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ORIGINAL PAPER

Sitotroga cerealella-resistant mexican maize races (*Zea mays* L.), new sources of resistance for commercial maize breeding

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Abstract

Sitotroga cerealella (Oliv.) (Lepidoptera: Gelechiidae) is one of the most important post-harvest pests of maize *Zea mays* L. Some Mexican maize races (*Z. mays*) could be a novel source of resistance against *S. cerealella* to improve commercial maize varieties, lines and hybrids. We studied the resistance of Mexican maize races, recollected at Chihuahua State to *S. cerealella*. We focused on antibiosis and tolerance of maize to *S. cerealella*. Cristalino-079 maize race shows low level of consumption in grams and percentage, increased larvae mortality before to entering the seed. In addition, Cristalino-079 reduced first adult's generation and show the largest biological cycle. Due to the small number of emerged adults, there was very little grain weight loss in resistant maize race. The compound that causes high mortality of larvae before to entering the grain is in the pericarp of resistant maize races. The compound that causes longest development time is in the endosperm and embryo. Cristalino-079 show the better level of resistance to *S. cerealella* infestation in almost all traits studied and this can be used as source of resistance for maize breeding.

Keywords *Zea mays* · *Sitotroga cerealella* · Insect resistance · Mexican maize races

Introduction

The area planted with maize in 2019, globally, exceeds 238.5 million of hectares, with a total production of 1409.4 million of tones (FAOSTAT 2021). *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) is one of the most serious and destructive pests of stored grains particularly wheat, rice and maize around the world (Shah et al. 2014). Some studies have reported losses around the 13% in grain weight and 76% of number of damaged grain caused by *S. cerealella* during 8 months of storage (Giga et al. 1991). This equates to a loss of 183.2 million of tones each year in the world caused by *S. cerealella*. *S. cerealella* is a devastating insect pest capable of causing severe crop losses in widespread regions around the world, because is considered the third most important pest (García-Lara et al. 2007b). Larvae burrow into the seed to feed and metamorphose from larva to adult within the seed. Adults cause no direct damage to the maize grain in storage because their consumption is imperceptible, but females can lay up to 150 eggs (García-Lara et al. 2007b).

Farmers use synthetic insecticides, e.g., pyrethroids, methyl bromide, deltamethrin and organophosphates, as the most effective control for *S. cerealella* (Fouad et al. 2014). However, the indiscriminate use of these pesticides leads to environmental contamination, mammalian health problems, pest resistance, ozone layer depletion and toxicity to nontarget organisms (Tavares et al. 2010; Yoza et al. 2005). Controls based on chemical insecticides mostly need to be repeated periodically and hence are more expensive in comparison with genetic manipulation of the crops themselves

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for resistance to storage pests (Keneni et al. 2011). In addition, the manufacture and importation of the insecticide methyl bromide should have been completely phased out in developed countries in 2005. In developing countries, phase-out should have been complete in 2015 (Yoza et al. 2005).

The use of resistant varieties against storage insect pests, when successful, has a number of comparative advantages over other control measures, particularly the use of chemical insecticides (Jiménez et al. 2017). The best approach is to develop resistant varieties to *S. cerealella* (García-Lara et al. 2007b; Jiménez et al. 2017). Previous bioassays reported significant reduction in the survival of *S. cerealella* reared on transgenic wheat seeds expressing the trypsin inhibitor BTI-CMe (Altpeter et al. 1999). Also, avidin gene was reported as effective control to *S. cerealella* from transgenic rice (Yoza et al. 2005). Transgenic avidin maize has shown toxic effects against *S. cerealella* (Kramer et al. 2000). Moreover, the development and application of transgenic maize have been a serious concern in the last years, due to low social acceptance and rigid regulations (Azadi et al. 2018).

Some resistant genotypes to *S. cerealella* have been reported such as: Pratap makka-5, causing delayed (38.3 days) and reduced adult emergence (3.5 adults), minimum grain damage 7.2% and grain weight loss of 1.4%; also accessions EH-2253 and EH-2101 have good level of resistance (Demissie et al. 2015). These resistant varieties were correlated with low ash, increased phenolic content and reduced amylase concentration (Demissie et al. 2015). The accessions WNCDMR18RYD820171 and WNCDMR11R 0913 were reported to be moderately susceptible to *S. cerealella* (Soujanya et al. 2015). Ubeda, Villanueva del Arzobispo and Codoñera popcorn landraces, along with the extra-early landrace Sajambre, were the least damaged by *S. cerealella* (Butrón et al. 2008). In hybrids, 8711-Hyb and 32W86-Hyb took longer time to develop and less *S. cerealella* emergence and grain damage (Ahmed et al. 2013). On AG1501 genotype, *S. cerealella* led to longer development period, shorter survival percentage and lower kernel weight loss percentage (Foaud et al. 2013).

Resistant hybrids possessed higher amount of phenol (0.497–0.641 µg/g), amylose (24.90–28.53%) and amylase activity (798–843 µg/min) compared to susceptible ones (Muthukumar et al. 2015).

The variables that have been mainly used for characterizing resistance were: number of emerged adults, grain damage, days to adult emergence, egg hatching, fecundity, adult weight, susceptibility index (Ahmed et al. 2013; Butrón et al. 2008; Soujanya et al. 2015; Demissie et al. 2015; Foaud et al. 2013; Shafique and Chaudry 2007; Muthukumar et al. 2015).

Few researchers measured mortality of larvae before entering the seed. We want to learn about the role of the pericarp as a barrier to the entry of *S. cerealella* larvae. The novelty of this manuscript is that we focus on almost all stages of the biological cycle of *S. cerealella* to visualize where the highest level of antibiosis is. Therefore, the objective was to look for new sources of resistance to *S. cerealella* in Mexican maize races. We focus on how the different maize races affect the adults and larvae *S. cerealella*.

Materials and methods

Plant material

In 2009, at the Chihuahua State, 13 maize races were found. Fourteen accessions into eight Mexican maize races, according to seed availability, were used to study the resistance to *S. cerealella*. The seed of the Mexican maize races used in the present research was reproduced in 2019 at INIFAP Experimental Station at Bachiniva, Chihuahua, Mexico.

Bioassay for resistance study

One bioassay was carried out to check for resistance to *S. cerealella* on April 08, 2020. The experiment was conducted based on a completely randomized design with eight repetitions. The *S. cerealella* eggs used in the experiment infestation were obtained from stock cultures reared at the SENASICA Laboratory (National Service of Agrifood Health, Safety and Quality), Navojoa Sonora, Mexico. We evaluated 14 maize accessions in bottles, 5 cm in diameter and 5 cm in height, together with 20 seeds per repetition and eight repetitions. The following variables were measured: (1) Seed initial weight (g), measured in a precision scale in grams; (2) Consumption (g), calculated after the first generation with formula: initial weight − final weight; Consumption (%), calculated with formula: consumption (g) * 100/initial weight; (4) Unhatched eggs (*n*), as number of unhatched eggs, saw and accounted in a stereomicroscopy; (5) dead larvae (*n*), as number of larvae mortality before entering the seed, accounted in a stereomicroscopy; (6) adults (*n*), number of adults accounted and (7) biological cycle (days), which estimated from the date of the experiment until the first adult emerged.

Statistical analysis

To analyze the data of the experiment, we used general linear models (GLM) in statistical package SAS 9.4 (SAS Institute 2016) and for mean comparisons we used the test of MSD (minimum significative difference) from Tukey at $p < 0.05$. Pearson correlation between traits was calculated in Excel 2007. The maize accessions were classified into types of endosperm and according to grain color and a comparison was made between groups (Table 1).

Table 1 Characteristics of seeds of 14 maize races originating from INIFAP evaluated for antibiosis and tolerance to *S. cerealella*

Accession	Maize race	Species	Color	Endosperm type
8-Carreras-PP	8-Carreras	*Zea mays*	White	Dent
8-Carreras-RP	8-Carreras	*Zea mays*	White	Dent
Cacahuacintle	Cacahuacintle	*Zea mays*	White	Floury
Azul	Azul	*Zea mays*	Black	Floury
Cristalino-061	Cristalino de Chihuahua	*Zea mays*	White	Flint
Bofo	Bofo	*Zea mays*	Purple	Floury
E-Zapata	–	*Zea mays*	White	Dent
Cristalino-279	Cristalino de Chihuahua	*Zea mays*	White	Flint
Cristalino-282	Cristalino de Chihuahua	*Zea mays*	Yellow	Flint
Apachito-r	Apachito	*Zea mays*	Pink	Flint
Cristalino-079	Cristalino de Chihuahua	*Zea mays*	Yellow	Flint
Apachito-b	Apachito	*Zea mays*	White	Flint
Gordo	Gordo	*Zea mays*	White	Floury
Palomero	Palomero de Chihuahua	*Zea mays*	Yellow	Flint

In maize races, we found 8 accessions with white color, 3 yellow and 3 colored (one black, one purple and one pink) (Fig. 1).

Results

Significant differences were found for seed initial weight between maize accessions. The variety with more seed initial weight is 8-Carreras-PP (9.28 g) and less Palomero (3.31 g) (Fig. 2). White accessions have more seed initial weight, 5.9 g, than yellow accessions with 4.1 g (Fig. 3). Dent accessions have more seed initial weight, 7.8 g, and less flint accessions with 4.5 g (Fig. 4).

Significant differences were found for consumption in grams between maize accessions. The accession with less level of consumption was Cristalino-079, being this accession the most resistant to *S. cerealella* attack. In addition, the accessions with more level of consumption, and therefore the most susceptible, were Bofo, Cacahuacintle, 8-Carreras-RP and 8-Carreras-PP (Fig. 5). Colored and white accessions have similar consumption, 0.61 and 0.60 g, respectively, and had more consumption than the yellow accessions, 0.39 g (Fig. 6). Dent accessions have more consumption, 0.82 g, than floury and flint accessions with 0.65 and 0.40 g, respectively (Fig. 7).

Significant differences were found for consumption in percent between maize accessions. The accessions with more consumption were Palomero, Bofo and Cacahuacintle. And the accessions with less consumption (%) were Cristalino-079, Cristalino-282, Cristalino-279 and Azul (Fig. 8). No differences were found between accession colors for consumption in percent, ranged from 10.13 in whites to 11.64 in coloreds (Fig. 9). Significant differences were found for consumption in percent between maize hardness ranged from 9.48 in flints to 12.08 in floury (Fig. 10).

Although high coefficient of variation was calculated, significant differences were found for unhatched eggs between maize accessions. The accession with more unhatched eggs was 8-Carreras-PP. The maize accession with less unhatched eggs was Palomero (Fig. 11). No differences were found between colors of accessions for unhatched eggs, ranged from 1.75 in yellows to 2.16 in whites (Fig. 12). No differences were found for unhatched eggs between maize hardness ranged from 1.86 in flints to 2.33 in dents (Fig. 13).

Significant differences were found for larvae mortality before to entering the seed between maize accessions. The accession with more mortality of larvae was Cristalino-079. And the maize accessions with less larvae mortality were Bofo, Cacahuacintle, E-Zapata, 8-Carreras-RP and Apachito-r (Fig. 14). Yellow accessions have more mortality of larvae, 2.42, than the colored accessions, 1.0 (Fig. 15). Flint accessions have more mortality of larvae, 2.04, than floury accessions with 0.94 (Fig. 16).

Significant differences were found for adult number between maize accessions. The accessions with more adult number were Bofo, Cacahuacintle and E-Zapata. And the maize accessions with less adult number were Cristalino-079, Cristalino-282 and Cristalino-279 (Fig. 17). Colored and white accessions have more adults, 8.54 and 8.14, respectively, than the yellow accessions, 5.83 (Fig. 18). Dent accessions have more adults, 9.58, than flint accessions with 6.32 (Fig. 19).

Significant differences were found for biological cycle between maize accessions. The accessions with more biological cycle were Cristalino-079 and Gordo. And the maize accessions with less biological cycle were Cacahuacintle, Bofo, E-Zapata and Palomero (Fig. 20). Yellow accessions have a longer biological cycle, 57.5 days, than the colored

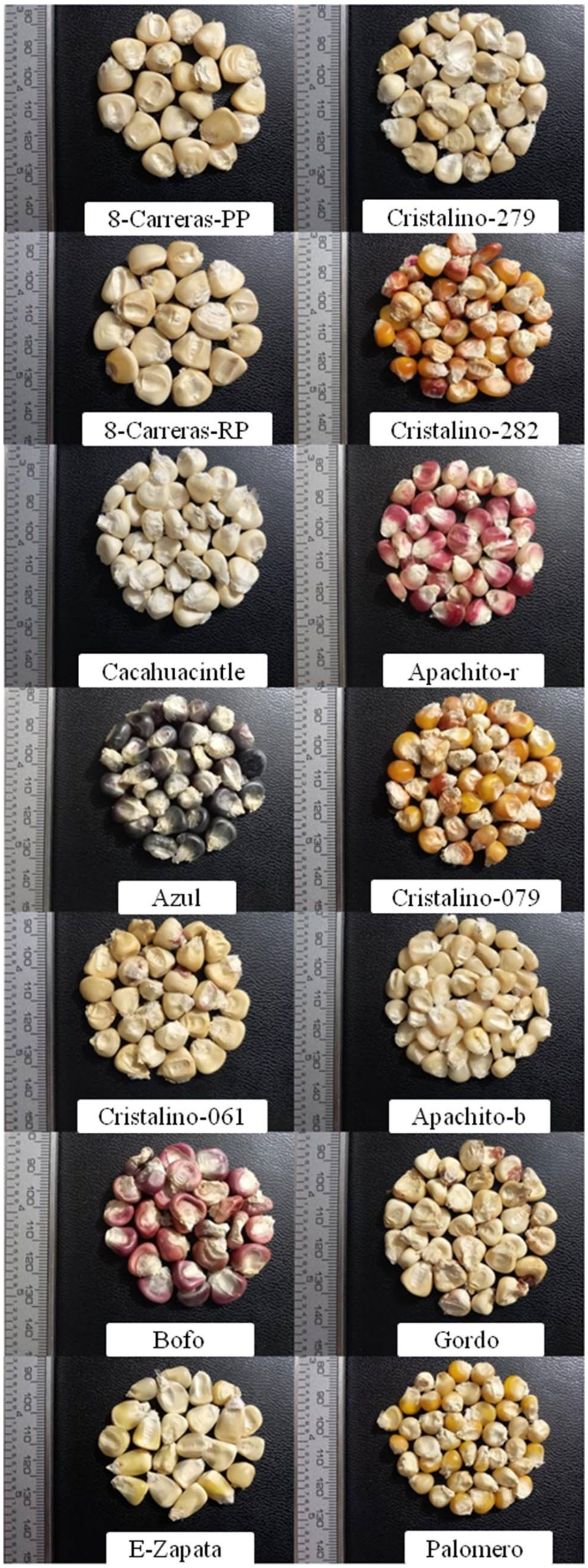

Fig. 1 Fourteen accessions into eight Mexican maize races

accessions, 52.8 days (Fig. 21). Flint accessions have a longer biological cycle, 56.3 days, than floury accessions with 53.4 days (Fig. 22).

Positive correlation was found between seed initial weight and consumption in grams (0.52). Positive correlation between consumption in grams and consumption in percent (0.75); On other hand negative correlation was shown between consumption, in grams and in percent with cycle (− 0.56, − 0.52, respectively), this mean that the susceptible accessions have a shorter biological cycle and resistant accessions have a longer biological cycle; while positive correlations were found between consumption, in grams and in percent, and adults number (0.78, 0.75, respectively), thus more number of adults means a higher level of consumption. And negative correlations between cycle and number of adults (− 0.60), this means that the susceptible accessions (with more number of adults) have a shorter biological cycle and resistant accessions (fewer adults) have a longer biological cycle (Table 2).

Discussion

None of the maize variety was found to be completely resistant to *S. cerealella* (Khattak et al. 1996; Shafique and Chaudry 2007). Some efforts have been made to study differences among maize genotypes for resistance to *S. cerealella* (Peters et al. 1960, 1972; Villacis 1972; Weston et al. 1997; Ahmed et al. 2013; Soujanya et al. 2015; Demissie et al. 2015; Foaud et al. 2013; Shafique and Chaudry 2007; Muthukumar et al. 2015; Butrón et al. 2008). Our research is one of the few to include Mexican maize races for resistance to *S. cerealella*. Ehrlich and Raven (1964) proposed "classic theory" where they claim that: the co-evolution is a dynamic process whereby plant and insect species exhibit reciprocal selective pressure. Along this evolutionary process, insects diversify their feeding habits and behaviors, whereas plants develop defense strategies against insect herbivores (Ehrlich and Raven 1964; Hogenhout and Bos 2011; Jermy 1984; Rausher 2001; Thompson 1999). The strategies of plant defense are based on physical barriers, constitutive chemical defenses and indirect inducible defenses including volatiles (Ehrlich and Raven 1964; Hogenhout and Bos 2011). As in previous studies, we have found genetic variability for resistance to *S. cerealella* among races of Mexican maize. As consumption in grams and consumption in percentage vary together, we choose the first trait as a measure of resistance because it indicates the net loss in grams that we would expect. Then based on the consumption in grams, we classified the accessions as resistant (Cristalino-079); partially resistant (Cristalino-282, Gordo, Cristalino-279, Apachito-b and Azul) and susceptible (Bofo, Cacahuacintle, 8-Carreras-RP and 8-Carreras-PP). However, damage percentage in the

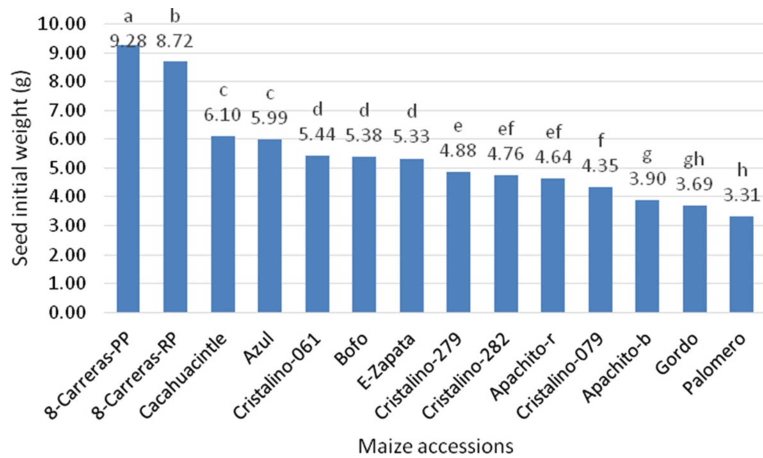

Fig. 2 Ten seeds initial weight from 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.98$, CV = 4.5, MSD = 0.42

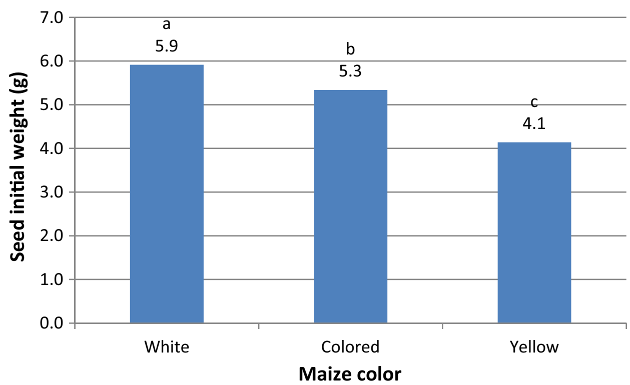

Fig. 3 Means for ten seeds initial weight from maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.15

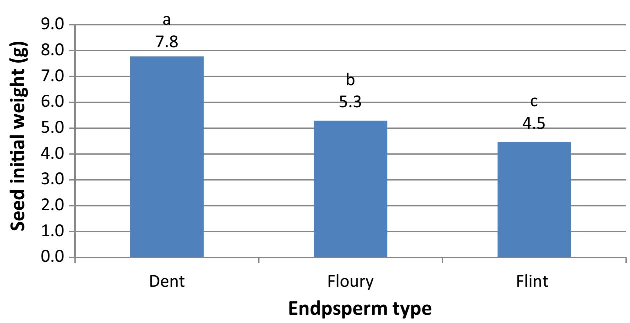

Fig. 4 Means for ten seeds initial weight from maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.14

present research (ranged from 4.5 to 20.6) and was lower that found by Ahmed et al. (2013) ranged from 5 to 95.2, but similar that found by Shafique and Chaudry (2007) ranged from 12.5 to 34.7.

The first character that explains the different degree of resistance in attacks is larval mortality before entering; this trait is given by pericarp. Thus, Cristalino-079 is resistant in part because it produces a high mortality of larvae, while the susceptible accessions: Bofo, Cacahuacintle and 8-Carreras-RP showed a low mortality. However, larval mortality is very poorly correlated with consumption, that is, its role in conferring resistance is smaller than the others traits. Therefore, the role of the pericarp as a producer of substances that kill larvae must be very small. However, its role as a physical barrier would not be ruled out because, although they do not have to produce a high mortality of larvae, they can produce a delay in entry that would clearly influence the length of the biological cycle. In stored grains pest insects it is very important the mortality of larvae before entering the grain because it is the second step, after of antixenosis, to reduce the spread of the pest (Jiménez et al. 2017). Jiménez-Galindo et al. (2020) reported the analysis of this characteristic to study the resistant of the bean testa to *Acanthoscelides obtectus* and reported a dominant gene with number of adults emerged. In the present research, the mortality of larvae before to entering the seed was negative correlated with number of adults (−0.49). Although it is important to mention that the role of larval mortality in total resistance does not seem to be so important in the present study.

Large size grains had heavy moths which caused high damage and small size varieties less weight loss (Ahmed et al. 2013; Peters et al. 1972). These results could be in agreement with the present study because we found positive correlation between initial weight and consumption in grams ($r = 0.52$).

High resistance in cereal grains to storage insects has been due to low adult progeny and prolonged developmental period (Ahmed et al. 2013; Butrón et al. 2008; Jiménez et al. 2017); Jiménez-Galindo et al. 2020). Previous results are according with the present study, where the cultivar Cristalino-079 is resistant to *S. cerealella* based on low adult progeny. Besides, Cristalino-079 showed long cycle. Consoli and Amaral Filho (1995) found significant differences in the development time of moth on all genotypes. This results are

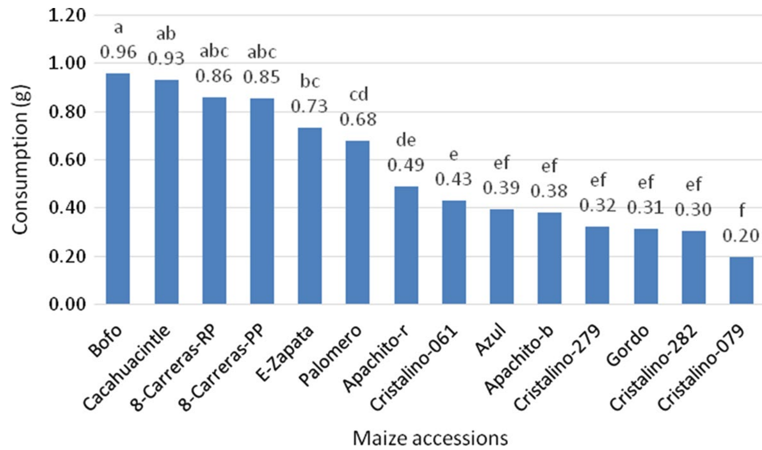

Fig. 5 Consumption in grams of 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.87$, CV = 21.0, MSD = 0.20

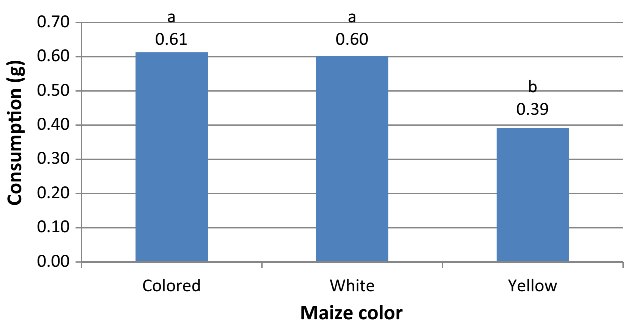

Fig. 6 Means for consumption in grams per maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.07

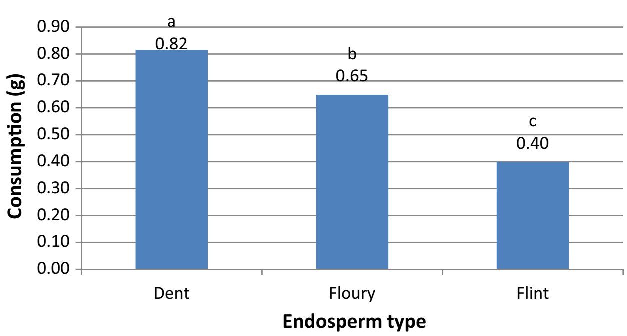

Fig. 7 Means for consumption in grams per maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.06

supported by Ahmed and Raza (2010) that indicate that varieties resistance cannot be judged with one criterion, rather many factors should be taken altogether.

In development and survivorship experiment, the susceptibility of corn genotypes to *S. cerealella* depended on the physical–chemical characteristics of kernels (Foaud et al. 2013). Modifications in physical–chemical characteristics of kernels may be an important trait to integrate in maize breeding programs (Foaud et al. 2013).

This resistance against post-harvest insects is usually associated with grain anatomical barriers, such as the pericarp thickness or toughness, grain hardness and type of endosperm. So vitreous endosperm has been directly correlated with the level of resistance (Akpodiete et al. 2015; García-Lara et al. 2004). The three susceptible accessions that have shown low mortality are the dent or floury grain while the resistant one is flint. So, in this material grain hardness plays a role as a defense mechanism against *S. cerealella*. In the present study, the most resistant accessions to *S. cerealella* were Cristalino-079 yellow and flint grain accession. Showed high mortality of larvae, longer biological cycle and fewer first generation adults and have smaller seed. Susceptible accessions have greater seed, floury varieties, shorter biological cycle, higher number of adults and also low larvae mortality before entering the seed. Other authors have reported a significant correlation between kernel weight and number of insects per kernel (Villacis 1972). We found that flint accessions (more resistant) have less seed initial weight, consumption in grams and adults number and higher larvae mortality and biological cycle than floury and dent accessions. Our results are according with Foaud et al. (2013) due to they found negative correlation between survival percentage and kernel hardness.

A strong negative correlation was observed between development period and kernel weight, moisture and protein contents (Foaud et al. 2013). We did not find correlation, between biological cycle and initial weight, because the susceptible accessions have heavier grains and shorter biological cycle.

Developmental period, progeny of emerging adults of *S. cerealella* and kernel weight loss were related to some kernel characteristics (Foaud et al. 2013). The present research is according because we found correlation between initial weight and consumption in grams 0.52. Although this

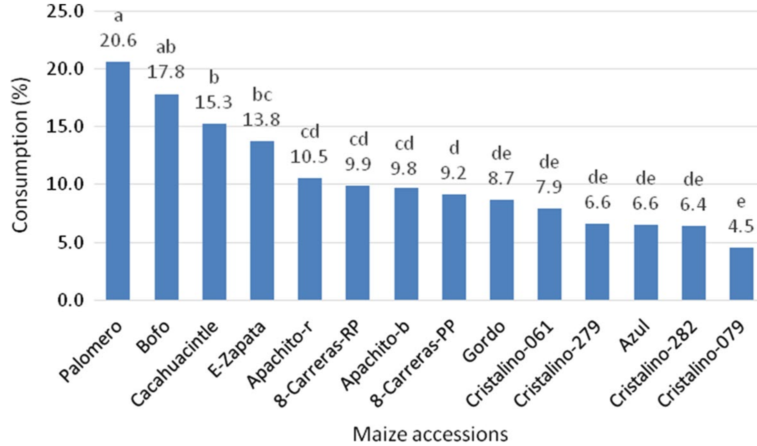

Fig. 8 Consumption in percent of 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.83$, CV = 23.4, MSD = 4.2

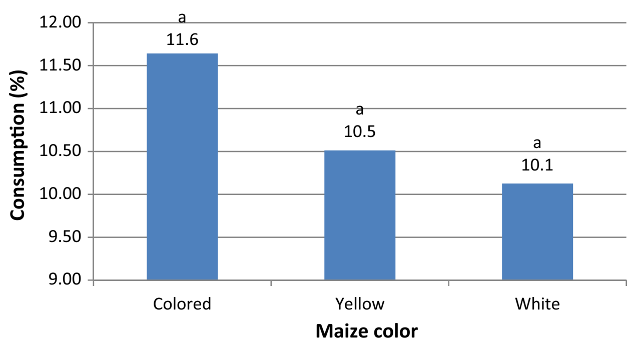

Fig. 9 Means for consumption in percent per maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 1.51

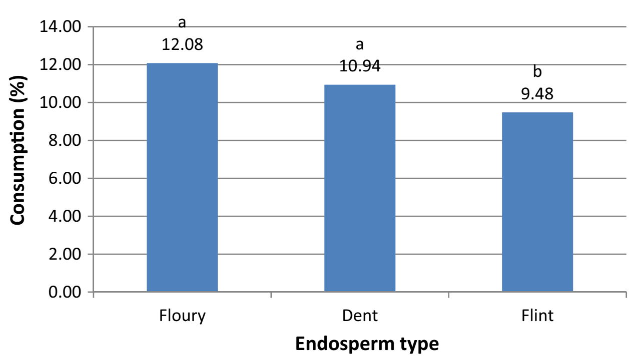

Fig. 10 Means for consumption in percent per maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 1.45

correlation was significant, it only partially explains the grain losses.

The correlation between adult moth progeny of *S. cerealella* and grain weight loss (0.977) was positive and significant (Shafique and Chaudry 2007). We found a positive correlation too, between adult's number and grain weight loss in grams 0.78 and percent 0.75. High number of adult progeny caused high weight loss of grain, which is clear indication of grains susceptibility to the insects (Shafique and Chaudry 2007).

High level of consumption and weight loss in Cacahuacintle and Bofo races are according with Wahla et al. (1984), Aslam et al. (2004), Shafique et al. (2006) and Shafique and Chaudry (2007). According with results obtained by Ahmed and Raza (2010) physical and morphological characters of maize grains may confer resistance in combination with some other factors particularly biochemical ones.

Some authors as Murayama et al. (2017), García-Lara and Bergvinson (2013) and Mwololo et al. (2012) have identified some native maize accessions as good natural sources of resistance, leading to loss reduction to less than 10%; however, their yield is still very low. Some breeding programs have therefore considered native varieties for the development of high-yield hybrids and varieties, and in addition with insect resistance (Abebe et al. 2009; Tefera et al. 2016).

The resistance in maize to storage pests is influenced by biophysical, biochemical and genetic factors, including kernel hardness, pericarp thickness/toughness, phenolic compounds, enzymes and structural components of the kernel (Akpodiete et al. 2015; García-Lara et al. 2004; García-Lara et al. 2007a; López-Castillo et al. 2018a; Saulnier and Thibault 1999; Sen et al. 1994).

Deeper studies in this area are necessary in future breeding programs (López-Castillo et al. 2018b). We are according with López-Castillo et al. (2018b) because they have considered the development of insect-resistant genotypes would be a sustainable alternative for pest control especially in developing countries.

The most resistant accession to *S. cerealella* was Cristalino-079 yellow and flint grain accession and it is promising source of resistance to *S. cerealella*. The most resistant accessions showed high mortality of larvae, longer biological cycle and fewer first generation adults. Also have smaller seed, flint and yellow grain. Susceptible accessions showed

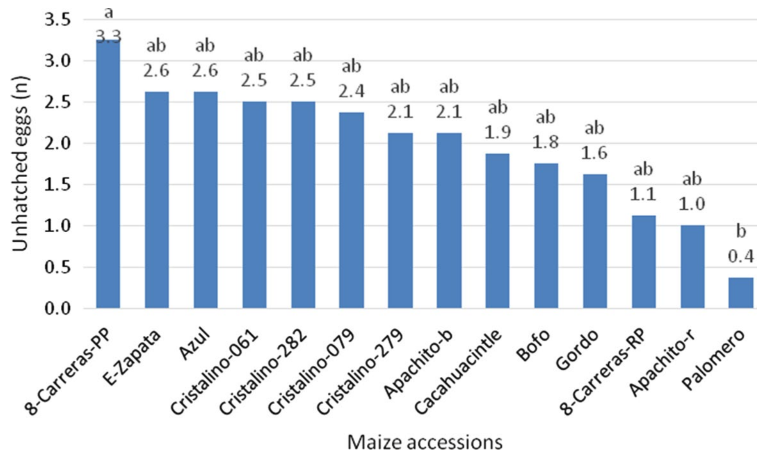

Fig. 11 Unhatched eggs of 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.37$, CV = 74.0, MSD = 2.5

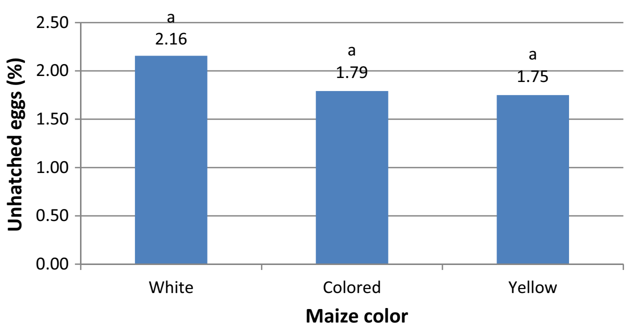

Fig. 12 Means for unhatched eggs per maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.90

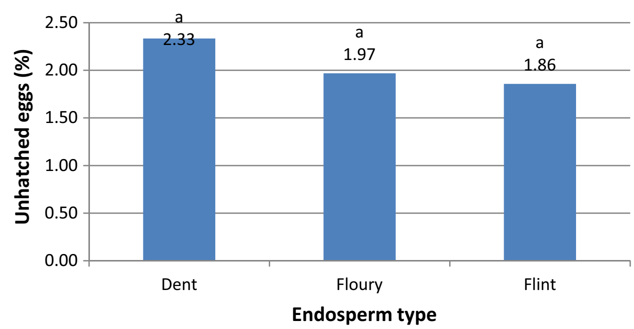

Fig. 13 Means for unhatched eggs per maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.86

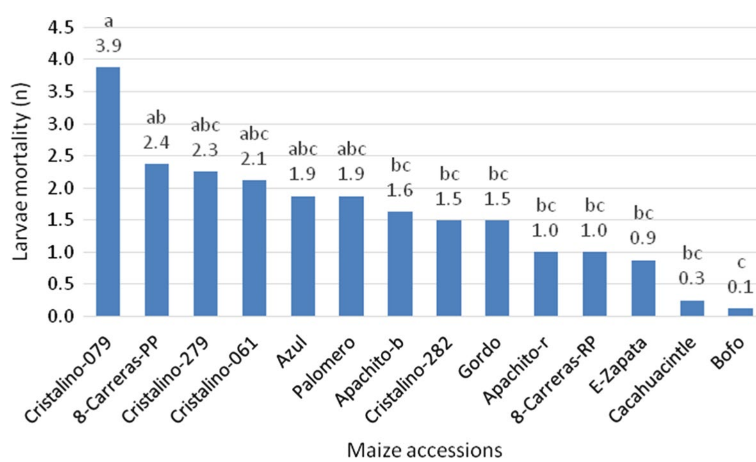

Fig. 14 Larvae mortality of 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.53$, CV = 77.9, MSD = 2.1

low larvae mortality before entering, shorter biological cycle, higher number of adults. Also greater and floury grain. Number of adults, high mortality of larvae before to entering the seed and biological cycle are the most interesting traits to study the resistance to *S. cerealella* in maize. Resistant and susceptible populations are an ideal material to find out what physical and chemical mechanisms are related to resistance to *S. cerealella*. Due to the small number of emerged adults, there was very little grain weight loss. The compound that causes high mortality of larvae before to entering the grain should be in the pericarp of resistant maize races; however, this trait had a small role in resistance. The compound or physical characteristics that cause largest biological cycle should be located in the endosperm

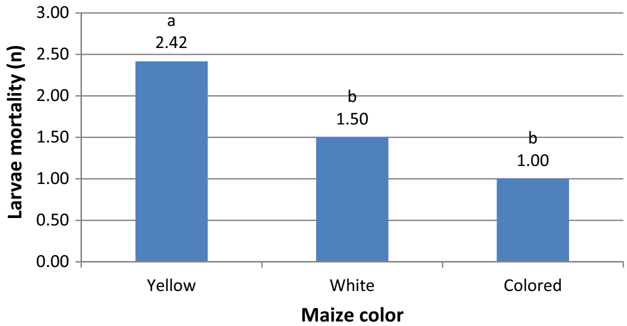

Fig. 15 Means for larvae mortality per maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.75

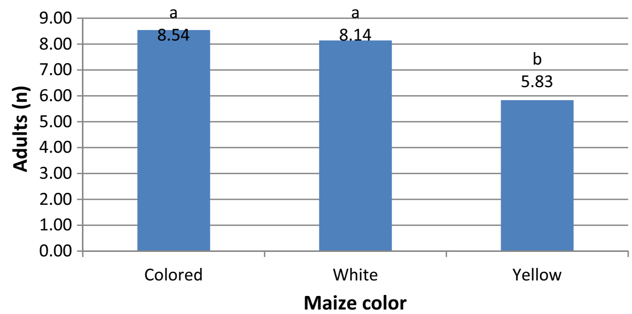

Fig. 18 Means for adults number per maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 1.31

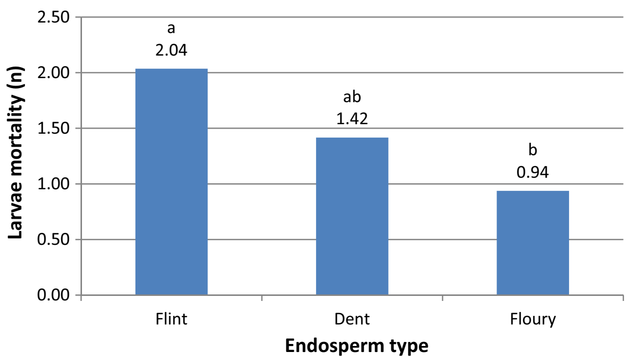

Fig. 16 Means for larvae mortality per maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 0.72

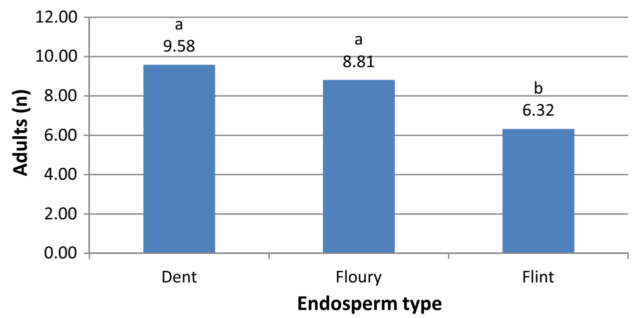

Fig. 19 Means for adults number per maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 1.25

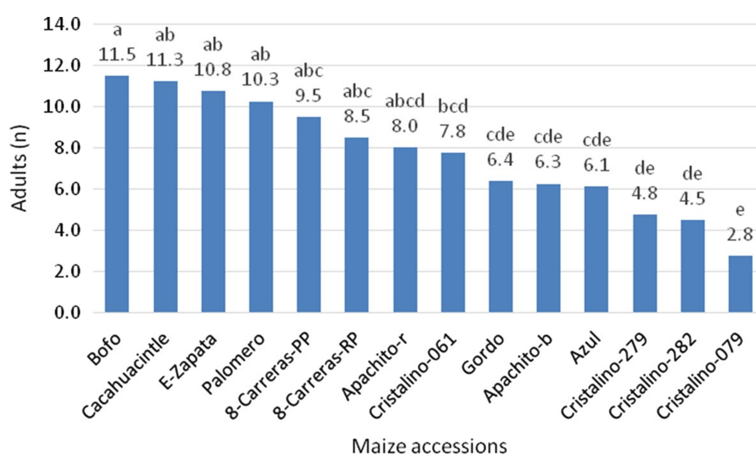

Fig. 17 Adults number of 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.71$, CV = 27.6, MSD = 3.7

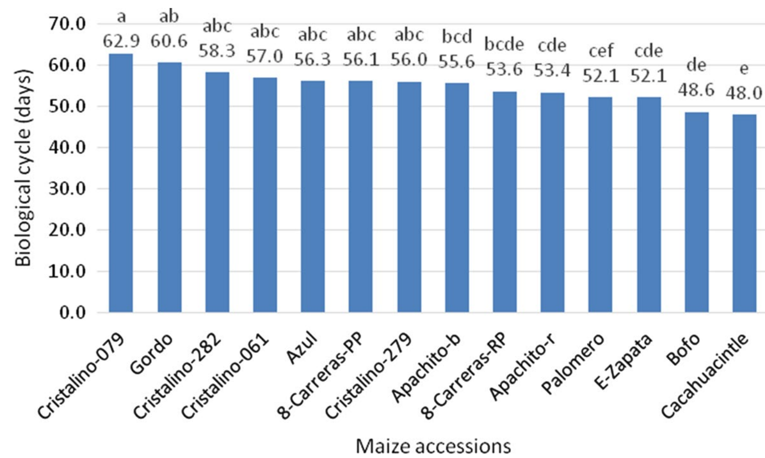

Fig. 20 Biological cycle of 14 maize accessions. Means followed by the same letter are not significantly different (Tukey = 0.05). $R^2 = 0.61$, CV = 7.5, MSD = 7.2

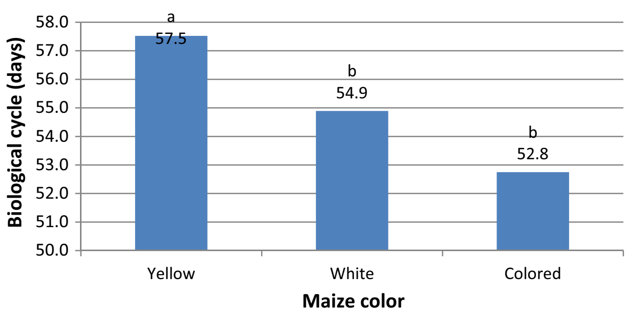

Fig. 21 Means for biological cycle per maize color. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 2.56

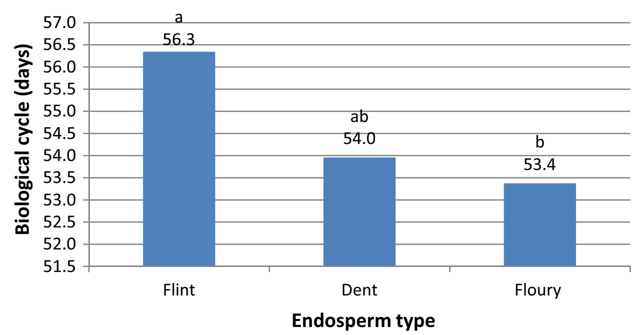

Fig. 22 Means for biological cycle per maize hardness. Means followed by the same letter are not significantly different (Tukey = 0.05). MSD = 2.44

Table 2 Pearson's correlations between seed and resistant traits for resistance to *S. cerealella* in Mexican maize races

	Initial weight (g)	Consumption (g)	Consumption (%)	Unhatched eggs (*n*)	Larvae mortality (*n*)	Biological cycle (days)
Initial weight (g)						
Consumption (g)	0.52*					
Consumption (%)	−0.12	0.75*				
Unhatched eggs (*n*)	0.17	−0.06	−0.25			
Larvae mortality (*n*)	−0.07	−0.43	−0.40	0.08		
Biological cycle (days)	−0.16	−0.56*	−0.52*	0.17	0.30	
Adults (*n*)	0.24	0.78*	0.75*	−0.13	−0.49	−0.60*

*Significant correlations with values greater than 0.50

and embryo but also in the pericarp. Cristalino-079 show the better level of resistance to *S. cerealella* infestation in almost all traits studied and this can be used as source of resistance for maize breeding.

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Author contributions PME, FOG and JCJG carried out bioassay in laboratory. JCJG realized statistical analysis of data and JCJG, PME and FOG realized the draft of initial manuscript. JCJG and FOG helped PME in the design of bioassay in laboratory, data collection, statistical analysis and discussion. AOO, FOG, GCP and JCJG were supervisors of Bachelor's degree of PME. All authors have edited, read and approved the final version of manuscript.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

Ethical approval Not applicable.

Informed consent Informed consent was obtained from all individual participants included in the study.

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