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*Corresponding author: Firoz Hossain,
Division of Genetics, ICAR-Indian
Agricultural Research Institute (IARI),
New Delhi 110012, India
E-mail: fh_gpb@yahoo.com

Reviewing editor:
Manuel Tejada Moral, University of
Seville, Spain

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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Genetics of resistance to stored grain weevil (*Sitophilus oryzae* L.) in maize

Rajkumar Zunjare¹, Firoz Hossain^{1*}, Vignesh Muthusamy¹, Sunil K. Jha², Pradyumn Kumar³, Javaji C. Sekhar⁴, Satish K. Guleria⁵, Narendra K. Singh⁶, Nepolean Thirunavukkarasu¹ and Hari S. Gupta^{7,8}

Abstract: Stored grain weevil (*Sitophilus oryzae*) has emerged as important storage grain pest of maize, causing substantial economic losses. Owing to high costs and environmental hazards of pesticides, host plant resistance holds promise for effective control of weevils. In the present study, a set of experimental maize hybrids generated using line × tester mating design were evaluated against *S. oryzae*. Significant variation for grain weight loss (GWL) (6.0–49.1%), number of insect progeny emerged (NIP) (17.8–203.3), grain hardness (GH) (263.1–495.4 N), and pericarp thickness (PT) (60.3–161.0 μm) was observed. Strong positive association was observed between GWL and NIP. GH and PT did not show any correlation with GWL and NIP. Additive and non-additive gene actions were important for both GWL and NIP. Promising inbreds and experimental crosses identified can be effectively utilized in the resistance breeding programme. In majority of promising crosses having desirable SCA effects, one of the parents had desirable GCA effects, indicating that selection of inbred parents based on per se performance for generating resistant crosses may be possible. The commercial hybrid checks were highly susceptible compared to experimental hybrids. The inbreds and experimental hybrids identified hold promise in developing weevil resistant maize cultivars offering sustainable solution to management of weevils in maize.

Subjects: Agriculture; Agriculture & Environmental Sciences; Crop Science; Pest Management

Keywords: storage pests; rice weevil; grain loss; gene action; *Zea mays*

1. Introduction

Maize (*Zea mays* L.) serves as an important crop in the world for its diverse utilization as a human food and livestock feed, besides serving as a major component for an array of industrial products (Gupta,

ABOUT THE AUTHORS

ICAR-Indian Agricultural Research Institute, New Delhi is a flagship organization for providing food and nutritional security in the country. The research group is involved in genetic improvement of maize for diverse biotic stresses. The present report was aimed to decipher the genetic basis of resistance to *Sitophilus oryzae*, a major post-harvest pest in maize causing substantial loss in Asian countries. The study identified promising inbreds and crosses possessing weevil resistance. These genotypes will serve as rich genetic resource in the resistance breeding programme.

PUBLIC INTEREST STATEMENT

The work presented in the manuscript describes the phenotypic characters and their association towards weevil (*S. oryzae*) resistance in maize. The genetic basis deciphered in the present study will help in designing suitable breeding strategy for imparting weevil resistance in maize. The resistant cultivars, thus developed will serve as sustainable and cost-effective solution to post-harvest loss of grains during storage.

Hossain, & Muthusamy, 2015). The ever-growing poultry industry will play a major role in growth of maize and by 2050, the demand for maize in the developing world will be doubled (Rosegrant et al., 2009).

Maize grains depending on climatic conditions are infested by a wide array of stored grain pests, of which weevil (*Sitophilus* sp.) causes major post-harvest losses worldwide, especially in the tropical and sub-tropical regions having high humidity and temperature (Muzemu, Chitamba, & Goto, 2013). *S. zeamais*, popularly known as “maize weevil”, is prevalent in Latin America, Europe, and Africa, while, “rice weevil” (*Sitophilus oryzae*) causes substantial losses in India and other Asian countries. *S. oryzae* is a major stored grain pest of rice and wheat, but because of its polyphagous nature, it also infects maize grain. The weevil can cause grain loss between 12 and 20%, and under favorable conditions, the extent of damage may go up to 80% (Keba & Sori, 2013; Tefera, Demissie, Mugo, & Beyene, 2013). The commencement of infestation by weevil starts in the field by penetrating through husk cover, and the damage is multiplied by several folds under storage conditions (Demissie, Tefera, & Tadesse, 2008). In developing countries like India, maize grains are often traditionally stored in jute bags. This leads to significant increase of moisture in grains especially during rainy season, thereby creating conducive conditions for grain weevil infestation (Hossain, Boddupalli, Sharma, Kumar, & Singh, 2007; Zunjare et al., 2014). Infested grain fetches lower market price due to reduced weight and nutritional value (Tefera, 2012). Seed viability of the damaged grains is drastically reduced and affects subsequent planting. Further, contamination of grains by mycotoxins due to the development of molds is a common phenomenon when humidity gets increased (Dowd, Johnson, & Williams, 2005; Hossain et al., 2007). Thus, infestation of weevils pose a serious threat to household livelihoods as well as local/regional food security (Dari, Pixley, & Setimela, 2010).

Chemical control using pesticides causes serious health and environmental hazards, besides high costs (Tefera, 2012). Indiscriminate application of pesticides may also lead to the development of resistance among the insect population (Adarkwah, Obeng-Ofori, Büttner, Reichmuth, & Schöller, 2012). Alternatively, resistance breeding holds significant promise as it is sustainable and eco-friendly; and provides economical means to minimize post-harvest losses caused due to storage pests (Abebe, Tefera, Mugo, Beyene, & Vidal, 2009; Mwololo, Mugo, Tefera, & Munyiri, 2013). Knowledge of nature of weevil resistance provides valuable leads in designing breeding strategies to develop resistant cultivars (Dari et al., 2010; Dhliwayo, Pixley, & Kazembe, 2005). Though studies on genetic analyses of resistance in maize to weevils are available, they were conducted against *S. zeamais* among germplasm especially from Africa (Castro-Álvarez, William, Bergvinson, & García-Lara, 2015; Dari et al., 2010; Derera, Giga, & Pixley, 2001; Derera, Pixley, Giga, & Makanda, 2014; Kim & Kossou, 2003). Till now, no report is available on genetics of weevil resistance against *S. oryzae* in maize. The present investigation, thus, was aimed at unraveling the genetics of weevil resistance in maize for adopting suitable breeding strategy for the development of weevil (*S. oryzae*) resistant cultivars.

2. Materials and methods

2.1. Generation and evaluation of experimental crosses

A set of normal inbreds (CA03139, CM140, CML336, Pant110, V340, MGHC4, MGHC2-2, CM135, and CML245) used as “line” were crossed with a set of popcorn inbreds (BLSBRIL92, MGP461, MGP462, MGP463, MGP464, MGP465, and BPCL51) as “tester”. The lines were of early to medium maturing type; and the testers were of early in flowering. Popcorn inbreds were highly resistant to weevils (Zunjare et al., 2014), while lines possessed higher degree of susceptibility to variable levels of resistance. Sixty-three experimental hybrids and their 16 parents along with eight commercial hybrid checks (Bio9681, HM-11, HM-9, HQPM-1, PMH-1, Parkash, Seed Tech-2324, and Vivek QPM-9) were evaluated at three diverse locations of the country viz. (i) IARI Experimental Farm, New Delhi (28°08' N, 77°12' E, 229 MSL) (ii) CSK-HPKV, HAREC, Bajaura (32°2' N, 77°9' E, 1090 MSL), and (iii) Crop Research Centre, GBPUAT, Pantnagar (29°3' N, 79°31' E, 244 MSL) during rainy season 2011. Genotypes were planted in a randomized complete block design with two replications per entry and one row per replication, with a plant-to-plant spacing of 25 cm and row-to-row spacing of 75 cm. Standard agronomic practices were followed for

raising and maintenance of the plants. Three to five plants in each of the replication were hand pollinated to avoid xenia effects.

2.2. Estimation of grain weight loss and insect progeny

A total of 100 randomly selected kernels per replication from the self-fertilized cobs per genotype were analyzed for their responses against weevil infestation. Kernels were wrapped in a cotton cloth and were put in desiccators having 25% KOH solution for 20 days to condition the seeds at ~15% moisture. The conditioned kernels were weighed, and transferred to a plastic petriplate with holes in the upper lid for ventilation. Fifteen pairs of newly emerged unsexed adult insects (equal male and female ratio is assumed) were kept for seven days for oviposition in each of petriplates (García-Lara, Khairallah, Vargas, & Bergvinson, 2009; Hossain et al., 2007; Tefera, Mugo, Tende, & Likhayo, 2011). Insects were allowed to mate and lay eggs just beneath the pericarp of the kernel. After seven days, the released insect pairs were taken out and the petriplates were kept in a BOD incubator at $28 \pm 2^\circ\text{C}$ and $70 \pm 5\%$ RH. After 30 days of incubation, the petriplates were monitored regularly for the emergence of insect progenies. After the emergence of first weevil, progenies were counted and removed from each petriplate on every alternate day for a period of next 40 days. After the completion of the experiment, grain weight loss (GWL) was calculated using $[(\text{Initial weight} - \text{final weight}) \times 100] / \text{initial weight}$. Number of insect progeny (NIP) per genotype was computed by adding the number of weevils emerged during 40 days period (Zunjare et al., 2014).

2.3. Grain hardness

Seven randomly selected kernels per replication were used for measuring grain hardness (GH) using texture analyzer (Scientific Microsystem, UK). The hardness of grains was measured at a moisture content of ~15%. For measurement of hardness, a cylindrical probe of 75 mm diameter was used. The test speed of the probe was fixed at 2 mm s^{-1} and the compression distance at 70%. The load cell of 500 kg capacity was used. The first peak force (N: newton) in the force deformation curve was noted as GH (Mohsenin, 1980).

2.4. Pericarp thickness

Three randomly selected kernels per replication were used for measuring pericarp thickness (PT) through compound microscope with ocular- and stage- micrometers. 2.5 gm of safranin stain in 100 ml of 95% ethanol was used to make a stock solution. Kernels were soaked for 24 h and crown of the kernel was removed using a single-edged razor blade. Free-hand section on the abgerminal side of the kernel was selected and was stained with dilute safranin. PT of the section was measured under power (10 \times) using an ocular micrometer (Tracy, Chandravadana, & Galinat, 1978). It was found that 1 ocular unit is equal to 0.0167 mm on the stage micrometer scale. PT (μm) was then calculated as ocular units \times 16.7.

2.5. Statistical analyses

The GWL was angular transformed as per the procedure given by Bliss (1937). Pearson's simple correlations among characters were computed using MS Office-Excel 2007. The data-sets from three locations were analyzed for combined ANOVA and pooled combining ability analyses using WINDOSTAT 8.5.

3. Results and discussion

3.1. Analyses of variability

Combined ANOVA revealed significant variations for GWL, NIP, GH and PT. GWL ranged from 6.0 to 49.1% with a mean of 24.4%. NIP among the genotypes varied from 17.8 to 203.3 with a mean of 91.1. This clearly indicates the scope for genetic improvement of weevil resistance in maize. Popcorn inbreds used as tester possessed low GWL (10.3%) and NIP (26.8) as compared to lines (GWL: 23.9%; NIP: 89.0), thereby indicating the presence of strong contrast among the parents used in the study (Table 1). Several researchers (Dari et al., 2010; Derera et al., 2014; Dhliwayo & Pixley, 2003; García-Lara et al., 2009; Masasa, Setimela, & Chiteka, 2013) have also reported wide variation for GWL and NIP among maize genotypes evaluated against *S. zeamais*. Variation for GWL, NIP, GH, and PT among the commercial checks is

Table 1. Details of inbreds used for genetic analyses of resistance against weevil infestation

| S. No. | Inbreds | Pedigree | GWL (%) | NIP | PT (µm) | GH (N) |
|----------------|-----------|---|---------|-------|---------|--------|
| Lines | | | | | | |
| 1 | CAO3139 | POP31 | 39.5 | 118.7 | 123.4 | 295.7 |
| 2 | CM140 | J 617-61-1-1-1-1-6-F55-1-1 | 34.5 | 136.7 | 152.6 | 349.9 |
| 3 | CML336 | 89[TL8645]/[P47s3/Mp78:518]B-24-1-1-4-1-3-B-#-B | 49.1 | 144.3 | 107.4 | 263.1 |
| 4 | Pant110 | Pop31-U18-2-1-1-4-2-2-U-2-U-3 | 6.6 | 26.8 | 96.0 | 315.1 |
| 5 | V340 | Derivative of (CM128 × CM129) | 10.2 | 40.2 | 107.7 | 340.7 |
| 6 | MGHC4 | (IML485-06-07)-3-1-3-2-3-U | 29.6 | 127.8 | 87.7 | 386.2 |
| 7 | MGHC2-2 | (Non NEH Pop-06-07)-8-3-2-U | 10.3 | 29.8 | 89.9 | 359.8 |
| 8 | CM135 | IPA-3 | 10.0 | 22.0 | 92.8 | 329.9 |
| 9 | CML245 | Pob86COHC77-21-2-1-2-1-1-1-b | 25.6 | 154.7 | 87.2 | 344.2 |
| Mean | | | 23.9 | 89.0 | 105.0 | 331.6 |
| Testers | | | | | | |
| 1 | BLSBRIL92 | (CM140 × CA00106)-U-U-U-U-U | 8.4 | 27.3 | 109.5 | 332.4 |
| 2 | MGP461 | (Pop Bulk-06-07)-4-7-1-2-2-U | 19.4 | 40.7 | 107.6 | 366.5 |
| 3 | MGP462 | (VL Pop Corn-06-07)-1-2-3-1-3-U | 7.1 | 17.8 | 90.0 | 281.7 |
| 4 | MGP463 | (VL Pop Corn-06-07)-2-1-2-3-1-U | 9.1 | 23.3 | 90.0 | 292.3 |
| 5 | MGP464 | (IML499-06-07)-1-2-5-3-2-U | 8.1 | 18.0 | 127.6 | 350.3 |
| 6 | MGP465 | (Non NEH Pop-06-07)-13-2-3-U | 7.9 | 22.8 | 76.9 | 332.3 |
| 7 | BPCL51 | Amber Pop corn 51-B | 12.3 | 37.8 | 132.7 | 332.1 |
| Mean | | | 10.3 | 26.8 | 104.9 | 326.8 |

Note: GWL: grain weight loss; NIP: number of insect progeny emerged; PT: pericarp thickness; GH: grain hardness.

presented in Table 2. In India, Hossain et al. (2007) and Zunjare et al. (2014) observed significant variation among inbreds for both GWL and NIP against *S. oryzae*. Soujanya, Sekhar, and Kumar (2013) also reported the similar trend among commercial hybrids. In the present study, GH varied from 263.1 to 495.4 N with a mean of 374.5 N. The mean PT was 97.5 µm, and it ranged from 60.3–161.0 µm. The mean for GH and PT among lines, testers, experimental crosses, and checks were similar. Broad variation for GH among maize genotypes have been reported earlier (Dari et al., 2010; García-Lara et al., 2009; Siwale, Mbata, Mrobert, & Lungu, 2009). Zunjare et al. (2014) reported a wide variation for GH (62.3–600.3 N) and PT (36.2–178.1 µm) in a set of specialty corn inbreds.

3.2. Association among characters

Correlation analyses revealed that GWL and NIP possess strong positive relationship ($r = 0.86^{**}$). However, GWL and NIP did not show any association with GH and PT in the present study. Studies by Abebe et al. (2009), Dari et al. (2010), Hossain et al. (2007), and Zunjare et al. (2014) also observed similar results; and they found strong association between GWL and NIP suggesting that these two characters are important for imparting resistance. García-Lara et al. (2009) reported no correlation between GH with GWL and NIP. The results thus revealed that only GWL and NIP have influence on imparting resistance to *S. oryzae*, while GH and PT do not contribute to resistance against weevil infestation (Zunjare et al., 2014). On the contrary, Siwale et al. (2009) reported that GH is closely related to maize weevil resistance. Kelvin (2002) reported snout penetration by the weevils into the maize grain depends on hardness of the grain. Grains with thick pericarp are harder in nature and are very tough to penetrate and suggested that PT may contribute to weevil resistance (Kelvin, 2002). Bergvinson (2001) and Ruswandi, Nono, Susanto, and Puspita (2009) reported negative correlation between GH and grain damage. Since the present study did not reveal any association of physical barriers such as GH and PT do not contribute to weevil resistance, biochemical properties such as α -amylase- and protease- inhibitors, and phenolics

Table 2. Performance of commercial hybrid checks to weevil infestation

| S. No. | Check hybrid | Pedigree | GWL (%) | NIP | PT (µm) | GH (N) |
|--------|----------------|--|---------|-------|---------|--------|
| 1 | Bio-9681 | Hybrid from Bioseed Pvt. Ltd. | 42.9 | 170 | 110.4 | 380.9 |
| 2 | HM-11 | HKI1128 × HKI163 | 36.1 | 143 | 62.7 | 340.5 |
| 3 | HM-9 | HKI1105 × HKI1128 | 34.5 | 156.3 | 74.2 | 377.9 |
| 4 | HQPM-1 | HKI193-1 × HKI163 | 36.7 | 195.2 | 77.9 | 319.5 |
| 5 | PMH-1 | LM13 × LM14 | 35.9 | 203.3 | 99.8 | 412.5 |
| 6 | Parkash | CM139 × CM140 | 29.7 | 87 | 115.1 | 429.7 |
| 7 | Seed Tech-2324 | Hybrid from Bisco Bioscience Pvt. Ltd. | 40.5 | 191.2 | 123.4 | 328.9 |
| 8 | Vivek QPM-9 | VQL1 × VQL2 | 33.8 | 116.8 | 127.6 | 379.3 |
| Mean | | | 36.3 | 157.9 | 98.9 | 371.1 |

Note: GWL: grain weight loss; NIP: number of insect progeny emerged; PT: pericarp thickness; GH: grain hardness.

such as (*E*)-ferulic acid may explain the basis of resistance to weevil infestation in maize (Arnason et al., 1994; Bergvinson & Garcia-Lara, 2004; Classen et al., 1990; Garcia-Lara & Bergvinson, 2014).

3.3. Effects of environment

Mean sum of square for environment was significant for NIP and GH, while GWL and PT did not exhibit any influence of environment. The study also revealed that genotype × environment interactions were non-significant for all the four characters. Kang, Zhang, and Magari (1995) also reported non-significance of cross × year interaction for GWL in a free choice weevil feeding experiment of maize. This indicates that specific maize genotype would not show differential response for weevil infestation under different environmental conditions. However, Kim and Kossou (2003) reported the significance of location × cultivar interaction for both egg plugs and weevil emergence. Garcia-Lara et al. (2009) also mentioned the quantitative trait loci (QTL) × environment interaction while experimenting with a mapping population for detecting QTLs for weevil resistance. The role of environment on GWL and NIP was also emphasized by Mwololo et al. (2012).

3.4. Gene action of contributing characters

Inbreds with less GWL and NIP are considered as resistant, while higher values of the same indicate severe susceptibility to infestation of *S. oryzae* (Hossain et al., 2007; Zunjare et al., 2014). Since GH and PT were not associated with either of GWL and NIP, combining ability analysis was carried out only for GWL and NIP. Variance due to lines, tester and line × tester were significant for both GWL and NIP. The study also revealed that GWL and NIP are governed by both additive and non-additive gene actions with almost equal magnitude (V_D/V_A : GWL = 1.23, NIP = 1.10). Several research groups have also reported that the resistance in maize against *S. zeamais* was governed by additive and non-additive gene actions (Dari et al., 2010; Derera et al., 2014; Kang et al., 1995; Kim & Kossou, 2003). However, Dhliwayo et al. (2005) reported that non-additive gene action was more important than additive gene action for weevil progeny emergence. Garcia-Lara et al. (2009) while mapping QTL governing maize weevil resistance against *S. zeamais* also reported that genetic effects were mainly of dominant type for both GWL and NIP. On contrary, various researchers observed preponderance of additive gene action in imparting resistance against *S. zeamais* in maize (Castro-Álvarez et al., 2015; Dhliwayo & Pixley, 2003; Kanyamasoro, Karungi, Asea, & Gibson, 2012). In the present study, narrow sense heritability for GWL (29.41%) and NIP (32.55%) was found to be of moderate magnitude. Garcia-Lara et al. (2009), while working with QTL mapping experiment for weevil tolerance in maize, reported narrow sense heritability being 48.0% and 45.0% for GWL and NIP, respectively. This suggests that it is possible to develop promising inbreds with higher degree of resistance through transgressive segregants generated from two diverse resistant inbreds (Castro-Álvarez et al., 2015).

Among the lines, Pant110 was identified as the best general combiner for both GWL and NIP with low level of weevil infestation (Table 3). Other promising inbreds with desirable GCA effects and low

Table 3. Mean and GCA effects of parents used in generating experimental crosses

| S. No. | Parents | GWL | | NIP | |
|----------------|-----------|-----------|-----------|-----------|-----------|
| | | Mean | GCA | Mean | GCA |
| Lines | | | | | |
| 1 | CA03139 | 39.5 | 0.72 | 118.7 | -1.39 |
| 2 | CM140 | 34.5 | 1.81** | 136.7 | 15.05** |
| 3 | CML336 | 49.1 | -1.06 | 144.3 | 6.86* |
| 4 | Pant110 | 6.6 | -8.88** | 26.8 | -26.53** |
| 5 | V340 | 10.2 | 1.92** | 40.2 | 2.46 |
| 6 | MGHC4 | 29.6 | 9.26** | 127.8 | 30.51** |
| 7 | MGHC2-2 | 10.3 | -1.61** | 29.8 | -26.34** |
| 8 | CM135 | 10.0 | -6.51** | 22.0 | -27.63** |
| 9 | CML245 | 25.6 | 4.34** | 154.7 | 27.01** |
| | | GM = 23.9 | SE = 0.56 | GM = 89.0 | SE = 2.78 |
| Testers | | | | | |
| 1 | BLSBRIL92 | 8.4 | 0.63 | 27.3 | 4.913* |
| 2 | MGP461 | 19.4 | 3.85** | 40.7 | 17.616** |
| 3 | MGP462 | 7.1 | -10.49** | 17.8 | -39.06** |
| 4 | MGP463 | 9.0 | -2.65** | 23.3 | -13.40** |
| 5 | MGP464 | 8.1 | 1.15* | 18.0 | 8.04** |
| 6 | MGP465 | 7.9 | 2.09** | 22.8 | 11.83** |
| 7 | BPCL51 | 12.2 | 5.41** | 37.8 | 10.06** |
| | | GM = 10.3 | SE = 0.49 | GM = 26.8 | SE = 2.45 |

*Level of significance at $p = 0.05$.

**Level of significance at $p = 0.01$.

Note: GWL: grain weight loss; NIP: Number of insect progeny emerged; GCA: general combining ability; GM: grand mean; SE: standard error.

means include CM135 and MGHC2-2. Among testers, MGP462 and MGP463 were identified as the promising general combiners for GWL and NIP with low weevil infestation. Based on level of infestation and SCA effects, V340 × MGP464 was the best cross-combination for both GWL and NIP, followed by MGHC2-2 × BLSBRIL92, CML336 × MGP462, Pant110 × MGP464, CM140 × MGP462, CML336 × MGP465, CML336 × MGP463, and CA03139 × MGP463 (Table 4). Kim and Kossou (2003) using diallel set identified two weevil resistant lines (TZi 30 and FLA2BT 106) with high GCA effects. The crosses with the low SCA effects included KU1414 × TZi1 and TZi25 × TZi28, Hi26 × TZi18, CM103 × KU1409 and CM116 × Hi26. Kang et al. (1995) identified Mo17 as the most promising inbred with lowest GCA effect for maize GWL against maize weevil infestation. Their study also led to the identification of L266 × L729, L605 × Mo17, and H111 × Mo17 with lowest SCA effects for GWL. Dhliwayo et al. (2005) while working with two diallel sets identified promising maize inbreds and hybrids for NIP based on combining ability estimates.

It is important to note that in majority of the promising cross-combinations (having desirable SCA effects for both the characters) identified in the present study, one of the parents of the crosses had desirable GCA effects. This is due to the importance of additive gene action underlying the characters. It therefore indicates that selection of inbred parents based on per se performance for generating resistant crosses may be possible. However, in few of the desirable cross-combinations, either of the parents was not having significant GCA effects in the desirable direction. This unpredictability of hybrid performance is due to contribution of non-additive gene action (Dari et al., 2010; Dhliwayo et al., 2005). Importance of both additive and non-additive gene action for GWL and NIP as observed in the study, revealed that recurrent selection could be employed to enhance the level of resistance in the population, which can further be used to derive promising inbreds with higher degree of resistance to weevils.

Table 4. Mean and SCA effects among promising experimental crosses

| S. No. | Crosses | GWL | | NIP | |
|--------|---------------------|-----------|-----------|-----------|-----------|
| | | Mean | SCA | Mean | SCA |
| 1. | V340 × MGP464 | 9.1 | -18.51** | 35.0 | -65.51** |
| 2. | MGHC2-2 × BLSBRIL92 | 9.1 | -14.52** | 40.2 | -28.41** |
| 3. | CML336 × MGP462 | 6.0 | -7.02** | 26.3 | -31.47** |
| 4. | Pant110 × MGP464 | 9.8 | -7.02** | 37.0 | -34.51** |
| 5. | CM140 × MGP462 | 8.9 | -7.03** | 39.2 | -26.83** |
| 6. | CML336 × MGP465 | 12.2 | -13.44** | 39.7 | -69.05** |
| 7. | CML336 × MGP463 | 12.5 | -8.41** | 43.2 | -40.31** |
| 8. | CA03139 × MGP463 | 14.5 | -8.15** | 41.8 | -33.38** |
| 9. | Pant110 × BLSBRIL92 | 13.0 | -3.31* | 49.0 | -19.38* |
| 10. | CM135 × BLSBRIL92 | 15.2 | -3.45* | 53.5 | -13.79 |
| 11. | V340 × MGP462 | 12.1 | -3.93* | 42.0 | -11.41 |
| 12. | Pant110 × BPCL51 | 15.6 | -5.49** | 71.7 | -1.87 |
| 13. | CM135 × MGP464 | 8.9 | 10.37** | 31.0 | -39.42** |
| | | GM = 24.6 | SE = 1.48 | GM = 90.0 | SE = 7.35 |

*Level of significance at $p = 0.05$.

**Level of significance at $p = 0.01$.

Note: GWL: grain weight loss; NIP: Number of insect progeny emerged; SCA: specific combining ability; GM: grand mean; SE: standard error.

Recently, Garcia-Lara and Bergvinson (2014) followed three cycles of intra-population recurrent selection in P84 population, and observed 2–3-fold increase in level of resistance against *S. zeamais*. The eight commercial hybrids evaluated in the present study, were found to have higher GWL (range: 29.7–42.9%, mean: 36.3%) and NIP (range: 87.0–203.3, mean: 157.9) (Table 2), as compared to experimental hybrids (GWL, range: 6.0–44.9%, mean: 24.6%; NIP, range: 26.3–168.5, mean: 90.0). Derera et al. (2014) demonstrated that grain yield is not correlated with weevil resistance, and it is possible to develop high yielding weevil resistant maize hybrids. Thus, imparting resistance to weevil infestation among high yielding maize hybrids warrants attention.

4. Conclusions

The present investigation revealed significant genetic variation for GWL, NIP, GH and PT. Positive correlation among GWL and NIP was observed, while GH and PT did not show any effects on imparting weevil resistance. Both additive and non-additive gene actions were important for imparting resistance against *S. oryzae*. Commercial checks were highly susceptible to weevil infestation, thus promising parents and hybrids identified in the present study possess great potential in the resistance breeding programme. These weevil resistant maize genotypes would offer sustainable, cost-effective, and eco-friendly solution to management of stored grain weevil (*S. oryzae*) in maize.

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Competing interests

The authors declare no competing interest.

Author details

Rajkumar Zunjare¹
 E-mail: raj_gpb@yahoo.com
 ORCID ID: <http://orcid.org/0000-0001-5001-2681>
 Firoz Hossain¹
 E-mail: fh_gpb@yahoo.com
 Vignesh Muthusamy¹
 E-mail: pmvignesh@yahoo.co.in
 Sunil K. Jha²
 E-mail: skj_ageg@iari.res.in
 Pradyumn Kumar³
 E-mail: pradyumn.kumar@gmail.com

ORCID ID: <http://orcid.org/0000-0002-0202-0350>

Javaji C. Sekhar⁴

E-mail: javajics@gmail.com

Satish K. Guleria⁵

E-mail: satishguleria_in@rediffmail.com

Narendra K. Singh⁶

E-mail: narendrksingh2@gmail.com

Nepolean Thirunavukkarasu¹

E-mail: tnepolean@gmail.com

ORCID ID: <http://orcid.org/0000-0002-6263-539X>

Hari S. Gupta^{7,8}

E-mail: hsgupta.53@gmail.com

¹ Division of Genetics, ICAR-Indian Agricultural Research Institute (IARI), New Delhi 110012, India.

² Division of Food Science and Post Harvest Technology, ICAR-Indian Agricultural Research Institute (IARI), New Delhi 110012, India.

³ ICAR-Indian Institute of Maize Research (IIMR), New Delhi 110012, India.

⁴ Winter Nursery Centre, ICAR-Indian Institute of Maize Research (IIMR), Hyderabad 500030, India.

⁵ CSK-Himachal Pradesh Krishi Vishwavidyalaya, Bajaura 175125, India.

⁶ G.B. Pant University of Agriculture and Technology, Pantnagar 263145, India.

⁷ ICAR-Indian Agricultural Research Institute (IARI), New Delhi 110012, India.

⁸ Borlaug Institute for South Asia (BISA), New Delhi 110012, India.

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