



Khapra Beetle: A Review of Recent Control Methods

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Abstract

Research work revealed that stored grain pests pose serious threats to stored food commodities and cause economic losses. Khapra beetle (*Trogoderma granarium*) considered one of the most destructive pests that has great economic importance because of starvation capability for three years and has best survival rate at low humidity. *T. granarium* cause heavy losses in stored commodities and decrease the quality and quantity of grains. Development of resistance in *T. granarium* against insecticides like malathion, phosphine and pyrethroids has further increased its economic importance. There is no review available in the literature for the stored products policy makers and managers to control this pest. Following study reveals the economic losses cause by Khapra beetle in storage structures and its control by using integrated pest management strategies

Keywords: Khapra beetle; *Trogoderma granarium* Everts; Economic losses; Integrated pest management

Introduction

The *Trogoderma granarium* Everts belongs to family Dermestidae and order Coleopteran and is a world's most destructive stored grain pest. 115 species of *Trogoderma* genus reported by [1] in the world out of which twelve (Table 1) are stored grain pests. In fact, *T. granarium* ranked as one of the 100 worst invasive species worldwide and has been recognized as an A2 quarantine organism [2]. Larval stage of this pest considered most destructive stage that causes heavy economic losses to stored grains and other food commodities. Depending upon temperature, complete development (egg to adult) occur from 26 to 220 days and 35°C is the optimum temperature for its best survival. For an impressive timeframe or if hatchlings are extremely swarmed, if temperature falls beneath 25°C they may enter diapause. In diapause conditions, hatchlings may stay for a long time in this condition [3].

Due to its continued occurrence on commodities status of *T. granarium* is of highly economic importance and become potential

for spread by use of roll-on roll-off road transport and dry cargo containers that make it a potential threat to global food security. Regrettably, the pest is very common in granaries, godowns, bins, silos as well as farm houses in Pakistan. To ensure food safety and food security situation it is not only vital to control of this pest but is pre-requisite for export of cereal grains. Although, khapra beetle may control by routine treatments of stored grains for domestic species of stored grain pests and sufficiently avert significant economic losses. Development of resistance against conventional pesticides has posed a new challenge for the researchers. Prohibition was done by WTO Committee on SPS on importation of cereals, oilseed commodities and similar grains, seeds, meals and flours, thereof, to prevent the spread of this pest and to protect domestic production. This restriction is applicable to products consigned from Europe, Africa, Oceania and particularly the following Asian countries: Chinese, Afghanistan, Taipei, Iraq Cyprus, Iran, Israel, Korea, India Lebanon, Myanmar, Pakistan, Bangladesh Saudi Arabia, Sri Lanka, Turkey, Syria, and Yemen and other countries in which *T. granarium*

has been reported. Such restrictions reinforced by facts that feeding by Khapra beetle larvae reduces quality of grain and weight loss. In Pakistan estimates of storage losses of food grains due to insects have been reported to vary widely; 4-10% [4], about 5.08% [5], 5% [6], 3.5 – 25.5% [7]. Rahman et al. [8] reported average damage levels in India ranged from 6% to 33% of the grain in a single storage season, with maximum damage at 73%. Wheat lost 24% of its viability and 2.6% of its weight at optimal conditions of 36°C and 15% infestation [9].

Table 1: *Trogoderma* species as stored grain pests.

Order	Family	Species
Coleoptera	Dermistidae	Trogoderma glabrum (Herbst, 1783)
		Trogoderma versicolor (Creutzer, 1799)
		Trogoderma ornatum (Say, 1826)
		Trogoderma inclusum (LeConte, 1854)
		Trogoderma variable (Ballion, 1878)
		Trogoderma sternale sternale (Jayne, 1882)
		Trogoderma simplex (Jayne, 1882)
		Trogoderma granarium (Everts, 1898)
		Trogoderma sternale plagifer (Casey, 1916)
		Trogoderma sternale maderae (Beal, 1954)
		Trogoderma parabile (Beal, 1954)
		Trogoderma grassmani (Beal, 1954)

Treatment may result in less profit for wholesalers due to loss of grain. Severe infestations may make stored unpalatable or unmarketable. Due to depletion of specific nutrients, quality may decrease. In wheat, Sorghum and maize grains, there was a decrease in crude fat, sugars, total carbohydrates, protein nitrogen, starch contents, vitamins thiamin, riboflavin, niacin, total lipids, phospholipids, glycolipids, polar and non-polar lipids; increases in the levels of uric acid, moisture, crude fiber, total protein and anti-nutrient polyphenol were observed [10,11]. *Trogoderma* have assigned a pest status due to quality deteriorating characteristics as technical barrier to trade. Use of chemicals, botanicals and physical

Table 2: Control measures for *Trogoderma granarium*.

Control	Treatments	Options	Remarks
Chemical	Fumigation	Methyl bromide, Phosphene	Effective in small and large closed areas (Mueller, 1994).
	Insecticides Dust	Malathion, pirimiphos-methyl	Effective against all storage areas and their surroundings (Pasek, 2004).
Physical	CO ₂	Any source of CO ₂	100% mortality was observed at >60% CO ₂ after 17–30 days' exposure in small storage localities. (YADAV and Mahla, 2002).
	N ₂	Any source of N ₂	Larvae killed within 6 days of purging with N ₂ in small storage areas. (Agboola, 2001).
	Heat Treatment	Exposure to 60°C for 30 min	100% kill of all stages (Burges, 2008).
	Vacuuming	Industrial vacuum conveying system	99.6% mortality after four passes through the system (Bahur, 1990).

strategies control the khapra beetle to some extent because they develop resistance against insecticides and botanicals and have best survival at low humidity and temperature. Biological control is effective against khapra beetle because naturel enemies only feed their host rather putting any damage to stored commodities.

As a stored grain pest Khapra Beetle *T. granarium* was first time reported from India in 1894 by Cotes. The latest literature reveals that the pest is present in more than 35 countries of the world [12]. This is a local pest of India yet favors hot and dry atmospheres of Asia, Africa and Eurasia [13] additionally reported in the USA [14,15]. It has achieved a status of extremely basic essential vermin of stored wheat, rice, and maize in the Indo-Pak subcontinent.

Damage in Pakistan

Agriculture area is the fundamental sector of Pakistan's economy that aides in Poverty Reduction Impact and gives crude materials to line industries. This division holds 21% in Gross Domestic Product, and 42.3% of the nation's labor force involve in this sector. First schematic survey of losses was conducted by [5] in Pakistan and he reported that during post-harvest operations, 15.3% aggregate losses of wheat occurs in the country. 10 to 15% post-harvest losses of grains in Pakistan observed by (Jilani, 1981), which were chiefly caused by attack of insect pests. Later, findings of (Ahmad and Afzal, 1984; AHMED, 1984) supported his report. In the same year, 22.7% post-harvest loss of wheat in Pakistan recorded by [3], out of which 13.2% during threshing and harvesting times while remaining 9.5% occurred during storage period. On country wide basis, Irshad and Baloch [7] reported in Pakistan that storage losses of wheat ranged between 3.5 to 25%. Losses of wheat grains stored for 4 months in go downs of Pakistan determined by TGM methods of loss assessment and Standard Volume Weight (SVW) are 2.03, 8.18 and 1.35% [16]. Average weight losses of 1.99, 6.33 and 2.01%, respectively resulted in six months' wheat storage, while losses were recorded 3.02, 9.41 and 2.06% in 7 months storage period, determined by G.M. methods, T.G.M and S.V.W respectively [17]. Annual storage losses in public sector and at farm level recorded as 7 and 4% respectively [18]. Different control measures for Khapra beetle shown in Table 2.

Botanical	Botanicals	Over 120 plants and plant products including plethora, oras seed, garlic, neem, lemon leaves, mint etc.	Cheap and effective method for stored product pests. (Ali et al., 2012).
Biological	Pathogens	Mattesia trogodermae, Metarhizium anisopliae, Bacillus thuringiensis, Parasitic nematodes	Mortality of pests in and around the storage areas. (Khashaveh, 2011).
	Parasatoid	ectoparasitoid Laelius pedatus	Control of Khapra Beetle in structures. (Rahman et al., 2009).
	Predator	Xylocoris flavipes	Control of Khapra Beetle in structures and surroundings (Rahman et al., 2009).

Chemical Control

Chemical control and especially fumigation remain the first choice for the eradication of the khapra beetle. Methyl bromide, the most effective fumigant against stored products pests is scheduled to be phased out worldwide by 2015, according to Montreal Protocol, given that it is considered as a significant ozone-depleting substance. Currently, its application is restricted only for quarantine and pre-shipment uses (United Nations Environment Programme, 2010). A very promising strategy is the combination of a fumigant with CO₂. Increased CO₂ concentration accelerates respiration of the insects thereby making them more susceptible to fumigants. Recent and older studies have proved that addition of high levels of CO₂ to phosphine resulted in significant additive effect and increased the mortality even against the most resistant stage of the khapra beetle, the diapausing larvae [19,20].

Residual surface treatments with insect growth regulators, contact insecticides and aerosol applications have also been studied as an alternative for the control of *T. granarium*. Recent and older studies indicated that deltamethrin [21,22], fluvalinate [2], bifenthrin [23,24], fenvalerate [23-25], cypermethrin [23-25] chlorpyrifos-methyl [23,26,27], monocrotophos [23], mathacrifos [26], spinosad [28,29] and methoprene had shown potential for effective control of the khapra beetle based mainly on laboratory tests. On the other hand, malathion [22,26,27,30], pirimiphos-methyl [27], endosulfan and carbaryl [25] cannot always control *T. granarium* infestation. Irrespective of pest's susceptibility, in the case of surface treatments it should be taken into consideration that they are not always reliable not only because of the unique ability of larvae that diapause and hide in crevices and cracks for a long time but also because of the decreased insecticide persistence when applied on certain surfaces [31]. It is evident that there is a lack of very recent studies on this field. For the control of *T. granarium*, evaluation of aerosols and surface treatments are needed that has been emphasized in a recent review [32]. Combinations of the contact insecticides such as malathion and pirimiphos methyl with N₂- or CO₂-modified atmospheres gave pronounced potentiation, demonstrating additive and antagonistic effects according to concentration and exposure time [30].

Physical Control

The phenomenon of resistance development by the khapra beetle to phosphine has forced the scientists to look for alternatives

such as modified atmospheres, use of elevated temperatures and others, which had conventionally been used for many years in the past. Some of them are practically applied during the last 20 years, while some others are still under experimental. The potential use of CO₂ atmosphere alone or in combination with heat as an alternative control method against *T. granarium* has also been demonstrated [33,34]. Diapausing larvae of the khapra beetle have been reported as the most tolerant stored product pest to a high-CO₂ atmosphere, requiring very long exposure times for efficient control [35]. Complete mortality was observed at >60% CO₂ after 17-30 days exposure at 25-30°C [36,37]. However, promising results have been derived when CO₂ was combined with heat. An atmosphere composed of 90% CO₂ at 45°C reduces LT99 values for diapausing larvae of *T. granarium* from 29 h at 35°C to about 10 h [33], whereas LT95 was decreased to < 8 h [34]. That is why heat combined with a CO₂-based modified atmosphere may be considered as one of the best alternatives to fumigants for treatment of storage pests [38]. N₂-based atmospheres have also been used against the khapra beetle with promising results. Larvae were killed within 6 days of purging with N₂ [39]. A novel 'vacuum-hermetic' technology has been developed recently (Finkelman et al., 2006). Developmental stages of *T. granarium* were exposed to low-pressure (50 mmHg) within test chambers containing cocoa beans (R.H. 55%, 30°C). Under those conditions, the most tolerant stage (egg) recorded complete mortality after 46 h. Good quarantine solution can be provided by vacuum treatment under certain circumstances.

The use of low or freezing temperatures does not seem to be a feasible alternative method for the control of the khapra beetle. Although, populations of *T. granarium* have been shown to decline at 20°C and 70% R.H. [40], it is well documented that khapra beetle is major pest of stored products in cold-hardy [41-43]. Recent experiments have shown that 24-48 h is necessary for complete mortality even under 'unrealistic' freezing temperatures (716°C) [43]. On the other hand, heat treatment has been well documented as an effective alternative against *T. granarium* [44-48]. Such methods may be practically applied mainly in countries where summer temperature exceeds 40°C and a little energy cost will incur to maintain temperature at 60°C. Exposure of *T. granarium* to 60°C for 30 min is sufficient to achieve 100% kill of all stages [40]. Moreover, when pupae were exposed to 45°C for 48 h the emerging adults were sterile [41]. There are not many data concerning the effectiveness of inert dusts against the khapra beetle. When several

types of inert dusts (DE, silico phosphates etc.) were evaluated against the major stored grain pests, they were somewhat less effective for khapra beetle larvae [49-52].

The combined action of DE and modified atmospheres of CO₂ and N₂ produced enhanced mortalities than each method separately against larvae and adults of *T. granarium*, indicating synergistic or additive effect [52]. Complete control of all stages of *T. granarium* has been also achieved when infested grain was pneumatically conveyed, ranking the pest among the most susceptible stored products pests. Conveying of wheat through an industrial vacuum conveying system gave 99.6% mortality after four passes through the system [53]. Gamma or other types of irradiation have also been evaluated as a quarantine treatment against the khapra beetle [54-57]. Radioisotopes such as electron beam accelerators and cobalt 60 gamma radiations can be used to disinfest stored grain products. Apart from gamma, UVC irradiation has also been evaluated as a control agent against the khapra beetle. Eggs and pupae were the most sensitive and tolerant stages, respectively [56]. Despite the rapid mortality caused by irradiation, certain limitations of the method (low acceptance from the consumers, not approved for use in storages in many countries etc.) are preventing the spread of its practical application in more countries. Currently, several stored grains and pulses are commercially irradiated in Indonesia, France, and South Africa. It is certainly a very promising quarantine treatment.

Plant Extracts (Botanicals)

The most extensive research on control methods against the khapra beetle that has been carried out during the last 10 years deals with the use of plant extracts (essential oils, botanical powders etc.). Repellence toxicity of a plethora of plant species against *T. granarium* have been evaluated [58-65]. Characteristically, the use of neem (*Azadirachta indica*) essential oil as a fumigant and oras seed powder seemed to be a cheap and effective method to manage insect pest especially in developing countries [63]. Despite the promising results, plant oils and powders remain mainly experimental because of certain limitations with their production, quality standardization, formulation, and commercialization.

Biological Control

Many natural enemies (predator's parasitoids, nematodes, pathogens etc.) have also been studied as control agents against the khapra beetle. The entomopathogens *Mattesia trogodermae* Canning (Protozoa: Neogregarinida) [66], *Metarhizium anisopliae* (Metschnikoff) (Ascomycota: Hypocreales) [67], *Bacillus thuringiensis* Berliner (Bacilli: Bacillaceae) [68,69] (Rhabditida: Steinernematidae), [70] the *Laelius pedatus* (Say) ectoparasitoid (Hymenoptera: Bethyridae) and the generalist *Xylocoris flavipes* (Reuter) predator (Hemiptera: Anthocoridae) Rahman et al. [71] have been found to parasitize or prey on the khapra beetle.

Conclusion

From the above study, 120 plants, their products and different chemicals have been used to control stored product pests [72]. Due to threat of insecticide resistance development in them, integrated pest management (IPM) practices should be followed. Chemicals, botanicals [73-79], physical and biological control measures should be used in a compatible manner to manage stored product pests below their infestation level and minimize the chances of resistance development in them [80].

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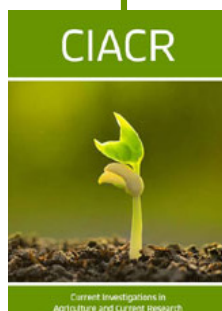
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