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Screening of M_5 Generation Mutant Lines for Charcoal Rot Resistance in Sorghum [*Sorghum bicolor* (L.) Moench]

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ABSTRACT

This study was carried out in augmented design during *rabi* 2021 (November–May) at Agriculture research station, Hagari, Karnataka, India to identify the charcoal rot resistant mutant line. Total 200 mutants and 7 checks were used to study the charcoal rot resistance in the present experiment. Charcoal rot is a major disease in the dry sorghum-growing regions of Asia, Africa, Americas and Australia. Charcoal rot disease is caused by *Macrophomina phaseolina* (Tassi) Goid. It appears in severe form on the improved varieties in hot dry weather with soil moisture stress. The process of mutation is recognized as one of the driving forces of evolution. Induced mutation breeding is a relatively quick method of creating variability in quantitatively inherited traits between plants. The parameters used in charcoal rot studies were lodging per cent, mean number of nodes crossed, mean length of spread and Charcoal rot index (CRI). The screening results revealed that 66 mutant lines shown moderate resistant reaction compared to the resistant check DSV-4 (0.5) and E-36-1 (0.27), among them eight mutants had exact only one node crossed by the pathogen. These mutant lines exhibited comparatively lowest number of mean nodes crossed. 84 mutant lines shown moderate resistant response to charcoal rot index trait. These resistant lines can be used for further confirmation and also for future resistant breeding programme.

KEYWORDS: Sorghum, CRI, mean length spread, mean node cross

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1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench], "The King of coarse cereals" is a multipurpose crop that can be grown as food, feed, fodder, and biofuel. It is a staple food crop in the drier parts of Africa, China, and India (Ajeigbe et al., 2018, Mrema et al., 2020). It is the fifth most important cereal crop worldwide, behind wheat, rice, maize and barley and one of the most significant in the semi-arid tropics (SAT) (Bantilan et al., 2004) Sorghum was cultivated in 5.13 mha area with production of 4.37 mt and productivity of 852 kg ha^{-1} (Anonymous, 2021). It is also called a camel of the desert because it produces a good yield under high temperature and low soil moisture. Sorghum is nutritionally good and comparable with other cereals and so it is indicated as a "nutritious grain" (Aruna et al., 2020).

It is the staple food in arid and semi-arid parts of the world and because of its drought tolerance property, it is considered as a failsafe crop. The chemical composition of sorghum is very similar to maize and millet whose essential components are starch, fat, protein, and non-starch polysaccharides, it is also a source of bioactive nutrients like vitamin B, fat-soluble vitamins (D, E, K), micro and macronutrients, as well as non-nutrients, for example, carotenoids and polyphenols (Przybylska et al., 2019). The highest concentration of phytochemicals in sorghum grains is found mainly in bran and germ (Blackwell et al., 2012). Polyphenols in sorghum are present as phenolic acids, flavonoids, and condensed tannins. Condensed tannins are frequent in sorghum with pigmented testa and these compounds in sorghum are those that have higher levels of antioxidants than in any other cereal (Chung et al., 2011). Whole grains of sorghum have key health benefits, such as free radical scavenging activity, which is associated with antimicrobial properties, reduced oxidative stress, anti-inflammatory and anti-cancer activity (Rao et al., 2018).

It is used as food, feed and for the production of ethanol, alcohol, starch, adhesives and paper. It is also an important animal feed (swine, poultry and cattle) used in countries like U.S.A, Mexico, South America and Australia (Burke et al., 2010).

Sorghum is vital to resource poor farmers due to its adaptation to drought and heat, its C4 photosynthetic system and resilience to climate variability (Haussmann et al., 2012), particularly with photoperiod sensitivity to match growth duration to moisture availability, and adaptation to soils with low phosphorus (P) availability (Leiser et al., 2012), a major constraint to production across West Africa (Buerkert et al., 2001). Sorghum grain is rich in starch, protein, micronutrients, and crude fiber but low in fat (Chavan and Patil, 2010), making it a good staple.

The process of mutation is recognized as one of the driving forces of evolution. Induced mutation breeding is a relatively quick method of creating variability in quantitatively inherited traits between plants (Camargo et al., 2000). Both physical and chemical mutagens induce genetic variability, of which gamma radiation is an important tool for inducing mutants with potential to enhance yield and yield contributing traits (Thapa, 2004). Sorghum is treated with 1% sodium azide to improve germination rate, root length, shoot length, bold seeds, and yield attributing traits (Dahot et al., 2011).

Charcoal rot is caused by *Macrophomina phaseolina* (Tassi). Goidanich and Fusarium stalk rot, also called 'soft rot', is caused by Fusarium spp. (Hassan et al., 1996, Tarr, 1962). Among various Fusarium spp., *F. thapsinum* Klittich, Leslie, Nelson and Marasas has been confirmed as one of the most aggressive charcoal rot pathogens of sorghum (Leslie et al., 2005, Tesso et al., 2005, Tesso et al., 2010, Tesso and Ejeta, 2011) This species is capable of infecting sorghum hybrids as early as 30 days after planting (Khune et al., 1984). Prolonged exposure to drought and high temperature stress during grain development increases charcoal rot incidence (Edmunds, 1964, Tesso et al., 2012). It is a complex disease associated with a variety of symptoms including root rot, soft stalks and premature drying stalks, lodging and poorly developed panicles with small and inferior quality grains. The disease is soil borne and causes high loss of grain and fodder, relatively more severe and destructive on high yielding sorghum cultivars when grain filling coincides with low soil moisture in hot dry weather. Therefore, the present investigation was planned to screen sorghum mutant population to identify tolerant mutants for Charcoal rot disease.

2. MATERIALS AND METHODS

Gamma irradiated mutant population was grown in the field during *rabi* 2021 (November–May) at Agricultural Research Station (ARS), Hagari, Karnataka, India. Geographically, the location is situated at North-Eastern Dry Zone (Zone-3) of Karnataka situated between 15°14' N latitude and 77°07' E longitude with an altitude of 414 m above the mean sea level.

200 mutants were sown in Augmented design, (Federer, 1979) in 4 m length with inter row spacing of 45 cm and intra row spacing of 15 cm. Each genotype sown in one row and each block contained 30 mutants with 7 checks viz., DJ 6514, IS 2312, M 35-1, DSV-4, E-36-1, SPV-86 and GS 23 replicated in 7 blocks for screening of charcoal rot resistant mutants.

2.1. Inoculum preparation

The pathogen was cultured (Rao et al., 1980) on wooden tooth-picks in honey-peptone medium (peptone 1 g, honey 5 ml, distilled water 94 ml). Tooth-picks were packed into 100 ml conical flasks along with the 20 ml of media and were sterilized at 15 psi for 20 m. A loop full of mycelial-sclerotial from stock cultures of *Macrophomina phaseolina* was seeded into each flasks of sterilized cooled honey peptone medium. The flasks were incubated at 35°C for 7 days at which time the tooth picks were covered with mycelia (Plate 1) and sclerotia of the charcoal rot fungus and ready for use in inoculation.

2.2. Field inoculation procedure

Plants were inoculated at 50% flowering. Irrigation was withheld before the lines were at the boot leaf stage. A fungus infected tooth pick was inserted obliquely into a hole made with an iron pocher into each stalk at its second internode from ground level (Plate 2). Care was taken to ensure that the tooth pick did not emerge through the other side of the stem, for this would promote rapid drying of the inoculum.

2.3. The following parameters were recorded to assess charcoal rot incidence

2.3.1. Lodging percentage due to charcoal rot

The number of plants lodging due to charcoal rot among the infected plants was recorded and lodging percentage was calculated. Lodging of plant due to charcoal rot (Plate 3).

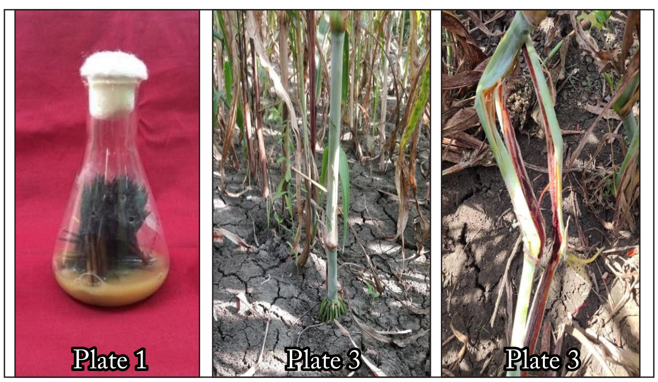

Plate 1: Tooth picks cultured with Macrophomina phaseolina; Plate 2: Toothpick inoculation to sorghum stalk; Plate 3: Lodging due to charcoal rot

Lodging(%)=(Number of plants lodged due to charcoal rot× Number of plants infected)×100 ...1

Based on charcoal rot percentage and mean length of spread of lesion, Disease reaction of each genotype was determined using the CRI scales (Das et al., 2018)

CRI=(Lodging percentage×0.4+Meanlength spread×0.6) ...(2)

2.3.2. Mean number of nodes crossed

The number of nodes crossed by the pathogen from the point of infection was recorded. Based on mean number of nodes crossed by charcoal rot disease the genotypes were graded using 1–5 scale where, 1=no inter node crossed and 5=≥4 internode crossed (Das et al., 2007)

2.3.3. Mean length of spread (cm)

The length of spread of disease from the point of infection to the tip of disease spread was recorded in centimeter.

3. RESULTS AND DISCUSSION

As compared to the resistant check DSV-4 (0.5) and E-36-1 (0.27), eight mutants had exact only one node crossed by the pathogen, namely IS925-7-1-1 (1), IS925-133 (1), IS925-RD-34(1), IS925-123(1), PV-RD-115(1), PV-58(1), PV-RD-29(1) and PV-RD-4(1). It indicates moderate resistance to charcoal rot in these mutants. The Mutants IS925-46 and PV-RD-28 showed the highest number of mean nodes crossed by the pathogen in comparison to the susceptible check SPV-86 (3.88). The charcoal rot disease is highly susceptible to these two mutants.

Mutant lines were graded using a 1–5 scale based on the mean number of nodes crossed by pathogens (Das et al., 2007). According to Table 1, total 3 mutant lines were resistant, 66 mutant lines were moderately resistant, 70 mutant lines were moderately susceptible, 58 mutant lines were susceptible and 10 mutant lines were highly susceptible. Badigannavar et al. (2018) have also reported similar results.

Among mutant lines screened and IS925-7-1-1 (8.4 cm) PV-5 (8.2 cm) showed least mean length of spread of charcoal rot disease, when compared to the resistant check DSV-4(17.98 cm) and E-36-1 (11.94 cm). PV-RD-34 (62.2 cm), PV-RD-28 (62.2 cm) and IS925-19 (61.2 cm) mutant lines showing highest mean length of spread of disease compared to susceptible check SPV-86 (39.21 cm) it is represented in Table 2. These results are identical with the findings of Jahagirdar et al. (2002) and Girish et al. (2016a).

Table 1: Disease reaction of genotype based on CRI scales

CRI value	Reaction
<5	Highly resistant
6–10	Resistant
11–25	Moderately resistant
26–40	Susceptible
>40	Highly susceptible

Using lodging percent and mean length of spread, the charcoal rot index (CRI) is calculated and mutant lines are classified into groups based on CRI scales 1–5 (Das et al., 2018). Among the 200 mutant lines studied, none was highly resistant or resistant to charcoal rot disease, 84 mutant lines were moderately resistant, 67 lines were susceptible and 56 lines were highly susceptible, as shown in Table 3. It is similar to the results reported by Chattannavar and Bannur (2020).

Table 2: Classification of M_5 sorghum mutant lines based on mean number of nodes crossed by charcoal rot infection

Grade scale	Disease reaction	Mutants		Total-mutants
		IS925	Phule vasudha	
1	Resistant (<1 node crossed)	E-36-1, DSV-4, IS-2312.	-	3+0
2	Moderately resistant (1 node crossed)	IS925-7-1-1, IS925-17, IS925-1, IS925-7, IS925-22, IS925-6, IS925-5, IS925-RD-16, IS925-RV-2, IS925-RV-11, IS925-RD-42, IS925-RD-140, IS925-RD-34, IS925-RD-84, IS925-130, IS925-133, IS925-RD-44, IS925-120, IS925-38, IS925-44, IS925-137, IS925-3, IS925-90, IS925-RD-19, IS925-83, IS925-123, IS925-109, IS925-132, IS925-124, IS925-RV-13, GS-23, DJ-6514.	PV-19, PV-7, PV-7-1, PV-9-1, PV-11-1, PV-17-1-1, PV-17-1, PV-13-1, PV-23-1, PV-RD-45, PV-58, PV-RD-48, PV-16, PV-RD-6, PV-RD-21, PV-RD-36, PV-RD-68, PV-RD-35, PV-RD-18, PV-35, PV-RV-95, PV-17, PV-RD-33, PV-RD-31, PV-RD-115, PV-RD-49, PV-RV-5, PV-RD-29, PV-39, PV-61, PV-RV-6, PV-RD-4, PV-RD-53, PV-1.	32+34
3	Moderately Susceptible (2 nodes crossed)	IS925-16-1, IS925-2, IS925-21-1, IS925-9, IS925-8, IS925-10, IS925-2-1, IS925-131, IS925-101, IS925-114, IS925-RV-41, IS925-29, IS925-136, IS925-RD-2, IS925-15, IS925-RD-31, IS925-31, IS925-RD-49, IS925-RD-50, IS925-RD-30, IS925-RV-4, IS925-RD-98, IS925-108, IS925-41R, IS925-37, IS925-RV-8, IS925-85, IS925-117, IS925-105, IS925-RD-48, IS925-RD-65, IS925-RD-6, IS925-39, IS925-7-1, M-35-1.	PV-8, PV-14, PV-5, PV-21, PV-26, PV-18, PV-RD-62, PV-48, PV-RD-9, PV-RV-62, PV-RD-19, PV-RV-22, PV-RD-43, PV-12, PV-RD-20, PV-6E, PV-10, PV-60, PV-RD-54, PV-RD-40, PV-2, PV-RD-60, PV-RD-5, PV-RD-30, PV-RD-87, PV-RD-41, PV-62, PV-37, PV-RD-57, PV-RD-13, PV-RD-51, PV-49, PV-38, PV-29, PV-45.	35+35
4	Susceptible (3 nodes crossed)	IS925-23-1, IS925-14, IS925-21, IS925-11, IS925-58, IS925-41, IS925-54, IS925-34, IS925-70, IS925-RD-45, IS925-RD-60, IS925-89, IS925-113, IS925-82, IS925-138, IS925-96, IS925-RD-53, IS925-RD-71, IS925-87, IS925-97, IS925-RV-3, IS925-RV-6, IS925-64, IS925-RD-21, IS925-20, IS925-80, IS925-RD-25, IS925-134, IS925-RD-101, IS925-RD-15, IS925-144, SPV-86.	PV-22, PV-16-1, PV-6-1, PV-RD-11, PV-RD-38, PV-RD-27, PV-RD-32, PV-RD-1, PV-RD-22, PV-RD-25, PV-RD-3, PV-13, PV-33, PV-RD-44, PV-50, PV-18-1, PV-52, PV-RD-10, PV-30, PV-RD-7, PV-57, PV-22-1, PV-3, PV-RD-14, PV-9, PV-RD-15.	32+26
5	Highly Susceptible (4 and>4 Nodes crossed)	IS925-24, IS925-19, IS925-46, IS925-RD-100, IS925-128.	PV-24, PV-1-1, PV-RD-34, PV-2-1, PV-RD-28.	5+5

According to the study, Honntagi local, Kannolli local and Muddehalli jola genotypes showed lower charcoal rot levels. According to these researchers, the genotypes resistance to the disease is the result of delayed senescence, accompanied by slow drying at physiological maturity and a stay green trait Jahagirdar et al. (2002), Avdhaniand Ramesh (1979), Anahosur et al. (1974) and Girish et al. (2016a). According to Anahosur and Naik (1985) resistant genotypes contain more sugar than susceptible genotypes. Similarly, Nalawade et al. (2008) found that genotypes with higher levels of sugar and phenolic compounds were resistant to charcoal rot. This has resulted in the lines in our study showing both a high

Table 3: Classification of M_5 sorghum mutant lines along with checks based on charcoal rot index (CRI)

Disease reaction	Mutants		Total-mutants
	IS925	PhuleVasudha	
Highly Resistant (<5)	-	-	-
Resistant (6–10)	-	-	-
Moderately Resistant (11–25)	IS925-7-1-1, IS925-17, IS925-2, IS925-21-1, IS925-1, IS925-7, IS925-22, IS925-6, IS925-5, IS925-RD-16, IS925-RV-2, IS925-29, IS925-15, IS925-RD-140, IS925-RD-34, IS925-RD-84, IS925-RD-50, IS925-RV-4, IS925-130, IS925-133, IS925-RD-44, IS925-37, IS925-RV-8, IS925-120, IS925-38, IS925-137, IS925-83, IS925-117, IS925-123, IS925-109, IS925-132, IS925-RD-48, IS925-124, IS925-RD-6, E-36-1, DSV-4, GS-23, IS-2312, DJ-6514.	PV-19, PV-14, PV-7, PV-7-1, PV-9-1, PV-11-1, PV-21, PV-26, PV-17-1-1, PV-17-1, PV-13-1, PV-23-1, PV-18, PV-RD-45, PV-RD-48, PV-16, PV-RD-21, PV-RD-62, PV-48, PV-RD-36, PV-RD-68, PV-RD-35, PV-RD-9, PV-RD-18, PV-12, PV-6E, PV-60, PV-RD-54, PV-35, PV-RV-95, PV-RD-60, PV-17, PV-RD-33, PV-RD-31, PV-RD-30, PV-RD-115, PV-RD-49, PV-RV-5, PV-RD-29, PV-39, PV-61, PV-RV-6, PV-62, PV-RD-4, PV-RD-53.	39+45
Susceptible (26–40)	IS925-14, IS925-16-1, IS925-21, IS925-9, IS925-8, IS925-10, IS925-2-1, IS925-58, IS925-131, IS925-101, IS925-34, IS925-114, IS925-RV-41, IS925-136, IS925-RV-11, IS925-RD-2, IS925-RD-42, IS925-RD-31, IS925-89, IS925-RD-53, IS925-31, IS925-97, IS925-RD-49, IS925-RD-30, IS925-RV-6, IS925-RD-98, IS925-108, IS925-RD-21, IS925-41R, IS925-85, IS925-44, IS925-3, IS925-90, IS925-RD-19, IS925-105, IS925-RD-65, IS925-39, IS925-RV-13, IS925-7-1, M-35-1.	PV-8, PV-5, PV-RD-38, PV-58, PV-RD-6, PV-RD-22, PV-RV-62, PV-RD-19, PV-RV-22, PV-RD-43, PV-RD-20, PV-10, PV-RD-40, PV-2, PV-RD-44, PV-RD-5, PV-RD-87, PV-37, PV-RD-57, PV-1, PV-RD-13, PV-22-1, PV-RD-51, PV-49, PV-38, PV-29, PV-45.	40+27
Highly Susceptible (>40)	IS925-23-1, IS925-24, IS925-19, IS925-11, IS925-46, IS925-41, IS925-54, IS925-70, IS925-RD-45, IS925-RD-100, IS925-RD-60, IS925-113, IS925-82, IS925-138, IS925-96, IS925-RD-71, IS925-87, IS925-RV-3, IS925-64, IS925-20, IS925-80, IS925-128, IS925-RD-25, IS925-134, IS925-RD-101, IS925-RD-15, IS925-144, SPV-86.	PV-22, PV-24, PV-16-1, PV-1-1, PV-6-1, PV-RD-11, PV-RD-27, PV-RD-34, PV-RD-32, PV-RD-1, PV-RD-25, PV-RD-3, PV-13, PV-33, PV-RD-50, PV-18-1, PV-52, PV-2-1, PV-RD-10, PV-RD-41, PV-RD-28, PV-30, PV-RD-7, PV-57, PV-3, PV-RD-14, PV-9, PV-RD-15.	28+28

Table 4: Mean performances of M_5 mutant lines for charcoal rot disease.

Sl. No.	Mutants	Lodging percentage	MNC	MLS	CRI
P+C(IS925)					
1.	IS925-7-1-1	20	1	8.4	13.04
2.	IS925-23-1	60	3.4	42	49.2
3.	IS925-14	40	3.2	37	38.2
4.	IS925-16-1	40	2.4	27.4	32.44
5.	IS925-24	80	4.4	51.8	63.08
6.	IS925-19	80	4.2	61.4	68.84
7.	IS925-17	20	1.8	22.6	21.56
8.	IS925-2	20	2.4	23.4	22.04
9.	IS925-21	20	3.8	42.4	33.44
10.	IS925-21-1	20	2.4	24.6	22.76
11.	IS925-1	20	1.8	23.8	22.28
12.	IS925-9	20	2.6	31.8	27.08
13.	IS925-11	60	3.8	43.2	49.92
14.	IS925-7	20	1.4	20.2	20.12
15.	IS925-8	40	2.4	29.6	33.76
16.	IS925-22	20	1.6	17.4	18.44
17.	IS925-6	20	1.4	25.8	23.48
18.	IS925-10	40	2.8	25	31
19.	IS925-5	20	1.6	17.2	18.32
20.	IS925-2-1	40	2.8	34.4	36.64
P+C(PV)					
1.	PV-19	20	1.6	20.6	20.36
2.	PV-8	40	2.6	30.2	34.12
3.	PV-14	20	2.4	26.2	23.72
4.	PV-22	60	3.4	45.2	51.12
5.	PV-5	40	2.6	29.4	33.64
6.	PV-7	20	1.6	19.4	19.64
7.	PV-7-1	20	1.8	25.4	23.24
8.	PV-9-1	20	1.8	24.6	22.76
9.	PV-11-1	20	1.8	22.4	21.44
10.	PV-21	20	2.6	28.2	24.92
11.	PV-26	20	2.6	24.8	22.88
12.	PV-17-1-1	20	1.8	22.4	21.44
13.	PV-24	80	4.4	51.4	62.84
14.	PV-16-1	60	3.4	43	49.8
15.	PV-1-1	80	4.4	55.4	65.24
16.	PV-17-1	20	1.6	22.8	21.68
17.	PV-6-1	40	3.6	47.8	44.68

Table 4: continue....

Sl. No.	Mutants	Lodging percentage	MNC	MLS	CRI
P+C(IS925)					
18.	PV-13-1	20	1.8	22.2	21.32
19.	PV-23-1	20	1.8	22.6	21.56
20.	PV-18	20	2.6	28.2	24.92
P(IS925)					
1.	IS925-46	80	4.4	60.2	68.12
2.	IS925-58	40	3.6	36.6	37.96
3.	IS925-41	40	3.8	51.8	47.08
4.	IS925-131	40	2.6	30.6	34.36
5.	IS925-RD-16	20	1.6	28.2	24.92
6.	IS925-101	20	2.6	33	27.8
7.	IS925-54	40	3.4	44.2	42.52
8.	IS925-34	40	3	39.8	39.88
9.	IS925-70	60	3.6	47.8	52.68
10.	IS925-RV-2	20	1.8	12.2	15.32
11.	IS925-114	40	2.4	35.2	37.12
12.	IS925-RV-41	20	2.8	43.2	33.92
13.	IS925-RD-45	60	3.4	49.6	53.76
14.	IS925-29	20	2.4	24.2	22.52
15.	IS925-136	40	2.6	27.2	32.32
16.	IS925-RD-100	60	4.2	46.2	51.72
17.	IS925-RD-60	40	3.6	40.4	40.24
18.	IS925-RV-11	40	1.6	23.2	29.92
19.	IS925-RD-2	20	2.8	40.4	32.24
20.	IS925-RD-42	20	1.6	27	24.2
21.	IS925-15	20	2.6	24.8	22.88
22.	IS925-RD-31	40	2.8	33.8	36.28
23.	IS925-RD-140	20	1.6	21.2	20.72
24.	IS925-89	40	3.4	37.6	38.56
25.	IS925-113	40	3.6	52.8	47.68
26.	IS925-82	80	3.6	44.2	58.52
27.	IS925-138	60	3.6	52.8	55.68
28.	IS925-96	60	3.6	45.6	51.36
29.	IS925-RD-34	20	1	12.2	15.32
30.	IS925-RD-53	40	3	34.8	36.88
31.	IS925-RD-71	40	3.8	45.6	43.36
32.	IS925-RD-84	40	1.4	14.4	24.64
33.	IS925-31	40	2.6	34.6	36.76
34.	IS925-87	40	3.8	46.8	44.08
35	IS925-97	40	3.4	30.8	34.48

Table 4: continue....

Sl. No.	Mutants	Lodging percentage	MNC	MLS	CRI
P+C(IS925)					
36.	IS925-RV-3	60	3.6	42.8	49.68
37.	IS925-RD-49	40	2.8	28.2	32.92
38.	IS925-RD-50	20	2.6	27.4	24.44
39.	IS925-RD-30	20	2.8	37.8	30.68
40.	IS925-RV-4	20	2.2	22.2	21.32
41.	IS925-RV-6	40	3.6	38.8	39.28
42.	IS925-130	20	1.8	22.8	21.68
43.	IS925-64	60	3.6	42.4	49.44
44.	IS925-133	20	1	24.2	22.52
45.	IS925–RD-98	20	2.6	43.6	34.16
46.	IS925-108	20	2.8	45.2	35.12
47.	IS925-RD-21	20	3.6	52.8	39.68
48.	IS925-20	60	3.8	53.2	55.92
49.	IS925-RD-44	20	1.6	27.4	24.44
50.	IS925-41R	40	2.8	27.2	32.32
51.	IS925-80	60	3.8	54.6	56.76
52.	IS925-37	20	2.2	28.2	24.92
53.	IS925-RV-8	20	2.6	23.2	21.92
54.	IS925-128	80	4.4	57.2	66.32
55.	IS925-RD-25	40	3.8	48	44.8
56.	IS925-120	20	1.8	23.2	21.92
57.	IS925-85	20	2.8	40.4	32.24
58.	IS925-38	20	1.6	27	24.2
59.	IS925-44	40	2.8	38.8	39.28
60.	IS925-137	20	2.6	24.2	22.52
61.	IS925-3	40	2.6	38	38.8
62.	IS925-90	40	2.8	36.6	37.96
63.	IS925-RD-19	40	2.8	34.2	36.52
64.	IS925-83	20	1.8	27.8	24.68
65.	IS925-117	20	2	26.2	23.72
66.	IS925-123	20	1	20.6	20.36
67.	IS925-105	40	2.8	35.4	37.24
68.	IS925-109	20	1.8	24.6	22.76
69.	IS925-132	20	1.8	21.8	21.08
70.	IS925-134	60	3.6	44.8	50.88
71.	IS925-RD-48	20	2.4	27.2	24.32
72.	IS925-RD-65	40	2.6	35.4	37.24
73.	IS925-124	20	1.8	25	23
74	IS925-RD-101	60	3.6	57.6	58.56

Table 4: continue....

Sl. No.	Mutants	Lodging percentage	MNC	MLS	CRI
P+C(IS925)					
75.	IS925-RD-6	20	2.8	25.2	23.12
76.	IS925-39	20	2.4	33.4	28.04
77.	IS925-RD-15	40	3.6	47.4	44.44
78.	IS925-144	60	3.8	43	49.8
79.	IS925-RV-13	40	1.6	26.6	31.96
80.	IS925-7-1	40	2.8	38	38.8
P(PV)					
1.	PV-RD-11	60	3.6	47.4	52.44
2.	PV-RD-45	20	1.8	22	21.2
3.	PV-RD-38	40	3.2	37.8	38.68
4.	PV-RD-27	40	3.6	47.8	44.68
5.	PV-RD-34	60	4.2	62.2	61.32
6.	PV-58	40	1	30.8	34.48
7.	PV-RD-48	20	1.8	23	21.8
8.	PV-16	20	1.4	8.8	13.28
9.	PV-RD-32	40	3.6	49.8	45.88
10.	PV-RD-6	40	1.8	24	30.4
11.	PV-RD-21	20	1.6	20	20
12.	PV-RD-1	60	3.2	40.4	48.24
13.	PV-RD-62	20	2.2	27.2	24.32
14.	PV-48	20	2	25.4	23.24
15.	PV-RD-36	20	1.8	24.2	22.52
16.	PV-RD-68	40	1.4	14.6	24.76
17.	PV-RD-35	20	1.6	24.4	22.64
18.	PV-RD-9	20	2	26.2	23.72
19.	PV-RD-22	40	3.2	31.2	34.72
20.	PV-RV-62	40	2.4	29.2	33.52
21.	PV-RD-18	20	1.6	16.2	17.72
22.	PV-RD-19	20	2.6	38.6	31.16
23.	PV-RD-25	40	3	42.8	41.68
24.	PV-RV-22	40	2.6	25.4	31.24
25.	PV-RD-43	40	2.8	30.4	34.24
26.	PV-RD-3	60	3.4	43.2	49.92
27.	PV-12	20	2	27.8	24.68
28.	PV-13	60	3.4	49.8	53.88
29.	PV-RD-20	40	2.2	29	33.4
30.	PV-6E	40	2.6	14.8	24.88
31.	PV-10	40	2.4	30.6	34.36
32.	PV-60	20	2.2	26.2	23.72

Table 4: continue....

Sl. No.	Mutants	Lodging percentage	MNC	MLS	CRI
P+C(IS925)					
33.	PV-RD-54	20	2.4	28	24.8
34.	PV-35	20	1.6	22	21.2
35.	PV-RD-40	40	2.6	34.6	36.76
36.	PV-33	60	3.4	41.4	48.84
37.	PV-2	40	2.2	26.8	32.08
38.	PV-RV-95	40	1.8	14.6	24.76
39.	PV-RD-60	20	2.6	27.6	24.56
40.	PV-17	40	1.6	14.8	24.88
41.	PV-RD-44	20	3	44.4	34.64
42.	PV-50	60	3.4	47.2	52.32
43.	PV-18-1	60	3.4	43	49.8
44.	PV-52	60	3.8	49.4	53.64
45.	PV-2-1	80	4.4	57.8	66.68
46.	PV-RD-33	40	1.4	14.6	24.76
47.	PV-RD-31	40	1.6	14.8	24.88
48.	PV-RD-10	60	3.6	49.2	53.52
49.	PV-RD-5	40	2.4	34.8	36.88
50.	PV-RD-30	20	2.4	26.8	24.08
51.	PV-RD-115	20	1	13.6	16.16
52.	PV-RD-49	40	1.6	14.8	24.88
53.	PV-RD-87	40	2.4	34	36.4
54.	PV-RV-5	20	1.2	8.2	12.92
55.	PV-RD-29	40	1	13.6	24.16
56.	PV-RD-41	60	2.6	36	45.6
57.	PV-RD-28	60	4.4	62.2	61.32
58.	PV-39	20	1.6	17.2	18.32
59.	PV-61	40	1.8	14.6	24.76
60.	PV-30	60	3.2	41.4	48.84
61.	PV-RD-7	60	3.4	45.2	51.12
62.	PV-RV-6	20	1.6	25.8	23.48
63.	PV-62	20	2.4	29.6	25.76
64.	PV-37	40	2.4	35.6	37.36
65.	PV-RD-4	40	1	14	24.4
66.	PV-RD-53	20	1.6	26.8	24.08
67.	PV-57	60	3.6	49.8	53.88
68.	PV-RD-57	40	2.6	34.8	36.88
69.	PV-1	60	1.8	24.4	38.64
70.	PV-RD-13	40	2.6	36.2	37.72
71.	PV-22-1	40	3.4	37	38.2

Table 4: continue....

Sl. No.	Mutants	Lodging percentage	MNC	MLS	CRI
P+C(IS925)					
72.	PV-3	60	3.4	41.8	49.08
73.	PV-RD-14	60	3.6	44.6	50.76
74.	PV-RD-51	40	2.6	36	37.6
75.	PV-49	40	2.4	34.8	36.88
76.	PV-9	40	3.4	47.2	44.32
77.	PV-RD-15	40	3	45	43
78.	PV-38	40	2.4	32.4	35.44
79.	PV-29	40	2.4	32.6	35.56
80.	PV-45	20	2	33	27.8
CHECKS					
1.	SPV-86	80	3.88	39.21	55.52
2.	E-36-1	20	0.27	11.94	15.16
3.	DSV-4	20	0.5	17.98	18.79
4.	M 35-1	40	2.05	20.27	28.16
5.	GS-23	20	1.2	17.58	18.55
6.	IS-2312	40	0.67	15.3	25.18
7.	DJ-6514	20	1.95	12.86	15.71
	CD (p=0.05)				
	Ci-Cj	0.044	0.002	0.008	0.026
	BiVi-BjVj	0.088	0.003	0.015	0.053
	BiVi-BjVj	0.094	0.004	0.017	0.056
	Ci-Vi	0.074	0.003	0.013	0.045

P+C: Physical+Chemical; P:Physical treated; PV:Phule Vasudha; MNC: Mean number of nodes crossed; MLS: Mean length of spread; CRI: Charcoal rot index; Ci-Cj: For two check means; BiVi-BjVj: For two test genotype means in same block; BiVi-BjVj: For any two entries means in the same block; Ci-VI: For means between a check and a test genotype

level of resistance as well as a high level of vulnerability to disease. Mean performances of 200 M_5 sorghum mutant lines for charcoal rot incidence is represented in Table 4.

4. CONCLUSION

Among 200 mutants, eight lines *viz*., IS925-7-1-1 (1), IS925-133(1), IS925-RD-34(1), IS925-123(1), PV-RD-115(1), PV-58(1), PV-RD-29(1) and PV-RD-4 (1) showed moderate resistant to charcoal rot component characters mean number of nodes crossed, mean length spread and lodging percentage based on charcoal rot index compared to resistant check DSV-4 and E-36-1 (Resistance). So, these lines may be used for further confirmation and future tolerance breeding programs.

5. REFERENCES

Ajeigbe, H.A., Akinseye, F.M., Jonah, J., Kunihya, A., 2018. Sorghum yield and water use under phosphorus fertilization applications in the Sudan savanna of Nigeria. Global Advanced Research Journal of Agricultural Science 7(8), 245–257.

Anahosur, K.H., Naik, S.T., 1985. Relationship of sugars and phenols of root and stalk of sorghum with charcoal rot. Indian Phytopathology 38(1), 131–134.

Anahosur, K.H., Rao, M.V.H., Patil, S.H., Hegde, R.K., 1974. Assessment of losses in sorghum seed weight due to charcoal rot. Indian Phytopathology 24(1), 85–88.

Anonymous, 2021. Agricultural Statistics at a Glance. Department of Agriculture, Cooperation & Farmers Welfare, Directorate of Economics and Statistics, Ministry of Agriculture & Farmers Welfare, Government of India.

Aruna, C.R., Ratnavathi, C.V., Suguna, M., Ranga, B., Praveen Kumar, P., Annapurna, A., Toapi, V.A., 2020. Genetic variability and G×E interactions for total polyphenol content and antioxidant activity in white and red sorghums (*Sorghum bicolor*). Plant Breeding 139(1), 119–130.

Badigannavar, A., Girish, G., Jayalakshmi, J., Ganapathi, T.R., 2018. Gamma ray induced genetic improvement of sorghum landraces for grain yield and charcoal rot tolerance. Electronic Journal of Plant Breeding 9(3), 894–898.

Bantilan, M.C.S., Deb, U.K., Gowda, C.L.L., Reddy, B.V.S., Obilana, A.B., Evenson, R.E., 2004. Sorghum Genetic Enhancement: Research Process, Dissemination and Impacts. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 320.

Blackwell, D.L., Thomas, J.H., Scott, R.B., Gadgil, P., 2012. Alkaline extraction of phenolic compounds from intact sorghum kernels. International Journal of Food Science & Technology 47(12), 2671–2675.

Buerkert, A., Bationo, A., Piepho, H.P., 2001. Efficient phosphorus application strategies for increased crop production in sub-Saharan West Africa. Field Crops Research 72(1), 1–15.

Burke, J.J., Franks, C.D., Burrow, G., Xin, Z., 2010. Selection system for the stay green drought tolerance trait in sorghum germplasm. Journal of Agronomy 102(1), 1118–1122.

Camargo, C.E., Tulmann Neto, A., Ferreira Filho, A.W., Carlos Felicio, J., 2000. Genetic control of aluminum tolerance in mutant lines of the wheat cultivar Anahuac. Euphytica 114(1), 47–53.

Chavan, U.D., Patil, J.V., 2010. Grain Sorghum Processing. CBS Publishers, Lucknow, India, 440.

Chung, I., Kim, E., Yeo, M., Kim, S., Cheol, M., Moon, H., 2011. Antidiabetic effects of three Korean sorghum phenolic extracts in normal and streptozotocin-induced diabetic rats. Food Research International 44(1), 127–132.

Dahot, M.U., Rind, E., Rafiq, M., 2011. Physical and biochemical analysis of sodium azide treated *sorghum bicolor* (L.) Monech. Pakistan Journal of Biotechnology 8(2), 67–72.

Das, I.K., Rakshit, S., Sharma, K.K., Chattanvar, S.N., Gholve, V.M., Jayalakshmi, S.K., Tonapi, V.A., 2018. Development of a charcoal rot index for multilocation trials of sorghum. Crop Protection 108(2), 102–109.

Edmunds, L.K., 1962. The relation of plant maturity, temperature and soil moisture to charcoal stalk rot development in grain sorghum. Plant Pathology 52(8), 731.

Edmunds, L.K., 1964. Combined relation of plant maturity, temperature and soil moisture to charcoal stalk rot development in grain sorghum. Phytopathology 54(5), 514–517.

Federer, W.T., 1979. Preface to special issue on covariance. Communications in Statistics-Theory and Methods 8(8), 719–721.

Girish, G., Ashok, B., Muniswamy, S., Jayalakshmi, S.K., Patil, J.R., 2016a. Genetic variability and character association studies for root traits and charcoal rot disease in sorghum. Proceedings of the National Academy of Sciences India Section B - Biological Sciences 88(1), 101–109.

Hassan, M.H.A., Sallam, M.A., Asran, M.R., 1996. Influence of certain factors on severity of stalk rot disease of grain sorghum in Upper Egypt. Assiut Journal of Agricultural Sciences 27(4), 179–190.

Haussmann, B.I.G., Rattunde, H.F., Weltzien-Rattunde, E., Traore, P.S.C., vom Brocke, K., Parzies, H.K., 2012. Breeding strategies for adaptation of pearl millet and sorghum to climate variability and change in West Africa. Journal of Agronomy and Crop Science 198(5), 327–339.

Jahagirdar, S., Ravikumar, M.R., Jamadar, M.M., Pawar, K.N., 2002. Field screening of local genotypes against charcoal rot of sorghum caused by *Macrophomina phaseolina* (Tassi) Goid. Agricultural Science Digest 22(2), 87–89.

Khune, N.N., Kurhekar, D.E., Raut, J.G., Wangikar, P.D., 1984. Stalk rot of sorghum caused by *Fusarium moniliforme*. Indian Phytopathology 37(2), 316–319.

Leiser, W.L., Rattunde, H.F.W., Piepho, H.P., Weltzien, E., Diallo, A., Melchinger, A.E., Parzies, H.K., Haussmann, B.I., 2012. Selection strategy for sorghum targeting phosphorus-limited environments in West Africa: Analysis of multi-environment experiments. Crop Science 52(6), 2517–2527.

Leslie, J.F., Zeller, K.A., Lamprecht, S.C., Rheeder, J.P., Marasas, W.F., 2005. Toxicity, pathogenicity, and genetic differentiation of five species of Fusarium from sorghum and millet. Phytopathology 95(3), 275–283.

Mrema, E., Shimelis, H., Laing, M., Mwadzingeni, L., 2020. Integrated management of *Striga hermonthica* and *S. asiatica* in sorghum: A review. Australian Journal of Crop Science 14(1), 36–45.

Nalawade, S.V., Agarkar, G.D., Chirame, B.B., 2008. Biochemical mechanism of hostresistance to *Macrophomina phaseolina* (Tassi.) Goid. of sorghum. Journal of Maharashtra Agricultural University 33(2), 193–195.

Przybylska, A., Frankowski, J., Stuper, K., 2019. Bioactive compounds in sorghum. European Food Research and Technology 245(5), 1075–1080.

Rao, S., Santhakumar, A.B., Chinkwo, K.A., Wu, G., Johnson, S.K., Blanchard, C., 2018. Characterization of phenolic compounds and antioxidant activity in sorghum grains. Journal of Cereal Science 84(2), 103–111.

Tarr, S.A.J., 1962. Root and stalk diseases: Red stalk rot, Colletotrichum rot, anthracnose, and red leaf spot. In: Diseases of sorghum, Sudan grass and brown corn. International Mycological Institute, Kew, 58–73.

Tesso, T., Ejeta, G., 2011. Stalk strength and reaction to infection by *Macrophomina phaseolina* of brown midrib maize (*Zea mays*) and sorghum (*Sorghum bicolor*). Field Crops Research 120(2), 271–275.

Tesso, T., Perumal, R., Little, C.R., Adeyanju, A., Radwan, G.L., Prom, L.K., Magill, C.W., 2012. Sorghum pathology and biotechnology - A fungal disease perspective: Part II. Anthracnose, stalk rot, and downy mildew. European Journal of Plant Science and Biotechnology 6(1), 31–44.

Tesso, T.T., Claflin, L.E., Tuinstra, M.R., 2005. Analysis of stalk rot resistance and genetic diversity among drought tolerant sorghum genotypes. Crop Science 45(2), 645–652.

Tesso, T.T., Ochanda, N., Little, C.R., Claflin, L., Tuinstra, M.R., 2010. Analysis of host plant resistance to multiple Fusarium species associated with stalk rot disease in sorghum [*Sorghum bicolor* (L.) *Moench*]. Field Crops Research 118(2), 177–182.

Thapa, C.B., 2004. Effect of acute exposure of gamma rays on seed germination and seedling growth of *Pinus kesiya* Gord and *P. wallichiana* AB Jacks. Our Nature 2(1), 13–17.