Society for Advancement of Wheat and Barley Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Journal of Cereal Research
12(2): 160-163

Short Communication

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Sources possessing multiple field resistance to bacterial stalk rot, banded leaf and sheath blight and maydis leaf blight of maize

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Article history: Received: 9 Jun., 2020 Revised: 15 July., 2020 Accepted: 29 July., 2020

Citation: Basandrai AK, D Basandrai and A Mehta. 2020. Sources possessing multiple field resistance to bacterial stalk rot, banded leaf and sheath blight and maydis leaf blight of maize. *Journal of Cereal Research* **12(2):** 160-159. http:// doi.org/10.25174/2582-2675/2020/100855

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Keywords: *Bipolaris maydis, dickeyazeae*, inbred lines, maize, resistance, *Rhizoctonia solani f.*sp. *sasakii.*

India ranks 4th and 7th in area and production, respectively among the maize producing countries. During the year 2018-19, the crop was grown in an area of 9.2 million ha with production of 27.8 million MT with productivity of 2965 kg/ha (https://iimr.icar.gov.in/india-maze-scenario/DACNET, 2020). The productivity of kharif maize, representing nearly 82% area, is low (2.2 t/ha). It is predominantly due to rainfed ecosystem. Moreover, prevalence of a large number of biotic stresses eg. bacterial stalk rot (BSR) caused by Dickeyazeae, banded leaf and sheath blight (BLSB), *Rhizoctonia solani* f.sp. *sasakii* and maydis leaf blight (MLB), *Bipolaris maydis* (Teleomorph: *Cochliobolus heterostrophus*) are the major constraints for low yield (Hooda *et al.,* 2012, Kumar *et al.,* 2017; Ding *et al.,* 2017; Mubeen *et al.,* 2017). In Himachal Pradesh, maize is the principal crop for food, fodder and feed (Lata *et al.,* 2014) and the state being a high rainfall area diseases viz. BSR, BLSB and MLB are the serious threats. Current practices for management of diseases and crop improvement involve development and selection of resistant inbred lines and use of synthetic pesticides (Mubeen *et al.,* 2017). Resistance breeding is considered the most effective and eco-friendly method to manage maize diseases but resistance to most of the prevailing diseases is scarce (Jindal *et al.,* 2019). However, identification of resistant inbred lines is a pre-requisite of any breeding program to develop hybrids and synthetics with superior resistance to the disease adapted to specific environments (Aregbesola *et al.,* 2020). In this context, 142 maize inbred lines, received through AICRP on maize were evaluated against the BSR, BLSB and MLB to identify sources with multiple resistance.

The material comprised 142 maize inbred lines received through AICRP on Maize during *Kharif* 2014. These were evaluated against three major diseases *viz.,* BSR, BLSB and MLB under artificial epiphytotics conditions at CSKHPKV, HAREC Dhaulakuan during the rainy season i.e. Kharif. The material was sown in paired row plot of 3 m length following standard package and practices for irrigated conditions (http://www.hillagric.ac.in/extension/dee/pdffiles /Kharif_28-8-09.pdf). The trial was sown in two sets i.e. one for BSR and other for BLSB and MLB. The susceptible checks were sown after every 10th test genotypes. The inbred lines were artificially inoculated with three pathogens separately as described by Hooda *et al.,* (2018) with slight modifications, where required.

Hypodermic syringe inoculation method was used for BSR using a local virulent isolate. The isolate was mass multiplied on nutrient agar broth. The inoculum was diluted 10 times with sterile water. The concentration of the bacterium was maintained ($1x10^{7-9}$ cells/ml of water). The inoculation was done at the pre-silking stage until 75 per cent flowered. A diagonal hole, deep up to the pith, was made with the help of a jaber in the middle of second internodes from the ground and about one millilitre of bacterial suspension at standard concentration was injected in the plant through that hole by a hypodermic syringe. After inoculations, the plants were frequently irrigated to maintain high humidity and soil moisture. Disease data were recorded on the basis of percentage of plants toppled/ rotten in each test entry and disease reaction was categorized as 1- 10 % as resistant; 10.1 -25.0% as moderately resistant; 25.1 -50.0 as moderately susceptible and > 50.0 susceptible.

The BLSB inoculations were done during the rainy days (July and August) at 30 to 45 days after sowing using

sheath inoculation technique. Grain culture of *Rhizoctonia solani* Kuhn f. sp. *saskii* Exnr was prepared for inoculation in the field for creation of epiphytotics (Ahuja and Pathak, 1978). Four inoculated barley grains were inserted at the junction between stalk and sheath at second or third inter-nodal level (Ahuja and Pathak, 1978). In addition to it, heavily BLSB infected leaves of susceptible varieties were cut into small bits which were placed at the junction of sheath and leaf about 20 days after the first inoculation to avoid escape. The data were recorded on the basis of modified 1-9 rating scale of AICMIP (1983) and Muisa and Quimiob (2006) after (Hooda *et al.,* 2018).

MLB appeared in epidemic form naturally. However, to avoid escape, the test lines and the susceptible check were inoculated using the powder of dry and heavily infected leaves collected during the previous year. Inoculation was done by placing a pinch of leaf meal (a heaped thimble ful) into the whorl of 30-35 days old plants during evening hours and was repeated 10 days, thereafter. Data were recorded after 30-35 days of the last inoculation using 1-5 scale as proposed by (Payak and Sharma, 1983).

One hundred forty two inbred lines were evaluated against BSR at HAREC, Dhaulakuan during *Kharif* 2014 season and the results are given in Table 1. Fifty eight inbred lines were free from the disease (Table 1), while 10 lines showing < 10% disease incidence were categorized as resistant. Thirty four inbred lines with disease incidence 11-25 % were categorized as moderately resistant (Table 1). As has been observed in the present studies, partial resistance against *E. chrysanthemi pv. zeae* has been reported in lines CM 101, CM 110, CM 104 and CM 105 and CM 600 (Kumar *et al.,* 2017). Similarly, for BLSB resistance, none of the line were found free from the disease whereas, one line i.e. Indimyt-145 -1-1 showed disease reaction 1. Moreover, 28 inbred lines showed disease reaction ≤2.0 (Table 1). As has been observed in the present studies, BLSB resistant inbred lines have been reported by Kumar and Singh (2002). Among the CIMMYT inbred lines, CA00310 was moderately resistant at Udaipur and Delhi, while CA00344 and CA00370 were moderately resistant at Pantnagar and Delhi (Garg *et al.,* 2007). Bhavana and Gadag (2009) identified inbred lines Pop145 and Suwan-1 as highly tolerant to BLSB. Similarly, Yang *et al.,* (2005) reported that inbred line CML 270 as highly resistant in China. Sharma *et al.,* (2002) reported lines PT 9630 18-1-B-B-B-B-B, Pop 352 co-hs 74-2-1-b-b, Pop145 co-hs-49-1-b-b-b-b, TOO 14901, TOO 14903, TOO 14903, TOO G1 802, CA 14510, CA 14524,CA 14522, TOO 35101, TOO 00310, IPA-2-2-f-1 and Suwan-1 (S) C #-B-B) as tolerant to BLSB. Thakur *et al.,* (2018) reported that under natural epiphytotic conditions six inbred lines *viz.,* CML161, CML189, BAJIMQ-08-27, CML193, CML162 and CML171 were moderately resistant to BLSB.

In case of maydis leaf blight resistance, one inbred line *viz.* PFSR (Y)-C0 -1-1 was found free from the disease and four inbred lines were highly resistant with disease rating scale of 1.0. Twenty six inbred lines with disease reaction ≤2.0 were resistant (Table 1). As has been observed in the present studies, inbred lines resistant to MLB have been identified and registered in India (https://iimr.icar.gov.in / wp- content/ uploads/2020/03/Registered-Germplasm-of-Maize.pdf). Singh *et al.,* (2018) reported that six genotypes (HKI 1128, HKI 5072-2BT (1-2-2), HKI 1352-58-9, MBR-139, HKI 190 and HKI 1352-58-9-2) were resistant whereas, 36 genotypes were moderately resistant against maydis leaf blight. Similarly, Kumar *et al.,* (2016) reported 25 inbred lines with stable resistance to MLB. Mubeen *et al.,* (2017) found two inbreds -SP-3 and NCML-73 as highly resistant under lab conditions and three inbreds - Margala, NRL-4, EV-1097 showed maximum resistance under field conditions to maydis leaf blight.

None of the line was free from all the three diseases. Nine inbred lines showed multiple resistance to BSR, BLSB and MLB. Seventeen inbred lines were highly resistant from BSR and resistant to BLSB (Table 1). Moreover, fifteen inbred lines were highly resistant from BSR and resistant to MLB, followed by eleven linesshowing resistance to MLB and BLSB (Table 1). As has been reported in the present studies, Hooda *et al.,* (2012) reported that out of 200 elite lines 66 lines showed multiple resistance to Turcicum leaf blight, MLB, BLSB, brown stripe downy mildew, post-flowering stalk rots, polysora rust, sorghum downy mildew, Rajasthan downy mildew, bacterial stalk rot and/or Curvularia leaf spot. Similarly, Jindal *et al.,* (2019) reported 26 inbreds of Canadian origin showed excellent resistance to multiple diseases. The present study showed that among the 142 inbred lines, six inbred lines showed multiple resistance to BSR, BLSB and MLB. These genotypes with multiple resistance may be directly used in the development of hybrid, composite and synthetic varieties with multiple resistance to these diseases for cultivation in the disease prone areas after their characterization for agronomic traits and synchronization etc.

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Table 1. Inbred lines possessing resistance to bacterial stalk rot, banded leaf and sheath blight and maydis leaf blight of maize

	Entries possessing resistance to								
Rating scale	MLB	Rating scale	BLSB	Inci-dence	BSR	MLB+ BLSB	MLB + BSR	BLSB + BSR	BLSB+BSR+ MLB
1 (HR)	PFSR (Y)-C0 -1-1, Indimyt-145 -1-1, CUBA 377, HKI 191-1-2-5 and HKI PC8	1 (HR)	Indimyt-145 -1-1	0 (HR)	58 lines	Indimyt-145 -1-1	Indimyt-145 -1-1	Indimyt-145 -1-1	Indimyt-145 -1-1
2 (R)	PFSR (Y)-C1-B -2-1-1- 1, V406 -2 -1-1 -1-1-1, Indimyt-100-2 -1-2-2-1, North east 4-1 (N)-1, PFSR(Y)-C1-A-B1White heart S. G. -1-2- 1-1 (Good), PFSR (White) -2-2-1-2, HEY Pool (Extra Early) -1-1-1-1, PFSR (Y)-C1-B -1-3, HKI 1344, CM 128, CML 446, DMSC 6, HKI Talar, EI 561, BML13, CM 111, CM 500, CML 117-3-4-1-1-4-1, CML 33, DMSC 16-1, DTPWC 9-F31-1-1-3, HKI 141, HKI-164-7-4-2, Tempx Trop (H0) QPM -B-B-B-57-B-B, TS2TR 1107 and WINPOP-43	2(R)	PFSR (Y)-C1-B -2-1-1- 1, Indimyt-100-2 -1-2-2-1, North east 4-1 (N)-1, Indimyt-145 -1-1-1-1, PFSR (Y)-C1-A-B1White heart S. G. -1-2- 1-1 (Good), PFSR(Y)-C1-A-B1White heart S.G. -2-1- 1-1, Indimyt-300-A(B.G.Yellow) -1-2-1-1, Indimyt-300-A(B. G. Yellow) -1-3-1-1 (Big), HEY Pool (Extra Early) -1-1-1-1, PFSR (Y)-C1-A-A1 (Pink heart BG) -1 -1, PFSR (Y)-C1-B -1-3, PFSR (Y)-C0 -1-1, Indimyt-300-B(BG Golden colour) -1-1, Indimyt -145 -1-1 and Indimyt-345 -1-1CML 446, HKI 1128, HKI 164-D-3-3-2, HKI Talar, HKI-2-6-2-4(1-2)-4, CM 119, CML165, HKI-164-7-4-2, ITNA 04, JCY 2-2-4-1-1, KML 3-3, SC 7-2-1-2-6-1 and TS2TR 1107	1-10.0 (R)	CM 502, HKI 164-D-3-3-2, HKI 31-2, SHD-1 ER6, Temp. HOC 15, CML165, CML 287, HKIC 78, ITNA 04 and Tempx Trop(H0) QPM-B-B-B-57-B-B	Eleven linesi.e.PFSR (Y)-C1-B -2-1-1-1, North east 4-1 (N)-1, PFSR(Y)-C1-A-B1White heart S. G. -1-2-1-1 (Good), HEY Pool (Extra Early) -1-1-1-1, PFSR (Y)-C1-B -1-3, PFSR (Y)-C0 -1-1, Indimyt-145 -1-1, CML 446, HKI Talar, HKI-164-7-4-2 and TS2TR 1107	PFSR (Y)-C1-B -2-1-1- 1, PFSR(Y)-C1-A-B1White heart S. G. -1-2-1-1 (Good), PFSR (White) -2-2-1-2, HEY Pool (Extra Early) -1-1-1-1, PFSR (Y)-C1-B -1-3, HKI 1344, CML 446, HKI Talar, BML13, CM 500, CML 117-3-4-1-1-4-1, HKI-164-7-4-2, Tempx Trop(H0) QPM-B-B-B-57-B-B and WINPOP-43	PFSR (Y)-C1-B -2-1-1- 1, North east 4-1 (N)-1, PFSR(Y)-C1-A-B1White heart S. G. -1-2- 1-1 (Good), PFSR(Y)-C1-A-B1White heart S.G. -2-1- 1-1, Indimyt-300-A(B. G. Yellow) -1-2-1-1, Indimyt-300-A (B. G. Yellow) -1-3-1-1 (Big), HEY Pool (Extra Early) -1-1-1-1, PFSR (Y)-C1-A-A1 (Pink heart BG) -1 -1, PFSR (Y)-C1-B -1-3, Indimyt -300-B(B G Golden colour) -1-1, Indimyt-345 -1-1, CML 446, HKI Talar, HKI-2-6-2-4(1-2)-4, HKI-164-7-4-2 and KML 3-3	PFSR (Y)-C1-B -2-1-1- 1, North east 4-1 (N)-1, PFSR (Y)-C1-A-B1 White heart S. G. -1-2- 1-1 (Good), HEY Pool (Extra Early) -1-1-1-1, PFSR (Y)-C1-B -1-3, , CML 446, HKI Talar and HKI-164-7-4-2
3 (MR)	39 lines	3(R)	85 lines	10.1-25 (MR)	34 lines	22 lines	17 lines	24 lines	10 lines
4 (S)	TL02A-1184A-32-1-3-1-2-1-1, AF-04-B-5796-A- 7-1-2-2-1-2-1-1-1, PFSR (Y)-C1-B -1-1-1- 2, PFSR (Y)-C1-B -2-2-1- 1, PFSR (Y)-C0 -2-1-1-1, PFSR (White) -2-2-1-1, AF-04-B-5796-A-7-1-2-2-1-2-2-2, Indimyt-145 -1-2-1-1, PFSR (White) -1-1, CM 212, CM 129, CM 132, CM 501, CM 105, CM 123, CM 149, CML 451(P2), DMSC 8, HKI 164-D-3-3-2, HKI 193-2-2-1, SHD-1 ER6, SKV 18, Temp.HOC 15, WS KHOTHAI-1-WAXY-1-1, EI 708, BML15, CM 115, CM 119, CM 130, CML175, CML 3, CML 321, IIMRQPM 58, G18seqcef 74-2-1, HKI 586-1 WG'33, HKI 164 —4(1-3), HKISCST, ITNA 04, KML 3-3, La Posta Seq C 7-F10-3-1-2-3-B-B-B-B-B-B, P 390AM/ CML C4F230-B-2-1, SC 24-(C12)-3-2-1-1, SC 7-2-1-2-6-1, WINPOP 2 and WSC Shru n ken X MUS MADHAU	4(MR)	PFSR (Y)-C1-A-A1 Pinkheart B.G. -1-2-1-1, Indimyt-145 -1-1-1-1, CM 129, CM 132, CM 128, DMSC 36, DMSC 1, DMSC 6, BML15, CML161, IIMRQPM 58, Gen 6033, HKI 586-1 WG'33, HKI PC8, HKI 164—4(1-3), HKISCST, La Posta Seq C 7-F10-3-1-2-3-B-B-B-B-B-B, SC 24-(C12)-3-2-1-1	25.1-50 (MS)	PFSR (Y)-C0 -2-1-1-1, Indimyt-100-2 -1-2-2-1, PFSR (Y)-C0 -1-1, CM 129, DMSC 6, HKI 1040-11-7, HKI 1128, EI 561, CM 115, CML 451Q, HKI 141, HKI 164-3 (2-1)-1, HKI-484-5, La Posta Seq C 7-F10-3-1-2-3-B-B-B-B-B-B, SC 24-(C12)-3-2-1-1, TS2TR 1107	AF-04-B-5796-A-7-1-2-2-1-2-2-2, CM 129, CM 132, BML15, IIMRQPM 58, HKI 586-1 WG'33, HKI 164—4(1-3), HKISCST, La Posta Seq C 7-F10-3-1-2-3-B-B-B-B-B-B, SC 24-(C12)-3-2-1-1	5 lines	4 lines	2 lines
5 (HS)	Nil	5 (MR)	Nil	>50 (S)	14 lines	Nil	Nil	Nil	Nil

HR= highly resistant; R= resistant; MR= moderately resistant; MS=moderately susceptible; S=susceptible; HS=highly susceptible

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