

Full Length Research Paper

Resistance of maize varieties to the maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae)

Fikremariam Abebe¹, Tadele Tefera^{2*}, Stephen Mugo², Yoseph Beyene² and Stefan Vidal³

¹Ministry of Agriculture and Rural Development, Plant Regulatory Department, Addis Ababa, Ethiopia.

²International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya.

³Georg-August-Universität Göttingen, Department of Crop Science, Agricultural Entomology Section, Grisebachstraße 6, D-37077 Göttingen, Germany.

Accepted 7 September, 2009

This study aimed at evaluating commonly used maize varieties, collected from Melkasa and Bako Agricultural Research Centers and Haramaya University, Ethiopia, against the maize weevil *Sitophilus zeamais* Motsch., one of the most important cosmopolitan stored product pests in maize. A total of 13 improved maize varieties were screened for their relative susceptibility to *S. zeamais*. The Dobie index of susceptibility was used to group the varieties. The variety, 'BHQP-542', had the least index of susceptibility and was regarded as resistant. The varieties, 'Katumani', 'Melkasa-I', 'Melkasa-II', 'Melkasa-III', 'Coree', 'BH-541', 'BH-660', 'BH-540', 'Rare-I', 'Awasa-511', 'ACV3' and 'ACV6', were moderately resistant. Weevils fed with the resistant variety produced low numbers of F1 progeny, had a high median developmental time and a low percentage of seed damage and seed weight loss. Maize varieties with a high F1 progeny tended to have a short median developmental time. An increasing number of F1 progeny resulted in an increasing seed damage and seed weight loss. We found an inverse relationship between the susceptibility index and percent mortality and median developmental time; however, the numbers of F1 progeny, percent seed damage and seed weight loss were positively related with the susceptibility index. The use of resistant varieties should be promoted in managing *S. zeamais* in stored maize under subsistence farming conditions in Africa.

Key words: Grain damage, maize; resistant variety, *Sitophilus zeamais*, susceptibility index.

INTRODUCTION

Post-harvest losses to storage insect pests such as the maize weevil *Sitophilus zeamais* have been recognized as an increasingly important problem in Africa (Markham et al., 1994). Cheap and effective methods for reducing *S. zeamais* damage are needed in these countries (Danho et al., 2002). Infestation by this weevil commences in the field (Demissie et al., 2008; Caswell, 1962), but most damage is done during storage. Damaged grains have reduced nutritional values, low percent germination and reduced weight and market values, respectively. Worldwide seed losses ranging from 20 to 90% have been reported for untreated maize due to the maize

weevil *S. zeamais* (Giga et al., 1991; Delima, 1987).

Synthetic chemical insecticides have been widely used for the control of pests of stored grain, particularly *S. zeamais*. The widespread use of insecticides for the control of stored-product insect pests is of global concern with respect to environmental hazards, insecticide resistance development, chemical residues in food, side effects on non-target organisms and the associated high costs (Cherry et al., 2005). To this effect, the increased public awareness and concern for environmental safety has directed research to the development of alternative control strategies such as the use of resistant maize varieties against *S. zeamais*. The resistant varieties provide practical and economical ways to minimize losses to insect pests. The main objective of this study was, therefore, to evaluate popular maize varieties from Ethiopia for

*Corresponding author. Email: t.tefera@cgiar.org.

their resistance to *S. zeamais* based on a susceptibility index.

MATERIALS AND METHODS

Culture of *S. zeamais*

A culture of *S. zeamais* was established to supply similar aged weevils for the experiments. About 25 kg seed of the maize variety BH-660 was procured and cleaned to remove seeds with visible damage symptoms. The cleaned seeds were stored in a refrigerator at -4°C for one month to eliminate potential field infestation. Seeds were then transferred to plastic bags and kept at rearing room conditions for three weeks. Unsexed *S. zeamais* were collected from infested maize seeds and cultured on clean and disinfested maize seeds (BH-660) in 7 jars, each jar with 1.5 l capacity, containing 100 weevils per 500 g of seeds. The jars were covered with muslin cloth and fixed with rubber band to allow aeration and to prevent escape of weevils and were kept at room temperature (21 - 23°C). Seven days after oviposition, all parent weevils were removed from each jar and were placed on another set of seeds kept at the same conditions. Removal of parent weevils and placement on a fresh seed medium repeated until sufficient numbers of laboratory-reared weevils of known age were available.

Maize varieties

A total of thirteen maize varieties, including four hybrids (BH-660, BH-540, BH-541 and BHQP-542), eight open pollinated (Rare-I, Melkasa-I, Melkasa-II, Melkasa-III, Awasa-511, ACV3, ACV6 and Katumani) and a local variety (Coree) were used. They were collected from Melkasa and Bako Agricultural Research Centers and Haramaya University, Ethiopia. The varieties are currently under production in different parts of Ethiopia. Freshly harvested seeds of each variety were procured, cleaned and disinfested by keeping them in a deep freezer at $-20 \pm 2^\circ\text{C}$ for two weeks prior to starting the experiments. The seeds were then kept for two weeks at the experimental conditions for acclimatization. The moisture content of the seeds was 12 - 13%.

Screening the maize varieties

About 100 g seeds, from each of the maize varieties were placed in a 250 cm³ glass jar with brass screen lids allowing ventilation and preventing escape of the weevils. The no choice test method, in which the weevils were introduced to each sample of seeds, was as follows: Thirty newly emerged unsexed adult weevils were introduced to the jars to infest the 100 g seeds of each variety and were kept for seven days for oviposition (Derera et al., 2001). Seeds of each variety without *S. zeamais* were kept under similar conditions and served as a control. The treatments were arranged in a completely randomized block design with three replications, conducted in a laboratory at 24 - 25°C, 65 - 70% RH and 12:12 (light: dark) photoperiod.

Adult mortality

Mortality was assessed 7 days after introduction of weevils. All insects were removed and dead and alive insects were counted.

F₁ progeny

After removing dead and alive weevils as described above, the

seeds were kept under the same experimental conditions to assess the emergence of F₁ progeny; therefore seeds were inspected daily. Emerging progeny was removed and counted per jar on each assessment day. These observations continued for 56 days until all F₁ progeny was expected to have emerged (Nwana and Akibi-Betts, 1982).

Seed damage and weight loss

Sixty-three days after introduction of the weevils, 100 seeds were randomly taken from each jar. The number of seeds damaged (holed seeds) by weevil feeding was assessed. Seed damage was expressed as a proportion of the total number of seeds sampled. Seed weight loss was determined using the count and weight method of Gwinner et al. (1996).

$$\text{Weight loss (\%)} = (W_u \times N_d) - (W_d \times N_u) \times 100 / W_u \times (N_d + N_u)$$

Where W_u = Weight of undamaged seed, N_u = Number of undamaged seed, W_d = Weight of damaged seed, and N_d = Number of damaged seed.

Median development time

The median development period was calculated as the time (days) from the middle of the oviposition period to the emergence of 50% of the F₁ progeny (Dobie, 1977).

Index of susceptibility

The index of susceptibility was calculated using the method of Dobie (1974). This involves the number of F₁ progeny and the length of median developmental time.

$$\text{Index of susceptibility} = 100 \times [\log_e (\text{total number of F}_1 \text{ progeny emerged}) / (\text{median development time})]$$

The susceptibility index, ranging from 0 to 11, was used to classify the maize varieties; where; 0 - 3 = resistant, 4 - 7 = moderately resistant, 8 - 10 = susceptible and ≥ 11 = highly susceptible (Dobie, 1974).

Data analysis

Data with regard to percent adult mortality, percent seed damage and weight loss were angular-transformed ($\arcsine \sqrt{\text{proportion}}$), while numbers of F₁ progeny were log-transformed, in order to stabilize the variance. The transformed data were analyzed using one-way analysis of variance. Significant differences between means were separated using Student Newman Keuls test ($P < 0.05$). Back-transformed (original) data are presented in tables and figures.

RESULTS

Adult mortality, F₁ progeny and median developmental time

Adult mortality did not significantly differ between the varieties (Table 1). However, weevils feeding on BHQP-

Table 1. Adult mortality and F₁ progeny of *S. zeamais* on different maize varieties.

Variety	Adult mortality (%)	F ₁ Progeny Emerged	Median developmental time (in days)
Rare-I	15.5 ± 6 a	55.6 ± 7de	46.3 ± 3 abc
Melkasa-I	13.3 ± 3 a	74.6 ± 7abc	42.6 ± 7 d
Melkasa-II	12.2 ± 2 a	74.6 ± 7abc	42.0 ± 5 d
Melkasa-III	11.1 ± 1 a	84.6 ± 7a	41.6 ± 7 d
BH-660	14.4 ± 4 a	68.3 ± 3bc	44.3 ± 3 bcd
BH-540	14.4 ± 4 a	62.3 ± 3cd	43.3 ± 3 cd
BH-511	13.3 ± 3 a	71.0 ± 5abc	42.3 ± 3 d
BHQP-542	16.6 ± 7 a	23.0 ± 8h	48.0 ± 6 a
Awasa-511	15.5 ± 6 a	49.6 ± 7e	45.0 ± 4 abcd
ACV3	16.6 ± 7 a	31.3 ± 3g	47.3 ± 3 ab
ACV6	15.5 ± 6 a	39.3 ± 3f	46.6 ± 7 ab
Katumani	11.1 ± 1 a	81.3 ± 3ab	41.6 ± 7 d
Coree (local variety)	12.2 ± 2 a	74.6 ± 7abc	42.0 ± 3d

Means followed by the same letter within the column are not significantly different at $p < 0.01$. Original (back-transformed) values are presented here; however, angular-transformed values were used for the analysis.

Table 2. Extent of seed damage and weight loss to the maize varieties by *S. zeamais*.

Variety	Seed damage (%)	Weight loss (%)
Rare-1	6.3 ± 0.1fg	4.4 ± 0.4e
Melkasa-I	10.6 ± 2.3cde	5.6 ± 0.5d
Melkasa-II	13.3 ± 3.1 bcd	6.2 ± 0.8 c
Melkasa-III	18.0 ± 3.4 a	8.3 ± 0.2 a
BH-660	7.6 ± 2.0 ef	4.5 ± 0.1 e
BH-540	8.6 ± 1.5 ef	5.4 ± 0.2 d
BH-541	9.6 ± 2.5 de	5.4 ± 0.9 d
BHQP-542	3.3 ± 0.5 h	3.2 ± 0.4 f
Awasa-511	7.3 ± 1.7 efg	4.5 ± 0.5 e
ACV3	4.6 ± 0.4 gh	3.4 ± 0.6 f
ACV6	6.0 ± 0.3 fg	3.5 ± 0.5 f
Katumani	15.0 ± 3.2 ab	8.2 ± 0.8 a
Coree	14.3 ± 3.7 abc	7.5 ± 0.4 b

Means followed by the same letter within the column are not significantly different at $p < 0.01$. Original (back-transformed) values are presented here; however, angular-transformed values were used for the analysis.

542 and ACV3 suffered the highest mortality. There were significant differences ($F_{12, 24} = 91$; $P < 0.05$) between the maize varieties in the number of F₁ progeny (Table 1). The highest number of F₁ progeny was counted in jars of the varieties Melkasa-I, Melkasa-II, Melkasa-III, Katumani and Coree, while the least number of F₁ progeny was found in BHQP-542, ACV3 and ACV6 11.

Significant differences ($F_{12, 24} = 8.71$; $P < 0.01$) among the varieties were recorded with regard to the median developmental time (MDT) (Table 1). The MDT ranged from 41.6 days for Katumani and Melkasa III, to 48.0

days for BHQP-542. *S. zeamais* reared on the varieties Katumani, Melkasa-I, Melkasa-II, Melkasa-III, Coree, BH-541, BH-660 and BH-540, respectively, had relatively lower MDT. However, Rare-I, BHQP-542, Awasa-511, ACV3 and ACV6 had the highest MDT. The general trend in MDT appeared to be similar to that of F₁ progeny emergence. Varieties with high F₁ progeny tended to have short MDT.

Seed damage and weight loss

Significant differences ($P < 0.01$) were observed in the percentages of seeds damaged and seed weight loss among the varieties tested (Table 2). The highest seed damage and seed weight loss were observed in Melkasa-III, followed by Katumani and Coree. The least seed damage and seed weight loss was observed in BHQP-542, ACV3 and ACV6. Seed damage and weight loss were positively related with the number of F₁ progeny (Figure 1). With increasing number of F₁ progeny, there was an increasing seed damage and seed weight loss.

Index of susceptibility

The index of susceptibility ranged from 2.8 in BHQP-542 and 4.6 in Melkasa-III (Figure 2). The variety BHQP-542 was rated as resistant while the remaining varieties were categorized as moderately resistant. The susceptibility index was inversely related with percent mortality and median developmental time (Figures 3a and c); however, the number of F₁ progeny, percent seed damage and seed weight loss showed a positive relationship with the susceptibility index (Figures 3b, d and e).

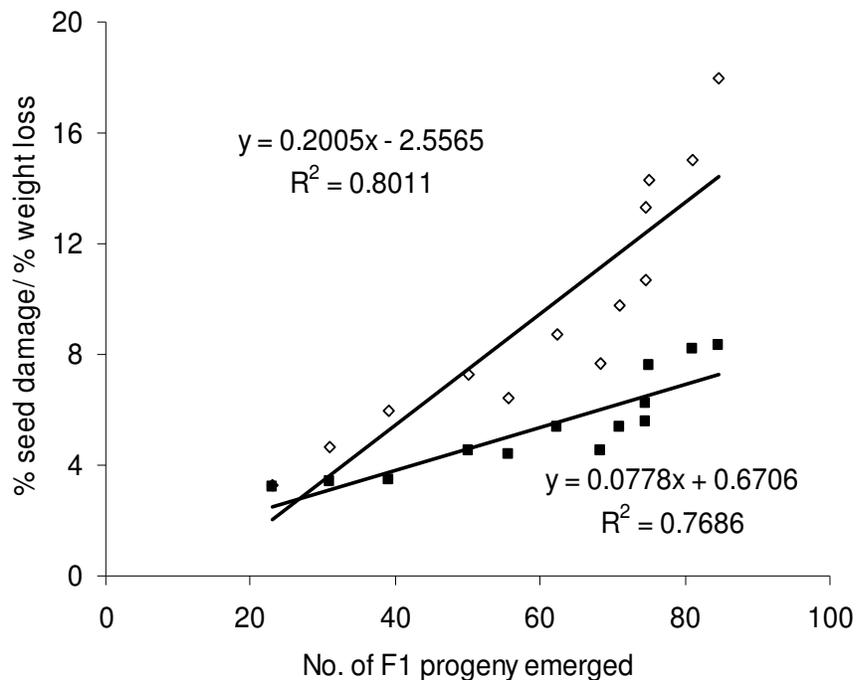


Figure 1. Correlation between seed damage (open dots) and seed weight loss (dark dots) and number of F1 progeny.

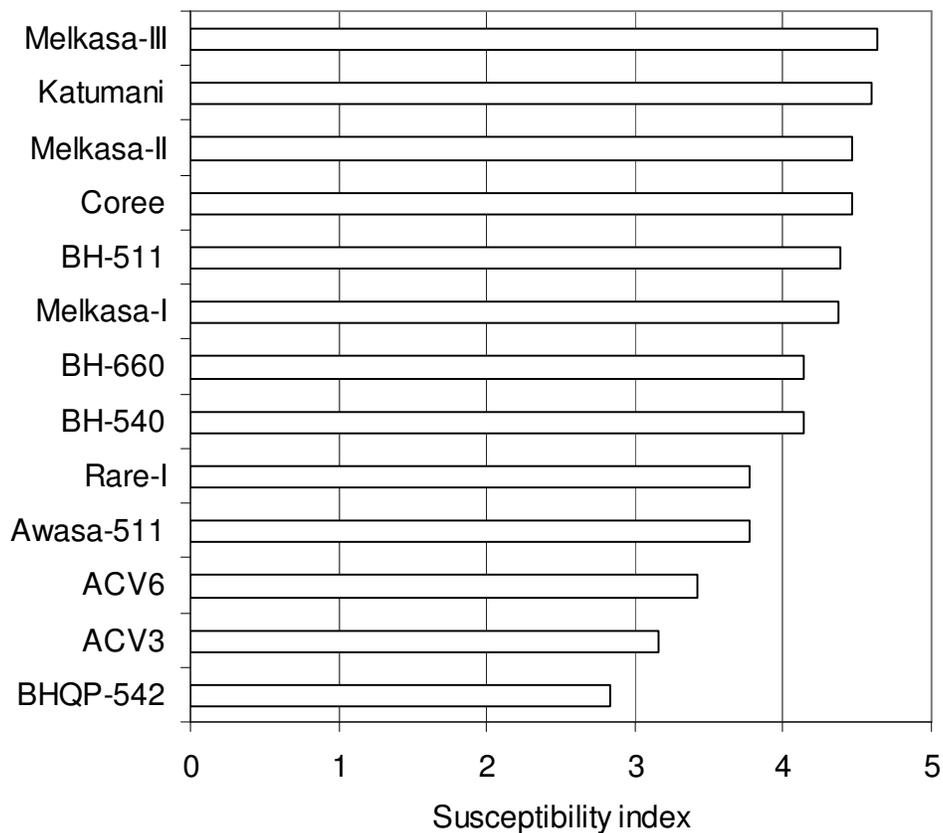


Figure 2. Susceptibility index of maize varieties (0 to 11 scale), where; 0-3 = resistant, 4 - 7 = moderately resistant, 8 - 10 = susceptible and ≥ 11 = highly susceptible.

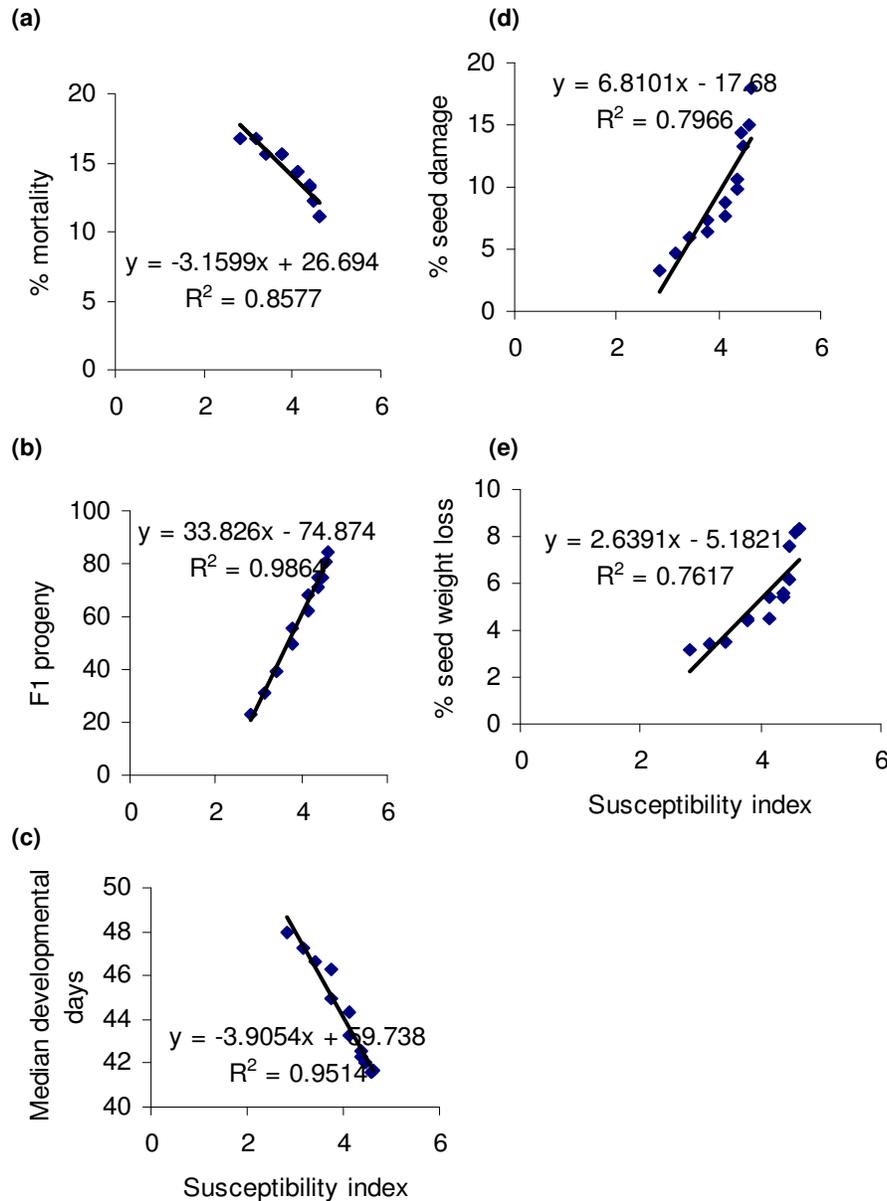


Figure 3. Correlation between (a) adult mortality, (b) F1 progeny, (c) median developmental time, (d) seed damage and (e) seed weight loss and the susceptibility index.

DISCUSSION

In our experiments we found considerable variation among the maize varieties with respect to F1 progeny, median developmental time, seed damage, seed weight loss and the susceptibility index. These differences in the susceptibility of the maize varieties indicate the inherent ability of a particular variety to resist *S. zeamais* attack. Resistance in stored maize to insect attack has been attributed to physical factors such as grain hardness, pericarp surface texture, nutritional factors such as amylose, lipid and protein content (Dobie, 1974; Tepping et

al., 1988) or non-nutritional factors, especially phenolic compounds (Serratos et al., 1987). Garcia-Lara et al. (2004) also reported that pericarp roughness was correlated with susceptibility. The role phenolics play in resistance formation in these surface tissues may be both related to structural components and antibiosis factors (Arnason et al., 1993). For *Sitophilus oryzae* grain hardness has been reported as the main resistance parameter (Bamaiyi et al., 2007).

Out of the thirteen maize varieties tested against *S. zeamais*, only one variety, BHQP-542, was resistant. The remaining twelve varieties were moderately resistant.

BHQP-542 is a hybrid, quality protein maize variety. The fact that this variety was resistant to *S. zeamais* may be attributed to a high tryptophan and lysine content. Protein content was negatively correlated with the susceptibility of maize cultivars to *S. zeamais* (Arnason *et al.* 2004). There were no apparent differences in resistance between the hybrids BH-660, BH-540 and BH-511 and the other cultivars tested, which are open pollinated varieties.

Adult weevil mortality was not significantly different between the varieties tested. Dobie (1974) found that the overall rate of mortality of adult maize weevils on different maize varieties was generally low and concluded that there was no evidence for a variation among the varieties in their effects upon the mortality of *S. zeamais*. Abraham (1991) also suggested that this parameter might not be a good indicator of susceptibility, because adult weevils were found to survive without food for more than ten days in a laboratory test.

Relatively longer developmental time was required on the resistant variety, BHQP-542, than on the moderately resistant varieties. Similarly, beetles on varieties having a high index of susceptibility displayed reduced periods for the completion of developments. Reduced survival and establishment will reduce the insect populations and the resultant crop damage. Prolongation of development periods will also result in reduction of number of generations in a season. According to Horber (1988), the index of susceptibility is based on the assumption that the more F₁ progeny and the shorter the duration of the development, the more susceptible the seeds would be. Abraham (1991) indicated that the extent of damage during storage depends upon the number of emerging adults during each generation and the duration of each life cycle and seeds permitting more rapid and higher levels of adult emergence will be more seriously damaged. Several maize varieties, including local land races, have been characterized as sources of resistance to *S. zeamais* (Giga and Mazarura, 1991; Arnason *et al.* 2004) and some sources of resistance have been incorporated into elite maize lines (Bergvinson, 2001).

It can be concluded that if resistant maize varieties extend the developmental period of *S. zeamais*, the post harvest loss incurred during storage of farm produce will be minimized to a large extent. Those varieties with low indices of susceptibility can be stored relatively for longer periods of time. Resistant varieties, therefore, can be utilized as an environmental friendly way to reduce damage by *S. zeamais* under traditional storage conditions. The resistant variety identified in the present study can also be used as a source of resistance in breeding programs to diversify the basis of resistance to this pest.

ACKNOWLEDGEMENT

We acknowledge the Ministry of Agriculture and Rural Development of Ethiopia for sponsoring this study. We

thank Prof. Kanaujia for his contribution during the initial stage of this work. We acknowledge the Alexander von Humboldt Foundation, Bonn, for offering Dr Tadele Tefera, a research fellowship during which this paper writing was initiated.

REFERENCES

- Abraham T (1991). The biology, significance and control of the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on stored maize. An M.Sc. Thesis presented to the School of Graduate Studies of Haramaya University of Agriculture, Ethiopia. p. 250.
- Arnason JT, Lambert JDH, Gale J, Mihm J (1993). Is Quality Protein Maize more susceptible than normal varieties to attack by the Maize Weevil, *Sitophilus zeamais*? Postharvest Biol. Technol. 2: 349-358.
- Arnason JT, Baum B, Gale J, Lambert JDH, Bergvinson D, Philogene B J R, Serratos J A, Mihm J, Jewell D C (2004). Variation in resistance of Mexican landraces of maize to maize weevil *Sitophilus zeamais*, in relation to taxonomic and biochemical parameters Euphytic, 74: 227-336.
- Bamaiyi LJ, Dike MC, Onu I (2007). Relative susceptibility of some sorghum varieties to the rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae). J. Entomol. 4: 387-392.
- Caswell GH (1962). Agricultural Entomology in the Tropics. Edward Arnold, London, p. 145.
- Cherry AJ, Bantino A, Djegui D, Lomers C (2005). Suppression of the stem borer *Sesamia calamistis* (Lepidoptera: Noctuidae) in maize following seed dressing, topical application and stem injection with African isolates of *Beauveria bassiana*. Int. J. Pest Manage. 50: 67-73.
- Danho M, Gaspar C, Haubruge E (2002). The impact of grain quality on the biology of *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae): oviposition, distribution of eggs, adult emergence, body weight and sex ratio. J. Stored Prod. Res. 38: 259-266.
- Demissie G, Tefera T, Tadesse A (2008). Importance of husk covering on field infestation of maize by *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) at Bako, Western Ethiopia. Afr. J. Biotechnol. 7: 3774-3779.
- Derera J, Pixley KV, Giga PD (2001). Resistance of maize to the maize weevil: I-Antibiosis. Afr. Crop Sci. J. 9: 431-440.
- Dobie P (1974). The laboratory assessment of the inherent susceptibility of maize varieties to post harvest infestation by *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) infesting field corn. J. Entomol. Sci. 21: 367-375.
- Dobie P (1977). The contribution of the tropical stored products center to the study of insect resistance in stored maize. Trop. Stored Prod. Info. 34: 7-22.
- Delima CPF (1987). Insect pests and post harvest problems in the tropics. Insect Sci. Appl. 8: 673-676.
- Giga DP, Mazarura UM (1991). Levels of resistance to the maize weevil, *Sitophilus zeamais* (Motsch.) in exotic, local open pollinated and hybrid maize germplasm Insect Sci. Appl. 12: 159-169.
- Giga DP, Mutumeerwa S, Moya G, Neeley D (1991). Assessment and control of losses caused by insect pests in small farmers' stores in Zimbabwe. Crop Prot. 10: 287-292.
- Gwinner J, Harnisch R, Muck O (1996). Manual on the prevention of post harvest seed losses, post harvest project, GTZ, D-2000, Hamburg, FRG. p. 294.
- Horber E (1988). Methods to detect and evaluate resistance in maize to seed insects in the field and in storage. In: Towards insect resistance maize for the third world: Proceedings of international symposium on methodologies for developing host plant resistance to maize insects. pp. 140-150. CYMMYT, El Batan, Mexico D.F. CYMMYT.
- Markham RH, Bosque-Pérez N, Borgemeister C, Meikle WG (1994). Developing pest management strategies for the maize weevil, *Sitophilus zeamais* and the larger grain borer, *Prostephanus truncatus*, in the humid and sub-humid tropics. FAO plant protection bulletin, 42: 97-116.
- Nwana IE, Akibo-Betts DT (1982). The resistance of some rice varieties

- to damage by *Sitophilus zeamais* Motsch., during storage. Trop. Stored Prod. Info. 43: 10-15.
- Serratos A, Ranason J, Nozzolillo C (1987). Factors contributing resistance to exotic maize populations to maize weevil, *Sitophilus zeamais*. J. Chem. Ecol. 13: 751-761.
- Tepping PW, Legg DE, Rodriguez JG, Ponelei CG (1988). Influence of maize pericarp surface relief on the resistance of the maize weevil. J. Kansas Entomol. Soc. 61: 237-241.