

Comparative incidence of maize stem borers on GM and non-GM maize under two smallholder cropping systems in the Eastern Cape province of South Africa

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Abstract

The assessment of the comparative performance of existing technologies especially those identified as alternatives under smallholder farmers' conditions can enhance the sustainable dissemination and adoption of improved agricultural technologies. To this end, the performance of a genetically modified (GM) stacked-trait herbicide and insect resistant *Bacillus thuringiensis* (Bt) maize hybrid was compared to a GM herbicide tolerant hybrid, a non-GM hybrid and an open pollinated variety (OPV). The trials were conducted in three localities under natural stem borer infestation in irrigated and non-irrigated (dryland) No stem borer infestation was observed on Bt maize plants from the seedling to the flowering stages in all fields at all trial sites. Stem borer infestation was higher under irrigation compared to dryland conditions. The stem borer complex on non-Bt maize plants under irrigation was dominated by *Chilo partellus* whilst only *Busseola fusca* larvae were recorded under dryland conditions. The yield of the Bt maize variety under irrigation was significantly higher than that of the OPV but not different ($P>0.05$) from that of the non-Bt hybrids. No significant ($P>0.05$) difference in yield was between Bt and non-Bt maize varieties under dryland conditions. The results highlight the need to base dissemination and adoption decisions of relatively expensive agricultural technologies such as GM maize on the results of context specific field trials.

Keywords: GM maize open pollinated maize, smallholder, stem borer

Introduction

Maize is one of the most important crops in sub-Saharan Africa. Historically, yields of the crop in Africa have been low compared to other maize producing regions. Attempts at increasing yields to meet the food demands of an increasing population have been constrained by abiotic and biotic stresses (Tandzi and Mutengwa, 2020). Notable amongst these is infestation by stem borer pests such as the African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and the spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) (Kfir et al., 2002; Van den Berg et al., 2015). Depending on agro-ecological zone, pest population density, plant growth stage at infestation and cultivar type, infestation by stem borers can result in yield losses of 88% (Kfir et al., 2002). *Chilo partellus* and *B. fusca* are the main pests of maize in South Africa occurring either singly or in mixed populations (Van den Berg et al., 1991a; Ntiri et al., 2016). Generally, smallholder farmers are aware of the negative impact of *C. partellus* and *B. fusca* infestation on their maize crop and yield (De Groote et al., 2003). Owing to the lack of resources (Smith, 1997), very few smallholder farmers apply insecticides onto their maize crop. Furthermore, the efficacy of insecticides may be limited by the lack of proper timing of application and difficulty to reach the target pests inside the maize whorl (Eizaguirre et al., 2002; Slabbert and Van den Berg, 2017). In view of these challenges, the availability of genetically modified (GM) insect resistant maize varieties in South Africa was seen as a potentially important development that could provide smallholder farmers with practical and economical ways to minimize maize yield losses due to stem borer pests (Hellmich et al., 2008; Brookes and Barfoot, 2014). In South Africa, Bt maize provides effective control of *C.*

partellus and *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) but partial to very good control of *B. fusca* (Van den Berg and Van Wyk, 2007; Kotey et al., 2017; Strydom et al., 2019).

Despite repeated efforts by both Government and non-governmental organizations to get smallholder farmers in South Africa to use Bt maize, the adoption of the technology by smallholders has been minimal. This is due to the use of top-down technology dissemination approaches, lack of adequate extension and advisory support, relatively high input costs and non-compatibility of Bt maize technology stewardship requirements with smallholder maize production practices (Jacobson and Myrh, 2012; Fischer et al., 2015; Kotey et al., 2016).

In contrast to large monoculture maize production, smallholder maize production is undertaken under varying agro-ecologies and conditions (Arias et al., 2013; Van den Berg and Campagne, 2014). In South Africa, smallholder maize production takes place under dryland conditions (Hamann and Tuinder, 2012) in outfields (farm lands situated outside villages or residential sites ranging in size from 1 to 5 hectares), home gardens (small plots of land between 0.1 and 0.5 hectares that are adjacent to residential dwellings) (Bryndum et al., 2007) or in open rangelands using simple outdated technologies (Pienaar, 2013) including recycled seeds of open pollinated varieties of maize (Gouse et al., 2005; Fischer and Hadju, 2014). In most instances, the main maize crop is intercropped with pulses, pumpkins, groundnuts, onions, carrots and sweet potatoes to mitigate the risk of crop failure (Bryndum et al., 2007; Jacobson & Myhr, 2012). Ploughing and planting operations in home gardens are generally undertaken using draught animals (Manona, 2005). The use of inputs such as fertilizer and mechanized equipment only occurs when outfields are cultivated as part of subsidized governmental and non-governmental initiatives (Kotey et al., 2017). Due to the diversity of production conditions and methods, the output and benefits of agricultural technologies used by smallholders may vary across locations and seasons (Heatherly et al., 2002; Kambhampati et al., 2006; Gouse et al., 2005; 2006). Thus, the evaluation of the performance of new maize varieties like Bt maize relative to varieties commonly cultivated by smallholders under local farming conditions and pest infestation levels may provide information that can be used in prioritizing and disseminating the most cost-effective technologies for improvement of smallholder maize production and livelihoods (De Groote, 2002; De Grassi, 2003). This study was conducted to assess the comparative incidence and damage of stem borers on Bt and non-Bt maize in smallholder farms under dryland and irrigation conditions in the Eastern Cape province of South Africa.

Materials and methods

Selection of trial locations

Two dryland maize production areas with high pest pressure were identified by means of field surveys in 13 different localities (10 fields per locality) in the Eastern Cape province of South Africa during the 2014/2015 cropping season. The selected locations were Bhala (S30.94832° E29.54863°) (mean incidence of stem borer infested plants per field = 35.3%) and Nxanxadi (S31.13137° E29.63938°) (mean incidence of infested plants = 36.2%). Another locality, the Zanyokwe irrigation scheme (S32.75783° E27.05600°), was included as a stem borer hot-spot based on farmers' reports of high incidence of these pests.

Maize varieties

Four maize varieties were evaluated in this study. These were: PAN 5R-993BR (a 'stacked' trait hybrid with Bt insect resistance and herbicide tolerance), PAN 5Q-649R (a herbicide tolerant hybrid with similar maturity to that of the stacked-trait hybrid), PAN12 (non-GM hybrid) and Okavango an Open Pollinated Variety (OPV).

Description of trial locations and experimental design

The study under irrigation conditions was conducted at the Zanyokwe irrigation Scheme in Keiskammahoek, in the Amathole District Municipality of the Eastern Cape Province. The irrigation scheme has a total irrigated land area of about 439 ha with approximately 61 farmers, each with an average land holding of 4.2 ha (Fanadzo et al., 2010). The area receives a mean annual rainfall of 580 mm which is supplemented with sprinkler irrigation. The soils in the area are characterized by Arcadia (Vertisol) and Shortlands soil forms (Chromic Luvisol) (Soil Classification Working Group, 1991). Bt maize was first cultivated at the Scheme as part of the Massive Food Production Program (MFPP) managed by the Eastern Cape Department of Agriculture (ECDA). At the time of the study,

farmers at the scheme cultivated Bt maize as part of the Cropping Program of the Department of Rural Development and Agrarian Reform (DRDAR). Under the Cropping Program, government subsidized inputs and services are supplied to farmers at the irrigation scheme.

The dryland trials were conducted at Nxanxadi and Bhala. These two areas fall under the Flagstaff service centre of DRDAR in the Ingquza Hill Local Municipality of the OR Tambo District Municipality. Flagstaff normally receives about 749 mm of rainfall per year. Most of the rainfall occurs between September and May. The underlying geology of the area is composed of hard quartzite rock of the Natal group sandstones which gives rise to sandy, highly leached and relatively shallow soils which are not suitable for intensive agriculture (Nicolson, 1993).

Each of the selected farms used for the experiment had previously been cultivated to maize. The experimental design was randomized complete block replicated three times at each location. Each replicate consisted of four 50 x 10 m plots. Planting was done in late October, 2015. All fields in one area were planted on the same day using a tractor drawn planter. Inter- and intra-row distances of 0.75 m and 0.33 m was used to achieve a plant population of 40,000 seeds per hectare as is the normal practice in the area. Plots of each replicate consisted of 12 rows of 120-130 plants. The four inner rows were used for data collection while the four outer rows on both ends of the inner rows were maintained as guard rows. The plant stand per row was determined at the six-leaf stage. Two rows of PAN 5Q-649R were planted around the perimeter of each field to prevent intrusion and tampering with the trials. All maize production practices recommended as part of the Cropping Program were observed. The action threshold for chemical control of stem borers in maize is when 10% of plants (mixed infestations of *B. fusca* and *C. partellus*) in a field show visible symptoms of whorl damage (Van den Berg et al., 2015). Under the Cropping Program however, farmers apply insecticides preventatively when maize plants are between four and seven weeks old. Weed control is also undertaken at the same crop growth stage.

The incidence of stem borer infested plants was determined at the seedling (emergence to V3 stage), vegetative (6 weeks after emergence (WAE)), flowering and post-flowering growth stages. During each assessment, a total of 100 maize plants in the four middle rows of each plot were inspected for symptoms of borer damage to whorl leaves, entry and exit holes in the stems and ears of plants. The number of plants with symptoms of borer damage in each plot was expressed as a percentage of the total number of plants per plot. During each damage assessment, 10 infested plants from the outer rows in each plot were dissected to identify the stem borer species present in fields. The number of ears per plant was determined at harvest. Thirty maize plants from the two middle rows of each plot (variety) at each location were randomly selected and tagged 20-24 WAE. The area from which ears were harvested in each plot was approximately 10 m². The number of ears per tagged plant was determined after which ears were harvested. Each harvested ear was assessed for the presence of stem borer damage after which the extent of damage (tunnel length) on each ear was recorded. The number of damaged internodes per plant was determined by dissecting the stems of all the 30 randomly selected plants from which ears were harvested. The harvested ears from each plot were individually weighed using a Sartorius balance (maximum weight=5000 g) and recorded. The weighed ears were threshed and used to calculate yield per plot, which was then expressed in tons/ha. Grain moisture content at harvest was determined with an intelligent grain moisture meter and used to calculate and compare the grain moisture-standardized yield of the maize varieties as follows (Badu-Apraku *et al.*, 2012):

$$Yield \text{ (at 12.5\% m. c)} = Grain \text{ yield } \left(\frac{\text{tons}}{\text{ha}} \right) \times \frac{(100 - \text{actual grain moisture \%})}{87.5}$$

Data analyses

Data on pre- and post-flowering stem borer incidence and grain yield for each trial site were analyzed separately by way of univariate analysis of variance (ANOVA), using SPSS (version 24) statistics software (IBM Corporation, USA). Multiple comparisons to identify differences among significant treatment means was done using Tukey's HSD test. Correlation analysis was performed separately using Microsoft Excel (Microsoft Office, version 10).

Results

Stem borer infestation levels

Only *B. fusca* larvae were recovered from non-Bt maize plants under dryland conditions. With respect to maize plants under irrigation conditions, *C. partellus* constituted 74.9%, 75.0% and 95.4% of the larvae recovered from maize plants at the vegetative, flowering and post flowering growth stages respectively. No stem borer damage was observed on any of the Bt maize plants from the seedling to the flowering stages in all fields at all trial sites (Table 1). On non-Bt maize plants, damage symptoms were first observed three weeks after emergence (WAE) and the incidence increased steadily up to the post-flowering stage. The incidence of damaged plants was higher under irrigation (Zanyokwe) than under dryland conditions (Nxanxadi and Bhala) (Table 1). Generally, the incidence of damaged plants at all plant growth stages was higher on the OPV than on the two non-Bt hybrids, PAN 5Q-649R and PAN 12.

The incidences of stem borer damaged plants at the seedling stage did not differ significantly between Bt and non-Bt maize plots at any of the locations ($P > 0.05$). Differences in the incidence of damaged plants between the non-Bt maize varieties were not significant at the vegetative and flowering stages under irrigation conditions. During the post-flowering stage however, significantly ($P < 0.001$) fewer plants of PAN 5Q-649R (47.4%) were infested as compared to OPV plants (83.0%).

At Nxanxadi, the incidence of damaged non-Bt maize plants ranged from 0.2% (PAN 5Q-649R) at the seedling stage to 29.3% (OPV) at the post-flowering stage. The incidence of damaged plants of PAN 12 (15.1%) at the flowering stage was significantly ($P=0.000$) lower than the incidence of damaged plants of the OPV (18.8%; Table 1). At Bhala, the incidence of damaged plants ranged between 1.0% (PAN 5Q-649R) and 32.2% (OPV) at the seedling and post flowering stages respectively (Table 1).

Table-1. Comparative incidence of stem borer damaged plants on Bt and non-Bt maize fields under irrigation and dryland conditions in the Eastern Cape, South Africa

Variety and site	Mean incidence of borer damage plants (%)			
	Seedling	Vegetative	Flowering	Post-flowering
Zanyokwe irrigation scheme				
OPV	1.0	31.1a*	39.1a*	83.0a*
PAN 12	0.8	29.0 ^a	36.1 ^a	67.8 ^{ab}
PAN 5Q-649R	0.0	23.0 ^a	29.4 ^a	47.4 ^b
PAN 5R-993BR	0.0	0.0 ^b	0.0 ^b	0.0 ^c
<i>F</i> -value	1.80	30.70	36.33	64.18
<i>P</i> -value	0.168	0.000	0.000	0.000
Nxanxadi				
OPV	0.7	14.2a*	18.8a*	29.3a*
PAN 12	1.1	13.2 ^a	15.1 ^b	27.3 ^a
PAN 5Q-649R	0.2	13.0 ^a	15.8 ^{ab}	26.3 ^a
PAN 5R-993BR	0.0	0.0 ^b	0.0 ^c	0.0 ^b
<i>F</i> -value	4.84	138.44	94.75	161.51
<i>P</i> -value	0.007	0.000	0.000	0.000
Bhala				
OPV	1.7	15.0a*	18.4a*	32.8a*
PAN 12	1.4	14.2 ^a	17.4 ^a	30.4 ^a
PAN 5Q-649R	1.0	14.7 ^a	17.3 ^a	30.2 ^a
PAN 5R-993BR	0.0	0.0 ^b	0.0 ^b	0.0 ^b
<i>F</i> -value	2.06	168.63	145.31	192.26
<i>P</i> -value	0.13	0.000	0.000	0.000

*Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

Under irrigation, the mean number of damaged internodes per plant of PAN 5Q-649R (0.6 per stem) was not significantly ($P > 0.05$) different from that of the Bt maize variety (0.0 per stem). A significantly ($P < 0.001$) higher number of internodes were damaged in stems of PAN 12 (3.4) than the other varieties under irrigation (Table 2). At both dryland trial sites, there were no significant differences between the mean number of damaged internodes per plant of PAN 5Q-649R and the Bt maize variety. At Bhala, the mean number of damaged internodes per plant of PAN 12 (0.1) was not significantly different from that of Bt maize plants (0.0%) (Table 2).

Under irrigation conditions, the mean length of tunnels bored by stem borer larvae in stems of PAN 5Q-649R (0.6 cm) were significantly shorter than those in stems of the OPV (21.5 cm) and PAN 12 (33.2 cm). Mean tunnel lengths per stem at both Nxanxadi and Bhala did not differ significantly (Table 2).

Table-2. Comparative damage caused by stem borer larvae to Bt and non-Bt maize plants at different locations.

Variety	Location of trial		
	Zanyokwe	Nxanxadi	Bhala
Mean number of internodes damaged			
OPV	1.0 ^{b*}	0.5 ^{a*}	0.2 ^{a*}
PAN 12	3.4 ^a	0.6 ^a	0.1 ^{ab}
PAN 5Q-649R	0.6 ^{bc}	0.1 ^b	0.1 ^{ab}
PAN 5R-993BR	0.0 ^c	0.0 ^b	0.0 ^b
<i>F</i> -value	51.72	9.64	2.93
<i>P</i> -value	<0.001	<0.001	0.034
Mean length of stem tunnel (cm)			
OPV	21.5 ^{a*}	17.3	10.8
PAN 12	33.2 ^a	12.5	14.7
PAN 5Q-649R	13.6 ^b	16.2	12.3
<i>F</i> -value	5.52	0.60	0.49
<i>P</i> -value	<0.005	>0.05	>0.05

*Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

The mean number of ears harvested from PAN 5R-993BR under irrigation was 1.7 per plant, which was significantly ($P < 0.001$) higher than that of any of the non-Bt maize varieties cultivated under irrigation conditions. There were no significant ($P > 0.05$) differences between the mean number of ears per plant among any of the varieties cultivated under dryland conditions at both Nxanxadi and Bhala. The mean number of ears per plant (1.1) was significantly ($P < 0.001$) lower for PAN 12 than the other varieties at Nxanxadi.

No stem borer damage was observed on ears harvested from Bt maize plants under irrigation. The incidence of stem borer damaged ears on non-Bt hybrids and the OPV under irrigation conditions ranged from 16.7 (PAN 5Q-649R) to 30.0% (PAN 12) (Table 3). No significant differences ($P > 0.05$) were observed between the percentage damaged ears of Bt maize and non-Bt maize under dryland conditions. At Nxanxadi, none of the harvested ears of PAN 5Q-649R and PAN 5R-993BR showed borer damage and only 6.7% (OPV) and 10% (PAN 12) of harvested ears were infested at this location. At Bhala, 7.8% of Bt maize ears showed signs of borer damage. The highest percentage of damaged ears at this location (21.1%) was observed in the OPV plots (Table 3).

Table-3. Incidence of damaged ears per plant and degree of damage caused by stem borer larvae to maize ears at harvest

Variety	Location of trial		
	Zanyokwe	Nxanxadi	Bhala

Mean percentage of ears exhibiting borer damage			
OPV	20.0	6.7	21.1
PAN 12	30.0	10.0	12.2
PAN 5Q-649R	16.7	-	11.1
PAN 5R-993BR	-	-	7.8
<i>F</i> -value	1.89	1.93	1.38
<i>P</i> -value	>0.05	>0.05	>0.05
Mean length of tunnel on ear (cm)			
OPV	5.3 ^{ab*}	4.3	3.6
PAN 12	6.2 ^a	6.0	4.8
PAN 5Q-649R	3.7 ^b	-	4.7
PAN 5R-993BR	-	-	4.2
<i>F</i> -value	3.64	2.82	1.36
<i>P</i> -value	0.033	>0.05	>0.05

*Means within the same column followed by different letter(s) are significantly different at the 0.05 level.

Damage to ears was characterized by tunnels and in most cases fungal infection was observed. The mean tunnel length ranged between 0.0 and 6.2 cm per ear with the lowest recorded for PAN 5Q-649R under irrigation. Differences in mean tunnel lengths on ears between varieties in both dryland trials were not significant ($P > 0.05$). Mean tunnel lengths in ears were 19.6% (PAN 5Q-649R), 30.5% (OPV) and 31.0% (PAN 12) of the mean total lengths of ears of these varieties under irrigation. With respect to dryland conditions, it was 26.2% (OPV), 29.2% (PAN 5R-993BR), 31.6% (PAN 12) and 32.8% (PAN 5Q-649R) of the mean total length of harvested ears at Bhala (Table 3).

Effect of stem borer infestation on maize grain yield

There was a significant ($P < 0.05$) negative correlation ($r = -0.99$) between stem tunnel length and grain yield obtained for PAN 12 plants cultivated under irrigation. For all other varieties, neither the number of damaged internodes per plant nor stem tunnel length correlated significantly ($P > 0.05$) with grain yield at any of the locations.

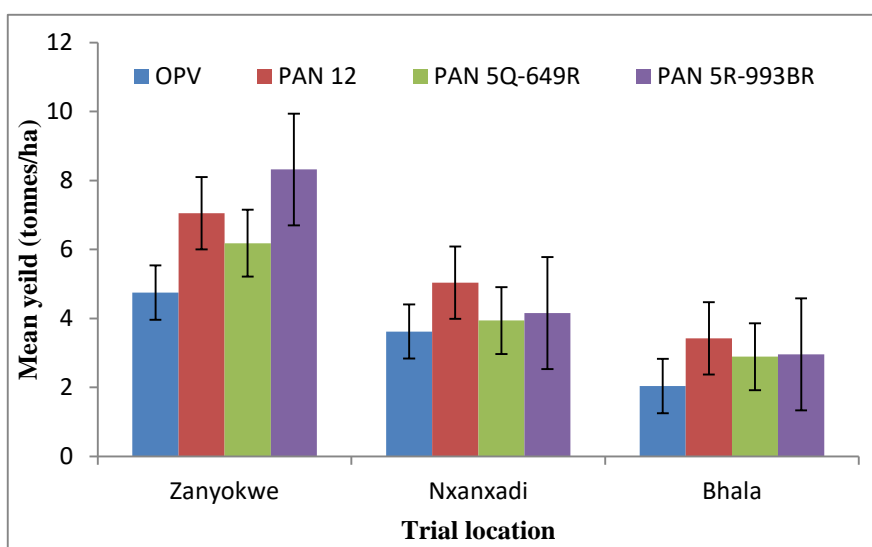


Figure-1. Yield of four maize varieties cultivated under irrigation and dryland conditions

The yield obtained under irrigation ranged from 8.32 tons/ha (PAN 5R-993BR) to 4.75 ton/ha (OPV). Whilst the yield obtained from the insect-resistant PAN 5R-993BR was significantly ($P < 0.05$) higher than that obtained from the OPV, it was not different from that obtained from PAN 12 or PAN 5Q-649R (Figure 1). Differences in yield obtained under dryland conditions at both Nxanxadi and Bhala did not differ significantly ($P > 0.05$). Yield obtained at Nxanxadi ranged from 3.62 ton/ha (OPV) to 5.04 ton/ha (PAN 12) while at Bhala it ranged from 2.04 ton/ha (OPV) to 3.42 ton/ha (PAN 12) (Figure 1).

Discussion

Results of the current study show that stem borer infestation was higher under irrigation compared to dryland conditions. The stem borer complex on non-Bt maize plants under irrigation was dominated by *Chilo partellus* whilst only *Busseola fusca* larvae were recorded under dryland conditions. No stem borer infestation was observed on Bt maize plants from the seedling to the flowering stages in all fields at all trial sites. Comparatively, more maize plants under irrigation showed symptoms of stem borer damage than maize plants cultivated under dryland conditions. More OPV plants were infested than plants of the other two non-Bt varieties, PAN 12 and PAN 5Q-649R, at all plant growth stages and at all locations. The comparatively high incidence of stem borer damaged plants under irrigation conditions concurs with Van Rensburg (2007) who reported that stem borer moths have a preference for high humidity conditions such as those prevailing in irrigated fields. Therefore, more serious infestations may occur under conditions of high precipitation (Van Rensburg et al., 1987a). In a previous study at the Zanyokwe irrigation scheme, Fanadzo et al. (2009) reported that plants of Okavango (the OPV) suffered increased borer attack after the late vegetative stage of crop development. Compared to the other varieties used in this study, the OPV has a relatively longer maturity period. It has been reported that maize cultivars with long growing seasons are more susceptible to stem borer damage than cultivars with short growing season (Van Rensburg et al., 1988a). This may therefore explain the relatively high incidence of stem borer damage on the OPV in this study.

No stem borer infestation was observed on Bt-maize plants at any location prior to the grain filling stage. The only damage to Bt maize plants occurred at Bhala where 7.8% of ears showed signs of borer damage. This may be ascribed to the ability of *B. fusca* larvae to survive on less toxic tissues of Bt maize plants during the post-flowering stages of maize development (Van Rensburg, 2001). Visual estimation of the incidence of borer infested plants indicated that more than 10% of non-Bt maize plants at all locations were infested during the vegetative and post flowering stages. The majority of farmers indicated that they made once-off applications of insecticides during the mid-vegetative growth stage. The rationale for this was that the Cropping Program budget mostly accounts for only one mechanized application (herbicide and insecticide) using a tractor-mounted boom sprayer. Insecticide application was therefore undertaken at this time when it was also expected that weeds would have been sufficiently established and of optimum size to warrant chemical control. Following insecticide application at all trial sites, there was a marked reduction in the incidence of newly infested maize plants at the flowering stage at all locations.

The incidence of stem borer damaged plants increased over time in spite of the application of insecticides at the mid-vegetative stages. It has been reported that the onset of tasseling causes larval migration from the disappearing whorls of plants to the tassel and ears as well as to neighboring plants where secondary stem borer attack occurs over a relatively short period of time (Van Rensburg et al., 1988b; Erasmus et al., 2016; Visser et al., 2020). The increased incidence of damaged plants over time observed in this study, suggests that migrating larvae were able to infest neighboring plants due to the short residual period of the insecticides applied (Van Rensburg and Van den Berg, 1992a) and the fact that applications often did not reach areas (Slabbert and Van den Berg, 2009) harboring stem borer larvae. Due to the migratory behavior of stem borer larvae, late or delayed insecticide application, particularly after the tasseling of maize plants has been suggested to provide some control of large larvae originating from infestations during the vegetative stages (Van den Berg, 1991; Van Rensburg and Van den Berg, 1992b). The Cropping Program's strategy of making once-off applications of insecticides at the early vegetative stage may therefore have to be revised or replaced by a threshold-based stem borer management approach. In South Africa, the accepted threshold for the initiation of chemical control actions against *C. partellus* is when 40% of plants exhibit whorl

damage symptoms (Bate and Van Rensburg, 1992). With regard to mixed infestations of *C. partellus* and *B. fusca*, the accepted threshold is when 10% of maize plants exhibit whorl damage (Van Rensburg and Bate, 1987).

In this study, with the exception of stem tunnel length which showed significant negative correlation with grain yield in plants of PAN 12, there were no significant correlations between other stem borer damage parameters and grain yield in any of the other varieties. Studies conducted by Ebenebe et al. (2000) reported that yield losses in local OPVs and commercial hybrids in Lesotho were generally not proportionate to the incidence of stem borer damaged plants. Van den Berg and Van Rensburg (1991) however reported that similar stem borer infestation levels in maize plantings with different yield potential results in significantly different yield losses with high-yielding varieties and plantings suffering a proportionately higher yield loss. The stem borer complex under irrigation was largely dominated by *C. partellus*. It has been reported to be less injurious to maize plants than *B. fusca* (Van den Berg et al., 1991a; 1991b). These factors may therefore explain the significant negative correlation between the degree of stem tunneling and grain yield of PAN 12 plants under irrigation conditions.

Conclusion

This study showed that Bt maize provides effective control of stem borers and increased yield under high input conditions. These advantages were however not achieved under conditions prevailing in smallholder systems in the Eastern Cape province of South Africa. Due to the technology fees associated with the use of GM maize seed and co-technologies, farmers may be burdened with upfront costs and debt, particularly in seasons with low pest and weed pressure and low amounts of rainfall. In view of these, evidence-based policy making, based on the evaluation of the value of available maize varieties and their profitability under pest and weed management systems and agronomic conditions prevailing in smallholder systems, should be a priority.

DISCLAIMER: The mention of any product in this manuscript does not constitute an endorsement.

CONFLICT OF INTEREST: None

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