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REVIEW

Developing and deploying insect resistant maize varieties to reduce pre-and post-harvest food losses in Africa

Tadele Tefera [1,2] · **Stephen Mugo** [1] · **Yoseph Beyene** [1]

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Abstract Maize grain yield in Africa is low, 1.5 t ha^{-1} compared to the global average of 4.9 t ha^{-1}. Maize production in Africa is constrained by various abiotic (drought, soil fertility) and biotic factors (insect pests, weeds and diseases). Stem borers and postharvest insect pests play considerable roles in reducing maize yield through damaging the leaves, stems, ears, and kernels. Stem borers can cause 10–15 % yield losses while the postharvest insect pests, particularly, the larger grain borer and maize weevil, can cause 14–36 % grain losses. The use of chemical insecticides has been recommended; however, in addition to health concerns, insecticides are expensive and not accessible to smallholders. Developing high yielding insect resistant maize varieties could do much to minimize the losses. Resistance of maize to stem borers and post-harvest insect pests are genetic traits which manifests themselves in resistant varieties. Resistance is available to farmers encapsulated in the seed, which ensures that after purchasing the seed, farmers need not invest in any further inputs to control stem borers and post-harvest pests. CIMMYT and its partners have developed through conventional breeding and have deployed several hybrids and open-pollinated varieties, which are insect resistant and high yielding. Sources of maize germplasm resistant to stem borers and postharvest insect pests, and performance of the new insect resistant and high yielding maize hybrids are reviewed and discussed.

✉ Tadele Tefera
t.tefera@cgiar.org; tadeletefer@yahoo.com; ttefera@icipe.org

1 International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 1041, 00621 Nairobi, Kenya

2 Present address: International Center of Insect Physiology & Ecology (icipe), ILRI Campus, Gurd Shola, PO Box 5689, Addis Ababa, Ethiopia

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Introduction

Maize is one of the most important food and feed crops in the world. Together with rice and wheat, maize provides at least 30 % of the food calories to more than 4.5 billion people in 94 developing countries (Shiferaw et al. 2011). Maize production spans the entire African continent and is a dominant cereal food crop in many countries, accounting for 56 % of total harvested area of annual food crops and 30–70 % of total caloric consumption. The annual per capita consumption is highest in Africa, averaging about 103 kg in Kenya, 181 kg in Malawi, 195 kg in South Africa, 168 kg in Zambia, and 153 kg in Zimbabwe (Hassan et al. 2001).

Yields of maize grain in Africa are low, 1.5 t ha^{-1}, compared to the global average of 4.9 t ha^{-1} and, in sub-Saharan Africa (SSA) countries where it is the most important staple food for over 300 million people, extremely variable compared to other regions (Tefera 2011a). For example, between 2005 and 2008, the average yield of maize was estimated by Smale et al. (2011) at 1.4 t ha^{-1}compared to 2.5 t ha^{-1} in the Philippines, 3.1 t ha^{-1}in Mexico, and 3.9 t ha^{-1}in Thailand. Constraints to maize production include both abiotic and biotic factors. Biotic constraints include field and storage insect pests. Stem borers and postharvest insects, play a considerable role in reducing maize yield in Africa through damaging the leaves, stem, ears, and kernels (Tefera 2012). There are five economically important species of stem borers in Africa: the spotted stem borer *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae), the African stem borer *Busseola fusca* Fuller (Lepidoptera: Noctuidae), coastal stem borer *Chilo orichalcocillielus* Strand (Lepidoptera: Crambidae), pink stem borer *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae), and sugarcane borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Polaszek 1998).

One of the key constraints to improving food and nutritional security in Africa, however, is the poor postharvest management that leads to 20–30 % loss of grains, with an estimated monetary value of more than US$ 4 billion annually (FAO 2010). Postharvest losses contribute to high food prices by removing part of the supply from the market. Insect pests causing damage of economic importance include the larger grain borer (LGB), *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) and the maize weevil (MW), *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). The LGB was accidentally introduced into Africa in the late 1970s from its area of origin in Mexico, where it had been recognized as an occasional pest of stored maize (Markham et al. 1994). It is now widely recognized as the most destructive pest of farm-stored maize and dried cassava in Africa (Nukenine 2010; Boxall 2002). The pest has spread to at least 17 African countries, Benin, Burkina Faso, Burundi, Ghana, Guinea Conakry, Kenya, Malawi, Mozambique, Namibia, Niger, Nigeria, Rwanda, South Africa, Tanzania, Togo, Uganda, and Zambia, becoming the most invasive destructive pest of stored maize. The maize weevil is an important cosmopolitan pest of maize stored on-farm, without control of moisture content and chemical protection. This paper, therefore, reports on development and deployment of maize varieties resistant to stem borers and post-harvest insect pests through conventional breeding and highlights the performance of new maize hybrids to these pests in reducing food losses in Africa.

Damage and losses caused by stem borers to maize

Stem borer injury to maize includes leaf feeding, stem tunneling and ear damage. Leaf feeding results in death of the central

Fig. 1 Stem borer dead-heart damage to susceptible maize (**a**); leaf damage to susceptible hybrid (**b**); comparing leaf damage of susceptible and resistant hybrids (**c**); stem tunneling damage of susceptible and resistant hybrids (**d**). All damages were evaluated under artficial infestation with the stem borer Chilo partellus (Source: IRMA (Insect Resistant Maize for Africa) Project)

growing tip, "dead-hearts" (Fig. 1a) whilst stem tunneling results in disruption of the flow of water and nutrients to the ear (Kfir et al. 2002; Polaszek 1998). Leaf lesions are formed by the scraping of the epidermis and parenchyma on one side of the leaf, leaving the other side intact and transparent. When the leaves unfold, the lesions are seen as small holes or windows on the leaves. In some cases, the larva bores through the perpendicular axis of some of the leaves in the inner whorl and when these unfold, the lesions appear as an array of holes of similar size and shape (Polaszek 1998). Foliar damage, caused by the first and second instar larvae, results in reduction of total leaf area and depression of the photosynthetic capacity of the plant (Fig. 1a, c). The third instar larvae bore into the stem or feed on the developing tassel. Stem tunneling is caused by the third to sixth instar larvae. At a later stage of growth, the larvae make extensive tunnels inside the stem (Fig. 1d), destroying the central pith and conducting tissues, thus causing reduction in nutrient uptake and flow to the grain, as well as stem breakage and infection by secondary microorganisms (Polaszek 1998; Adugna and Trond 2001). In older plants, the first generation larvae bore into the main stem, but later, some of the second generation larvae bore into the maize cobs.

The amount of loss of grain yield depends on the severity of leaf damage and stem tunneling. Loss estimates vary greatly, depending upon the country, season, maize variety, and fertilization (Overholt et al. 1996; Kfir et al. 2002; De Groote et al. 2002). In East Africa, yields were reduced by 15–45 % (Seshu Reddy and Sum 1992), while in South Africa, losses exceeded 50 % (Kfir et al. 2002). A survey of farmer fields in Kenya, with and without insecticidal control found that average annual loss caused by all stem borer species was 13.5 %, valued at US$ 80 million (De Groote et al. 2002).

Damage and loss caused to maize by postharvest insect pests

Losses of 12–20 % grain weight caused by the maize weevil have been reported, and up to 80 % loss may occur for untreated maize grain stored in traditional structures in tropical countries (Boxall 2002). Weevil damage results directly in lost food through reduced grain weight, and may reduce future maize production for farmers who plant saved grain as seed. This practice accounts for about 70 % of all maize planted in eastern and southern Africa (Boxall 2002). There is also a health risk associated with consumption of weevil-infested maize grain, as it has been reported to have higher levels of aflatoxin contamination than non-infested grain (Tefera 2012; Wareing 2002).

The larger grain borer is a key pest of stored maize, attacking maize on the cob after harvest. Adults bore into maize husks, cobs or grain, making round holes and tunneling extensively, producing large quantities of grain dust as they tunnel (Fig. 2). The adults prefer grain on the cob to shelled grain, thus damage on unshelled maize is greater than that on loose, shelled maize. When infesting stored maize cobs with the husk intact, the adults frequently begin their attack by boring into the maize cob cores, and eventually gain access to the grain at the apex of the cob by crawling between the cob and husk. They may also bore directly through the husks causing considerable losses in stored maize. Grain weight losses of 35 % have been observed due to the LGB after 3-6 months storage in East Africa (Hodges et al. 1983; Muhihu and Kibata 1985; Tefera 2012; Tefera et al. 2011a&b; Schneider et al. 2004; Gueye et al. 2008). The larger grain borer is spread over long distances through the import and export of infested grain. Local dispersal is through the movement of infested maize from surplus to deficit areas, and by flight. The LGB develops best at high temperatures and relatively high humidity, but can also tolerate dry conditions.

Fig. 2 Damage to maize ears from three LGB resistant hybrids (*top row*) and four checks (*bottom row*) by LGB after storage for 3 months (Source: IRMA Project)

LGB may develop in grain at as low as 9 % moisture content (Haines 1991). This contrasts with many other storage insect pests, which do not increase in number under low moisture conditions. Infestations of the LGB with other storage pests results in the LGB being the predominant storage pest under dry conditions (Boxall 2002).

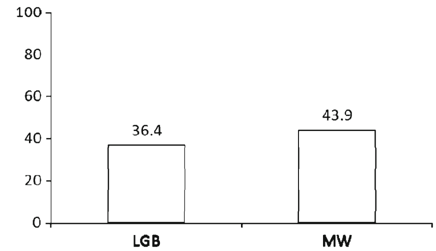

Fig. 3 Percentage weight loss reduction by the new insect resistant hybrids (mean of 28 hybrids) over the susceptible commercial check (Duma-41) against LGB (larger grain borer) and MW (maize weevil) evaluated in Kenya in 2010 (Source: IRMA Project)

General approaches to maize insect pest control in Africa

A combination of cultural, chemical and biological measures are used to control insect pets of maize in Africa as well as host plant resistance. For stem borers, cultural practices, including appropriate disposal of crop residues, time of planting, tillage and mulching, spacing, intercropping, removal and destruction of volunteer and alternative hosts, fertilizer application and crop rotation are practiced (Unnithan and Seshu Reddy 1989). Early planting lowers stem borer infestations (Abu 1986) and intercropping sorghum with cowpea delayed the build up of *C. partellus* larval populations (Minja 1990). Grain drying to appropriate moisture content before storage, sanitation of storage containers, use of hermetic storage and chemical treatments of grains during storage are some of the pest management practices recommended to reduce loss against postharvest insect pests (Tefera 2012).

Introduction and release of natural enemies have been made for stem borers and postharvest insect pests, particularly the LGB. Establishment of the parasitoid, *Cotesia flavipes*, against the stem borers has been reported but the overall rate of parasitism of stem borers was low (10–14 %) (Seshu Reddy 1998). Two populations of *Teretrius nigrescens* Lewis, a histerid predator, were introduced into several African countries, among them Kenya, with varying degrees of success in controlling LGB (Schneider et al. 2004). Several insecticides for the control of maize stem borers (e.g., carbofuran, carbaryl, deltamethrin, endosulfan, trichlorfon and synthetic pyrethroids) and postharvest insect pests (e.g., Actellic dust, Actellic Super, phostoxin) have been recommended in different regions in Africa (Seshu Reddy 1998). Chemical insecticides have been associated with human health risks and these chemicals are either unavailable or too expensive for subsistence farmers in Africa (Golob 2002; Dhliwayo and Pixley 2003). Therefore, an environmentally safe and economically feasible stem borer and postharvest insect pest control practice needs to be made available. Developing high yielding maize varieties with resistance to stem borers and postharvest insect pests has been regarded as a potential option to minimize the overall cost of maize production and storage (Mugo et al. 2001; Beyene et al. 2011a; 2012; Fig. 3). These varieties may also reduce the potential risk associated with consumption of maize treated with insecticides. Genetic variability has been reported among maize varieties for resistance to stem borers and postharvest insect pests (Dobie 1974; Serratos et al. 1987; Tipping et al. 1988; Tefera et al. 2011b; Mwololo et al. 2010; Beyene et al. 2011a).

Host plant resistance to insect pests in maize

Host plant resistance (HPR) is defined as the collective heritable characteristics by which a plant species can reduce the possibility of successful use of the plant as a host by an insect species (Beck 1965). HPR is available to farmers encapsulated in the seed, which ensures that after purchasing the seed, farmers need not invest in any more inputs to control stem borers and post-harvest pests of maize. In this way, stem borer and post-harvest insect resistant maize reduces yield losses and eliminates the expense of insecticides and their associated health risks (Mugo et al. 2001).

Host plant resistance to stem borers and post-harvest insect pests is a genetic trait, which manifests itself as antibiosis, antixenosis, and tolerance (Kumar et al. 2006; Ordás et al. 2002; Tefera et al. 2011b). Antibiosis is where the biology of the pest is adversely affected after feeding on the plant or the seed. Antixenosis or non-preference is where the plant and the seed are not desirable as a host and the stem borer and post-harvest pests seek alternative hosts. Tolerance refers to a situation where the plant is able to withstand or recover from stem borer damage. Resistance may be controlled by different allelochemicals that kill or impair the growth of the pest. For instance, phenolic acids have been studied extensively as biochemical components correlated with resistance to the maize weevil through mechanical resistance (cell wall bound hydroxycinnamic acids) and antibiosis (phenolic acid amides) in the pericarp and aleurone layer (Garcia-Lara et al. 2004). Morphological factors, such as increased leaf fiber, silica, surface wax and high hemicelluloses content have been associated with resistance mechanisms against stem borers (Bergvinson et al. 1995, 1997).

Source population to develop germplasm resistant to maize insect pests

The International Maize and Wheat Improvement Center (CIMMYT) followed conventional pedigree breeding methods to develop maize germplasm resistant to stem borers (Fig. 4). A sub-tropical source population with multiple borer resistance (MBR population) was developed by recombination and recurrent selection under infestation with southwestern corn borer (SWCB), sugarcane borer (SCB, *Diatraea sacharalis*), European corn borer (ECB), *Ostrinia nubilalis* and fall armyworm (FAW, *Spodoptera frugiperda*) (Smith et al. 1989). MBR was developed on the premise that new germplasm with resistance to a single insect pest species is not as useful as one that is resistant to several insect pests in a given area. The resistance must be relatively durable, and the germplasm acceptable for yield potential and other agronomic characteristics in its intended area of use (Datta et al. 2002).

Sources of resistance to SWCB were gathered from Mississippi State University, CIMMYT population 47 and the Islands of Antigua for resistance to SWCB, Cornell University and University of Missouri for resistance to ECB. The genotypes were screened for resistance to SWCB. In general, sources of resistance to ECB were susceptible to SWCB but were included to provide sources of resistance to other insect pests. Initial recombination was undertaken in the absence of deliberate selection for insect resistance. This allowed maximum recombination of genes or blocks of genes without early-generation pressure, which might have fixed sub-optimal combinations of genes (Smith et al. 1989; Mihm 1985).

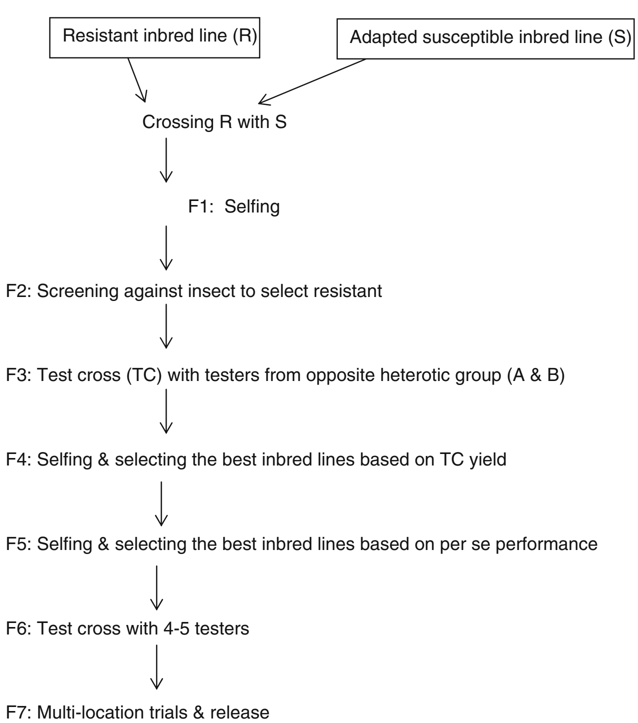

Fig. 4 Summary of conventional pedigree breeding in developing insect resistant maize hybrids/lines at CIMMYT (Source: Authors breeding program)

Bergvinson et al. (1995) evaluated MBR maize genotypes and found that the resistance mechanism was morphological in nature. Leaf tissue of MBR maize genotypes is tougher due to thick epidermal cell walls, which restricts feeding by early instar larvae. MBR maize genotypes also tend to have reduced nutritional value (lower nitrogen content) and elevated levels of fiber and cell wall phenolics, which contribute to increased leaf toughness. Bergvinson et al. (1995) reported that proteins, fiber and diferulic acid content in leaf tissue at the mid-whorl stage in plant development accounted for approximately 80 % of the variation in field leaf damage scores for ECB.

Beyene et al. (2011a) evaluated 45 insect resistant hybrids generated from 10 elite insect resistant lines in diallel crosses and found that GCA effect for grain yield was five times greater than SCA effect suggesting that variation among crosses was mainly due to additive rather than non-additive gene effects, and selection would be effective in improving grain yield. Beyene et al. (2011a, b) also reported non- significant genotype by location interaction for stem borer leaf damage, number of exit holes and tunnel length suggesting that screening maize germplasm at one location would be adequate.

Resistance source to LGB was identified from a few Caribbean germplasm bank accessions (CubaGuard) at CIMMYT that were collected from hot spots for LGB in the Americas, where LGB originated. These materials showed significant levels of LGB resistance, but with poor agronomic characteristics (Kumar 2002). LGB resistant maize lines were developed from a cross between "CubaGuard" and "Kilima". Kilima is a Tanzanian OPV (open pollinated variety) with resistance to LGB (Derera et al. 1999). The "CubaGuard" was derived at CIMMYT in 1993 from a seed regeneration nursery of Caribbean maize land races that had undergone over four cycles of selection and inbreeding under infestation with LGB. Maize inbred lines developed from this effort were crossed with inbred lines from Kenya and Zimbabwe to improve the level of LGB resistance in African germplasm (Tefera et al. 2011b; Mugo et al. 2001).

Maize germplasm resistant to stem borers and postharvest insect pests, adapted to African environments and improved through conventional breeding techniques is available from CIMMYT's breeding programs in Mexico, Zimbabwe, and Kenya. The most important sources of stem borer resistance are populations (F1 through S4), multiple borer resistant MBR (Sub-tropical population 590), multiple insect resistant tropical MIRT (Population 390), second-generation borer (sub-tropical population 591), second-generation borer (tropical population 391), MBR elite and several subtropical insect resistant synthetics. Resistant accessions to postharvest insect pests Cuba 89, 90 and 106 are available at CIMMYT Mexico gene bank (Mugo et al. 2001). Recently (Beyene et al. 2011a) identified elite lines with good general combining ability that may be useful for improving levels of stem borer resistance in maize breeding programs in eastern and southern Africa

Deployment of insect resistance maize varieties in Africa

Developing high yielding insect resistant maize varieties will considerably minimize losses due to stem-borers and post-harvest pests. In an effort to design effective and efficient methods to control maize insect pests, CIMMYT developed and deployed insect resistant, high yielding, and adapted maize hybrids and open-pollinated varieties through conventional breeding. To abate heavy losses caused by stem borers and storage insect pests in Africa, CIMMYT- Global Maize Program (GMP) includes breeding for resistance through the Insect Resistant Maize for Africa (IRMA) Project (Mugo et al. 2008). Insect resistance is polygenic or inherited as a quantitative trait, thus breeding against insect pests is time- and resource-intensive. The recent identification of resistant sources and their incorporation into a limited number of adapted materials could be useful in setting up successful insect resistant breeding programs in eastern and southern Africa that are impact-oriented (Mugo et al. 2008).

Significant breeding efforts have been used to incorporate the complex insect resistance traits into elite maize varieties acceptable to farmers. These efforts have recently resulted in the release of open-pollinated varieties (OPVs) and hybrids in Kenya (Mugo et al. 2001, 2003, 2008). Extensive testing and evaluation of insect resistant hybrids in the region has led to the development of new stem borer resistant (SBR) and storage pest resistant (SPR) inbred lines. This germplasm has been tested in regional trials and the varieties released in Kenya. CIMMYT developed several insect resistant hybrid combinations and tested them in 2010 in regional trials (Kenya, Uganda, Tanzania, Ethiopia, Zimbabwe, Malawi, Zambia and Mozambique; insect resistant hybrids performed better than some of the local checks that were included in the trials (Beyene et al. 2012). The encouraging performance of insect resistant hybrids in regional trials resulted in seed requests for insect resistant parental lines from CIMMYT by local partners in different countries.

Four sets of half diallel crosses were formed from SPR and SBR lines and each consisted of 10 lines. Seeds of 45 F1s along with four commercial checks were planted in four locations in two seasons to determine the general combining ability of the lines and to release some of the best as CML lines. Pooled analyses combining ability in insect resistant lines resulted in the identification of potential parental lines (donor lines) in hybrid breeding programs for insect resistance and for release as CML lines (Beyene et al. 2011a). A total of 15 maize varieties (3 open pollinated and 12 hybrids) developed through conventional breeding with resistance to either stem borer or postharvest insect pests was released in Kenya between 2006 and 2011 (Table 1). In addition, international collaborators in China, Indonesia, Mali, Nigeria, Philippines, Peru, Thailand and Vietnam requested and received experimental stem borer resistant maize germplasm for evaluation and use in their breeding programs in 2006 and 2007. Vietnam identified CIMMYT insect resistant inbred MIRTC4AmF101

Table 1 Insect resistant maize hybrids and open pollinated varieties (OPV) developed by CIMMYT and released from 2006 to 2011 by the Kenya Agricultural Research Institute (KARI)

Name	Type	Trait	Nominating center	Year released	Maturity	Agro-ecology	Yield t ha^{-1}
KATOPV	OPV	Stem borer resistant	KARI Katumani	2006	Early	Katumani	4
KATOPV	OPV	Stem borer resistant	KARI Katumani	2006	Early	Katumani	4
KATEH2006-1	Hybrid	Stem borer resistant	KARI Katumani	2007	Early	Katumani	5
KATEH2006-2	Hybrid	Stem borer resistant	KARI Katumani	2007	Early	Katumani	5
KATEH2006-3	Hybrid	Stem borer resistant	KARI Katumani	2007	Early	Katumani	6
EMB-215	Hybrid	Stem borer resistant	KARI Embu	2007	Medium	Embu	6
KM 0403	OPV	Stem borer resistant	KARI Kakamega	2007	Medium to late	Kakamega	5
KM 0404	Hybrid	Stem borer resistant	KARI Kakamega	2007	Medium to late	Kakamega	6
KM 0406	Hybrid	Stem borer resistant	KARI Kakamega	2007	Medium to late	Kakamega	6
MTPEH 0701	Hybrid	LGB resistant	KARI Mtwapa	2010	Early	Mtwapa (Coastal areas)	5
MTPEH 0702	Hybrid	LGB resistant	KARI Mtwapa	2010	Early	Mtwapa (Coastal areas)	5
MTPEH 0703	Hybrid	Stem borer resistant	KARI Mtwapa	2011	Early	Mtwapa (Coastal areas)	5
KATEH 2007-3	Hybrid	Stem borer resistant	KARI Katumani	2010	Early	Katumani	4
EMB 0701	Hybrid	LGB resistant	KARI Embu	2010	Medium	Embu	6
EMB 0703	Hybrid	Stem borer resistant	KARI Embu	2010	Medium	Embu	5

Table 2 Yield performance of storage pest (SP) and stem borer (SB) resistant maize hybrids in Malawi and Zambia, in 2010 cropping season

Malawi				Zambia			
SP Hybrid	Yield t ha^{-1}	SB Hybrid	Yield t ha^{-1}	SP Hybrid	Yield t ha^{-1}	SB Hybrid	Yield t ha^{-1}
CKPH09001	7.9	CKIR07010	7.2	CKPH09001	8.3	CKIR07010	7.7
CKPH10001	7.9	CKIR07011	6.6	CKPH10001	7.5	CKIR07011	7.4
CKPH09002	9.2	CKIR07012	5.5	CKPH09002	8.5	CKIR07012	9.3
CKPH10002	8.0	CKIR07013	6.9	CKPH10002	7.7	CKIR07013	8.3
CKPH09003	7.3	CKIR07017	6.3	CKPH09003	9.7	CKIR07017	7.6
CKPH08035	7.3	CKIR07018	7.4	CKPH08035	7.3	CKIR07018	7.3
CKPH08036	7.9	CKIR07001	7.3	CKPH08036	8.5	CKIR07001	5.6
CKPH08037	8.0	CKIR07002	6.7	CKPH08037	8.6	CKIR07002	6.7
CKPH08038	8.4	CKIR07003	7.2	CKPH08038	8.5	CKIR07003	6.5
CKPH08039	8.0	CKIR07004	5.7	CKPH08039	7.9	CKIR07004	5.1
CKPH08040	7.5	CKIR07005	5.9	CKPH08040	8.1	CKIR07005	6.8
CKPH08041	7.7	CKIR07008	5.9	CKPH08041	8.4	CKIR07008	7.6
CKPH08043	4.9	CKIR07009	4.9	CKPH08043	8.0	CKIR07009	7.0
CKPH08044	7.4	CKIR09001	6.1	CKPH08044	8.5	CKIR09001	5.8
CKPH08001	7.4	CKIR09002	4.7	CKPH08001	8.9	CKIR09002	4.9
CKPH08002	7.8	CKIR09003	5.3	CKPH08002	8.7	CKIR09003	5.5
CKPH08003	7.4	CKIR09004	5.4	CKPH08003	9.3	CKIR09004	4.5
CKPH08004	7.1	CKIR09005	6.0	CKPH08004	8.5	CKIR09005	5.3
CKPH09004	8.3	CKIR09006	5.4	CKPH09004	7.9	CKIR09006	6.0
CKPH08009	7.2	CKIR09007	4.6	CKPH08009	8.9	CKIR09007	6.3
CKPH08012	6.9	CKIR09008	6.2	CKPH08012	8.1	CKIR09008	5.2
CKPH08013	8.4	CKIR06001	4.6	CKPH08013	9.1	CKIR06001	5.1
CKPH08018	8.7	CKIR06004	6.2	CKPH08018	8.1	CKIR06004	4.8
CKPH08020	8.1	CKIR06006	5.6	CKPH08020	7.6	CKIR06006	5.3
CKPH08024	6.5	CKIR06007	4.5	CKPH08024	8.9	CKIR06007	5.7
CKPH08025	8.0	CKIR06008	4.6	CKPH08025	9.3	CKIR06008	6.1
CKPH08028	7.7	CKIR06009	5.0	CKPH08028	8.5	CKIR06009	5.6
WH505*	6.0	WH505	5.9	WH505	9.0	WH505	7.4
Mean	7.5		5.9		8.5		6.4
LSD	10.4		10.8		5.5		
P-value	<0.01		<0.01		<0.01		<0.01

*Commercial check

as a good combiner with a Vietnamese commercial inbred (Vietnam Country Report, RETA No. 6208, 2007) (Mugo et al. 2001).

The new maize hybrids were tested in Malawi and Zambia for yield performance and general adaptation compared to commercial checks. Hybrids CKPH 09002 (yield = 9.2 t ha^{-1}) in Malawi and CKPH08003 (yield = 9.7 t ha^{-1}) in Zambia showed superiority in grain yield compared to the commercial standard check (Table 2). In another trial, the resistant hybrids showed an increased level of resistance to maize weevils and LGB. For instance, resistant hybrids reduced weight losses by 36.4 % against the LGB and by 43.9 % against the maize weevil over the commercial check (Fig. 3).

Conclusion

The use of insect resistant maize is an effective control method against insect pests. Resistant maize hybrids provide an inherent control that involves no environmental problems, and they are generally compatible with other insect-control methods. Therefore, resistant varieties can be used as a vital component in an integrated pest management strategy against pre-and post-harvest insect pests of maize. However, testing and the deployment of insect resistant hybrids requires strong partnerships among national agricultural research systems and seed companies. The wider adoption and cultivation of insect resistant maize varieties will have an impact on maize production and household food security in Africa. In Africa, maize is predominantly grown by subsistence farmers under diverse and genetically non-uniform farming practices, which are believed to play a role in delaying the evolution of resistance to stem borers. In Africa, the target lepidopteran stem borers attack a wide range of wild grass species as well as cultivated cereal crops. Wild grasses generally occur in the vicinity of maize and other cereal fields, and may provide a refuge if insect resistant maize is introduced into the farming systems. This could lead to the evolution of biotypes of insect pests able to overcome the resistance bred into the new varieties. Access to these improved varieties is possible through Kenya national maize research programs; however, seed production and marketing of the improved varieties are largely made through local seed companies in Kenya. There are several factors affecting production, adoption and marketing of improved crop varieties in Africa including lack of appropriate seed policy, support for emerging seed companies and unavailability of sufficient quantities of foundation seed for certified seed production. The current varieties are white in color which is a grain color most preferred by farmers in most parts of Kenya and elsewhere in Africa.

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Tadele Tefera studied for his PhD in Agricultural Entomology at Stellenbosch University and worked as a maize entomologist for the International Maize and Wheat Improvement Center (CIMMYT) based in Nairobi, Kenya; his research focused on developing effective postharvest technology against postharvest insect pests of maize and developing resistant maize varieties against stem borers, the maize weevil and larger grain borer. He led the project, Effective Grain Storage for Sustainable Livelihoods of African Farmers; he has published over 50 papers in refereed journals, one book, and two training manuals and has a patent right. Before joining CIMMYT, he was associate professor at Haramaya University, Ethiopia and was Alexander von Humboldt Foundation Research Fellow at the Georg-August University Gottingen. Currently, he is Country Head, International Center of Insect Physiology and Ecology (*icipe*), Ethiopia; he leads Maize, Rice and Chickpea Integrated Pest Management in East Africa.

Stephen Mugo studied for his PhD in Plant Breeding and Genetics at Cornell University, MSc in Plant Breeding and Genetics at the University of Missouri, and BSc at the University of Nairobi. He is currently a Principal Scientist and Maize Breeder at the International Maize and Wheat Improvement Center (CIMMYT) based in Nairobi, Kenya. His research focuses on developing drought tolerant maize, and developing resistant maize varieties against pre-and postharvest insect pests including stem borers, the maize weevil and larger grain borer. He leads two projects; Water Efficient Maize for Africa (WEMA) and Insect Resistant Maize for Africa (IRMA); he has published over 50 papers in refereed journals and two training manuals. Before joining CIMMYT, he was a maize breeder at Kenya Agricultural Research Institute (KARI).

Yoseph Beyene holds a PhD in Plant Genetics and Breeding from the University of Pretoria and currently is a senior Maize breeder at the International Maize and Wheat Improvement Center (CIMMYT) based in Nairobi, Kenya. His research interests are developing high-yielding and climate resilient maize inbred lines and hybrids for sub-Saharan Africa (SSA) using conventional and molecular breeding including integration of novel tools/techniques such as doubled haploid (DH) and marker assisted recurrent selection and genomic selection. He has developed and released more than 30 maize hybrids for commercial production in Kenya, Uganda, Tanzania and South Africa. Currently he is a Co-chair of the Water Efficient Maize for Africa (WEMA) project product development team and responsible for coordination of the WEMA breeding (conventional, molecular and transgenic) among the various WEMA partners. He has published over 35 papers in referred journals