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Review Article

BIONOMICS AND MANAGEMENT OF MAIZE WEEVIL, *SITOPHILUS ZEAMAIS* MOTSCHULSKY

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ABSTRACT

The maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera:Curculionidae) is an important pest of maize in storage in term of losses caused in food quality and quantity in Nepal. Attempt made to review bionomics and management practices of this pest gleaning published literatures/papers on national and international journals, proceedings, reports, newsletter and books. The paper discusses on nomenclature, morphology, distribution, biology and ecology of maize weevil and provides prospect of using various physical, sanitary, cultural, botanical, biological and chemical control measures to manage weevil. This information is useful to personnel involved on agricultural research and development for developing location specific integrated pest management approach of this pest. Finally, it also shows importance of farmers' awareness on pest biology and ecology, appropriate maize harvesting time, storage structures and post-harvest handling practices to reduce losses in maize storage.

Key words: Biology, nomenclature, identification, maize, management, Sitophilus zeamais

INTRODUCTION

Maize weevil (*Sitophilus zeamais* Motschulsky) belongs to family Curculionidae and subfamily Dryophthorinae in the order Coleoptera under the class Insecta (CABI, 2007). This insect is commonly known as grain weevil in Nepal (Neupane, 2001). It can be found in all warm and tropical parts of the world and is also a major pest of post-harvest maize storage in Nepal (Paneru and Giri, 2011). The loss and damage caused by *S. zeamais* in post-harvest maize storage has been variably estimated by numbers of researchers to be in the range of 10-100% (Boxall and Gillet, 1980; Khanal *et al.*, 1990; Golob, 1994; Paneru *et al.*, 1996; Sah, 1998; Shivakoti and Manandhar, 2000; Bhandari *et al.*, 2015). Ransom (2000)

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reported that the level of damage and losses caused by *S. zeamais* in maize storage varied depending upon several factors including physical, biological, mechanical and socio-economic factors. Losses during post-harvest on maize grain storage due to *S. zeamais* is high in Nepal, but there is still lacking of effective technologies for its management. Effectiveness of existing available technologies is inconsistent and varies at farmer's condition depending upon the location and farmer storage conditions. Due to lack of suitable options, it is being difficult to reduce the use of hazardous chemical insecticides in maize storage. There is need of effective and ecofriendly technology to reduce losses in maize utilizing available scientific and local resources, knowledge and skills for food security enhancement in Nepal. Therefore, pertinent literatures were gleaned and overviews prepared for the management of the *S. zeamais* in maize.

MATERIALS AND METHODS

The important information related to bionomics and the management of maize weevil (*S. zeamais*) was collected from published literatures/papers on national and international journals, proceedings, reports, newsletters and books. The information mainly included nomenclature, morphology, distribution, biology and ecology of maize weevil, and its various management measures. Relevant information was arranged systematically, summarized in the texts and tables with conclusive outlines.

RESULTS AND DISCUSSION

Nomenclature

Grain weevils, *Sitophilus* spp. were first described by Linnaeus in 1798 as *Curculio oryzae*, this group was later revised by De Clairville & Scheltenburg in 1798 as *Calandra oryzae*, which were the commonest generic synonym for *Sitophilus* (CABI, 2007). Many workers subsequently recognized that two distinct forms of the species existed, which were described as the 'large' and 'small' forms. In 1855, Motschulsky recognized the large form as a distinct species, which he named *Sitophilus zeamais*. Unfortunately, few workers recognized this revision and the name *Calandra oryzae* continued to be applied to all insects in this complex. Takahashi in 1928 and 1931 complicated matters by raising the small form to specific status as *Calandra sasakii*. This confused situation continued until 1959, when Floyd and Newsom (1959) revised the complex; this was followed by a further revision by Kuschel (1961). This revision validated that Linnaeus originally described the smaller species and that Motschulsky's description of the larger species. Both species were therefore placed in the genus *Sitophilus* with the specific names proposed by Linnaeus and Motschulsky. The genus *Sitophilus* and its species may be identified using the keys of Gorham (1987) or Haines (1991). The *S. oryzae* and *S. zeamais* species can be separated from *S. granarius* by the presence of wings beneath the elytra (absent in *S. granarius*) and by having circular, rather than oval, punctures on the prothorax. Some molecular and morphological markers for the diagnosis of *S. oryzae* and *S. zeamais* are reported by Hidayat *et al.* (1994).

Identification

Both *S. zeamais* and *S. oryzae* are almost indistinguishable from each other externally; identification is done by examination of the genitalia. Both have the characteristic rostrum and elbowed antennae of the family Curculionidae. The antennae have eight segments and are often carried in an extended position when the insect is crawling. Both species usually have four pale reddish-brown or orange-brown oval markings on the elytra, but these are often indistinct. But they can be separated from *S. granarius* by the presence of wings beneath the elytra (absent in *S. granarius*) and by having circular, rather than oval, punctures on the prothorax. The developmental stages (eggs, larvae and pupae) are all found within tunnels and chambers bored in the grain and are thus not normally seen. The larvae are apodous. Molecular characters also separate *S. oryzae* and *S. zeamais* and confirm reproductive isolation (Hidayat *et al.*, 1996). Adults are usually darker with fine microsculpture and shiny as compared to *S. oryzae*. Scutellum with lateral elevations is further apart than their longitudinal length, which is about half as long as the scutellum. Male possesses median lobe of aedeagus with two longitudinal grooves dorsally, except in the apical quarter, and is thus sinuous in cross section. Female possesses with lateral lobes of the Y-shaped sclerite pointed and their separation is greater than for *S. oryzae* (CABI, 2007). *S. zeamais* has 2-4 mm body length with its head protruded into a snout. At the end of the snout, there is a pair of mandibles. It has a long snout with clubbed segmented elbowed antennae and four light reddish brown oval spots on the elytra (Khare, 1994).

Distribution

The weevil, *S. zeamais* occurs in all warm and tropical parts of the world especially in locations where maize is grown. This weevil is transported to all over the world in grain shipments and can establish wherever there is food and where grain moisture and temperature are favorable. *S. zeamais* is able to multiply on a wide range of cereals and also on processed cereal products. However, the food preferences are variable; it is predominantly associated with maize grains (CABI, 2007).

Biology and ecology

Longstaff (1981) reported that the longevity of *S. zeamais* adults was several months to one year, the female laid eggs throughout the adult life, although 50% were laid in the first 4-5 weeks; each female could lay up to 150 eggs. The eggs are laid individually in small cavities chewed into cereal grains by the female; each cavity is sealed, thus protecting the egg, by a waxy secretion (usually referred to as an 'egg-plug') produced by the female. The incubation period of the egg is about 6 days at 25°C (Howe, 1952). Eggs are laid at temperatures between 15 and 35°C (with an optimum around 25°C) and at grain moisture contents over 10%; however, rates of oviposition are very low below 20°C or above 32°C, and below about 12% moisture content (Birch, 1944). Where grain is stored on small farms, *S. zeamais* is more likely than *S. oryzae* to fly to the ripening crop in the field and infest the grains. Although both species are capable of flight, *S. zeamais* has a greater ability and tendency to fly (Giles, 1969).

The lifecycle is on average 36 days at 27±1°C, and 69±3% relative humidity (RH) (Sharifi and Mills, 1971). The eggs, larvae and pupae are not normally seen because they develop inside intact grains. Adult emergence holes (about 1.5 mm diameter) with irregular edges are apparent some weeks after the initial attack. Throne (1994) reported that the survival from egg to adult emergence was the greatest at 25°C. He reported that sex ratio of emerging adults did not differ from l:1. The maximum daily rate of fecundity, duration of development, and number of progeny produced were optimal at 30°C and 75% RH. Ojo and Omoloye (2016) reported that egg incubation, oviposition periods, and the fecundity were not different significantly among the food hosts but the mean fecundity was the highest on maize (67.2±3.16) and lowest on millet (53.8±0.17) (Table 1). There was significant different (P=0.01 < 0.05, F=3.99, and df=3) on adult longevity among the cereals used; adult maize weevil significantly lived longest on maize and millet (122.3±1.87 and 126±3.20 days) than on rice and sorghum (120.3±3.24 and 117.6±2.07 days), respectively (Table 1).

Table 1. Incubation, oviposition, longevity periods, and fecundity (±SE) of *S. zeamais* on cereal grains (24–30°C; 60±10% RH; 12 h photophase)

	Oviposition period (days)	**Egg incubation period (days)**	**Fecundity (number)**	**Adult longevity (days)**
Maize	22.21 ± 0.50 (10–28)	5.25 ± 0.19 (3–7)	67.2 ± 3.16 (19–114)	122.3 ± 1.87^{ab} (99–135)
Rice	21.1 ± 2.75 (10–26)	5.14 ± 0.05 (3–7)	57.3 ± 4.68 (17–87)	120.3 ± 3.24^{bc} (99–138)
Sorghum	21.72 ± 0.42 (11–29)	5.22 ± 0.21 (3–7)	63.1 ± 3.23 (14–109)	117.6 ± 2.07^{c} (97–126)
Millet	20.28 ± 0.71 (9–25)	5.38 ± 0.17 (3–7)	53.8 ± 0.17 (12–99)	126 ± 3.20^{a} (84–129)
CV	5.73	1.95	0.67	1.26
F-test	ns	Ns	ns	*

Means followed by the same letter in the same column are not significantly different (p<0.05, Tukey’s honestly significant difference test). Range is in parenthesis. SE= standard error, CV= coefficient of variation, ns = no significant difference & * significant. Source: Ojo and Omoloye (2016).

Ojo and Omoloye (2016) also reported that number of immature (larva and pupa) and adult stages varied significantly among the cereal grains. There were four larval instars with a varied mean total instar larval developmental period of 23.1, 22.2, 22.2, and 21.6 days on maize, rice, sorghum, and millet, respectively. The mean developmental period from egg to adult was the highest on maize (34.7 days) and the lowest on sorghum (33.5 days). The development period and body measurement of 1st, 2nd, 3rd and 4th instar larvae on maize, rice, millet, and sorghum, are shown on Table 2.

Table 2. Developmental period (days) and body measurements (mm) ± SE of the life stages of *S. zeamais* on different cereal grains (24-30°C; 60 ± 10% RH; 12 h photophase)

	1st instar larva			2nd instar larva			3rd instar larva			4th instar larva		
	Length (mm)	**Width (mm)**	**Developmental period (days)**	**Length (mm)**	**Width (mm)**	**Developmental period (days)**	**Length (mm)**	**Width (mm)**	**Developmental period (days)**	**Length (mm)**	**Width (mm)**	**Developmental period (days)**
Maize	0.54 ± 0.22	0.28 ± 0.05	5.3 (4-6)	0.59 ± 0.12	0.47 ± 0.02	6.5(5-7)^{a}	0.8 ± 0.05^{ab}	0.64 ± 0.04^{a}	5.7(4–6)^{b}	1.67 ± 0.07^{a}	1.06 ± 0.02^{a}	5.6(3–6)^{a}
Rice	0.54 ± 0.22	0.28 ± 0.05	5.3 (4-6)	0.59 ± 0.12	0.45 ± 0.02	5.7(5-6)^{b}	0.81 ± 0.05^{a}	0.6 ± 0.04^{b}	6.5(4–7)^{a}	1.63 ± 0.05^{ab}	1.02 ± 0.02^{a}	4.7(3–5)^{b}
Sorghum	0.53 ± 0.22	0.28 ± 005	5.3 (4-6)	0.59 ± 0.12	0.46 ± 0.02	5.5(4-6)^{b}	0.78 ± 0.05^{b}	0.61 ± 0.04^{ab}	5.7(4–6)^{b}	1.59 ± 0.07^{bc}	0.96 ± 0.02^{b}	4.7(3–6)^{a}
Millet	0.54 ± 0.12	0.28 ± 0.15	5.3 (4-6)	0.59 ± 0.17	0.47 ± 0.02	5.7(5-7)^{b}	0.72 ± 0.07^{c}	0.54 ± 0.04^{c}	5.3(4–6)^{b}	1.55 ± 0.13^{c}	0.91 ± 0.03^{b}	5.3(4–6)^{ab}
CV	1.85	1.19	0.95	1.69	2.16	1.71	1.29	2.21	3.34	1.20	1.96	1.54
F-test	ns	ns	ns	ns	ns	*	*	*	*	*	*	*

Means followed by the same letter in the same column are not significantly different (p<0.05, Tukey's Honestly Significant Difference test), SE= standard error, CV= coefficient of variation, ns = no significant difference & * significant. Source: Ojo and Omoloye (2016)

According to Ojo and Omoloye (2016), the fourth instar larva transformed into white, oval, and slender head prepupa which molted into pupa few hours later. The pupa is exarate and the wings and legs are glued to the body. The pupa stage ranged between 6 and 7 days.

Post-harvest losses during storage of maize grain by *S. zeamais* in Nepal

Many researchers variably estimated extent of grain weight loss and damage caused by weevil during maize storage which was to be in the range of 10-100% depending upon maize storage structures and physical environment (Table 3).

Table 3. Extent of grain weight and damage due to weevils during maize storage in Nepal

Storage structures	Grain weight loss (%)	Grain damage (%)	Location	Reference
Thankro/Cribs/Kunew	5.5		Eastern hills, Nepal	Boxall and Gillet (1980)
Bamboo Baskets/Jute Bags	10.6		Eastern hills, Nepal	Khanal *et al*. (1990)
Bamboo baskets/Jutebags	32		Eastern hills, Nepal	Paneru *et al*. (1996)
Thankro/Cribs/Kunew	10-20	50-100	Eastern hills, Nepal	Golob (1994)
Thankro/Cribs/Baskets	8-13		Mountains, hills and Terai in Nepal	Upadhyay (1998)
Thankro/Cribs/Baskets	21.5		Mountains, hills and terai in Nepal	Pradhan and Manandhar (1992)
Kunew	-	51-97	Mid to low altitude in eastern hills, Nepal	Sah (1998)
Buckets	-	60-100	Mid to low altitude in eastern Nepal	Sah (1998)
Thankro/Cribs/Baskets	22-36		Western hills, Nepal	GC (2002)
Thankro/Cribs/Kunew/Suli/Jhutta/Erim	8.4		Chambas, Tanahu, Nepal	Manandhar *et al*. (2004)
Thankro/cribs/baskets	15.5-21*		Mid to low altitude in eastern Nepal	Timsina *et al*. (2007)
Jutebags/Thankro/Cribs	10-20*		Western hills of Nepal	Bhandari *et al*. (2015)
Jutebags/Thankro/Cribs	19.5**		Mid- and far-western mid hills of Nepal	Paneru *et al*. (2018)

*Loss caused by moths and weevils both ** Loss caused by weevil, moths and rats

Management practices

Monitoring of weevil occurrence

The weevil monitoring is frequently needed, especially after first storage, to enable pest-management decisions (Subramanyam and Hagstrum, 1995). The disturbance of the grain causes adult *Sitophilus* spp. to come them upwards and become visible on the surface (CABI, 2007). Sitophilure, 5-hydroxy-4-methyl-3-heptanone, was reported to be the aggregation pheromone common for *S. oryzae* and *S. zeamais* (CABI, 2007) and Levinson *et al.* (1990) confirmed the activity of 4S, 5R sitophinone and 2S, 3R-sitophilate to monitor *Sitophilus* spp. The responses of *S. zeamais* to pheromone and synthetic maize volatiles as lures in crevice or flight traps have been studied in Kenya (Hodges *et al.*, 1998). Three types of traps (probe, cone and sticky) were used to monitor *S. zeamais* populations infesting shelled maize housed in galvanized steel storage bins (CABI, 2007). Likhayo and Hodges (2000) reported the field monitoring of *S. zeamais* and *S. oryzae* using refuge and flight traps baited with synthetic pheromone and cracked wheat. The combination of pheromone and cracked wheat had an additive effect on trap catch. Prior to store, the grains need to be checked thoroughly if there is any evidence of eggs and insect frass, exit holes and adult insects.

Physical measures

The use of screens over windows and doors can prevent entry of insects. Any holes or crevices from where insects can enter into the store should be closed or repaired (Neupane, 2001). The weevils do not prefer airy, shady, cool and dry places. Exposure to 50°C for 2 hours eliminates most insect pests (CABI, 2007). Use of a controlled atmosphere for storage of grain involves the use of high CO_2 (9.0–9.5%) and low O_2 (2–4%) levels that are lethal to all insects. Nakakita *et al.* (1997) reported that both hatching and metamorphosis of *S. zeamais* were completely inhibited at 10°C; a small number of adult *S. zeamais* emerged at 15°C. Dry heat treatment has been found to be an effective control against all developmental stages of *S. zeamais* (Mohammed-Dawd and Morallo-Rejesus, 2000). All eggs and adult weevils were killed following exposure to 60°C for 2 hours, or 70-80°C for 1 hour (CABI, 2007).

Cultural and sanitary measures

i. Storage hygiene

The grain storage in airy, shady, cool and dry places may be unfavorable to growth and development of *S. zeamais*. It is important to store new and old lots of grains in a separate store room to avoid contamination (Neupane, 2001). The storage containers should make free from weevil eggs, larvae, pupae and adults through repairing and disinfesting all insect hiding cracks and crevices before storing grains. Only the grains without any damaging insects and its immature may be stored in the containers with proper locked system against insect entry (Neupane, 2001).

ii. Grain moisture content

The higher grain moisture content is favorable for growth and development of *S. zeamais*. It is necessary to maintain grain moisture not more than 12–13% by sun drying or by other appropriate means before storing. Moisture percentage of grain will be reduced for suitable to store by sun drying grains 4 hours for 3–4 days (Paneru and Giri, 2011).

iii. Maize harvesting time and storage structures

Physiologically matured grains are hard enough to bore by *S. zeamais*. Timely harvesting followed by drying the grains is less favorable to growth and development of weevils. Paneru *et al.* (2018) reported those farmers who harvested maize cobs before the first week of September and the farmers who stored shelled grains in jute bags (katto), suffered grains loss by 14% and 5%, respectively. The use of metal bins for grain storage is less favorable to *S. zeamais*. GC (2006) reported that the metal bin was superior to jute bag and bamboo mat to store maize grains for six months. Malla *et al.* (2007) reported that jute bag with inner plastic lining was superior to plastic jar and plastic bag to store grains for the period of 75 days.

Botanical pesticides use

There are references reported by Grainge and Ahmed (1988), Stoll (1988), Golob and Webley (1980), and Neupane (1999, 2001) who have suggested to use plant materials to protect storage grains from weevil. About 2400 species of botanicals inherited with pesticide properties are reported in the world (Grainge and Ahmed, 1988), and among them 311 species are commonly available in Nepal (Neupane, 1999). Paneru and Thapa (2018a) reported that the maize grain treatment with *Acorus calamus* (L.) dust @ 25g/kg was effective against *S. zeamais* for 230 days, which was 16 times better than grains stored without any treatment to reduce grain damage. They also reported that grain storage in aluminum container with *A. calamus* dust treatment was 28 times better than jute bag without botanical treatment (82.5%) in term of grain damage. Padmasri *et al.* (2017) reported that seeds treated with *A. calamus* rhizome powder @ 10 g/ kg seed had recorded highest germination percentage (85.67), seedling vigour index (2354), less infestation (0.18%) and weight loss (0.02%) at the end of 9 months of storage at Seed Research and Technology Centre (SRTC), PJTSAU, Rajendranagar, Hyderabad during 2015/16. Some of the promising botanicals against *S. zeamais* are listed below in Table 4.

Table 4. Name of plants effective against *S. zeamais* in Nepal

SN	Family/botanical name	English Name	Nepali Name	Parts used	Reference
1.	Araceae:*Acorus calamus* (Hamilt)	Sweetflag	Bhojo	Stolen	Paneru and Thapa (2018b); Padmasri *et al.* (2017); Paneru and Sah (2001); Joshi and Paneru (1999); NARC (1999); Sah (1998); Paneru *et al.* (1996)
2.	Rutaceae: *Zanthoxylum alatum* (Roxb.)	Pricklyash	Boketimur		Joshi and Paneru (1999)
3.	Asteraceae*: Artemisia vulgaris* (L.)	Mug-wort	Titepati	Leaves twigs	Joshi and Paneru (1999)
4.	*Meliaceae: Azadirachta indica* (A. Juss)	Margosa tree	Neem	Leaves, fruits	Joshi and Paneru (1999); NARC (1999); Mulungu *et al.* (2007)
5.	*Acanthaceae: Adhatoda vascica* (Nees)	Malabar nut tree	Asuro	Leaves, twigs	Joshi and Paneru (1999)
6.	Zingiberaceae*: Corcuma domestica* (Valot)	Turmeric	Haledo/Beshar	Rhizome	NARC (1999)
7.	*Rutaceae: Evodia fraxinifolia* (Hook)		Babis	Leaves	Gyawali (1993)
8.	Asteraceae: *Eupatorium adenophorum* (Spreng.)	Crofton weed	Banmara	Leaves, twigs	Gyawali (1993)
9.	Alliaceae*: Allium sativum* (L.)	garlic	Lasun	Bulbs, oils	Gyawali (1993); Ho *et al.* (1997)
10.	Solanaceae: *Capsicum annum* (L.)	Hotpepper	Pirokhursani	Fruits	Gyawali (1993)
11.	Lamiaceae*: Mentha arvensis* (L.)	Field mint	Pudina	Leaves	Gyawali (1993)
12.	Asteraceae: *Tagetes patula* (L.)	French dwarf marigold	Hotcho saypatri	Leaves	Gyawali (1993)
13.	*Verbenaceae: Vitex negundo* (L.)	Indian privet	Simali	Leaves	Gyawali (1993)
14.	Agavaceae: *Agave americana (L.)*	Century plant	Ketuki	Leaves	Ahmed *et al.* (1984)
15.	Rutaceae: *Citrus aurantiifolia* (Christm.)	Lime	Kagati	Peel oils	Don-Pedro (1996)
16.	Rutaceae:*Citrus reticulate* Blanco	Mandarin orange	Suntala	Peel oils	Don-Pedro (1996)
17.	Arecaceae: *Cocos nucifera* L.	Coconut	Nariwal	Oils	Obeng-Ofori and Reichmuth (1999)
18.	Asteraceae : *Helianthus annuus* L.	Sunflower	Suryamukhi	Oils	Obeng-Ofori and Reichmuth (1999)
19.	Pedaliaceae: *Sesamum indicum L.*	Sesame	Til	Oils	Obeng-Ofori and Reichmuth (1999)
20.	Cruciferae: *Brassica campestris* L.	Mustard	Tori	Oils, cake	Obeng-Ofori and Reichmuth (1999); Bajracharya *et al.* (2012)
21.	Lauraceae: *Cinnamomum camphora* (L.) Nees & Eberm.	Camphor	Kapur	Oils	Obeng-Ofori and Reichmuth (1999)
22.	Caricaceae: *Carica papaya* L.	Papaya	Mewa	Leaves	Mulungu *et al.* (2007)
23	Fabaceae: *Pisum sativum* L.	Pea	Kerau	Grain flour	Bajracharya *et al*. (2012)

Maize varietal resistance

Phenolic compounds have been associated with grain resistance to *S. zeamais*. Phenolic acid content was correlated strongly with hardness of the grain (Arnason *et al.*, 1997). Simbaras *et al.* (2013) reported that maize varieties had different response to maize weevil attack from very susceptible, moderately to tolerance. According to Sharma *et al.* (2010), among the 24 maize genotypes, Rampur Composite and Hill Pool Yellow (Manakamana-6) were observed least damaged by *S. zeamais*. Paneru and Thapa (2018b) reported that the maize genotypes had different response to maize weevil damage ranging from susceptible to tolerance. They reported that the genotypes Manakamana-3, Lumle White POP Corn and Ganesh-2 showed their tolerance to *S. zeamais* as evidenced by lower number of weevil emerged/attracted, lower amount of grain debris release and lower proportion of bored grains. Sharma and Tiwari, 2016 reported that among 8 maize varieties (QPM, Rampur Composite, RML, Mankamana-4, Arun-2, Across, Deuti and Manakamana-3) the Deuti was the most susceptible to weevil and grain damage was recorded up to 40% in both free-choice and no-choice test at Rampur, Chitwan condition. Paneru and Sah (2001) reported that the choice of maize variety with hard intact teguments or tightly closed husks is an indigenous method to combat with post-harvest insect in maize storage.

Biocontrol agents

The bionomics of the pteromalid parasitoid *Lariophagus distinguendus* (Förster) and its effect on *S. zeamais* were studied by Li *et al.* (1998). *L. distinguendus* was found to have five generations each year in the laboratory, with final-instar larvae of the parasitoid over-wintering in larvae of *S. zeamais*. The parasitoid *Theocolax elegans* (Westwood) has also been recorded to attack *S. zeamais* (Helbig, 1998). Both *S. zeamais* and *S. oryzae* are commonly parasitized by pteromalids (and occasionally other hymenoptera). Female parasitoids preferred to oviposit on *S. zeamais* developed in brown rice grain kernels in both tests (Sitthichaiyakul and Amornsak, 2017). *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) is a well-known ectoparasitoid that attacks late-instar larvae of several stored product pests (Belda and Riudavets, 2010). Common pteromalid parasites found in the tropics include *A. calandrae, L. distinguendus* and *T. elegans* (Table 5).

Table 5. List of parasites/parasitoids of maize weevil (*S. zeamais*)

SN	Parasites/parasitoids	Pest stage attacked
1.	*Anisopteromalus calandrae* (Howard)	Larvae, pupae
2.	*Cerocephala dinoderi* (Gahan, 1925)	Larvae
3.	*Cerocephala oryzae*	Larvae, pupae
4.	*Cerocephala* spp.	Larvae
5.	*Lariophagus distinguendus* (Förster)	Larvae, pupae
6.	*Theocolax elegans* (Westwood)	Larvae, pupae

SN	Parasites/parasitoids	Pest stage attacked
	Predators	
1.	*Acaropsellina docta*	Larvae, pupae

Source: CABI (2007)

The effects of different isolates and formulations of *Beauveria bassiana* (white muscardine fungus) on *S. zeamais* in stored maize are reported by Adane *et al.* (1996); Moino and Alves (1997); Hidalgo *et al.* (1998); and Junior and Alves (1998). *B. bassiana* can be an effective microbial control agent if used as a preventative treatment (*Moino et al.*, 1998). The fungal pathogens of maize storage pests in Kenya were surveyed by Oduor *et al.* (2000).

Chemical control measures

i. Use chemical fumigants

Applying chemical fumigants, such as aluminum phosphide (trade name: Celphos) in between piles of grain sacs (a) under airtight room @ 20 tablets per 30 cubic meter, (b) under partial airtight room @ 40–80 tablets per 30 cubic meter, satisfactorily keep grains free from weevil infestation (Neupane, 2001). Similarly, applying fumigants into the grains under air tight container @ 1 tablet Celphos per metric ton grains, and under partial air tight container @ 2–4 tablets/ metric ton grains minimizes grain infestation (Paneru and Giri, 2011). Each celphos tablet is wrapped with muslin cloth before using them to avoid contamination of their ashes with grains.

Sitophilus spp., particularly in the pupal stage, have a lower natural susceptibility to the fumigant phosphine and to carbon dioxide used in controlled-atmosphere storage than do other species tested and thus inadequate treatments are particularly likely to result in some survival (CABI, 2007). Grains kept in jute bags may be protected by spraying malathion 0.05% solution on the surface of the stack. *Sitophilus* spp. have a low susceptibility to synthetic pyrethroids but are readily killed by organophosphorous compounds, such as fenitrothion and pirimiphos-methyl (CABI, 2007).

ii. Surface treatment

Disinfection of the store room and container by 0.05% solution of malathion 50% EC and grains kept in jute bags by spraying malathion 0.05% solution on the surface of the stack protect grains from weevils (Paneru and Giri, 2011).

CONCLUSION AND RECOMMENDATION

Linnaeus originally described smaller species as well as Motschulsky’s description of the larger species were both placed in the genus *Sitophilus* with the specific names as proposed by them. The genus *Sitophilus* and its species may be identified using the keys of Gorham (1987).

S. zeamais is found in all warm part of world where maize is cultivated. It is able to multiply on a wide range of cereals and also on processed cereal products. It causes damage on food value, quality and acceptability of maize grains. The knowledge regarding its identification, distribution, biology and ecology, extent of losses are prerequisite for developing their management strategy. Integration of the following practices before and during maize storage effectively helps sustainable management of the pest and protection of stored grains from this pest.

- The persons involved in grain storage must be trained to identify weevils and damage caused to the grain and access loss in quantity and quality.
- The grain store room and structures should be clean and tidy. All cracks, crevices and holes should be sealed because insects can hide inside.
- The maize cobs should be monitored in the field for physiological maturity and the presence of adult weevils to ensure the harvesting time and reduce field infestation. The physiologically matured cobs should be harvested and only uninfected cobs should be selected for storage.
- The stored grains/cobs should be sampled and examined regularly (at 2 weeks intervals through storage structures) to detect early infestation with increase in temperature.
- If weevil infestation started on maize stored in cribs/thankro/kunew/jhutta, then the grains should be shelled, dried and sieved to remove debris and adult insects. The infested residues and insects should be disposed immediately.
- The new and old lots of grains should be stored in a separate room and storage structure to avoid cross contamination.
- The maize grain should be dried properly (less than 14% moisture content) before storage.
- The grain storage in metal containers acts as moisture proof and rodent barrier. The grains treated with inert dust such as wood ash or rice husks ash @ 5-10 g per kg is also effective to reduce weevil damage.
- The storing of maize grains like Manakamana-3 in almunium storage container with *A. calamus* rhizome dust treatment @ 25 g /kg grains can be recommended under farmers store condition for the storage of maize under mid hill condition.
- The store room and containers should be disinfected with spraying 0.05% solution of malathion 4-6 weeks before storing grain to kill any weevils left from previous harvest or storage.
- The weevil infestation can be managed with chemical fumigation of grains. The chemical fumigants, such as aluminum phosphide (trade name: Celphos) in between piles of grain sacs (a) under airtight room @ 20 tablets per 30 cubic meter, (b) under partial airtight room @ 40 – 80 tablets per 30 cubic meter, can be applied.

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