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Bio rational green approaches for effective management of post flowering stalk rot in maize (*Zea mays*)

KALPANA YADAV[1], S S SHARMA[1], VINITA DAHIMA[1] and M K KHOKHAR[2]

Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan 313 001, India

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Maize (*Zea mays* L.) is prominent cereal crop after wheat and rice with 1211.64 m tonnes production and 5573 kg/ha productivity which is grown in 191.89 m ha area (Anonymous 2020). Among the maize growing countries India stands 4th in terms of area and 7th in production, and occupied 4% in area and contributed 2% in production globally (India stat 2018–19). Its production is limited due to many biotic and abiotic constraints including the fungal diseases. Among the biotic constrants, post flowering stalk rot (PFSR) caused by *Fusarium verticillioides* is one of the most important diseases of maize worldwide (Khokhar *et al.* 2014). Post flowering stalk rot typically decrease maize yield by 10 to 50% (Li *et al.* 2010, Cota *et al.* 2012, Yu *et al.* 2017) in maize growing regions of the globe. The PFSR symptoms are observed during pre- and post flowering stage of crop. Affected plants leaves dry, wilted and die within few days specially in water stress conditions (Singh *et al.* 2012). It is extremely difficult to manage this disease with just one control method due to its soil borne infection nature. Systemic fungicides like bavistin, mancozeb etc. reported as suitable fungicides in disease management but high dosage of chemical fungicides have been associated with several consequences related to environment pollution and residual effects in soil that may responsible for hazardous effects on human health, cattle and other animals (Chowdary *et al.* 2018). Beside this, Bio-agents are alternative green approaches for effective and eco-friendly management of soil borne pathogens (Akhtar and Siddiqui 2008). Therefore, the present study was carried out to control the PFSR using of bio-control agents and organic ITK's formulations, which applied to evaluate their efficacy against stalk rot under *in vitro* and in field conditions.

Collection, isolation, identification and maintenance of the culture: Diseased samples of PFSR collected from different maize growing areas of Rajasthan and brought to the laboratory at Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan for isolation and purification of the pathogen during 2019–20. Culture of *F. verticillioides* was isolated and identified on the basis of cultural and morphological characters with the help of "Laboratory Manual for Identification of *Fusarium* Species" (Booth 1971).

In vitro *evaluation of bio agent against* Fusarium verticillioides: Three bio agents (*T. harzianum*, *T. viride* and *Bacillus subtilis*) were used for *In vitro* evaluation using Dual culture method (Dennis and Webster 1971) and per cent inhibition of mycelial growth was calculated as:

$$\text{Per cent growth inhibition} : \frac{C - T}{C} \times 100$$

where C, Colony growth in control; T, Colony growth in treatment.

In vivo *efficacy of bio agents and organic ITK's against* Fusarium verticillioides: Field trials were carried out in RBD maize with spacing of 60 cm × 30 cm by using susceptible maize variety Surya in 4 replications.

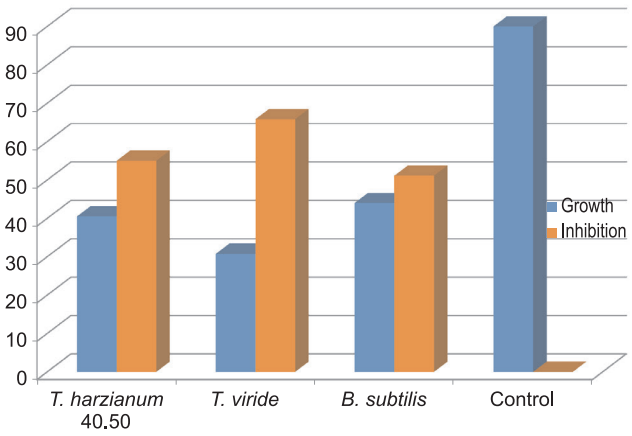

Fig 1 *In vitro* evaluation of bio control against *Fusarium verticillioides.*

[1]Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan; [2]ICAR-National Research Centre on Integrated Pest Management, New Delhi. *Corresponding author email: khokharmk3@gmail.com

All standard practices were followed as per recommended package and practices. After 30–35 days of sowing (DAS) artificial inoculation by toothpick was done (Jurgenson *et al.* 1992).

Three biocontrol and 6 organic ITK's treatment were applied after symptom appearance with doses of bioagents (1% and 2%), and organic formulations (10% and 15%) were sprayed under field conditions. The disease scoring and calculations of PDI was recorded at drying stage of crop for each treatment (Jat 2016).

Disease rating score and disease index: Observations were recorded on the appearance of disease symptoms and diseases severity of pathogen. For calculation of disease rating score disease severity was calculated on a 1 to 9 disease rating scale described by Sobowale (2011).

Per cent disease incidence (PDI) and per cent efficacy of disease control (PEDC) was calculated as (Wheeler 1969):

$$\text{Per cent disease incidence} = \frac{\text{No. of infected plants}}{\text{Total no. of plant assessed}} \times 100$$

Table 1 Effect of different bio agents and organic ITK's treatments on PFSR disease development and grain yield

Treatment	PDI 2019	PEDC 2019	PDI 2020	PEDC 2020	Pooled PDI	Pooled PEDC	Disease rating 2019	Yield 2019	Disease rating 2020	Yield 2020 (g/plot)	Pooled disease rating	Pooled yield (g/plot)
Trichoderma viride @1%	33.55 (35.40)	49.54	30.55 (33.54)	54.74	32.05 (34.47)	52.14	3.10	1097.00	3.10	1087.00	3.10	1092.00
Trichoderma viride @2%	25.20 (30.13)	62.27	24.20 (29.46)	62.65	24.70 (29.80)	62.46	3.00	1191.00	3. 5	1190.00	3.25	1190.50
Trichoderma harzianum @1%	35.23 (36.40)	47.02	32.23 (34.59)	52.25	33.73 (35.49)	49.63	3.50	1047.00	3.40	1067.00	3.45	1057.00
Trichoderma harzianum @2%	27.80 (31.82)	58.38	26.80 (31.17)	58.64	27.30 (31.49)	58.51	3.30	1115.00	3.10	1105.00	3.20	1110.00
Neem seed kernel extract @10%	45.90 (42.65)	30.97	41.90 (40.34)	37.92	43.90 (41.49)	34.44	3.70	1000.00	3.90	1009.00	3.80	1004.50
Neem seed kernel extract @15%	40.10 (39.29)	39.97	39.10 (38.70)	39.66	39.60 (39.00)	39.81	3.00	1085.00	3.70	1054.98	3.35	1069.99
Jivamrut @10 %	50.05 (45.03)	24.73	48.50 (44.14)	28.14	49.28 (44.58)	26.43	4.30	960.00	4.10	956.00	4.20	958.00
Jivamrut @15%	45.20 (42.24)	32.33	40.20 (39.35)	37.96	42.70 (40.79)	35.14	4.10	977.00	3.90	967.00	4.00	972.00
Vermi wash @10%	50.20 (45.11)	24.51	49.20 (44.54)	27.11	49.70 (44.83)	25.81	4.50	965.00	4.20	962.00	4.35	963.50
Vermi wash @15%	47.20 (43.39)	29.34	45.20 (42.24)	29.73	46.20 (42.82)	29.53	4.60	968.00	4.20	968.98	4.40	968.49
Bijamrut @10%	52.32 (46.33)	21.32	42.32 (40.58)	37.30	47.32 (43.45)	29.31	5.00	870.00	4.90	852.00	4.95	861.00
Bijamrut @15%	48.60 (44.20)	27.24	42.60 (40.74)	34.25	45.60 (42.47)	30.74	4.90	877.00	4.10	857.00	4.50	867.00
Panchgavya @10	51.20 (45.69)	23	49.20 (44.54)	27.11	50.20 (45.11)	25.05	5.20	896.00	5.00	890.00	5.10	893.00
Panchgavya @15%	45.20 (42.24)	32.33	44.20 (41.67)	31.79	44.70 (41.96)	32.06	5.00	910.00	5.90	919.00	5.05	914.50
Amrit Pani @10	55.20 (47.99)	16.90	53.20 (46.84)	21.18	54.20 (47.41)	19.04	6.00	863.00	5.60	860.00	5.80	861.50
Amrit Pani @15%	47.10 (43.34)	29.49	49.10 (44.48)	24.22	48.10 (43.91)	26.85	5.60	900.00	5.40	900.00	5.50	900.00
Control Plot	66.50 (54.65)	0.00	67.50 (55.25)	0.00	67.00 (54.95)	0.00	7.50	823.00	6.50	830.00	7.00	821.00
CD at 5% (C×T) =	3.71		3.26		2.50		0.26	74.24	0.33	82.75	0.21	56.27
C.V.=	6.45		5.98		4.81		4.54	6.18	5.97	6.92	4.09	5.06

*Data are average of 4 replications **Figures in parentheses are arcsine √per cent angular transformed value; PDI, Per cent Disease Incidence; PEDC, Per cent efficacy of disease control.

$$PEDC = \frac{\text{PDI in Control - PDI in Treatment}}{\text{PDI in Control}} \times 100$$

Statistical analysis: The data obtained from various experiments were analyzed by using coefficient of deviation for laboratory work and factorial randomize block design was used for field trials to compare significance between treatments. All data were analysed statistically using Microsoft Excel and MSTAT-C computer package program.

In vitro *efficacy of bio agents*: The results of dual culture revealed that, *T. viride* recorded 65.83% mycelial growth inhibition of *Fusarium verticillioides* followed by *T. harzianum* showed 55.00% inhibition. Similarly, *Bacillus subtilis* recorded 51.11% inhibition of mycelial growth of *F. verticillioides* (Fig 1). Srivastava (2017) reported a significant reduction of growth of *Fusarium oxysporum* f.sp. *cucumerinum* when tested in dual culture technique with *Trichoderma*. Similar results were also reported by Thori *et al.* (2012), Choudhary and Mohanka (2012), Khokhar *et al.* (2014).

Field efficacy of bio agents and organic ITK's: Results of *in vivo* efficacy (2019 and 2020) showed that disease rating for each bio agent and organic ITK's concentrations differed significantly (P=0.05). Results of the bio control agents *T. viride* in 2019 showed low disease rating 3.0 and 3.10 at 1 and 2% concentrations with 33.55 and 25.20% mean PDI with 49.54 and 62.27% PEDC respectively. Grain yield was 1097 and 1191 g/plot respectively followed by *T. harzianum* with 3.50 and 3.30 disease rating in both concentrations with 35.23 and 27.80% mean PDI and 47.02 and 58.38% PEDC (Table 1). Similar trend of the observations was also found for the next tested season of 2020 in which *T. viride* resulted minimum rating (3.10 and 3.00), PDI (30.55 and 24.20%), PEDC (54.74 and 62.65%) and grain yield was 1087 and 1190 g/plot at 1 and 2% concentrations, respectively followed by *T. harzianum* with 3.40 and 3.10 disease rating with 32.23 and 26.80% mean PDI and 52.25 and 58.64% PEDC at tested concentrations. In case of organic ITK's, (2019) neem seed kernel extract found best treatment with disease rating 3.0 and PDI 40.10% with 39.97% efficacy of disease control with yield 1085 g/plot at 15% concentrations (Table 1). Least effective organic ITK was Amrit pani with maximum disease rating 6.00 with 55.20% mean PDI with grain yield 863 g/plot at 10% concentrations. Pooled analysis indicates that comparatively less disease score was achieved by *T. viride* followed by *T. harzianum*. Results of the bio control agents and organic ITK's indicated that bio control agents are effective against the *Fusarium verticillioides* and we can not take organic ITK's in consideration for management except neem seed kernel extract if the extent of the disease pressure is higher. These results are in accordance with the outcome by Khokhar *et al.* (2014) where neem seed kernel extract was significantly more at higher concentration (0.2%). Our study was also corroborated with Mallikarjuna *et al.* (2017), Saravana *et al.* (2017) and Moosa *et al.* (2017).

SUMMARY

Present study was carried out to assess efficacy of bio agents and organic ITK's against post flowering stalk rot at Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan during 2019–20. The results of *in vitro* studies revealed that *Trichoderma viride* (65%) significantly inhibited the mycelium growth of *Fusarium verticillioides*. In field conditions, *T. viride* showed low disease rating 3.0, low per cent disease incidence (25.20%) and high efficacy of disease control (62.27%) with good grain yield 1191 g/plot against the pathogen at 2% concentrations. Maize growers can protect their crop from this disease by using the sustainable, environmentally friendly disease control strategies that were found in our study.

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