Indian Phytopathology (2020) 73:203–211
https://doi.org/10.1007/s42360-020-00208-z

RESEARCH ARTICLE

Leaf stripping: an alternative strategy to manage banded leaf and sheath blight of maize

Harleen Kaur[1] · Sanjay Kumar[2] · K. S. Hooda[3] · Robin Gogoi[4] · Pravin Bagaria[3] · R. P. Singh[5] · Rakesh Mehra[6] · Ashwani Kumar[6]

Received: 14 March 2019 / Revised: 7 August 2019 / Accepted: 13 February 2020 / Published online: 22 February 2020

Abstract
Banded leaf and sheath blight disease caused by *Rhizoctonia solani* f. sp. *sasakii* is a major constraint of *Kharif* maize. Wide host range of pathogen, its ability to survive as sclerotia under adverse environmental conditions and lack of resistant sources are some of the bottlenecks in its management. To reduce our dependence on chemicals, experiment was conducted at five hot-spots in India viz., Ludhiana (PAU and Ladhowal), Delhi, Karnal and Pantnagar centres to study the effect of leaf stripping method on disease severity and yield parameters of present day maize hybrids of different maturity groups as well as speciality corn cultivars. Per cent disease control achieved with leaf stripping treatment in different cultivars varied from 16.66 to 54.76% being highest at PAU, Ludhiana centre and lowest at Pantnagar centre. Maximum percent increase in yield was observed at Delhi centre (28.37%) closely followed by PAU, Ludhiana centre (28.23%). Positive correlation (r) was observed between mean per cent disease control and mean percent increase in yield.

Keywords Banded leaf and sheath blight · Hot-spots · Leaf stripping · Maize · *Rhizoctonia solani* f.sp. *sasakii*

Introduction

Maize (*Zea mays* L.) is the third most essential cereal crop in the world widely utilized as sustenance and domesticated animal fodder, as well as material in industries for items mainly starch and biofuels. Maize ranks fourth in production and fifth in area among the major cereals in India. Considering the losses caused by diseases, 16 out of 62 diseases have been identified as the major constraints. Among the foliar diseases, leaf blights and downy mildew are of economic importance. Among blights, banded leaf and sheath blight (BLSB) incited by *Rhizoctonia solani* f.sp. *sasakii* Exner (*Thanatephorus sasakii* (Shirai) Tu and Kimbrough) (Tu and Kimbrough 1978) is an important disease causing huge economic losses in maize growing areas of the world. *Rhizoctonia solani* being most widespread, versatile and destructive pathogen is responsible for causing varying type of symptoms such as seed or cob decay, damping-off, root rot, stem canker and aerial blight in different hosts (Ogoshi 1987). It has attained the status of an economically important disease in South and Southeast Asia (Sharma and Saxena 2002). In India, BLSB was reported for the first time from Tarai region of Uttar Pradesh (Payak and Renfro 1966). Later, reported from states of Assam, Haryana, Madhya Pradesh, Meghalaya, Rajasthan, Uttar Pradesh, Himachal Pradesh, Orissa, Punjab and West Bengal (Rani et al. 2013).

Rhizoctonia solani being soil borne pathogen, survives in the form of mycelium or sclerotia in soil and on infected crop debris. Warm-humid weather at vegetative stage of the crop favours development of the disease. An optimum temperature 28 ± 2 °C coupled with more than 88% relative humidity favours rapid disease development (Sharma

✉ Harleen Kaur
harleenkaur@pau.edu

[1] Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab 141004, India

[2] Department of Plant Pathology, Punjab Agricultural University, Ludhiana, Punjab 141004, India

[3] ICAR-Indian Institute of Maize Research, PAU Campus, Ludhiana 141 004, India

[4] Division of Plant Pathology, ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi 110012, India

[5] Department of Plant Pathology, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263001, India

[6] CCS Haryana Agricultural University, Regional Research Station, Uchani, Karnal, Haryana 132001, India

2005; Singh and Shahi 2012). These conditions prevail in the plains during *Kharif* season, a time when crop is at susceptible stage and causes a significant reduction of high yielding varieties. Several workers (Zhang et al. 1993; Tang et al. 2004; Izhar and Chakraborty 2013; Gao et al. 2014) have studied yield losses of BLSB on maize cultivars. In India, around 1 per cent of the total grain yield is reduced annually by BLSB (Payak and Sharma 1985). Lal et al. (1980, 1985) estimated that the loss of grain yield in India ranged from 23.9 to 31.9%, while Singh and Sharma (1976) reported from 10 to 40%. However, if the ear rot phase of this disease predominates, the magnitude of grain loss may go up to 100% (Huang et al. 2007).

The utilization of fungicides to manage BLSB in maize is limited and has unfavourable ecological implication, while the identification of resistant hybrids has not progressed much because of the non availability of the resistant donor (Sharma et al. 2002). Resistance breeding, therefore, appears to be difficult and distant possibility. Besides, wider host range and hard survival structures of the pathogen are further limitations in managing this disease (Groth and Bond 2006; Hooda et al. 2017). Since the pathogen has predilection for reaching the ear shoot from lower internodes through the overlapping leaf sheath, the concept of leaf stripping method was introduced by Sharma and Hembram in the year 1989. It was observed that a simple solution will be disrupting leaf sheath continuity at one of the lower internodes to prevent its further spread up. So keeping this in view, detailed study was planned across five hot spot locations in India under All India Coordinated Maize Improvement Project to study the effect of leaf stripping method on disease severity of BLSB and yield parameters of present day maize cultivars.

Materials and methods

Locations and field preparation

Five hot spot locations in India viz., Ludhiana (PAU and Ladhowal), Pantnagar, Karnal and New Delhi identified for banded leaf and sheath blight of maize were selected for this study. These locations represented a wide diversity in longitude from 75.54° at Ludhiana (Punjab) to 79.48° at Pantnagar (Uttarakhand) and altitude from 216 m to 344 m in New Delhi and Pantnagar respectively (Table 1).

Popular and promising maize cultivars of respective State were selected and were sown as per the standard package of practices for *Kharif* season.

(a) Ludhiana centre: The trial was conducted at two locations viz; Punjab Agricultural University, Ludhiana and ICAR-Indian Institute of Maize Research, at Ladhowal Farm, Ludhiana.

Table 1 Hot-spot locations for banded leaf and sheath blight of maize in All India Coordinated Maize Pathology Programme of India

Location	State	Latitude	Longitude	Altitude
Ludhiana	Punjab	30.55	75.54	262
New Delhi	Delhi	28.40	77.20	216
Karnal	Haryana	29.68	76.99	227
Pantnagar	Uttarakhand	29.02	79.48	344

(i) At PAU Ludhiana, experiment was conducted on four released hybrids from different maturity groups viz: late maturity (PMH 1 and Buland), medium maturity (PMH 4), early maturity (PMH 5) and one speciality corn composite (Punjab sweet corn 1) during *kharif* seasons 2016 and 2017.
(ii) At Ladhowal farm, six hybrids of different maturity groups viz; PMH 1, PMH 2, PMH 4, PMH 5, Parkash and DKC 9164 were evaluated against banded leaf and sheath blight of maize during *kharif* seasons 2017 and 2018.

(b) Delhi centre: Five hybrids (CP-999, CP-838, IM-8222, KH-2192 and Rasi-864) and one speciality corn early maturing hybrid-Vivek QPM 9 were evaluated against BLSB during *kharif* season 2016.
(c) Karnal centre: Three hybrids of different maturity groups viz; late maturity (HM-5), medium maturity (HM-4), early maturity (HM-6) and four speciality corn hybrids (HQPM1, HQPM4, HQPM5 and HQPM7) released by CCSHAU, Karnal, Haryana were selected for this study during *kharif* seasons 2016 and 2017.
(d) Pantnagar centre: Experiment was conducted on four composites (Amar, Kanchan, Gaurav and PSM3) and one susceptible inbred line—CM 600 during *kharif* seasons 2016 and 2017.

Experiment was laid out in randomized block design with two treatments:

(i) Stripped treatment—all plants inoculated and leaf sheath, just above inoculated internode, removed by sharp incision with scalpel, done after 48–72 h of inoculation.
(ii) Unstripped treatment—all plants inoculated but no sheath stripping was done, this represented control.

Mass multiplication and inoculation

Most virulent isolate of respective locations viz; Ludhiana, Pantnagar, Karnal and New Delhi identified on the basis of pathological and morphological characterization was

mass multiplied on maize-sand media in flasks (Riker and Rikar 1936). Inoculation was done after 30–40 days of sowing by artificial sheath inoculation method (Pascual and Raymundo 1989).

Data collection

Periodical observations on disease severity were recorded at 10, 20 and 30 days after inoculations following 1–9 rating scale (Hooda et al. 2018). Harvesting was done as soon as the husk-covers turned brown and the silks became completely dry. Grain yield and percent increase in yield was computed.

$$\text{Disease severity (\%)} = \frac{\text{Sum of numerical rating of disease scale}}{\text{No. of plants examined} \times \text{Maximum grade}} \times 100.$$

Statistical analysis

The significance of difference between means of two treatments was computed with critical differences (CD). Data were subjected to analysis of variance using the CPCS 1 and SPSS software. Correlation and standard error bar graph was computed between PDC and PIY by using excel software.

Results

PAU, Ludhiana centre

Data in Table 2 presented mean disease index of BLSB on five maize cultivars during *Kharif* 2016 and 2017. The pooled analysis of variance over two seasons showed highly significant difference between stripped and unstripped treatment. It is evident that in both the years, artificial inoculation was highly successful in inducing disease severity. Disease index was found maximum in unstripped treatment of PMH 4 (52.52%) followed by PMH 5 (48.92%) and Buland (46.27%). Minimum disease index was found in PMH 1(36.62%) followed by Punjab sweet corn 1 (40.90%). PMH 1, being a late maturity hybrid and ear height is more as compared to other hybrids, disease takes comparatively more time to infect ear. Therefore, disease index remained low in PMH 1 in both stripped and unstripped treatments. Maximum disease control was achieved in PMH 4 (62.90%) followed by PMH 5 (56.39%) (Fig. 1a). Similarly, pooled data of grain yield showed significant ($p < 0.001$) difference between treatments (Table 2). Mean grain yield recorded in

Table 2 Effect of leaf stripping treatment on severity of banded leaf and sheath blight and yield of different maturity groups of maize cultivars at PAU, Ludhiana centre

Treatments	Parameter	Year	Maize cultivars of different maturity groups				
			Late maturity		Medium maturity	Early maturity	Speciality corn
			PMH-1	Buland	PMH-4	PMH-5	Punjab sweet corn-I
Stripped	Disease severity (%)	2016	12.20^{a}	20.50^{b}	16.83^{ab}	19.73^{b}	17.17^{ab}
		2017	20.80^{a}	27.20^{b}	22.13^{a}	22.93^{a}	21.73^{a}
		Mean	16.50	24.02	19.48	21.33	19.45
	Grain yield (q/ha)	2016	68.51^{d}	54.16^{b}	65.27^{cd}	62.95^{c}	32.40^{a}
		2017	65.23^{b}	58.56^{b}	62.37^{b}	61.13^{b}	35.24^{a}
		Mean	66.87	56.36	63.82	62.04	33.82
Unstripped	Disease severity (%)	2016	33.90^{a}	50.00^{b}	55.83^{b}	54.23^{b}	39.27^{a}
		2017	39.33^{a}	42.53^{ab}	49.20^{c}	43.60^{b}	42.53^{ab}
		Mean	36.62	46.27	52.52	48.92	40.90
	Grain yield (q/ha)	2016	57.88^{d}	45.37^{bc}	49.54^{c}	44.44^{b}	24.07^{a}
		2017	56.70^{d}	49.56^{b}	47.13^{b}	42.89^{b}	27.40^{a}
		Mean	57.29	47.47	48.34	43.67	25.73

Treatment	Mean disease severity (%)		Mean grain yield (q/ha)	
	2016	2017	2016	2017
Stripped	17.35	22.96	56.66	56.51
Unstripped	46.65	43.44	44.26	44.74
CD (P = 0.05)	5.72	3.73	5.07	4.63

Values within experiments (same row) followed by the same letter are not significantly different at P = 0.05

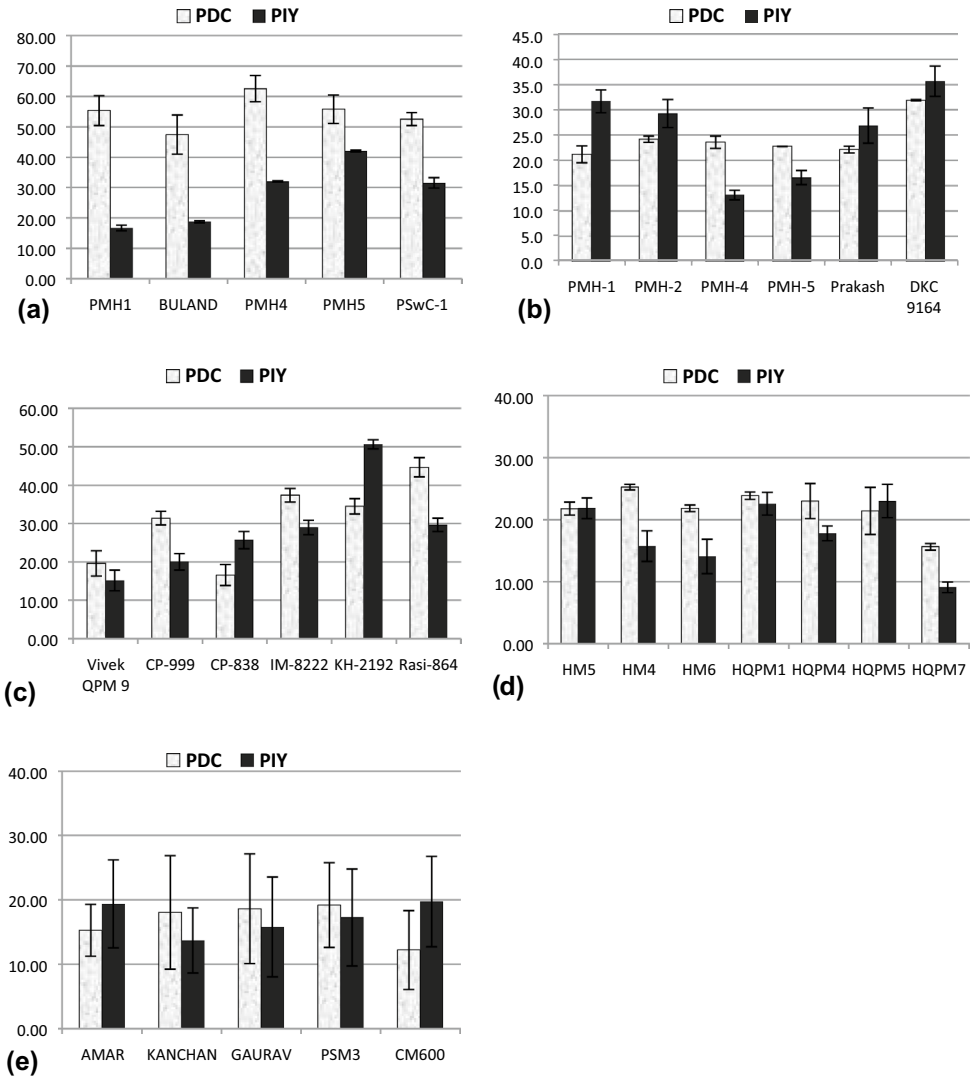

Fig. 1 Effect of leaf stripping on per cent disease control (PDC) of banded leaf and sheath blight of maize and and per cent increase in yield (PIY) on different maturity groups of maize cultivars at **a** PAU Ludhiana, **b** IIMR Ladhowal, Ludhiana, **c** Delhi, **d** Karnal and **e** Pantnagar centres

stripped treatment was 56.58 q/ha over unstripped treatment (44.50 q/ha). Percent increase in yield was found maximum in PMH 5 (42.27%) followed by PMH 4 (32.04%). However, there was significantly less increase in yield in PMH 1(16.70%) and Buland hybrid (18.76%) (Fig. 1a). Positive correlation (r = 0.47) was found between percent disease control and percent increase in yield (Table 7).

Ladhowal, Ludhiana centre

Data in Table 3 revealed that in stripped treatment, disease severity ranged from 61.6 to 71.6% in six hybrids of different maturity groups, being maximum in PMH 2 (early maturity hybrid). However in unstripped treatments, minimum disease severity recorded was 81.1% in PMH 1 (late maturity hybrid) and maximum (94.5%) in early maturity hybrid, PMH 2. Per cent disease control ranged from 31.9 to 21.0% being highest in DKC 9164 (Private sector hybrid) and lowest in PMH 1 (Fig. 1b). Similarly, grain yield varied from 24.9 to 49.3 q/ha and 18.4 to 37.5 q/ha in stripped and unstripped treatments respectively. The yield increase was found maximum (35.5%) in DKC 9164 hybrid. There was direct correlation between disease control and yield increase (r = 0.44) (Table 7).

Delhi centre

During *Kharif* 2016, Delhi centre conducted leaf stripping trial of BLSB on six maize hybrids and found that mean disease severity of 52.77% in unstripped treatment reduced to 36.57% in stripped treatment. Mean grain yield of different hybrids increased from 36.3 to 46.39 q/ha when leaf stripping treatment was followed (Table 4). There was 37.38% disease control in maize hybrid- IM 8222, resulting in 28.98% increase in yield. Speciality corn hybrid-Vivek QPM-9 recorded 19.62% disease control with 15.19% increase in yield (Fig. 1c). Mean per cent disease control

Table 3 Effect of leaf stripping treatment on severity of banded leaf and sheath blight and yield of different maturity groups of maize cultivars at Ladhowal, Ludhiana centre

Treatments	Parameter	Year	Maize cultivars of different maturity groups					
			Late maturity	Medium maturity	Early maturity			Private sector hybrid
			PMH 1	PMH 4	PMH 2	PMH 5	Parkash	DKC 9164
Stripped	Disease severity (%)	2017	56.6^{a}	64.0^{b}	70.3^{c}	67.2^{bc}	69.6^{bc}	58.5^{a}
		2018	71.5^{bc}	72.6^{bc}	73.0^{c}	74.4^{c}	69.6^{b}	64.6^{a}
		Mean	64.0	68.3	71.6	70.8	69.6	61.6
	Grain yield (q/ha)	2017	52.8^{d}	30.4^{ab}	40.1^{c}	33.7^{bc}	28.9^{ab}	25.3^{a}
		2018	45.8^{c}	31.5^{b}	28.0^{ab}	32.5^{b}	29.0^{ab}	24.5^{a}
		Mean	49.3	31.0	34.0	33.1	29.0	24.9
Unstripped	Disease severity (%)	2017	74.6^{a}	81.5^{b}	91.5^{c}	86.9^{bc}	88.2^{c}	86.1^{bc}
		2018	87.6^{a}	97.6^{b}	97.6^{b}	96.5^{b}	90.7^{a}	94.6^{b}
		Mean	81.1	89.5	94.5	91.7	89.5	90.4
	Grain yield (q/ha)	2017	41.3^{d}	27.3^{bc}	32.1^{c}	29.5^{c}	21.7^{ab}	19.4^{a}
		2018	33.7^{d}	27.4^{c}	20.8^{ab}	27.3^{c}	24.0^{bc}	17.4^{a}
		Mean	37.5	27.4	26.5	28.4	22.9	18.4

Treatment	Mean disease severity (%)		Mean grain yield (q/ha)	
	2017	2018	2017	2018
Stripped	64.4	70.9	35.2	31.9
Unstripped	84.8	94.1	28.5	25.1
CD (P = 0.05)	5.47	3.39	6.54	5.10

Values within experiments (same row) followed by the same letter are not significantly different at P = 0.05

Table 4 Effect of leaf stripping treatment on severity of banded leaf and sheath blight and yield of different maturity groups of maize cultivars at IARI, Delhi centre

Treatments	Parameter	Maize cultivars					
		Vivek QPM 9	CP-999	CP-838	IM-8222	KH-2192	Rasi-864
Stripped	Disease severity (%)	49.99^{b}	30.55^{a}	36.10^{a}	38.88^{ab}	36.10^{a}	27.77^{a}
	Grain yield (q/ha)	48.43^{bc}	44.66^{b}	46.24^{b}	54.53^{d}	50.15^{c}	34.33^{a}
Unstripped	Disease severity (%)	61.10^{b}	44.44^{a}	41.66^{a}	63.88^{b}	55.55^{ab}	49.99^{ab}
	Grain yield (q/ha)	41.86^{c}	36.95^{b}	36.89^{b}	42.38^{c}	33.29^{b}	26.44^{a}

Treatment	2016	
	Mean disease severity (%)	Mean grain yield (q/ha)
Stripped	36.57	46.39
Unstripped	52.77	36.30
CD (P = 0.05)	7.86	4.04

Values within experiments (same row) followed by the same letter are not significantly different at P = 0.05

showed positive correlation (r = 0.44) with yield increase (Table 7).

Karnal centre

Seven maize hybrids of different maturity groups tested under stripped and unstripped treatments showed mean disease severity of 49.6 and 63.5% respectively. Mean grain yield recorded was 63.2 and 54.1 q/ha in stripped and unstripped treatments respectively (Table 5). Highest disease control was observed in medium maturity hybrid—HM 4 (25.2%) followed by speciality corn hybrid- HQPM 1 (23.9%), thus increasing their grain yield by 15.7 and 22.6% respectively (Fig. 1d). Hence, positive correlation (r = 0.52)

Table 5 Effect of leaf stripping treatment on severity of banded leaf and sheath blight and yield of different maturity groups of maize cultivars at Karnal centre

Treatments	Parameter	Year	Maize cultivars of different maturity groups						
			Late maturity	Medium maturity	Early maturity	Specialty corn			
			HM-5	HM-4	HM-6	HQPM-1	HQPM-4	HQPM-5	HQPM-7
Stripped	Disease severity (%)	2016	56.4^{de}	50.3^{c}	46.8^{b}	58.2^{e}	54.7^{d}	55.2^{d}	42.3^{a}
		2017	46.2^{bc}	41.7^{a}	41.7^{a}	50.4 ^{cd}	53.8^{d}	52.5^{d}	41.7^{a}
		Mean	51.3	46.0	44.3	54.3	54.3	53.9	42.0
	Grain yield (q/ha)	2016	67.6^{c}	59.2^{a}	66.2^{c}	63.4^{b}	61.8^{b}	59.8^{a}	63.2^{b}
		2017	67.6^{c}	61.8^{b}	56.0^{a}	63.2^{b}	67.6^{c}	63.2^{b}	63.8^{b}
		Mean	67.6	60.5	61.1	63.3	64.7	61.5	63.5
Unstripped	Disease severity (%)	2016	70.5^{d}	66.6^{c}	60.6^{b}	77.5^{e}	75.8^{e}	76.4^{e}	50.7^{a}
		2017	60.5^{d}	56.4^{c}	52.7^{b}	65.3^{e}	65.6^{e}	61.5^{d}	48.9^{a}
		Mean	65.5	61.5	56.7	71.4	70.7	69.0	49.8
	Grain yield (q/ha)	2016	54.2^{bc}	53.1^{b}	56.2^{c}	50.4^{a}	53.4^{b}	50.5^{a}	58.7^{d}
		2017	56.8^{c}	51.5^{ab}	48.4^{a}	52.9^{b}	56.4^{c}	49.5^{ab}	57.7^{c}
		Mean	55.5	52.3	56.2	51.7	54.9	50.0	58.2

Treatment	Mean disease severity (%)		Mean grain yield (q/ha)	
	2016	2017	2016	2017
Stripped	52.0	46.9	63.0	63.3
Unstripped	68.3	58.7	53.8	54.1
CD (P = 0.05)	4.20	3.76	4.34	5.16

Values within experiments (same row) followed by the same letter are not significantly different at P = 0.05

was recorded between disease control and yield increase (Table 7).

Pantnagar centre

Among four composites and one inbred tested, mean disease severity of BLSB was 82.89 and 99.45% in stripped and unstripped treatments (Table 6). There was no significant difference observed in percent disease severity of different maize composites under stripped and unstripped treatments within the same year. Mean grain yield increased from 25.87 q/ha in control to 30.4 q/ha in stripped treatment. Per cent disease control and percent increase in yield varied from 12.21 to 19.17% and 13.7 to 19.75% respectively (Fig. 1e).

Discussion

Banded leaf and sheath blight of maize is soil borne and its mode of spread is through lower leaves which are in contact with infested soil. Seed borne inoculum may not play a major role in severe disease outbreaks. Control measures available are partly effective because *R. solani* is able to produce sclerotia that come up on the soil surface during field operations and thus cause infection (Ou 1985; Sumner and Minton 1989; Simon et al. 2014). Secondary spread is mainly due to contact of infected leaves and sheaths with healthy plants (Gilligan 2002). Thus, the disease progress upwards through the leaf sheath and reaches the ear shoot causing maximum damage by inducing complete ear rotting. If infection occurs at the reproductive stage, seed germination is adversely affected resulting in seed rot and seedling blight (Maiti 1978). Direct loss results in premature drying, stem breakage and ear rot; however indirect loss cause deterioration in grain quality.

Rhizoctonia solani has a wide adaptability including weeds (Kaur and Singh 2014) and due to intensive cultivation in Punjab State, pathogen continuously survives in rice-maize-potato cropping system. Being the preferred hosts, the disease severity aggravates in this cropping system as the pathogen causes sheath blight in rice (Zhang et al. 1993), BLSB in maize (Ahuja and Payak 1983) and black scurf in potato (Wick et al. 2001). Maize cultivars developed through crossing of tolerant inbreds show inconsistent results under artificial inoculation conditions. Several workers have mapped resistant QTLs in maize multiple genes by marker assisted selection (MAS) that may control different mechanisms for resistance (Prasanna et al. 2010). But till now no hybrid has been developed through MAS to give complete resistance to BLSB (Sharma et al. 2002). Lack of sources of host plant resistance, extensive use of chemicals,

Table 6 Effect of leaf stripping treatment on severity of banded leaf and sheath blight and yield of different maturity groups of maize cultivars at Pantnagar centre

Treatments	Parameter	Year	Maize cultivars				
			Amar	Kanchan	Gaurav	PSM3	CM600
Stripped	Disease severity (%)	2016	91.67[a]	97.22[b]	96.11[b]	92.22[a]	98.33[c]
		2017	75.56[a]	66.67[a]	66.67[a]	69.44[a]	75.00[a]
		Mean	83.62	81.95	81.39	80.83	86.67
	Grain yield (q/ha)	2016	17.22[b]	15.22[a]	20.67[c]	21.43[c]	14.29[a]
		2017	41.25[ab]	45.00[b]	50.70[c]	46.05[bc]	37.50[a]
		Mean	29.24	30.11	35.69	33.74	25.90
Unstripped	Disease severity (%)	2016	100.00[a]	100.00[a]	100.00[a]	100.00[a]	100.00[a]
		2017	97.22[a]	100.00[a]	100.00[a]	100.00[a]	97.22[a]
		Mean	98.61	100.00	100.00	100.00	98.61
	Grain yield (q/ha)	2016	16.17[b]	14.64[ab]	20.43[c]	20.75[c]	13.43[a]
		2017	31.80[ab]	37.20[c]	39.75[c]	35.70[bc]	28.80[a]
		Mean	23.99	25.92	30.09	28.23	21.12

Treatment	Mean disease severity (%)		Mean grain yield (q/ha)	
	2016	2017	2016	2017
Stripped	95.11	70.67	17.77	44.10
Unstripped	100.00	98.89	17.08	34.65
CD (P = 0.05)	1.01	8.46	NS	5.60

Values within experiments (same row) followed by the same letter are not significantly different at P = 0.05

Table 7 Mean disease control of BLSB with leaf stripping and increase in yield in maize hybrids of different maturity groups at five hot-spot locations of India

Mean percent	Hot spot locations				
	Ludhiana		Delhi	Karnal	Pantnagar
	PAU	Ladhowal			
Disease control	54.76	24.30	30.68	21.83	16.66
Increase in yield	28.23	25.50	28.37	17.74	11.79
r*	0.47	0.44	0.44	0.52	#

*Correlation (r) between per cent disease control and per cent increase in yield

#Variation within the treatment was low in disease severity of different maize cultivars

environmental and health hazards have forced the researchers to think of viable alternative cost effective management practices.

Management of BLSB in maize is effective only when the pathogen is completely eliminated or the inoculum level is below the economic threshold limit at field level. In the present study, mean percent disease control caused by leaf stripping in different maize cultivars varied from 16.66 to 54.76% at different hot-spot locations, found maximum at PAU, Ludhiana centre and minimum at Pantnagar centre (Table 7). At almost all the centres, different maize cultivars showed a significant response under the same disease pressure in stripped and unstripped treatment respectively. Kato and Incue (1995) observed restricted spread of disease after the fall of the lower leaf sheath. BLSB severity could also be correlated with the plant and ear height of maize plant. These results of present study indicated that more is the plant/ear height, comparatively less is the severity of the disease. At Ludhiana centre, ear height of PMH 1 is more as compared to other cultivars so the disease severity in both stripped and unstripped treatments of PMH 1 is comparatively less than other cultivars. However, PMH 5 and PMH 2, short duration hybrids have comparatively less plant and ear height; hence disease reaches ears in comparatively less time and intensity is more in both stripped and unstripped treatments as compared to other cultivars.

Subedi (1996) reported that the mechanical stripping of lower leaves does not affect the yield per se of the plant. Lower leaves contribute very little to grain dry matter accumulation, therefore, stripping of these leaves before silking and 30 days after, resulted in no significant reduction in grain yield. Presently, maximum increase in yield in stripped treatments was recorded at Delhi center (28.37%) closely followed by Ludhiana centre—PAU (28.23%) and Ladhowal (25.5%) (Table 7). Hence, a positive correlation was found between disease control and yield gain as confirmed by Liang et al. (1997).

Development of resistant varieties is a slow process and its durability is uncertain, chemical control also has its own limitations such as escalated costs, health hazards and environmental pollution. Even the use of biocontrol agents exhibit inconsistent performance resulting in their limited commercial use for suppression of soil borne plant pathogens (Harman 2000; Chaube et al. 2002). Considering these limitations, leaf stripping is a viable option towards management of BLSB in a sustainable manner. Similar effect has also been studied by Wang and Wang (1991), Mukherjee and Nayak (1997) in rice and Kumar and Krishanamurthy (2008) in finger millet. Furthermore, this technique of leaf stripping was also found cost effective, though validamycin provided maximum return from each rupee investment (Batsa et al. 2004).

Integrated disease management (IDM) which encompasses the strength of various management strategies viz; physical, biological, cultural, genetic resistance and chemical are the pre-requisite for BLSB management. Our present results indicated that the removal of lower two/three leaves along with sheaths before flowering (approximately 40 days after sowing) can be included as one of the important component in IDM module. Since still efforts are being done to manage this disease through host resistance. This approach will emphasize the importance of cultural practice along with other management strategies for getting maximum yield with minimum costs and hazards.

References

Ahuja SC, Payak MM (1983) A rating scale for banded leaf and sheath blight of maize. Indian Phytopathol 36:338–340

Batsa BK, Sharma RC, Rai SN (2004) Comparative efficacy of cultural, chemical and biological control against banded leaf and sheath blight in maize. In: Proceedings of the 24th national summer crops research workshop on maize research and production in Nepal, p 232

Bhukal N, Singh R, Mehta N (2015) Assessment of losses and identification of slow blighting genotypes against sheath blight of rice. J Mycol Plant Pathol 45(3):285–291

Chaube HS, Mishra DS, Varshney S, Singh US (2002) Biological control of plant pathogens by fungal antagonists: Historical background, present status and future prospects. Annu Rev Plant Pathol 2:1–42

Gao J, Chen Z, Luo M, Peng H, Lin HJ, Qin C, Yuan GS, Shen YO, Ding HP, Zhao MJ, Pan GT, Zhang ZM (2014) Genome expression profile analysis of the maize sheath in response to inoculation to *Rhizoctonia solani*. Mol Biol Rep 41:2471–2483

Gilligan CA (2002) An epidemiological framework for disease management. Adv Bot Res 38:1–64

Groth DE, Bond JA (2006) Initiation of rice sheath blight epidemics and effect of application timing of azoxystrobin on disease incidence, severity, yield and milling quality. Plant Dis 90:1073–1076

Harman GE (2000) Changes in perceptions derived from research on *Trichoderma harzianum* T-22. Plant Dis 84:377–393

Hooda KS, Khokhar KM, Parmar H, Gogoi R, Joshi D, Sharma SS, Yadav OP (2017) Banded leaf and sheath blight of maize: historical perspectives, current status and future directions. Proc Natl Acad Sci India Sect B Biol Sci 87:1041–1052

Hooda KS, Bagaria PK, Khokhar M, Kaur H, Rakshit S (2018) Mass screening techniques for resistance to maize diseases. ICAR-Indian Institute of Maize Research, PAU Campus, Ludhiana, p 93

Huang M, Tan J, Yang J, Yang K (2007) Research advances on Banded leaf and Sheath Blight of maize. Southwest China J Agric Sci 8:129–137

Izhar T, Chakraborty M (2013) Genetic analysis of banded leaf and sheath blight resistance (*Rhizoctonia solani*) in maize. J Pharmacogn Phytochem 1:1–5

Liang J, Chen H, Zhu H, Liu WJ, Huang Liu JYF, Zhao GD (1997) Yield losses of maize caused by sheath blight and its occurring pattern. Acta Phytophylactica Sin 24:101–106

Kato A, Incue Y (1995) Resistance to banded leaf and sheath blight (*Rhizoctonia solani* Kuhn) after fall of lower sheaths in maize (Zea mays L). Bull Natl Grass/Res Inst (Japan) 51:1–5

Kaur H and Singh S (2014) Effect of different weed flora on the development of banded leaf and sheath blight on *Kharif* maize. In: Proceedings of the national symposium on crop improvement for inclusive sustainable development. PAU, Ludhiana, pp 287–289

Kumar VBS, Krishinamurthy AT (2008) Employing some epidemiological tools for understanding the progress of leaf blast caused by *Pyricularia grisea* (Cke.) Sacc in finger millet. Mysore J Agric Sci 42(4):665–668

Lal S, Baruah P, Butchaiah K (1980) Assessment of yield losses in maize cultivars due to banded sclerotial disease. Indian Phytopathol 33:440–443

Lal S, Butchaiah K, Baruah P (1985) Comparitive efficacy of some fungicides and antibiotics in control of banded sclerotial disease of maize. Pesticides 19:17–19

Maiti AP (1978) Two new ear rots of maize from India. Plant Dis Rep 62:1074–1076

Mukherjee AK, Nayak P (1997) Association among the components of slow blasting resistance in rice. J Mycol Plant Pathol 27(2):175–183

Ogoshi A (1987) Ecology and pathogenicity of anastomosis and interspecific groups of *Rhizoctonia solani* Kuhn. Ann Rev Phytopathol 25:125–143

Ou SH (1985) Rice diseases, 2nd edn. Commonwealth Mycological Institute, Kew, p 380

Pascual CB, Raymundo AD (1989) Evaluation of resistance and yield loss in sorghum due to *Rhizoctonia* sheath blight. Philippine J Crop Sci 14:133–135

Payak MM, Renfro BL (1966) Diseases of maize new to India. Indian Phytopathol Soc Bull 3:14–18

Payak MM, Sharma RC (1985) Maize diseases and approaches to their management in India. Trop Pest Manag 31:302–310

Prasanna BM, Pixley K, Marilyn L, Warburton Chuan XX (2010) Molecular marker-assisted breeding options for maize improvement in Asia. Mol Breed 26:339–356

Rani VD, Reddy PN, Devi GU (2013) Banded leaf and sheath blight of maize incited by *Rhizoctonia solani* f.sp. *sasakii* and its management. Int J Appl Biol Pharm 4:52–60

Riker AJ, Riker RS (1936) Introduction of research on plant disease. St Lousi, John Swift Co, p 117

Sharma RC (2005) Banded leaf and sheath blight (*Rhizoctonia solani* f.sp. *sasakii*) of maize. In: Zaidi PH, Singh NN (eds) Stresses of maize in tropics. New Delhi, pp 159–71

Sharma RC, Hembram D (1989) Leaf stripping new method to control banded leaf and sheath blight of maize. Curr Sci 59:745–746

Sharma G, Saxena SC (2002) Integrated management of banded leaf and sheath blight of maize (*Zeamays* L.) caused by *Rhizoctonia solani* (Kuhn). Adv Plant Sci 15:107–113

Sharma RC, Vasal SK, Gonzalez, Fernando, Batsa, BK, Singh NN (2002) Redressal of banded leaf and sheath blight of maize through breeding chemical and biological agents. In: Srinivas G, Zaidi PH, Prasanna BM, Gonzalez F, Lesnik K (eds) Proceedings of the 8th Asian regional maize workshop: new technologies for the new millenium, pp 391–397

Simon TE, Le Cointe, Delarue R, Morliere P, Montfort F (2014) Interplay between parasitism and host ontogenic resistance in the epidemiology of the soil-borne plant pathogen *Rhizoctonia solani*. PLoS ONE 9:105–159

Singh A, Shahi JP (2012) Banded leaf and sheath blight: an emerging disease of maize. Maydica 57:215–219

Singh BM, Sharma YR (1976) Evaluation of maize germplasm to banded leaf and sheath blight and assessment of yield loss. Indian Phytopathol 29:129–132

Subedi KP (1996) Effect of leaf stripping, detasselling and topping of maize on maize and relay intercropped finger millet. Exp Agric 32:57–61

Sumner DR, Minton NA (1989) Crop losses in corn induced by *Rhizoctonia solani* AG2-2 and nematodes. Phytopathology 79:934–941

Tang HT, Rong TZ, Yang JP (2004) Research advance on sheath blight (*Zea mays* L.) in maize. J Maize Sci 12:93–96

Tu CC, Kimbrough JW (1978) Systematics and phylogeny of fungi in the Rhizoctonia complex. Bot Gaz 139:454–466

Wang QF, Wang QM (1991) Study on slow blasting resistance of rice cultivars to *Pyricularia oryzae* Cav. Acta Phytophylactica Sin 13(2):97–102

Wick T, Hall B, Thurn R (2001) South Rhizoctonia or black scurf on potato. Australion Research & Development Institute, Plant Research Centre, Hartley Grove, Urrbrae South Australia, p 5064

Zhang PQ, Leon C, Yang H (1993) Investigation on the yield loss caused by *Rhizoctonia solani* on maize. In: Report of Gaungxi Maize Research Institute, p 56