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Effects of crop improvement technologies on downy mildew of pearl millet [*Pennisetum glaucum* (L.) R. Br.

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Pearl millet is potentially prone to diseases as such downy mildew caused by *Sclerospora graminicola* causing losses in grain yield. Crop improvement technologies such as seed priming and fertilizer micro-dosing have only been applied to improve crop production without assessing their implications in the diseases of crops. This study examines the effects of these technologies on downy mildew of pearl millet. An experiment was conducted for three years (2012, 2013 and 2014) cropping seasons at the University of Maiduguri teaching and research farm. The experiment consisted of four pearl millet varieties Ex-Borno, SOSAT-C88, LCIC 9702 and a local check. Each was subjected to four treatments viz: primed, micro-dosed, primed + micro dosed and untreated (control). These were laid out in split-plot design with three replications. The variety served as the main plot and the treatment served as the sub-plot. Seed priming resulted in significantly higher percentage of stand establishment, reduced downy mildew severity and increased yield. However, plants from micro-dosed seeds suffered lower stand establishment, higher downy mildew incidence and lower yield than in the control seeds. The efficiency of micro-dosing alone increased only when combined with seed priming. SOSAT-C88 had the highest plant stands, the lowest disease incidence and severity, and the highest yield. The interaction of seed treatment (priming and micro-dosing) × variety on yield of pearl millet showed seed priming alone was more effective on the landrace Ex-Borno, while micro-dosing alone was more effective on the improved cultivar SOSAT-C88. Combination of seed priming with micro-dosing gave the highest yield increase in cultivar LCIC 9702. Seed priming remains a potential option for farmers in the semi-arid region of Nigeria. But more studies are needed to determine the precise effect of fertilizer on downy mildew of pearl millet.

Key words: Downy mildew, severity, incidence, pearl millet, seed priming, micro-dosing.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br]. is an important crop in the semi-arid and tropical parts of the world, grown annually on about 26 million ha (Raj and Wati, 2014). In Nigeria, pearl millet is second only to sorghum as staple food crop. Over 40% of land sown annually with cereal is for millet, sown on about five million hectares (Ikwelle, 1998), with an annual production figure of 7.7 million metric tons of grain, putting Nigeria

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second only to India (FAO, 2008).

It is grown mainly in the northern part of Nigeria, throughout the Sahel and in parts of Sudan and Northern Guinea Savanna (Ikwelle et al., 1993; Okeke-Agulu and Onogwu, 2014). As food, the grain is ground and used to make thin porridge known as kunun zaki, kunun kanwa or kunun tsamiya and thick porridge commonly called tuwo, burabusko or ndaleyi in the north-eastern part (Nkama, 1998).

Although, industrial utilization of the grain remains largely unexplored, there is a growing interest in the crop because of the technological possibilities of its utilization in industrial applications such as starch production (Ojediran et al., 2010). Also, the crop has a potential of becoming an important component of intensive agriculture because it responds well to management inputs (Izge and Song, 2013) and it has unique ability to tolerate and survive under adverse condition of continuous or intermittent drought as compared to most other cereals like *Zea mays* and *Sorghum bicolor* (LCRI, 1997; Zhang et al., 2015).

Despite the great potential of the crop in Nigeria, it is prone to various pathogenic diseases. The most important among them is downy mildew caused by *Sclerospora graminicola* (Sacc.) Schroet. limiting the productivity. It occurs in all millet growing areas of Nigeria. The disease incidence ranged from 0 to over 43% (Gupta and Angarawai, 1998; Anaso and Kwari 2001; Bdliya and Anaso 2001). Annual grain yield losses due to the disease ranged from 6-9% (Anaso, 1996), although up to 55-73% yield loss has been recorded in some fields in Nigeria (Ajayi et al., 1998). The magnitude of loss depends on millet cultivar and management practices.

Management practices such as seed priming and fertilizer micro-dosing have been applied to improve certain crop yields. Seed priming is a technology whereby seeds are soaked for carefully determined length of time (typically overnight) before sowing. This technology had shown faster emergence, better stands, and low incidence of re-sowing, more vigorous plants, better drought tolerance, earlier flowering, earlier harvest (Harris et al., 1999, 2001; Zhang et al., 2015) and higher grain yield in maize, rice, sorghum, groundnut and chickpea (Harris et al., 1999; Ousman and Aune, 2011; Sime and Aune, 2014). Fertilizer micro-dosing on the other hand, involves the application of small amounts of mineral fertilizer (0.3 to 4 g) onto or close to the seed during planting (Tabo et al., 2006; Twomlow et al., 2010; Bagayoko et al., 2011; Aune and Ousman, 2011). This method was reported to increase crop yields at low cost (Aune and Bationo, 2008; Aune et al., 2007; Buerkert et al., 2001; Hayashi, 2008; Klaij et al., 1994; Aune and Ousman, 2011; Camara et al., 2013).

The aim of the present study was to assess the effects of these two technologies (seed priming and micro-dosing of fertilizer) on the incidence and severity of downy mildew of pearl millet in the semi-arid zone of north eastern Nigeria.

MATERIALS AND METHODS

A three-year field trial was conducted in 2012, 2013 and 2014 cropping seasons. The trials were conducted at the University of Maiduguri teaching and research farm. Three pearl millet varieties, a landrace (Ex-Borno) and two improved (SOSAT-C88 and LCIC 9702) were obtained from Lake Chad Research Institute, Maiduguri, Nigeria. One local variety was obtained from the grain market in Maiduguri.

From each variety, four batches of 20 g seeds were weighed. Two batches from each variety were soaked in water (seed primed) for overnight (Harris et al., 1999) and surface dried two hours before planting. A batch of the primed seed was sown with compound fertilizer placed close to it as a micro-dose using a three-finger pinch (ICRISAT, 2009) per planting hole. This served as seed primed + micro-dosed treatment. The second batch of the primed seed was sown without micro-dosing (seed primed alone). One of the two remaining batches of seed was only micro-dosed and sown without seed priming. The last batch served as control without seed priming or micro-dosing. The NPK fertilizer applied was 20-10-10 in the 2012 and 2013 field trials, while NPK 15-15-15 fertilizer was applied in the 2014 field trial. The type of fertilizer used was determined by its availability at the time of research.

The treatments control, primed seeds, micro-dosed seeds and primed + micro-dosed seeds, and the four varieties of pearl millet (SOSAT-C88, LCIC 9702, EX-Borno and a local variety) were laid out in split-plot design. The variety served as the main plot and the treatment served as the sub-plot. These were replicated three times. The experimental plot was 3×2 m^2 and the distance between rows was 75 cm and distance between plants (intra- row) was 50 cm. The plants were thinned to three per hole at 3 weeks after sowing (WAS). Weeding was done twice by hoe. The first and second weeding were done 3 and 7 WAS, respectively. The parameters used and methods of collection of various data were as follows:

Seedling establishment (%)

At 30 days after seedling emergence, number of established stands per plot was counted and then expressed as a percentage of total number of stands per plot.

Downy mildew incidence

The incidence of downy mildew was computed as the percentage of diseased plants over the total number of plants in each plot. This was calculated using the following formula:

$$I = \frac{n}{N} \text{ x } 100\%$$

Where N is the total number of observed plants, n is the total number of diseased plants.

Downy mildew severity

At physiological maturity, each plant was rated using visual rating scale (Williams, 1984), and disease severity was calculated

Table 1. Effects seed treatment and cultivar on seedling establishment of pearl millet during 2012, 2013 and 2014 field trials.

Treatment	Seedling establishment (%)			
	2012	2013	2014	Combined
Seed treatment				
Primed	70.39^{a}	75.94^{a}	49.84^{a}	65.39^{a}
Micro-dosed	57.67^{b}	63.93^{b}	45.94^{c}	52.51^{b}
Primed + micro -dosed	65.00^{ab}	59.96^{b}	41.35^{bc}	55.44^{b}
Control	67.11^{a}	73.19^{a}	48.91^{ab}	63.07^{a}
SE±	4.24*	4.28**	4.06**	2.51**
Variety				
SOSAT-C88	71.11^{a}	63.60	47.68	60.80
LCIC 9702	68.19^{ab}	67.51	42.12	59.28
EX-BORNO	60.92^{b}	72.01	46.59	59.84
LOCAL	59.94^{b}	69.91	39.65	56.50
SE±	4.24*	4.28^{ns}	4.06^{ns}	2.51^{ns}

Means followed by the same letter(s) in each column are not significantly different by LSD at P ≤ 0.05 (*) or P ≤ 0.01 (**); ns = not significant

according to the formula of Mbaye (1994):

$$S = \frac{\Sigma Y_i n_i}{4N} \times 100\%$$

Where Y_i is the severity class, n_i is the number of plants in each class, 4 is the highest severity class and N is the total number of observed plants.

Yield

At harvest, the entire plot was harvested, and the grains were sun-dried and weighed.

Statistical analysis

All the data collected from each cropping season were analysed separately and combined. Analysis of variance was performed on the data using STATISTIX 8.0 for windows (Analytical Software, Tallahassee, Florida, USA).

RESULTS

Table 1 shows the effects of seed priming, fertilizer micro-dosing and cultivar on establishment of pearl millet during the three year-trial and that combined. Seed priming resulted in significantly (P≤0.05) higher percentage of stand establishment than seeds only micro-dosed and seed primed + micro-dosed. Seed priming increased plant stand by 19.7 and 3.5% as compared to micro-dosed seeds and control, respectively. Control seeds were more efficient than micro-dosed or seed primed + micro-dosed in all the three trials. Cultivar had a significant effect on establishment in 2012 trial. Plant stand establishment was significantly higher in SOSAT-C88 than in other cultivars. The lowest stand count was observed in the local variety.

Seed priming and micro-dosing significantly affected downy mildew incidence in the 2014 trial (Table 2). Plants from both primed and micro-dosed seeds had higher downy mildew incidence than those from the untreated control. Plants from micro-dosed seeds consistently had higher downy mildew incidence than those from primed seeds in all the trials. The lowest percentage disease incidence was observed in plants from control seeds. The effect of cultivar on downy mildew incidence was significant. The disease incidence was significantly (P≤0.05) lower in SOSAT-C88 than in the other cultivars. The local variety had the highest disease incidence.

Combined data for the three years showed the significant effects of seed priming and micro-dosing on downy mildew severity (Table 3). Seed priming reduced downy mildew severity by 5.1 and 46.3% in the control and micro-dosed seeds, respectively. Cultivar had a significant effect on downy mildew severity. The three-year combined data showed that disease severity was significantly lower in SOSAT-C88 and LCIC 9702 than in Ex-Borno and the local variety. The local variety had the highest downy mildew severity.

The effects of seed priming, micro-dosing and cultivar on grain yield of pearl millet in 2012 and 2014 and combined are presented in Table 4. Seed priming significantly (P≤0.05) affected pearl millet yield. It increased yield in the control by 9.6 and 8.7% in 2012 and 2014, respectively. Combination of seed priming + micro-dosing significantly increased grain yield in micro-dosing alone in both years. The yield of the cultivars differed significantly from each other in the 2012 and 2014 trials. Local variety yield was significantly (P≤0.05) lower than the other cultivars in 2012 trial. Seed

Table 2. Effects of seed treatment and cultivar on incidence of downy mildew of pearl millet during 2012, 2013 and 2014 field trials

Treatment	Downy mildew incidence (%)			
	2012	2013	2014	Combined
Seed treatment				
Primed	3.15	4.64	10.60[ab]	6.13
Micro-dosed	4.98	6.63	15.77[a]	9.13
Primed + micro-dosed	2.73	4.38	12.29[ab]	6.45
Control	4.98	3.88	7.08[b]	5.31
SE±	1.49[ns]	2.11[ns]	4.31*	1.68[ns]
Variety				
SOSAT-C88	1.21b	3.54	5.23[b]	3.33[c]
LCIC 9702	1.67b	3.47	13.38[ab]	6.18[bc]
EX-BORNO	5.23a	5.86	12.48[ab]	7.86[ab]
LOCAL	7.72a	6.66	14.65[a]	9.68[a]
SE±	1.49**	2.11[ns]	4.31*	1.68**

Means followed by the same letter(s) in each column are not significantly different by LSD at P ≤ 0.05 (*) or P ≤ 0.01 (**); ns = not significant.

Table 3. Effects of seed treatment and cultivar on severity of downy mildew of pearl millet during 2012, 2013 and 2014 field trials.

Treatment	Downy mildew Severity (%)			
	2012	2013	2014	Combined
Seed treatment				
Primed	1.72	0.84	4.19[ab]	2.25[b]
Micro-dosed	3.03	1.62	7.91[a]	4.19[a]
Primed + micro -dosed	1.41	0.88	6.83[ab]	3.04[ab]
Control	2.64	0.83	3.63[b]	2.37[b]
SE±	0.91[ns]	0.45[ns]	2.10*	0.77*
Variety				
SOSAT-C88	0.46[c]	0.90	3.03	1.46b
LCIC 9702	1.24[bc]	0.59	6.56	2.80[ab]
EX-BORNO	2.83[ab]	1.45	6.78	3.69[a]
LOCAL	4.27[a]	1.22	6.19	3.89[a]
SE±	0.92**	0.45[ns]	2.10[ns]	0.78**

Means followed by the same letter(s) in each column are not significantly different by LSD at P ≤ 0.05 (*) or P ≤ 0.01 (**); ns = not significant

treatment × cultivar interaction was significant for grain yield in 2012.

Table 5. Cultivar LCIC 9702 after seed priming and micro-dosing had significantly (P≤0.05) higher grain yield than other cultivars subjected to the same or other treatments; followed by seed primed Ex-Borno. Seed priming + micro-dosing of LCIC 9702 increased grain yield considerably as compared to untreated local variety. Generally, the local variety had the lowest yield, either seed primed or micro-dosed. Micro-dosing alone or in combination with seed priming favoured the improved

Effects of interaction of seed priming, micro-dosing and cultivar on yield of pearl millet in 2012 are presented in cultivars (SOSAT-C88 and LCIC 9702), while seed priming alone favoured Ex-Borno and the Local variety.

DISCUSSION

The present study has shown that seed priming alone was more effective on seedling establishment than either micro-dosing alone or their combination. Seed priming

Table 4. Effects of seed treatment and cultivar on grain yield of pearl millet during 2012 and 2014 field trials.

Treatment	Grain yield (kg ha^{-1})		
	2012	2014	Combined
Seed treatment (A)			
Primed	365^{ab}	583^{a}	474^{a}
Micro-dosed	329^{b}	432^{b}	381^{b}
Primed + micro dosed	411^{a}	484^{ab}	447^{ab}
Control	330^{b}	532^{ab}	431^{ab}
SE±	38.9*	65.8*	38.1*
Variety (B)			
SOSAT-C88	418^{a}	477	448
LCIC 9702	403^{a}	544	473
EX-BORNO	358^{a}	452	405
LOCAL	256^{b}	557	406
SE±	38.9*	65.8^{ns}	38.1^{ns}
Interactions			
A×B	**	ns	ns

Means followed by the same letter(s) in each column are not significantly different by LSD at P ≤ 0.05 (*) or P ≤ 0.01 (**); ns = not significant.

Table 5. Effect of interaction of seed treatment × variety on yield (kg ha^{-1}) of pearl millet in 2012 field trial.

Seed treatment	Variety			
	SOSAT-C88	LCIC 9702	EX-Borno	Local
Primed	330^{c-g}	310^{d-g}	518^{ab}	303^{d-g}
Micro-dosed	472^{a-c}	358^{c-f}	245^{fg}	243^{fg}
Primed + micro-dosed	453^{a-d}	527^{a}	370^{b-f}	292^{e-g}
Control	420^{a-e}	418^{a-e}	300^{d-g}	185^{g}
SE±		77.8**		

Means followed by the same letter(s) in each column and row are not significantly different by LSD at P ≤ 0.01 (**); ns = not significant

increased plant stand by 19.7 and 3.5% as compared to micro-dosed seeds and control, respectively. Chivasa et al. (2000), Harris (2006), Akbar et al. (2009) and Zhang et al. (2015) used seed priming technique to improve seed germination and seedling establishment of chickpea, maize, millet, rice and sorghum. Primed seeds showed faster emergence, better stands and more vigorous plants (Harris et al., 1999; Aune and Ousman, 2011).

Downy mildew severity was significantly (P≤0.05) reduced and pearl millet yield was improved by seed priming. Observations by Musa et al. (2001) in farmers' field in India and Bangladesh, showed primed *Cicer arietinum* with less damage from some pests and diseases than those grown from non-primed seeds. Seed priming alleviates physiological and pathological stresses and results in mobilization, activation and enhancement of various cellular defense responses resulting in induction of resistance (Raj et al., 2004). Apart from water, seed priming with root colonizing Pseudomonads have enhanced the host plant's resistance to pathogen attack in many host-pathogen interactions (Mathre et al., 1999; Conrath et al., 2002). While biopriming pearl millet seeds with *Pseudomonas fluorescens* isolates induced resistance to downy mildew and enhanced yield (Raj et al., 2004).

Micro-dosing fertilizer enhances fertilizer use efficiency because the fertilizer is applied adjacent to the seeds, thereby ensuring a high uptake (Aune et al., 2007; Hayashi et al., 2008). This fertilizer application method has been found to be effective for sorghum and pearl millet production in Mali and Sudan (Aune et al., 2007; Aune and Ousman, 2011). However, micro-dosing of pearl millet seeds with fertilizer in the present study reduced stand establishment and favoured downy mildew development. Plants from micro-dosed seeds consistently had higher downy mildew incidence than those from primed and non-primed seeds in all the trials.

Selvaraj (1979) reported that fertilizer modified disease symptom expression but could not determine the precise effect of fertilizer on downy mildew. Yields were significantly (P≤0.05) lower in plants from micro-dosed than in control seeds. Although, fertilizer was applied at the rate of 0.6 g/hole, too much of it could be toxic to the seedlings, causing root burn (Evans, 1992). He recorded 100% mortality when 6 g/hole fertilizer was applied on *Diospyros mespiliformis* seeds.

The performance of the cultivars varied considerably with respect to seedling establishment, downy mildew incidence and severity, and yield. SOSAT-C88 had the highest plant stands, the lowest disease incidence and severity, and the highest yield, while the local variety had the highest disease severity. This is in conformity with earlier reports by Jidda and Anaso (2012) that SOSAT-C88 developed low or no downy mildew in two seasons of their field experiments.

The interaction of seed treatment (priming and micro-dosing) and cultivar on yield of pearl millet showed seed priming alone was more effective on the landrace Ex-Borno, while micro-dosing alone was more effective on the improved cultivar SOSAT-C88. Combination of seed priming with micro-dosing gave the highest yield increase in variety LCIC 9702. Similarly, seed priming combined with micro-dosing increased sorghum, millet, groundnut, cowpea and sesame yield (Aune and Ousman, 2011; Ousman and Aune, 2011). They observed that the highest yield increases were consistently obtained when micro-dosing was combined with seed priming.

Conclusion

The results of the present study has revealed that seed priming, though, a technology used for crop improvement, can also serve as another option for management of downy mildew in pearl millet. It is a technology developed and tried in drier parts of Asia and Africa but can be used in the semi-arid parts of northern Nigeria as well. Fertilizer micro-dosing alone has its disadvantage unless combined with seed priming. The efficiency of the technology is enhanced only when in combination with seed priming. But more studies are needed to determine the precise effect of fertilizer on downy mildew of pearl millet.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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