major constituents. Furthermore they evaluated the fumigant activity of these constituents against Khapra beetle and found that it can cause 93.5% mortality to larval stage of Khapra beetle. Citrus fruits have also been documented to cause mortality to khapra beetle under storage conditions. Sagheer *et al*. (2013) evaluated four different species of citrus fruits namely *Citrus paradise*, *C. sinensis*, *C. aurantium* and *C. reticulate* against larval stage of khapra beetle and found that *C. aurantium* can cause 27.30% mortality to khapra beetle when exposed to larva for 9 days at concentration of 8%. The acquos and organic extracts of plants may cause variation in effectiveness of a given plant extracts. Elamin and Satti (2013) compared the water and organic extracts obtained from desert date plant and found that organic oil extracts manifested 72.7% repellency to Khapra beetle as compared to water based extracts. It may be due to the fact that organic solvents also pose their insecticidal activity in addition to chemical components of the plant origin. But the utilization of plant extracts has not been adopted commercially, due to some issues in their formulation and economical adoptability. While under laboratory conditions plants extracts have been widely used.

Biological Control: Many predators, nematodes and entomopathogens have been studied to control Khapra beetle under laboratory conditions. But this method has not been practiced commercially (Khshaveh *et al*., 2011; Ahmedani *et al*., 2007; Kamionek and Sander, 1977; Ali *et al*., 2011; Ahmed *et al*., 1991; Rahman *et al*., 2009).

Scope for future Research in Pakistan: Being an agricultural country, cultivation of main crops including wheat and rice as well as other cereal crops is adopted on large scale throughout the country. In terms of post-harvest practices, storage of grains like wheat, rice and other cereals for long period is a very common practice to make available the continuous supply of these food items to public. However, inappropriate storage material and poor sanitation conditions promote the development of different stored grains pest, out of which Khapra beetle is known to be the most notorious insect pest of wheat and rice. Moreover, economic issues raised during recent years due to detection of Khapra beetle in rice consignments by partner countries have directed exporters and researchers to find an appropriate management strategy to inhibit the movement of this pest within country. Management tactics can only be strengthened on the basis of biological studies and observing phenology of this pest with respect to storage conditions within the country. It is the dire need of the day that studies need to be conducted to confirm the prevalence of Khapra beetle in stored rice and to sort out possible factors responsible for this infestation and then designing appropriate control methods for Khapra beetle.

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