

REVIEW

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# Rice stem borer species in Tanzania: a review



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## Abstract

Rice is an important cereal crop and is cultivated virtually in all agro-ecological zones in Tanzania. However, production capacity is far below the national requirement. One of the major reasons for the low yields of rice in Tanzania is damage by insect pests, particularly rice stem borers. Four rice stem borer species reported to infest rice crop in Tanzania includes the white stem borer, *Maliapha seperatella* Ragonot, African pink borer, *Sesamia calamistis* Hamson, spotted stem borer, *Chilo partellus* Swinhoe and stalk-eyed fly, *Diopsis thoracica* Westwood. Inappropriately, the potential for proper management of these stem borers to enhance yield has not been fully realized due to limited information available for the respective stem borer species. Proper management of rice stem borers, therefore, is a pre-requisite for enhanced and sustainable rice production among smallholder farmers that epitomize the rice production industry in Tanzania. In this review, rice stem borers were reviewed with emphasis on occurrence and distribution, nature of damage, biology and life cycle, host plant and management options.

**Keywords:** Damage, Host plants, Life cycle, Management strategies, *Oryza sativa*, Stem borers

## Background

Rice, *Oryza sativa* L, is the most cultivated cereal crop worldwide due to its high-calorie provision per hectare compared to other cereal food crops (IRRI, 2002; Pillai, 2005). Rice is one of the most important sources of employment and income generation for rural people (Maclean, Dawe, Hardy, & Hettel, 2002). In Tanzania, rice is the second most important staple crop after maize with average annual production estimated at 1,700,000 metric tonnes (TRVC, 2015). It is cultivated in three agro-ecologies which include rain-fed lowland, irrigated lowland and rain-fed upland (Mghase, Shiwachi, Nakasone, & Takahashi, 2010). Lowland conditions (irrigated and rain fed) account for about 80% and upland for about 20% of the production (Kanyeka, Sangu, Fargette, Pinel-Galz, & Hébrard, 2007). The population in Tanzania is currently growing at a rapid rate of 2.8%

annually (URT, 2013) and self-sufficiency ratio for food is 81% whereas the recommended ratio according to Food and Agriculture Organization (FAO) is 120% (MAFSC, 2009). This results in a continuous increase in demand for rice and other food, hence the need to increase production and productivity (Kanyeka et al., 2007).

Despite the high demand for rice in Tanzania, yield remains low in the range of 1–1.79 tonnes/ha as compared to potential yield of 6–10 tonnes/ha due to several production constraints (MAFSC, 2009; FAO, 2015). Of all the production constraints of rice, one major reason for the low yield in Tanzania is the damage by stem borers (January, Rwegasira, & Tefera, 2018a), but there is limited information on damage symptoms, its biology including life cycle which limits on insect pest monitoring and timely planning for appropriate management practices.

Stem borers are considered as the major problem in almost all the rice-growing area in African countries (Nwilene et al., 2013). They are major field insect pests of rice with high economic importance in Tanzania (Leonard & Rwegasira, 2015; January, Rwegasira, &

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Tefera, 2018b). They are primarily from two insect orders: Lepidoptera (Noctuidae, Crambidae and Pyralidae) and Diptera of Diopsidae family. Among all rice stem borer species, four of them have been reported in Tanzania. These include *Maliarpha separatella* Ragonot, of Pyralidae family, African pink borer, *Sesamia calamistis* Hampson of Noctunidae family, *Chilo partellus* Swinhoe of Crambidae family and *Diopsis thoracica* Macquart of Diopsidae family (Banwo, 2002; Leonard & Rwegasira, 2015). The species are distributed in almost all rice-growing regions in Tanzania. The purpose of this review was, therefore, to update previous information available on rice stem borers based on literature by sticking on occurrence and distribution, nature of damage, biology and life cycle, host plants and management strategies. This information will guide in pest monitoring and timely planning for appropriate management practices.

### **White stem borer, *Maliarpha separatella* Ragonot, Lepidoptera: Pyralidae**

#### **Occurrence and distribution**

The *M. separatella* is a worldwide paddy pest which is found throughout African countries such as Cameroon, Mali, Réunion, Madagascar, South Africa (De Prins & De Prins, 2018) and Asian paddy-cultivating countries such as Myanmar, India and Sri Lanka, though not specifically in rice but in other crops (Heinrichs & Barrion, 2004). *Maliarpha separatella* was first reported as a pest in 1955, when it was found feeding on irrigated rice in Swaziland (Hall, 1955). The reports by Alam, John, and Kaung (1985) and Jaetzold, Schimdt, Hornetz, and Chisanya (2006) indicated *M. separatella* as major rice pest in sub-Saharan Africa and islands of Comoros and Madagascar. It is also the major pest for upland rice in West Africa (Akinsola & Agyen-Sampong, 1984) and irrigated lowland rice in Kenya (Kega, Kasina, Olubayo, & Nderitu, 2017). It is second to *C. partellus* in abundance in both rain-fed and irrigated lowland rice ecosystems of Tanzania (Leonard & Rwegasira, 2015; January et al., 2018b). It is widely distributed in Mbeya, Morogoro, Mwanza, Shinyanga and Zanzibar Regions of Tanzania (Banwo, 2002).

#### **Biology and life cycle**

The male adult *M. separatella* is about 110–130 mm long, while the female is about 130–150 mm long. All are recognized through their long pale-yellow wings which overlap along the body when the moth is at rest (Heinrichs & Barrion, 2004). The antennae for females are longer than that of males. The pest lays eggs which are enclosed in a foliar envelope in groups of long masses on the upper surface of rice leaves attached to the leaf by a strong adhesive force. Eggs are about 0.6 to

0.7 mm long and 0.4 to 0.5 mm broad laid close together. One group of entire mass may contain up to 100 eggs (Heinrichs & Barrion, 2004). Eggs are clear yellow when laid but become paler and finally darken to brownish black in later days. They take about 7 to 10 days prior hatching. The *M. separatella* larvae emerged with white dark-brown heads which later turns yellow as it grows (Heinrichs & Barrion, 2004). The larvae develop a silken thread which is a special aid for dispersion from one plant to another through wind (Banwo, 2002). The larvae feeds on green tissues within the sheath for approximately 5 days; thereafter, borers into the stems move between the first and/or second internode where they actually complete their life cycle without migrating between tillers as they lodge themselves within the stem (Akinsola & Agyen-Sampong, 1984).

Feeding of larvae within the stem takes about 45 to 60 (Appert, 1970), developed into 5–7 instars before pupation (Heinrichs & Barrion, 2004). Before pupation, the larva cuts an exit hole within stem for adult emergence (Heinrichs & Barrion, 2004). The pupa stage lasts approximately 12 days (Appert, 1970), or 32–65 days according to Heinrichs and Barrion (2004), and the whole lifecycle lasts for approximately 40–90 days (Breniere, 1977). Fully fed larvae can sometimes undergo a resting stage (Diapause) in stubbles when the crop is harvested and pupate when the condition is favourable (Appert, 1970). The diapause for *M. separatella* can last for up to 251 days (Akinsola & Agyen-Sampong, 1984).

#### **Nature of damage**

Unlikely other stem borer species, the damage by *M. separatella* is peculiar such that larvae feeding is within the stem without cutting the growing apical portion of the plant at the base. Therefore, the usual symptom of dead heart or white head is not initiated during plant growth for this pest (Banwo, 2002; Heinrichs & Barrion, 2004). This is due to its habitation of remaining at the lower internodes of rice than the uppermost which favours initiation of panicle at the last node (Ogah & Nwilene, 2017). Nevertheless, reduction in plant vigour, tiller number and panicle weight due to *M. separatella* infestation is highly recorded from rice fields in many places in the World. *M. separatella* damages start as the larva penetrates a stem just after hatching and feed on the stem tissues above the node. This results into perforated nodes with necrosis inside the internodes and reduction in plant height as infestation continues during the tillering stage. The infestation during the booting stage resulted into reduction of the number of spikelets per panicle, hindering ripening of panicles which eventually lead to grain weight loss (Nwilene et al., 2013). The *M. separatella* tends to limit their feeding by strictly feeding on one or two internodes of only one tiller

through the larvae stage unlike other stem borer species (Ogah & Nwilene, 2017). According to Kega, Olubayo, Kasina, and Nderitu (2016), *M. separatella* may cause a yield loss ranging from 50–90% if control measures are not initiated at the early stages of rice growth.

#### Host plant

*M. separatella* is a monophagous insect specific to *Oryza* species with limited alternate hosts, while rice (stem) serves as a residual population between rice crops (Ogah & Nwilene, 2017). However, studies by Khan, Ampong-Nyarko, Chiliswa, Hassanali, and Kimani (1997) have reported some plants such as *Andropogon tectorum* Schum. and Thonn, *Sorghum bicolor* (L.) Moench. and the wild rice *O. barthii*, *O. longistaminata* and *O. punctata* as commonly alternative hosts for this insect pest.

#### African Pink Borer, *Sesamia calamistis* Hamson, Lepidoptera: Noctuidae

##### Occurrence and distribution

This is commonly found in wetter localities at all altitudes from sea level to 2400 m altitude. It is more common in Uganda, with its extensive swampy areas, than in Kenya and Tanzania, where it tends to be limited to the hills, lakesides, rivers and irrigated areas. The main crops affected are maize, sorghum, pearl millet, wheat, rice and sugarcane. In Tanzania, *S. calamistis* has been reported to occur in Mbeya, Morogoro, Mwanza, Shinyanga and Zanzibar (Banwo, 2002).

##### Biology and life cycle

The moths are nocturnal in habit and can travel long distances. The wingspan in females of the *S. calamistis* is 20–30 mm and in males a little less. The forewings are pale-brownish, with variable but generally inconspicuous darker markings along the margin and an overall silky appearance (Banwo, 2002). Just after adult emergence, mating as well as egg laying takes place in the same night. Eggs are characterized by having a spherical and flattened shape at the poles. The egg stage undergoes an incubation period of 7–12 days prior hatching. The larvae are characterized by having a yellowish pink on their dorsum, with greyish lateral and dorsal stripes. The larval stage undergoes an incubation period of 28 to 42 days (Banwo, 2002). Pupation takes place within the base of the stem and it lasts for 10 to 15 days before the larva develops into adult (Heinrichs & Barrion, 2004).

##### Nature of damage

*S. calamistis* attacks rice plant at all stages but increases with the crop age, thus with the highest incidence mostly at the latter stage of crop growth starting from the booting stage to maturity. Feeding during the vegetative stage (before panicle initiation) causes the death of

the central shoot leading to a dead heart symptom and it is at this stage when *S. calamistis* larvae population is low (Leonard & Rwegasira, 2015). At the booting stage of rice crop is when the population of *S. calamistis* larvae starts to increase, but larvae population doubles as from panicle initiation to maturity stage of rice crop (Ogah & Nwilene, 2017). *S. calamistis* feedings during the reproductive stage of rice crop causes splitting of the developed panicle at its base. This will therefore result into development of unfilled or empty panicles known as white head, causing yield loss due to reduction of productive tillers (Ogah & Nwilene, 2017).

##### Host plants

*S. calamistis* is a polyphagous species found on about 55 host plants belonging to the families Poaceae (Andropogoneae, Arundineae, Cynodonteae, Eragrostideae, Orizeae, Paniceae) and Cyperaceae. Primary host plants are maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.), rice (*Oriza sativa* L.), sugarcane (*Saccharum officinarum* L.) and wheat (*Triticum aestivum* L.). Wild hosts include many species of wild grasses such as *Cymbopogon nardus* L., *Echinochloa pyramidalis* Lam., *Eriochloa fatmensis* (Hochst. and Steud.), *Hyparrhenia* spp, *Jardinea congoensis* (Franch.), *Megathyrsus maximus* (Jacq.), *Paspalum virgatum* L., *Pennisetum* spp., *Phragmites mauritianus* Kunth, *Rottboellia cochinchinensis* (Lour.), *Setaria* spp.; wild sudan grass such as *Sorghum verticilliflorum* Steud., *Sorghum arundinaceum* (Desv.), *Sporobolus* sp., *Urochloa mosambicensis* (Hack.), *Vossia cuspidata* (Roxb.) and sedges such as *Cyperus* spp. and *Pycreus mundtii* Schoenoplectus *corymbosus* (Roem. and Schult) (Ong'amo et al., 2006).

#### The spotted stem borer, *Chilo partellus* Swinhoe, Lepidoptera: Crambidae

##### Occurrence and distribution

*Chilo partellus* is a moth from the family Crambidae and was first described by Charles Swinhoe in 1885 as *Crambus partellus*. It is native to Asia where it is a pest of maize and sorghum in India and Pakistan (Polaszek, 1998). It is the major stem borer among stem borers reported in Tanzania (Leonard & Rwegasira, 2015; January et al., 2018b). It was first reported from Africa in the 1930s and became established in East Africa in the 1950s (Seshu Reddy, 1983). It is now widespread throughout Eastern and Southern African countries such as Ethiopia, Lesotho, Madagascar, Malawi, South Africa, Sudan, Tanzania, Uganda and Mayotte (De Prins & De Prins, 2017), and it is also occurring in west Africa (Mohamed, Khan, Overholt, & Elizabeth, 2004). It occurs in low- to mid-altitude areas (1230 masl and below). It is found in both irrigated and rain-fed rice ecosystems (Banwo, 2002).

### Biology and life cycle

Eggs are laid in batches of 10–80 on the upper side and underside of leaf surfaces, usually close to the midrib which hatch after 4–10 days (Kfir, 1992). Larvae emerge after 4–8 days and are attracted to light. They bore into the stem about an hour after hatching, penetrate into the stem tissues, feed and produce an extensive tunnel in stems. When these larvae grow completely, they pupate in the tunnels, after excavating emergence windows to facilitate the exit of moths (Dale, 1994). The larvae may enter a resting period (Diapause) during dry seasons for several months, where it will pupate as rain begins. Pupae can be up to 15 mm in length, slender and shiny (Van Hamburg, 1980). They take about 1–2 weeks prior becoming adults emerging of the adult moth. The adult emerges through an exit hole made by the full-grown larva just after sunset (Dale, 1994). When the adult develops, they emerge from the stem through exit hole and move to other plants where they lay eggs and continue causing damage to the rice crop. Emergence of adults from pupae usually takes place during late afternoon or early evenings but they are active at night. Adults will rest on plants during the day. The whole life cycle takes about 3–4 weeks; however, it can vary due to temperature, humidity and other factors (Ogah & Nwilene, 2017).

### Nature of damage

All parts of rice plant are attacked by *C. partellus* with exception of the roots (Kamala et al., 2012). Just after hatching, the active larvae move and feed on plant leaves and leaf sheaths shortly before they enter the stem through the leaf sheath. The first instar larvae feed on the leaf while the second to sixth instar larvae feed within the rice stem from the upper internodes. When the stem decays and nourishments are exhausted, the larvae migrate to new stems and continue feeding until it develops into pupa (Ogah & Nwilene, 2017).

Damages initiated by *C. partellus* are similar to those caused by other lepidopterous stem borers (Ukwungwu & Odebiyi, 1984). When stem borers infests rice crop during the vegetative stage through feeding inside stem, this results into damage symptoms called dead hearts (death of the central shoot) and, during the reproduction stage (before panicle initiation), will result into damage symptoms known as white head all of which contributes to the grain yield losses (Leonard & Rwegasira, 2015; January et al., 2018b). For example, Ukwungwu and Odebiyi (1984) have reported yield losses due to *C. partellus* ranging from 15 to 50% when infestations occur in resistant and susceptible rice varieties respectively.

### Host plant

*Chilo partellus* is a polyphagous insect pest of rice (Ogah & Nwilene, 2017). It has been reported to attack both

cultivated and wild gramineaceous plants whereby wild plant species served as alternate hosts during the off-season (Heinrichs & Barrion, 2004; Akinsola, 1990). These alternative host plants includes *Echinochloa crus-galli* (L.), *E. pyramidalis* (Lamarck) Hitchcock and Chase, *Pennisetum* spp, *Saccharum officinarum* L, *Rottboellia cochinchinensis* (Loureiro) W.D. Clayton, *Sorghum arundinaceum* (Desv.) Stapf, *Zea mays* L and *O. barthii* (Dale, 1994; Akinsola, 1990).

### The stalk-eyed fly, *Diopsis thoracica* Westwood, Diptera: Diopsidae

#### Occurrence and distribution

About three species of genus *Diopsis* are recognized as pests of cultivated rice in Africa. These include *Diopsis thoracica*, *D. apicalis* and *D. collaris*. Among the three species, *D. thoracica* is considered to be of more concern (Heinrichs, 2000). Several other unidentified species of genus *Diopsis* are also known to exist. For example, Feijen and Feijen (2012) have reported two species from genus *Diopsidae* viz: *Diopsis eisentrauti* and *D. stuckenbergi* belonging to the same group as *D. thoracica* in South Africa and Swaziland. These insect species are commonly found in Cameroon, the Democratic Republic of Congo, Gabon and Togo. Pathak and Khan (1994) have as well reported other two subspecies belonging to the species *Diopsis apicalis* Dalman viz: *Diopsis circularis* Macquart and *Diopsis ichneumonaea* Linnaeus and one subspecies *Diopsis servillei* Macquart which exists in Africa. These *Diopsids* have been reported to exist abundantly and distributed in humid, Equatorial and Eastern tropical zones of African countries. They have been reported to occur in Côte d'Ivoire and Benin, especially in irrigated and lowland rice, with much less in upland rice fields, in Senegal (Bernard, 1982). Also it has been reported in Togo, Ghana, Cameroon, Liberia, Guinea, Sierra Leone, Guinea Bissau and Nigeria (Heinrichs, 2000). Likewise, its presence was reported in Madagascar (Heinrichs & Barrion, 2004). It has been reported in Tanzania and Uganda where it extends in all the rice ecologies (Banwo, 2002; Weelar, Lamo, Otim, Awio, & Ochwo-Ssemakula, 2017). In Tanzania, *D. thoracica* has been reported to occur in Coast, Morogoro, Mwanza, Shinyanga and Zanzibar regions (Banwo, 2002).

#### Biology and life cycle

Eggs are laid by females on the upper surface of young leaves where they are affixed with adhesive which prevents them from being detached during heavy rains. An average of 30 eggs is laid in 20 days which lasts for 2–3 days prior hatching (Bocco, Elie, & Gandonou, 2017). As the larvae emerges, they move down the leaf sheath to the meristem where they feed and cause drying of the central shoot or dead heart symptom. The larvae are

whitish cream with yellow marking on terminal segments. They are about 12–18 mm long and 3 mm wide with very small heads. Larval incubation period ranges from 25 to 35 days prior pupal emergence. The pupal stage lasts for about 10–12 days before adult emergence. The pupa is characterized by presence of red and brown bands on the dorsal parts and adult by having red colouration on the abdominal parts (Ogah & Nwilene, 2017).

#### Nature of damage

Like other stem borer species, *D. thoracica* has also been reported to attack all stages of the rice plant, but younger plants are more prone to be attacked compared to older ones due to low silicon deposits (Ogah & Nwilene, 2017). Damages due to *D. thoracica* occur just after hatching. The emerged larvae move down the leaf sheath, while feeding above the meristem on the central spindle of young leaves. The larvae then move from one tiller to another of the same rice hill for similar destruction. Maximum of up to 10 tillers can be damaged by one larva (Kamala et al., 2012). Normally, only one larva dwells in a stem, feeding and leading to dead heart symptom. Larvae feeding within the stem causes death of last emerged leaf, but left the stem undamaged (Feijen & Feijen, 2012). Damages due to *D. thoracica* delay booting of rice crop which resulted in the reduction of panicle numbers and ultimately yield losses (Ogah & Nwilene, 2017). Yield losses ranging from 60 to 100% have been reported to be caused by *D. thoracica* in heavily infested fields (Heinrichs & Barrion, 2004).

#### Host plants

The main hosts of *D. thoracica* are cultivated rice. But some plants such as wild rice (*Oryza longistaminata* L.) and sedge grass (*Cyperus difformis*), the common weeds found in rice fields have been reported as alternative hosts of *D. thoracica* (Bocco et al., 2017).

#### Management strategies for rice stem borers

Several authors have investigated various control measures against stem borers even though, none of them have been documented to be used by farmers in Tanzania. The methods are either currently reported by researchers to be effective for stem borer control in Tanzania or are applied elsewhere in the world. These are cultural, biological and chemical control methods.

#### Cultural control

This is an economical method of stem borer control which seems to be relevant to most resource-poor farmers (Rami, Overholt, Khan, & Polaszek, 2002). It includes various techniques such as management of crop residues, manipulation of planting date, application of

nitrogenous fertilizer, habitat management through intercropping, the use of trap crop and use of resistant varieties (Polaszek, 1998). Other control methods may be very expensive for farmers to adopt, not available or unsuccessful, thus making the need of cultural control methods to be most relevant (Seshu-Reddy, 1998; Polaszek, 1998). Management of stem borers through cultural practices goes hand to hand with understanding its biology, ecology and relationship with its respective crop (Kfir et al., 2002).

Cultural control is considered as the first line of defence against pests (Kfir et al., 2002). They are more appropriate practices to farmers in developing countries because they are easy to implement with less cost and they are compatible to all other control measures (Togola, Boukar, Tamo, & Chamarthi, 2020). Cultural control options for stem borer management appear promising, but they have not been adopted by many African farmers (Rami et al., 2002). Cultural control is severely constrained by the lack of management capabilities of farmers, especially in areas where farming communities lack the support of an adequate extension service (Rami et al., 2002). The policy makers should therefore ensure that extension services are close to farmers that could assist in implementation of management tactics.

#### Management of crop residues

Crop residues are important for carrying stem borer larvae population from one growing season to another. Management of crop residues is mainly directed toward the control of rice stem borer (Polaszek, 1998). Study by Kfir et al. (2002) reported various stem borer species observed in stalks after harvest in Kenya whereas in Ethiopia, various stem borer larvae were observed survived in stubble (Kfir, Van Hamburg, & Van Vuuren, 1989). Under these conditions, borers from the previous season stalks constantly infested the newly planted crops. For effective control practice, it is therefore important to reduce the first generation of adult stem borer by destroying the larvae in previous season stalks.

#### Manipulating of sowing date

Growing crops at the period of least abundance of the pest ensures that the most susceptible stage of crop growth will not interfere with the period of peak stem borer activity (Rami et al., 2002). Manipulation of sowing date is a disadvantage to the pest, which is susceptible to air or water temperature extremes, heavy rainfall, non-preferred crop growth stage and an abundance of natural enemies. Early planting may minimize the incidences of various pests including stem borers (IRRI, 2001). In Pakistan, sowing time showed the impact on the incidence of stem borer by which early-sown rice crop was

the most resistant having the lowest borer infestation among other plantings (Mohamed, 2012). In Tanzania, Leonard and Rwegasira (2015) reported that rice planted in from 28 December to 5 January was more prone to infestation by stem borers compared to rice planted from 15 November to 20 December. Predicting peak populations of pests, regarding seasons is therefore a useful tool in helping to control insect pests such as stem borers.

#### **Application of nitrogenous fertilizer**

Application of nitrogen fertilizer has been investigated to encourage stem borer damage to various crops. Ukwungwu and Odebiyi (1984) reported increased damage by *C. zacchoni* in rice crop to be caused by unbalanced nitrogen fertilizer application in Nigeria whereas Van den Berg and Van Rensburg (1991) reported sorghum planted without nitrogen fertilizer to have less stem damage than that which was having nitrogen fertilizer in South Africa. In Tanzania, increasing nitrogen rates beyond 80 kgN/ha have been reported to increase damage by rice stem borers, *C. partellus* and *S. calamistis*, while decreasing grain yield (January, Rwegasira, & Tefera, 2020). Nitrogen fertilization has therefore direct impact on rice yield but too much fertilizer may encourage damage by stem borers. Nitrogen fertilization to rice crop is still encouraged to be applied for maximum yield, but only up to optimum levels.

#### **Habitat management**

Habitat management is considered as a part of conservation biological control method which changes habitat to improve availability of natural resources for natural enemies for optimal performance (Litsinger, 1994). This management can occur within crop, farm or landscape level. Inter cropping has been widely practiced in Africa by small-scale farmers for the aim of reducing risk of crop failure, increasing yield and improving soil fertility. In East Africa, studies have been carried out to find crop combinations for reducing stem borer population on cereal crops. A study by Khan et al. (1997) in Kenya has reported the effectiveness of intercropping maize with the non-host molasses grass, *Melinis minutiflora* L. In field trials, molasses grass showed no colonization by stem borers, and when used as an intercrop with maize, it significantly reduced stem borer infestation of the main crop. Another study by Kfir et al. (2002) revealed that inter cropping maize with rice was found to be an effective way of reducing damage caused by *C. partellus* larvae migrating from one plant to another. However, this is possible for upland rice varieties only where flooding is not required as source of water for rice crop.

#### **The use of trap crop**

Trap crops have been recommended as an effective method in combating stem borer problem elsewhere. For example, Nwilene et al. (2011) have reported the use of maize as trap crop against *M. separattella* when intercropped with upland New Rice of Africa (NERICA) rice varieties in Nigeria.

#### **Use of resistant varieties**

Use of host resistance is sought as the major tactic in an integrated approach in the management of insect pests. Incorporation of insect resistance into varieties of crops is a major objective of most breeding programmes in developing countries in the recent time as cultural technique in stem borer control (Nwilene et al., 2013; Kega, Kasina, Olubayo, & Nderitu, 2013). Host plant resistant varieties have no effect on the environment, and the method is compatible with other insect control methods (Rami et al., 2002). Farmers in Africa depend on traditional varieties whereby most of them are low yielding and less resistant to stem borers (Nwilene et al., 2013a). Many research trials concluded that certain rice varieties had less stem borer damage than susceptible varieties (Khan et al., 2005, b). Some examples of rice varieties which are resistant to stem borer damage include NERICA6, IR32, IR66 and IR77 (Nwilene et al., 2008a) and some of African rice varieties such as NERICA1 and NERICA5 in Côte d'Ivoire and NERICA4 in Nigeria (Nwilene et al., 2013). Other studies revealed use of resistant varieties such as CG14, K85 and some accessions from *O. glaberrima* and TOG (Tropical *Oryza glaberrima*) (Bocco et al., 2017).

The use of resistant varieties is most attractive as compared to the use of insecticides which is beyond the means of the small farmer. Substantial development has been made in screening and breeding for host plant resistance to cereals' stem borers, but a limited number of varieties have shown a good level of resistance (Togola et al., 2020). Some stem borer-resistant varieties contain some biophysical characteristics such as stem hardness and leaf hairiness which are important features to consider in variety selection (Kega et al., 2013). Further, Togola et al. (2020) reported that rice varieties having ability to produce new tillers to compensate the infested stems can tolerate the damage by stem borers. Although there is limited achievement on varietal resistance to stem borer, this option remains promising as an integrated pest management component. The recent advancements in biotechnology can enhance the efforts of generating resistance materials and quicken the transfer of gene for improving new genotypes resistant to stem borer's damage.

### Biological control

This involves the use of other organisms in regulating species population below the economic injury level (Rami et al., 2002). It is environmentally friendly and effective when the use of pesticides has been eliminated due to its effect on natural organisms (Charudattan et al., 2006; Abdulla, 2007). It involves the use of natural enemies of an organism such as parasitoids, predators, pathogens, antagonists or competitors' population to suppress a pest population, making it less abundant and less damaging than it would otherwise be (Ogah & Nwilene, 2017). Polaszek et al. (1994) have reported five parasitoid species namely Braconidae: *Chelonus maudae* Huddleston, *Rhaconotus carinatus* Polaszek; Ichneumonidae: *Pristomerus bullis* Fitton, *Pristomerus cans* Fitton, *Venturia jordanae* Fitton as important for *M. separatella* control after critical field surveys in in Cameroon, Ivory Coast, Kenya, Madagascar, Senegal and Tanzania. The recent studies by Souobou et al. (2015) have reported two more species: *Bracon* sp. and *Goniozus indicus* Muesebeck as parasitoids of *M. separatella* in Burkinafaso. Various rice stem bore predatory insects are known. These are spiders, dragonflies and earwigs, which feed on both larva and adult stem borers (Noorhosseini et al., 2010). In Kenya, East Africa, studies by Kega et al. (2013) have reported the use of Entomopathogenic nematode, *Heterorhabditis indica* Poinar, Karunakar and David applied to rice cultivars at the rate of  $6.7 \times 10^4$  infective juveniles (IJs) per litre of distilled water at 3 weeks after planting is effective against *M. separatella* infestation in rice fields. Some insect pathogens are mostly manipulated biological control agents. Furthermore, important pathogens in the management of rice stem borers such as *Metarhizium*, *Beauveria* (Ogah & Nwilene 2017; January et al., 2018b), *Hirsutella* and *Pacilomyces* (Ogah and Nwilene, 2017) have also been reported as natural biological agents.

For any biological control method to be effective and sustainable, it depends on availability of the biocontrol agents at appropriate density. Studies by Togola et al. (2020) revealed that practices such as habitat management or avoiding continuous use of extensive range insecticides can contribute to the increase of the carry-over of population of natural enemies which can maintain the pest population below a critical level.

### Utilization of synthetic sex pheromones

This is another biocontrol method which involves the use of synthetic sex pheromone-baited traps to control rice stem borers as alternative to chemicals (Su et al., 2003). Male adult moths can be attracted by hormone-like chemicals called pheromones baited in the traps in rice fields. These sex pheromone-baited traps are also used by researchers for monitoring moth population in

fields (Abdulla, 2007). In China, some sex pheromones like Z-11-hexadecenal, Z-13-octadecenal and Z-9-hexadecenal have shown success in controlling stem borers. The moth's catches can provide information which is useful in timing for insecticide applications as well as mating disruption (Campion & Nesbitt, 1983). The main constraints of the biocontrol measures are the difficulties in finding the specific biocontrol agents for targeted pest species, mass rearing complexity and the complication to be explained by extension workers to farmers for implementation. The extension workers are therefore required to be trained on specific and important biocontrol agents for specific insect pest species and how to transfer the information to farmers for implementation.

### Chemical control

The use of insecticides for the management of rice pests became widespread, especially in endemic areas where appropriate resistant varieties are not available. At present, various categories of pesticides (starting with chlorinated hydrocarbons, then phosphates and the recent carbamates and pyrethroids) are available for farmers and have been evaluated for use in the management of various rice pests, especially under emergency/heavy infestation situations (Ogah & Nwilene, 2017). Pesticide application is recommended when the bore damage is more than 10% for dead heart and 5% for white head (Nwilene et al., 2008b). Insecticide application can be economical when the number of stem borer egg masses per sampling unit of 1 m × 1 m, taken every 10 days from 20 days after transplanting is higher than 3.5% (Appert, 1970). On the other hand, insecticides to be applied should have low toxicity to human and other non-targeted species (Abdulla, 2007). Some of insecticides used to control stem borers include Fipronil, Carbofuran, Carbosulfan, Diazinon, Chlorpyrifos, Phenthoate and Quinalphos (Leonard, 2015). Others are Regent 3G, Rogor (Dimethoate 40 EC) and Isofenphos (Mbapila, 1987; Kakema, 1994; Kibanda, 2001). Despite the fact that the use of chemical insecticides in pest control may cause hazardous to environment, still it is the only option to be used in a situation where pest population is already established. Chemical control can also be used as an integrated pest management component with cultural practices or resistant varieties (Togola et al., 2020). Chemical control can be achieved by application of granules or dust during early plant growth on leave whorls to kill first instars of stem borer larvae (Mbapila, 1987). Apart from chemical insecticides being hazardous to environment and being expensive beyond farmer's accessibility, frequent use of one insecticide to control one species of insect pest may cause pest resistance (January et al., 2018b). In all cases, chemicals should be applied

only when all other control methods seem to be ineffective. Choice of selective systemic insecticides is needed to avoid adverse effects on non-target organisms and biodiversity.

## Conclusions

Rice stem borers have been considered as the most devastating pests among insect pests that affect rice in Tanzania, which so far requires suitable management strategies to be initiated. Many control measures including biological, cultural and chemical control strategies have been suggested under this review among which fewer of them are practiced in Tanzania. Despite the fact that most of control measures were reported to be effective against rice stem borers, none of them have achieved 100% control as a single management option. Therefore, a need for integration study of different stem borer management options is vital in order to eradicate stem borer problems in the future.

## Abbreviations

FAO: Food and Agriculture Organization; NERICA: New Rice of Africa; TOG: Tropical *Oryza glaberrima*

## Acknowledgements

The authors are very grateful to anonymous reviewers for helping in the improvement of this manuscript.

## Authors' contributions

BJ drafted the manuscript. GMR and TT reviewed the manuscript. Both authors read and approved the final manuscript.

## Funding

Not applicable.

## Availability of data and materials

Not applicable.

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Competing interests

The authors declare that they have no competing interests.

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Received: 6 December 2019 Accepted: 2 June 2020

Published online: 19 June 2020

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