

Full Length Research Paper

Evaluation of CIMMYT drought tolerant maize germplasm for resistance to weevil (*Sitophilus zeamais* Motschulky) damage

Amen Mandizvidza¹, Peter Setimela^{2*} and Shorai Dari²

¹Department of Crop Science, University of Zimbabwe, Box 167, Mount Pleasant, Harare, Zimbabwe.

²CIMMYT, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe.

Received 6 August, 2015; Accepted 18 September, 2015

This study was carried out to evaluate and assess the phenotypic correlation between the primary and secondary weevil resistant traits of 20 drought tolerant (DT) late maturing maize hybrids (LHYB) to weevil (*Sitophilus zeamais* Motschulsky) damage. Well-conditioned experimental samples with uniform grain moisture content were infested with 32; 10 to 14 day old weevils in the controlled temperature and humidity (CTH) environment for 55 days. Data were collected on kernel volume (KV) and grain hardness (GH) at the start of the experiment, percent weevil mortality (%WM) at the 21st day and percent grain weight loss (%GWL) and F₁ weevil progeny emergence (F₁WPE) at the 55th day of oviposition. Data were collected on starch, oil and protein content to confer resistance to weevil damage. There were highly significant differences (P<0.001) in F₁WPE and %GWL, (P<0, 01) in KV while no significant differences were observed for %WM and GH. The obtained data confirmed that, there was a positive and significant correlation between F₁WPE and %GWL, while a negative and significant correlation was observed between F₁WPE and %WM. Hybrids CZH131022, CZH131003, CZH132064, CZH132069 and CZH132068 were the top five weevil resistant while hybrids CZH132066, CZH132065, CZH132074, CZH131008 and CZH132063 were the top five most susceptible.

Key words: Controlled temperature and humidity, late maturing maize hybrids, *Sitophilus zeamais*.

INTRODUCTION

Maize weevil (*Sitophilus zeamais*) is among the major causes of maize yield losses in both field and storage conditions in sub Saharan Africa (Mwololo et al., 2013). The devastating effects of the maize weevil are terminal, thus pose serious threats to household livelihoods and to regional and global food security (Dari et al., 2010). Mvumi et al. (1995) report that weevils can cause 9%

yield losses of farmer's total maize soon after physiological maturity prior to harvesting. In addition, Winkler and García-Lara (2010) assert that grain yield losses can go up to 60% in untreated maize grain thereby causing drastic food shortages in affected areas. Furthermore, Giga and Mazarura (1991) affirm that the maize weevil can cause 20 to 90% yield losses in both treated and

*Corresponding author. E-mail: p.setimela@cgiar.org. Tel: 0772963436.

untreated maize grain respectively. This evidence shows that the maize weevil interferes with farmer's goals and activities therefore the need to control its disturbing activities is inevitable. In a bid to protect grain against post-harvest losses, many farmers use synthetic chemical pesticides (Masasa et al., 2013). Concern over environmental and health (Dubey, 2009) hazards caused by synthetic chemical pesticides have however pushed many researchers of today to focus on alternative methods of protecting farmer's grain. Biological, cultural, hermetic and Host Plant Resistance (HPR) are some of the best alternatives under research by scientists. Each of these methods comes with its own advantages and disadvantages (Tefera et al., 2011). Biological control usually put particularly low risk of toxic effects on both mammals and human beings, save on cost as some of the techniques are currently exempted from registration and it provides an additional tool for integrated pest management (IPM). However, biological control has not received extensive study due to problems with the introduction of insects into a food product. In addition biological techniques rarely eliminate pests, the biological control agent itself is an unwanted extra residue on a commodity and also the technique requires extensive monitoring to achieve best results (Flinn et al., 2012). Like biological control, cultural control method is also environmentally friendly and is cheaper than any other control method. However most cultural methods are not highly effective, not proven and documented and they are not consistent in rate, timing and composition (Dhliwayo and Pixely, 2004). Hermetic control techniques involve manipulation of the physical environment thereby killing insects by suffocation. Though this method is non-chemical and reduces the risk of mammalian toxicity, it is not widely used by many smallholder farmers due to lack of knowhow and sufficient funds to buy the necessary equipment for example metal silos. Moreover the technique require the maize grain to be stored at <14% moisture content (Tefera et al., 2011) yet most smallholder farmers do not have moisture meters to test the grain and on top, some of them are illiterate that they can't use the moisture meter even at their disposal; therefore there is a risk of losing tons of grains when stored at a wrong moisture content.

Among the mentioned methods HPR can be the best alternative method of weevil control which can be easily adopted by small scale farmers as many benefits can be derived. Once farmers have bought weevil resistant seeds there will be no need for them to spare any more money to cater for weevil control. In addition the method is more than natural and it offers all advantages offered by physical, hermetic and biological control methods (Tefera et al., 2012). HPR involves the breeding of maize varieties that are not prone to attack by weevils. Generally there are three mechanisms of insect resistance: antibiosis, antixenosis (non-preference) and tolerance (Mihm, 1997). Mechanisms and level of

resistance to weevil damage varies among maize genotypes and this is determined by the composition of particular kernels of a maize variety. Some varieties (weevil resistant) contain different compounds that discourage their successful utilization as hosts by insect species while others (susceptible) contain compounds favorable for weevil oviposition (García-Lara et al., 2004). These compounds vary greatly among maize varieties and can be passed on from one generation to another. Plant breeders have taken advantage of such heritable characteristics in order to produce weevil resistant maize varieties. Breeding for weevil resistance needs an understanding of the resistance mechanisms. Antibiosis and antixenosis are two important useful mechanisms of resistance whereas tolerance is good for field insects rather than storage pests. This is attributed to the fact that the feeding mechanism of weevils in storage is incurable and as such tolerance cannot be useful as the tissues do not regenerate in storage but rather they deteriorate. Antixenosis (non-preference) resistance has been reported to be governed by both additive and non-additive gene action for grain weight loss (Derera et al., 2001). This implies that both general combining ability (additive) and specific combining ability (non-additive) are important for weevil resistance. Some researchers have reported the trait for weevil resistance to be governed by maternal effects (Dari et al., 2010). More research needs to be done in order to obtain more information on weevil resistant/susceptible hybrids produced every year to make recommendation to smallholder farmers.

Few studies have been carried out to determine the level of weevil damage to late maturing tropical maize hybrids. Therefore the main objectives of this study were to evaluate and assess the phenotypic correlation between the primary and secondary weevil resistant traits of 20 drought tolerant (DT) late maturing maize hybrids (LHYB) to weevil damage.

MATERIALS AND METHODS

Maize hybrids

The experiment consists of twenty DT late maturing maize hybrids which have been developed under a special program called drought tolerant maize for Africa (DTMA) in the year 2014. These hybrids grow and perform well under water stressed conditions and they are specifically designed for resource poor farmers who are located in low potential areas and are incapable of buying specialized equipment for irrigation (Magorokosho and Tongoona, 2004). After a bumper harvest of DT cultivars farmers need to protect their grain against weevil/post-harvest damage and most resource poor farmers cannot afford to buy expensive storage chemical pesticides (Tefera et al., 2011). Few studies have been carried out to evaluate the level of weevil damage to tropical late maturing maize. Therefore we carried out this research to provide information that will be helpful for our partners (seed companies) to make proper recommendations upon delivering DT varieties to the end users (farmers) and also to offer them a room for improvement of susceptible varieties that might be high yielding. Some detail about the maize hybrids used in this study is shown in Table 1.

Table 1. Drought tolerant and late maturing maize hybrids evaluated for weevil resistance.

Name	Origin of pedigree	Maturity group	Location of seed production	Year of seed production
CZH132074	CIMMYT	Late	Zimbabwe	2014
CZH132064	CIMMYT	Late	Zimbabwe	2014
CZH131005	CIMMYT	Late	Zimbabwe	2014
CZH132066	CIMMYT	Late	Zimbabwe	2014
CZH131007	CIMMYT	Late	Zimbabwe	2014
CZH131006	CIMMYT	Late	Zimbabwe	2014
CZH132067	CIMMYT	Late	Zimbabwe	2014
CZH132075	CIMMYT	Late	Zimbabwe	2014
CZH131003	CIMMYT	Late	Zimbabwe	2014
CZH131022	CIMMYT	Late	Zimbabwe	2014
CZH132069	CIMMYT	Late	Zimbabwe	2014
CZH128	CIMMYT	Late	Zimbabwe	2014
CZH122	CIMMYT	Late	Zimbabwe	2014
CZH132072	CIMMYT	Late	Zimbabwe	2014
CZH132063	CIMMYT	Late	Zimbabwe	2014
CZH123	CIMMYT	Late	Zimbabwe	2014
CZH132065	CIMMYT	Late	Zimbabwe	2014
CZH131008	CIMMYT	Late	Zimbabwe	2014
CZH132073	CIMMYT	Late	Zimbabwe	2014
CZH132068	CIMMYT	Late	Zimbabwe	2014

Weevil culturing

Culturing of weevils was done in order to obtain the same generation of weevils. Weevils were collected from the University of Zimbabwe (UZ) farm, Agricultural Research Trust (ART) farm and also from plant protection under the Department of Research and Specialist Services (DR&SS). Grain from a susceptible variety (SC707) (Masasa et al., 2013) was used for culturing. The grain had a 15% moisture content, which was suitable for culturing (Dari et al., 2010). An amount of 500 g of grain was put in pollen bags and then placed in a refrigerator for two weeks in order to kill any infestations on the grain. An amount of 400 g of grain was put in 1000ml jars and covered with brass screen leads to allow free air circulation. The jars were then left in the CTH laboratory (temperature 28±2°C, humidity 65±5%) (Tefera et al., 2011) for a two week period in order to acclimatize the grain to laboratory conditions and also to attain uniform grain moisture content. An estimate of 200 weevils were sieved off and added into maize grain (SC707) in each 1000 ml jar (Tefera et al., 2011). Weevils from different sources were cultured separately. The jars were then left in a CTH for a 21 day incubation period on top of shelves to avoid molding, after which the adult weevils were sieved off and removed from the grain. The jars were then left for 45 days, after which the newly emerged weevils were now ready for the experiment. Healthy cultures from different sources were mixed in order to maintain heterogeneity in weevil populations (Dhliwayo and Pixley, 2004).

Study site and experimental design

The experiment was carried out in the CTH entomology laboratory under the Department of Crop Science at the University of Zimbabwe. Humidity and temperature were maintained in the range of 65±5% and 28±2°C respectively (Tefera et al., 2011). The

experiment was laid out in a Completely Randomized Design (CRD) with three replications.

Maize weevil resistance evaluation

F₁ weevil generations obtained from the cultures were used to infest DT late maturing maize hybrids (experimental samples). All non-grain material was removed from experimental samples by thorough cleaning. Four hundred grams of each of the DT late maturing maize hybrid sample was put in pollen bags and disinfested in a deep freezer at -20°C for a two week period (Masasa et al., 2013). The grain was then preconditioned for a two week period. Grain samples were weighed a day before infestation in order to minimize time interval within replications during infestation (Tefera et al., 2011). An amount of 50±0.1 g of grain was put in to each (250 ml) jar (Tefera et al., 2011). Thirty two 10 to 14 day old weevils were added to each jar for all three replications (Masasa et al., 2013). Small tags containing replication number, entry number and initial grain weight for each DT late maturing maize hybrid was put inside of each 250 ml jar. The jars were then left in the CTH for 21 days incubation period. After this period adult weevils were then sieved off from the grain. The samples were left in the CTH for 45 to 59 days (CIMMYT protocol for weevil screening). At the 55th day, data for F₁ weevil progeny emergence and percentage grain weight loss were then collected and the weevils removed from the grain.

Data collection

Data for kernel volume were measured using a 100 ml measuring cylinder using the displacement method. Fifty kernels from each maize hybrid were used for kernel volume measurement. Grain

Table 2. Summary of the analysis of variance for all measured maize weevil resistant components.

Source	DF	F1 WPE	%GWL	%WM	GH	50 KV
Entry MS	40	0.09138***	0.0036808***	79.11NS	8.726NS	6.408**
Residual MS	40	0.01574	0.0007794	80.73	9.543	2.308
Total SS	40	2.36590	0.1011126	4732.26	547.512	214.083
Total	59					

, *-significant at probability level 0.01 and 0.001 respectively, NS-not significant, F₁WPE- F₁ weevil progeny emergence, %GWL- percentage grain weight loss, %WM- percentage weevil mortality, GH- grain hardness and KV- kernel volume.

hardness for each maize hybrid was measured from five randomly selected kernels using an auto zero, AACU Force Cadet that records the compression as the peak force in newtons to the fracture point of the kernel (Dari et al., 2010). Data for protein, oil and starch content for the grain were collected using a grain analyzer which records percentage protein content by mass automatically once the samples are put inside. Percentage grain weight loss was calculated according to (Tefera et al., 2011) using the following formula.

$$\% \text{ Grain weight loss} = \frac{\text{Initial weight} - \text{Final weight} * 100}{\text{Initial weight}}$$

Data analysis

All data were subjected to Minitab in order to test fulfillment of the assumptions of the analysis of variance (ANOVA). All recorded data met ANOVA assumptions and carried forward to one way ANOVA in GenStat version 14th addition. However, data for F₁ weevil progeny emergence and grain weight loss were transformed using log and arcsine transformations respectively prior to statistical analysis (Tefera et al., 2011). Treatments were more than eight, hence Turkey's 95% confidence interval was used to separate means for all significant traits measured. Pearson's correlation was used to test the phenotypic correlation between resistant components measured in this study.

RESULTS AND DISCUSSION

F₁ Weevil progeny emergence (F₁WPE), percentage grain weight loss (%GWL), Kernel volume (KV), percentage weevil mortality (%WM) and grain hardness (GH)

There are significant (P<0.001) differences in F₁ weevil progeny emergence and percentage grain weight loss, (P<0.01) in kernel volume among the maize hybrids evaluated for weevil resistance. There are no significant (P>0.05) differences observed in percentage weevil mortality and grain hardness among all twenty drought tolerant maize hybrids evaluated for weevil resistance in this study (Table 2).

Variation observed in F₁weevil progeny emergence implies that the DT maize hybrids are displaying different levels of weevil resistance (Table 3). Hybrids

CZH132074, CZH132072, CZH132066, CZH131008 and CZH132063 exhibited high F₁weevil progeny emergence while CZH131022, CZH131003 and CZH132064 exhibited low F₁ weevil progeny emergence (Table 3). Hybrids CZH123, CZH132068, CZH128 and CZH132069 recorded middle values of F₁weevil progeny emergence among all DT late maturing maize hybrids evaluated for weevil resistance in the present study. These results were consistent with other researchers who did related work (Abebe et al., 2009; Dari et al., 2010). Variation in F₁ weevil progeny emergence is mainly attributed to differences in maize kernel characteristics. Resistant maize genotypes are usually characterized with no/very low F₁weevil progeny emergence after a long period of time (64 days) while susceptible maize varieties are characterized with greater numbers of F₁WPE in a very short time period (32 days) under favorable humidity (70±5) and temperature (28±2) conditions (Dhliwayo and Pixley, 2004). Basing on the literature gathered from García-Lara et al. (2004) it can be postured from this study that, hybrids (CZH131022, CZH131003 and CZH132064) that exhibited low F₁ weevil progeny emergence might contain phenolic compounds that might have discouraged faster rate of weevil oviposition and development. There is also a possibility that these hybrids are lacking nutrients that are required to support weevil oviposition and development. This can be supported by the observation made from this study; hybrid (CZH131022) which exhibited lowest value of F₁ weevil progeny emergence was found to exhibit high protein and oil content while at the same time exhibiting low starch content as compared to almost all hybrids. Basing on this result we may conclude that the nutritional status of this hybrid was not favoring/supporting faster rate of weevil oviposition and development.

There is also variation in percentage grain weight loss amongst drought tolerant maize hybrids evaluated for weevil resistance in this particular study (Table 3). Hybrids CZH132066 and CZH132065 exhibited highest percentages of grain weight loss while on the contrary hybrids CZH131022, CZH131003 and CZH132064 exhibited lowest percentages of grain weight loss. Many researchers have also confirmed such variation for this trait (Masasa et al., 2013; Derera et al., 2010; Mwololo et al., 2012a; Mwololo et al., 2013; Dari et al., 2010;

Table 3. Means for F₁ weevil progeny emergence (F1WPE), percentage grain weight loss (%GWL), percentage weevil mortality (%WM), 50 kernel volume (50 KV) and grain hardness (GH).

Variety	F1WPE	%GWL	%WM	50 KV(cm ³)	GH (N)
CZH132074	1.889 ^d	0.10950 ^a	9.4	10.33 ^{ab}	15.77
CZH132064	1.371 ^{abc}	0.06533 ^a	8.3	13.67 ^{ab}	12.41
CZH131005	1.653 ^{bcd}	0.09080 ^a	9.4	11.50 ^{ab}	12.88
CZH132066	1.827 ^d	0.21541 ^b	11.5	11.67 ^{ab}	13.68
CZH131007	1.684 ^{bcd}	0.07333 ^a	1.0	13.33 ^{ab}	15.54
CZH131006	1.736 ^{cd}	0.10010 ^a	5.2	14.67 ^b	15.34
CZH132067	1.729 ^{cd}	0.08265 ^a	8.3	9.33 ^a	16.71
CZH132075	1.626 ^{bcd}	0.09134 ^a	22.9	12.17 ^{ab}	14.54
CZH131003	1.325 ^{ab}	0.06067 ^a	6.2	13.83 ^{ab}	15.33
CZH131022	1.213 ^a	0.05202 ^a	6.2	13.50 ^{ab}	18.54
CZH132069	1.567 ^{abcd}	0.07003 ^a	5.2	12.67 ^{ab}	17.57
CZH128	1.540 ^{abcd}	0.07464 ^a	17.7	13.00 ^{ab}	16.89
CZH122	1.607 ^{bcd}	0.08471 ^a	6.2	13.67 ^{ab}	13.36
CZH132072	1.871 ^d	0.10472 ^a	1.0	10.00 ^{ab}	13.70
CZH132063	1.761 ^d	0.10756 ^a	4.2	12.50 ^{ab}	14.86
CZH123	1.592 ^{abcd}	0.07535 ^a	7.3	13.67 ^{ab}	15.14
CZH132065	1.618 ^{bcd}	0.12924 ^{ab}	6.2	14.33 ^b	13.48
CZH131008	1.775 ^d	0.10940 ^a	5.2	13.67 ^{ab}	12.71
CZH132073	1.602 ^{bcd}	0.07268 ^a	12.5	11.67 ^{ab}	16.85
CZH132068	1.563 ^{abcd}	0.07201 ^a	7.3	12.50 ^{ab}	15.08
Mean	1.627	0.0921	8.1	12.58	15.02
P-value	***	***	NS	**	NS
SE±	0.1255	0.02792	8.98	1.519	3.089
LSD(0.05)	0.2070	0.04607	14.83	2.507	5.098
CV%	7.7	30.3	111.3	12.1	20.6

** , *** significant at 0.01 and 0.001 significant levels, NS-not significant, N-newtons.

Serratos et al., 1987). Grain weight loss is a very useful trait/characteristic used to classify maize genotypes into resistant/susceptible classes for evaluation purposes (Tefera et al., 2011b; Mwololo et al., 2012b; Mwololo et al., 2013). Differences in percentage grain weight loss among maize hybrids observed in the present study can be attributed to variation in F₁weevil progeny emergence observed among the drought tolerant maize hybrids. F₁weevil progeny emergence and grain weight loss are analogues and as such the maize genotype that emerges more weevils is bound to lose more weight due to insect feeding. This explanation is supported by the observation made in the present study; the hybrids that exhibited lowest F₁ weevil progeny emergence (CZH131022, CZH131003 and CZH132064) are the same hybrids that conferred the least percentage grain weight loss values (Table 3). Maize hybrids that exhibit low grain weight loss for example, CZH131022 are often characterized with high levels of phenolic compounds. Different phenolic compounds such as coumaric acid esterified to carbohydrates on the maize pericarp tend to discourage successful utilization of a maize variety as an ideal host by an insect thereby resulting in low percentages of grain

weight loss (García-Lara et al., 2007).

As suggested by the results (Table 3), there is high variation in kernel volume amongst all drought tolerant maize hybrids evaluated for weevil resistance in this particular study. Hybrids CZH132065 and CZH131006 recorded high kernel volumes while hybrids CZH132067, CZH132072 and CZH132074 recorded lowest kernel volumes amongst all evaluated hybrids. There was no clear distinction of resistant/susceptible maize genotypes basing on kernel volume since there was no consistence for the trait. This was evidenced by the trends that have been observed in the present study: the extreme hybrids in kernel volume CZH 132065 and CZH131006 (highest) and CZH132072 and CZH132074 (lowest) ended up being classified in the same category (susceptible). Another striking evidence of non-consistence observed from the study was that the hybrids that exhibited middle values in kernel volume (CZH132075, CZH132063, CZH132068 and CZH132069), where equally distributed among the resistant/susceptible classes (the former two were susceptible while the latter two were resistant) confirming no clear relationship between weevil resistance/susceptibility and kernel volume. Some

Table 4. Pearson correlation coefficients between the primary (F₁WPE) and secondary (GH, %GWL, % WM, KV) weevil resistant traits.

Variable	F ₁ WPE	GH	%GWL LOSS	% WM
GH	-0.123			
%GWL LOSS	0.568***	-0.192		
% WM	-0.329**	-0.046	-0.113	
KV	-0.053	0.162	-0.006	-0.503***

** , *** significant at P<0.01 and 0.001 respectively, GH-grain hardness, %GWL- percentage grain weight loss, %WM- percentage weevil mortality and KV- kernel volume.

researchers have reported larger kernel size as a trait that is associated with weevil resistance as compared to smaller kernel size (Gudrups et al., 2001). However, this might not be an obvious case as many commercial varieties that are grown in Zimbabwe are prone to weevil damage while their kernel size is large for example SC707.

No variation was observed in both percentage weevil mortality and grain hardness amongst all drought tolerant maize hybrids evaluated for weevil resistance in the present study (Table 3). These results might mean that there was a narrow genetic base for the DT late maturing maize hybrids to exhibit a considerable variation in their hardness. Gudrups et al. (2001) and Siwale et al. (2009) have reported weevil mortality and grain hardness as traits that are associated with weevil resistance. However, according to our view, weevil mortality can be influenced by experimental disturbances or it can be facilitated by harsh weather in case of electricity shortages, temperatures might fluctuate thereby creating tough conditions for insect survival; therefore weevil mortality cannot be a reliable resistant measure unless the information is in conjunction with reliable traits such as F₁ weevil progeny emergence and grain weight loss.

Phenotypic correlation between primary (F₁WPE) and secondary (%GWL, % weevil mortality, KV and GH) weevil resistant components

F₁ weevil progeny emergence is positively and significantly correlated to percentage grain weight loss (Table 4). Many researchers who did related work have reported the same result (Abebe et al., 2009; Dhliwayo and Pixely, 2003). Dari et al. (2010) found that grain weight loss was moderately and highly correlated among S₁, S₂, S₃ and S₄ populations indicating that grain weight loss is a very useful weevil resistant trait. Maize hybrids that emerge more weevils lose more grain weight due to weevil feeding while on the contrary maize genotypes that emerge fewer weevils also lose very little grain weight. Therefore these two characteristics (F₁weevil progeny emergence and grain weight loss) are major determinant weevil resistant/susceptible characteristics

of different maize varieties. F₁weevil progeny emergence is negatively and significantly (P<0.01) correlated to percentage weevil mortality. This implies that as weevil mortality was increasing F₁weevil progeny emergence was decreasing because there were few parents to oviposit on the grain. F₁ weevil progeny emergence is also negatively correlated to grain hardness and kernel volume. Grain hardness has been reported to be correlated with weevil resistance (Mazarura and Denash, 1991). However, grain hardness cannot be a consistent and a reliable weevil resistant trait as it can be genotype dependent (Dari et al., 2010).

Classification of evaluated DT late maturing hybrids into resistant/susceptible classes

All late maturing maize hybrids evaluated for weevil resistance in this study were classified as according to Mwololo et al. (2013) and two broad resistant categories have been deduced. It was observed from the study that half of the late maturing maize hybrids are resistant to weevil damage while half of the maize hybrids are susceptible to weevil damage (Table 5). The top five weevil resistant DT maize hybrids are CZH131022, CZH131003, CZH132064, CZH132069 and CZH132068 with percentage grain weight loss values of 5.2, 6.1, 6.5, 7.0, and 7.2% respectively. On the other hand the most susceptible maize hybrids are CZH132066, CZH132065, CZH132074, CZH131008 and CZH132063 with the following corresponding percentage grain weight loss values 21.3, 12.9, 10.9, 10.9 and 10.7% (Table 5). It was observed and identified from the study that the top five weevil resistant maize hybrids contained high levels of proteins as compared to susceptible hybrids. Hybrids CZH131022, CZH131003, CZH132064, CZH132069 and CZH132068 (top five resistant hybrids) exhibit protein percentages of 10.1, 10.1, 10.1, 10.9, and 9.6% respectively. On the contrary hybrids CZH132066, CZH132065, CZH132074, CZH131008 and CZH132063 (top five susceptible hybrids) exhibit protein percentages of 9.2, 9.6, 10.3, 9.9, and 10.1% respectively. Values that are being exhibited by top five susceptible hybrids are generally low as compared to the values exhibited by top

Table 5. Classification of DT late maturing maize hybrids into resistant/susceptible classes and the associated characteristics.

Hybrid	Starch content (%)	Oil content (%)	Protein content (%)	Grain texture in scores	Resistant/susceptible classes
CZH132074	70.2	5.2	10.3	Intermediate	Susceptible
CZH132064	69.8	5.1	10.1	Semi flint	Resistant
CZH131005	71.2	4.5	9.5	Semi flint	Susceptible
CZH132066	71.2	4.4	9.2	Dent	Susceptible
CZH131007	70.5	4.6	9.9	Semi flint	Resistant
CZH131006	69.9	5.2	9.2	Intermediate	Susceptible
CZH132067	70.9	4.9	9.1	Semi flint	Resistant
CZH132075	70	5.3	9.8	Semi flint	Susceptible
CZH131003	69.6	5.2	10.1	Flint	Resistant
CZH131022	69.1	5.4	10.1	Intermediate	Resistant
CZH132069	69.1	5.5	10.9	Intermediate	Resistant
CZH128	70.9	5.1	9	Semi flint	Resistant
CZH122	69.6	5	9.3	Intermediate	Susceptible
CZH132072	70.8	5.2	9.2	Semi flint	Susceptible
CZH132063	68.6	5	10.1	Intermediate	Susceptible
CZH123	70	5	9.7	Intermediate	Resistant
CZH132065	69.7	5.2	9.6	Semi dent	Susceptible
CZH131008	69.8	5.1	9.9	Semi dent	Susceptible
CZH132073	69.2	5.6	10	Semi flint	Resistant
CZH132068	68.9	5.4	9.6	Intermediate	Resistant

%-percentage.

five weevil resistant hybrids with the exception of only CZH132074 which is exhibiting high protein percentage (10.3%) but with a higher starch percentage which might be the reason why it had fall under the susceptible category as in the case with the other hybrids that are exhibiting high starch content. These results are consistent with other researchers who also did related work (Siwale et al., 2009; Derera et al., 2001; Dhliwayo and Pixley, 2003; Garcia-Lara et al., 2004). Basing on literature gathered together with the obtained results we may posture that maize genotypes with higher protein content are not prone/preferred by weevils as compared to those that contain low protein content. Further studies needs to be done in order to identify maize varieties with high protein content that are weevil resistant for recommendation. Plant breeders can take advantage of this characteristic to breed for weevil resistant varieties. Breeding of high protein weevil resistant maize is quite advantageous as two problems (nutrition deficiencies and storage yield loss) can be solved at once.

It has been also observed from the study that the maize hybrids that confer high protein content are the ones that are exhibiting high oil content. Top five weevil resistant maize hybrids exhibit oil contents of 5.4, 5.2, 5.1, 5.5, and 5.4% in that descending order from the top most weevil resistant hybrid CZH131022. On the other hand the least five resistant hybrids exhibit generally low values of oil content (4.4, 5.2, 5.2, 5.1 and 5%) in that order from the

most susceptible hybrid CZH132066. From these observations we deduced that maize hybrids that are exhibiting high oil content are resistant to weevil damage while maize hybrids that are exhibiting low oil content are susceptible to weevil damage. These results confirmed the relationship between protein and oil contents in maize. Breeders can take advantage of such combination to make future elite lines that can be used to make useful commercial hybrids that are superior in resisting weevil damage while at the same time containing a balanced nutrition. Another observation made from the study was that, maize hybrids that exhibit high starch content are more prone to weevil damage as compared to those hybrids that exhibit low starch content. Hybrids with low starch content are also exhibiting high oil content and as such are resistant to weevil damage. On the contrary hybrids that are exhibiting high starch content are exhibiting low oil content and are susceptible to weevil damage.

Furthermore when a comparison was made between the top five and the least five weevil resistant maize hybrids it was observed that flint and semi flint hybrids are containing high oil and protein content as compared to starch content and as such they are resistant to weevil damage. On the contrary dent and semi dent hybrids are containing high starch content as compared protein and oil content and they are susceptible to weevil damage (Table 5). Many researchers who did related work have

reported flint maize varieties to be resistant to weevil damage (Dari et al., 2010; Derera et al., 2010; Mwololo et al., 2012a; Giga and Mazarura, 1991). Basing on our results we can conclude that it is the ability of most flint varieties to exhibit high protein and oil content which makes them to resist weevil damage.

Conclusion

Breeding for weevil resistant maize varieties is ideal and it depends on the richness of the gene bank. Maize genotypes that emerge more weevils are associated with some characteristics that support weevil oviposition and development while genotypes that emerge very few weevils are associated with characteristics that discourages weevil oviposition and development. It was apparent from this study that maize hybrids with high protein and oil content while exhibiting low carbohydrate content are more resistant to weevil damage as compared to those that exhibit high carbohydrate content and low protein and oil content. Hybrids CZH131022, CZH131003, CZH132064, CZH132069 and CZH132068 are therefore recommended for small scale farmers as they are the top five weevil resistant varieties.

Conflict of Interests

The rate at which the world population is increasing has a direct impact on the demand of food. Many researchers have focused on ways of increasing yield of maize and it has been deduced that maize crop has got a potential of reaching ten tons/ha. Further researches will rather increase yield by approximately one percent per year and it can be a waste of resources to continue investing in yield increment studies solely. This therefore means that present and future studies must focus on best methods of protecting available food so that it will not deteriorate faster. Thus our research is mainly focussed on yield protection rather than yield increment.

ACKNOWLEDGEMENTS

Above all we want to thank God for guiding us throughout this project. Academic support from, Dr Icishahayo, Dr. Addis, Mr Ndor, Mr Randi and Dr. Mabasa is also appreciated. We would also want to thank fellow students Nyika Rwatirera, Macdonald Mubaiwa, Casper Kamutando, Tariro Kusada, Malven Mushayi, Tinashe Makahamadze for academic and technical support throughout this project and also not forgetting Mr Mare, Mr W. Mateta and Mr Choga for their help during the culturing of weevils. Great appreciation is also given to the department of Crop Science of the University of Zimbabwe and the CIMMYT organization for providing all

the necessary equipment and facilities for the project.

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