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Dr. Rajan Sharma

ICRISAT, Global Theme- Crop Improvement, Patancheru, Hyderabad, AP, India, 502 324, +91 40 3071 3395; r.sharma@cgiar.org

Mr. AG Girish

Laboratory, Hyderabad, Andhra Pradesh, India; girishpql@gmail.com

Dr. Hari D Upadhyaya, PhD

ICRISAT, Genebank, ICRISAT, Genebank, Patancheru, Hyderabad, Andhra Pradesh, India, 502324, +91 40 3071 3333, +91 40 3071 3075; h.upadhyaya@cgiar.org

P Humayun

ICRISAT, Plant Quarantine Laboratory, Hyderabad, Andhra Pradesh, India; p.humayun@cgiar.org

Dr. Kiran Babu Talluri

Acharya N. G. Ranga Agricultural University (ANGRAU), Department of Plant Pathology, College of Agriculture, Rajendranagar, Hyderabad, Andhra Pradesh, India, 500030; kiranbabutalluri@gmail.com

Veeranki Panduranga Rao

ICRISAT, Hyderabad, India; vpao847@gmail.com

Dr. R P Thakur

ICRISAT, Pathology, Hyderabad, Andhra Pradesh, India; thakur.rp08@gmail.com

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Identification of blast resistance in a core collection of foxtail millet germplasm

Rajan Sharma, A. G. Girish, H. D. Upadhyaya, P. Humayun, T. K. Babu, V. P. Rao, and R. P.

Thakur

International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, Andhra Pradesh, India

Corresponding author : Rajan Sharma

E-mail: r.sharma@cgiar.org

Phone: +91 40 3071 3395

Fax: +91 40 3071 3074

Abstract

Blast, also known as leaf spot, caused by *Pyricularia grisea* [teleomorph: *Magnaporthe grisea*], is a serious disease affecting both forage and grain production in foxtail millet in India. For the identification of new and diverse sources of blast resistance, a foxtail millet core collection comprising 155 accessions was evaluated against Patancheru isolate (Fx 57) of *M. grisea*. In a field screen during 2009 and 2010, 21 accessions were identified with neck and head blast resistance against Fx 57. In a greenhouse screen, 11 of the 155 accessions exhibited seedling leaf blast resistance to the same isolate. Further evaluation of the selected 28 accessions (found resistant to neck and head blast under field conditions during 2009 and 2010, and/or leaf blast in the greenhouse screen) against four *M. grisea* isolates Fx 57, Fx 58, Fx 60 and Fx 62 from Patancheru, Nandyal, Vizianagaram and Mandya, respectively, led to the identification of 16 accessions with leaf, sheath, neck and head blast resistance to at least one isolate. Two accessions (ISe 1181 and ISe 1547) were free from head blast infection and showed resistance to leaf (score ≤ 3.0 on a 1-to-9 scale), neck and sheath blast (score ≤ 2.0 on a 1-to-5 scale) against all the four isolates. In addition, ISe 1067 and ISe 1575 also exhibited high levels of blast resistance. Blast-resistant accessions with superior agronomic and nutritional quality traits can be evaluated in multilocation yield trials before releasing them for cultivation to farmers.

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Foxtail millet (*Setaria italica* (L.) Beauv.) is one of the ten small-grained cereals (small millets) grown as a food crop in Asia and for animal feed in the USA and Europe (19). China, India and Japan are the chief foxtail millet growing countries, and the millet is believed to have been first domesticated in central China (4). Foxtail millet comprises two subspecies, *S. italica* subsp. *italica* and subsp. *viridis*. Subspecies *viridis* is considered as the progenitor of the cultivated form. Based on the comparative morphology of the foxtail millet

accessions, Prasada Rao et al. (14,15) suggested three races of foxtail millet – *moharia* common in Europe, southeast Russia, Afghanistan and Pakistan; *maxima* common in eastern China, Georgia (Eurasia), Japan, Korea, Nepal and northern India (it has also been introduced in the USA); and race *indica* in the remaining parts of India and Sri Lanka. Another report mentions four races (*maxima*, *moharia*, *indica* and *nana*), each related to a specific geographic region – race *maxima* from East Asia, *moharia* from Europe, *indica* from South Asia and *nana* from Afghanistan and Lebanon (11).

In India, foxtail millet is grown on about 1 m ha, mainly in northern Karnataka, parts of coastal Andhra Pradesh, Uttarakhand, Tamil Nadu and some parts of the northeastern states. The grain is used both for food and feed. A seed oil content of 5.45%, with a range between 4.0 and 7.3% has been reported in the foxtail millet germplasm (18). The grain is also a rich source of protein, minerals (calcium, iron, potassium, magnesium, and zinc) and vitamins (16). It is not only widely used as an energy source for pregnant and lactating women, but also for sick people and children, and especially for diabetics (20). It has been suggested that foxtail millet protein be used as a food component to fight type 2 diabetes and cardiovascular diseases (6). In general, foxtail millet is valued as a crop of short growth duration, which is fairly resistant to insect pests and diseases, with grain that makes a nutritious and healthy food. However, blast disease is the only yield limiting biotic constraint to this crop, especially in northern China and India (12).

Blast caused by the fungus *Pyricularia grisea* (Cooke) Sacc. [teleomorph: *Magnaporthe grisea* (Herbert) Barr] affects both forage and grain production of foxtail millet. Symptoms of the disease appear as circular spots with straw-colored centers on leaf blades. The spots are small and scattered, and are 2–5 mm in diameter surrounded by a dark brown margin. When the disease appears in severe form during humid weather conditions, especially with a dense plant stand, the leaves wither and dry. Plants are infected at all growth

stages (9); lower leaves are the most severely affected. Node, neck and stem tissues are also infected in addition to leaf sheaths. The blast pathogen infects several cereal crops, including rice, wheat, pearl millet, finger millet and foxtail millet, and several grasses (12,13,21,26). The pathogen is variable, but highly specialized in its host range. Thus, *M. grisea* strains from rice or any other hosts do not infect foxtail millet and *vice versa*.

The disease can be best managed through host plant resistance; therefore, extensive screening for blast resistance among local cultivars of foxtail millet has been conducted in India and China (5,7,24). However, differential reactions of cultivars have been observed among Chinese cultivars, demonstrating the existence of pathogenic races among *M. grisea* populations adapted to foxtail millet (33). Therefore, it is important to evaluate foxtail millet germplasm of diverse geographic origins to identify new sources of blast resistance for utilization in breeding programs. In this context, plant genetic resources conserved in genebanks can be tapped for the identification of resistance sources (29). The genebank at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India has assembled 1535 foxtail millet accessions from 26 countries. However, the large number of accessions in the germplasm collections often hinders their evaluation and utilization for specific breeding purposes. To overcome these problems, Frankel and Brown (8) proposed the establishment of a core collection (10% of the total) that could be selected from the existing collection of crop species resources in a gene bank. Core collections based on phenotypic data have been reported in several crops (3,27,28,32). Using passport information and data on 23 morphological descriptors, Upadhyaya et al. (29) developed a core collection consisting of 155 foxtail millet accessions. This core collection comprises accessions of all the races and sub-races of foxtail millet of diverse geographical origins. The present study was planned to evaluate all accessions in the foxtail millet core collection against *M. grisea* to identify new and diverse sources of blast resistance.

Materials and Methods

Seed source. Seed of the 155 germplasm accessions of the foxtail millet core collection comprising three races – *indica* (102), *maxima* (24) and *moharia* (29) was obtained from the ICRISAT Genebank at Patancheru, India.

Pathogen isolates. Cultures of *M. grisea* were established from diseased samples collected from the foxtail millet fields in the 2008 rainy season from Patancheru (Fx 57), Nandyal (Fx 58), Vizianagaram (Fx 60) and Mandya (Fx 62), India. Isolations were made from diseased samples on Oat-meal agar (OA) medium and the pathogen was purified through single-spore isolation. Mass multiplication of fungal spores for inoculation was achieved by growing the fungus on OA medium in Petri plates (9 discs/plate) at 25±1°C for 10 days. The plates were flooded with 20 ml of sterile distilled water (SDW) and the fungal growth containing mycelium and conidia was gently removed by scraping with a plastic inoculation loop. The suspension was transferred to a 100 ml conical flask, stirred to facilitate the release of conidia into water and filtered through a muslin cloth (1). The conidial concentration was adjusted to 1×10^5 spores mL⁻¹ and 3-4 drops of Tween 20 were added to the suspension just before using it for inoculation.

Field evaluation of foxtail millet core collection for blast resistance. The foxtail millet core collection comprising 155 accessions along with 4 checks (ISe 375, -376, -1468 and -1541) was evaluated at Patancheru (18°31'N, 78°16'E, 545 m above sea level, and 600 km from the sea), Andhra Pradesh, India in a randomized complete block design (RCBD) with 2 replicates, 1 row 2 m long/replicate, for neck and head blast resistance during the 2009 and 2010 rainy seasons following artificial inoculation with Patancheru isolate (Fx 57) of *M. grisea*. The susceptible line (ISe 1118) was planted at every 5th row to increase disease pressure. Plants were thinned to 20 plants/row at 15 days after emergence and spray-

inoculated until runoff at tillering with an aqueous conidial suspension (1×10^5 spores mL⁻¹) of *M. grisea* isolate Fx 57. This was done during the evening hours using a Knapsack power sprayer. High humidity and leaf wetness was provided by perfo-irrigation twice a day on rain-free days, 30 min each during morning and evening hours to facilitate disease development. Blast incidence (neck and head) was recorded as percentage of infected plants in a row at the dough stage. Based on blast incidence, these accessions were categorized into resistant ($\leq 10\%$ incidence), moderately resistant (11 to 30%), susceptible (31 to 50%) and highly susceptible ($> 50\%$ incidence).

Greenhouse evaluation for leaf blast resistance. For leaf blast resistance, core collection accessions were evaluated at the seedling stage in a greenhouse. The experiment was conducted in a completely randomized design (CRD) with 2 replicates, 1 pot/replicate; 10 plants/pot. The 15-day-old potted seedlings were spray-inoculated until runoff with an aqueous conidial suspension (1×10^5 spores mL⁻¹) of Fx 57, covered with polyethylene bags and incubated at 25°C for 24 h. Bags were then removed and the inoculated seedlings were exposed to $> 90\%$ RH under misting for 7 days in a greenhouse. Percentage of diseased leaf area was visually assessed 10 days after inoculation (DAI) and leaf blast severity was recorded using a progressive 1-to-9 scale, where 1 = no lesions, to small brown specks of pinhead size, and 9 = $> 75\%$ leaf area covered with lesions or all the leaves dead (1).

Identification of resistance to different isolates of *M. grisea*. Twenty-five accessions (found resistant to neck and head blast under field conditions during both 2009 and 2010, and/or leaf blast in the greenhouse screen) were further screened for leaf, sheath, neck and head blast resistance against four *M. grisea* isolates (Fx 57, Fx 58, Fx 60 and Fx 62) along with germplasm checks (ISe 376 and -1541) and a susceptible check (ISe 1118). In addition, ISe 1204, which was found resistant in 2010 field screen but failed to germinate in 2009, was also included in the screening. The experiment was conducted in a CRD with 2

replicates, 1 pot/replicate; 10 plants/pot for leaf blast, and five plants/pot for sheath, neck and head blast screening. For leaf blast reaction, 15-day-old seedlings were screened as described above. For sheath, neck and head blast reaction, plants were inoculated at anthesis, covered with polyethylene bags and incubated at 25°C for 24 h to prevent cross contamination. Bags were then removed and the inoculated plants were exposed to >90% RH under misting for 7 days in a greenhouse. Lesion size was measured on the sheaths and necks of infected plants and a 1-to-5 progressive rating scale (1 = no lesions to pin head size of lesions on the neck/sheath; 2 = 0.1 to 2.0 cm; 3 = 2.1 to 4.0 cm; 4 = 4.1 to 6.0 cm and 5 = >6.0 cm of lesions on the neck/sheath region) was used to record the neck and sheath blast severity at dough stage (1). Head blast was recorded as a percentage of infected panicles at maturity.

Evaluation for agronomic and nutritional traits. The foxtail millet core collection was evaluated for agronomic traits (days to 50% flowering, plant height, basal tiller number) and for nutritional traits(protein and minerals contents during rainy season 2008) along with four controls ISe 375, ISe 376, ISe 1468 and ISe 1541 as described previously (28). The experiment was conducted in an alpha-lattice design with three replicates, where each plot consisted of 1 row of 4 m. Data on days to 50% flowering, plant height and basal tillers were recorded using the foxtail millet descriptors (10). Data on plant height and basal tillers were recorded from five randomly selected plants. A random well-cleaned grain sample from each plot was used to record observations on grain protein, calcium (Ca), iron (Fe) and zinc (Zn) concentrations in the core collection accessions. Grain samples were powdered and digested using the tri-acid mixture, and Ca, Fe, Zn in the digests were determined by atomic absorption spectrometer (17), while protein was determined in the digests using an Autoanalyzer (22).

Statistical analysis. The replicate-wise values of disease scores were used for statistical analysis of each environment (where “environment” is field screen 2009/2010 or

greenhouse screen) using the residual maximum likelihood (REML) method and considering genotypes as random effects. Variance components due to genotypes (σ^2_g) and error (σ^2_{er}) and their standard errors were determined. Environment-wise best linear unbiased predictors for the core accessions were calculated. The significance of variance components were tested using respective standard errors.

For the pooled analysis, homogeneity of variance was tested using Bartlett's test (2). Environment was considered a fixed effect. The variances due to genotypes (σ^2_g) and genotype \times environment interaction (σ^2_{ge}), and their standard errors were determined. The significance of environment was assessed using the Wald statistic (31) that asymptotically follows a χ^2 distribution.

The associations between pairs of variables such as leaf, neck, sheath and head blast were determined in terms of Pearson's correlation coefficients using the correlation procedure in SAS (SAS Institute Inc. 2008. SAS/STAT® 9.2 User's Guide. Cary, NC).

Results

Blast resistance in the field screen. REML analysis indicated significant genotypic variance in both years separately, and genotypic and genotype \times environment variances in the pooled analysis (Table 1). The Wald statistic indicated significant differences between seasons. Therefore, data of two seasons were not averaged to categorize the accessions into resistant, moderately resistant, susceptible and highly susceptible. One accession ISe 1204 failed to germinate in the 2009 field screen. Of the remaining 154 accessions, 34 were found resistant, 96 moderately resistant, 16 susceptible and 8 highly susceptible during 2009; whereas, in 2010, numbers of accessions in the resistant, moderately resistant, susceptible and highly susceptible categories were 46, 65, 15 and 29, respectively (Fig. 1). However, 20 accessions (ISe 375, -748, -751, -769, -771, -785, -846, -1059, -1067, -1137, -1286, -1320, -1335, -1387, -1419, -1547, -1563, -1593, -1685 and -1704) were found resistant in both

years. Although ISe 1204 failed to germinate in 2009, it was found resistant in the 2010 field screen. In addition, two germplasm checks, ISe 376 and ISe 1541, were also found resistant in both years. Thus, these 23 accessions were selected for further screening against four isolates Fx 57, Fx 58, Fx 60 and Fx 62 of *M. grisea*.

Leaf blast resistance in the greenhouse screen. Greenhouse screening of foxtail millet core accessions for leaf blast reaction at seedling stage identified 11 accessions resistant (≤ 3.0 score on a 1-to-9 scale) to leaf blast. Two accessions, ISe 828 and ISe 1209, did not germinate; thus could not be evaluated for leaf blast resistance. Twenty-three accessions were moderately resistant (3.1 to 5.0 score), 18 were susceptible (5.1 to 7.0 score) and the remaining 101 were highly susceptible (> 7.0 score) to Fx 57 (Fig. 1). Of the 11 leaf blast resistant accessions, six (ISe 375, -1059, -1067, -1547, -1563 and -1685) were also found resistant in the field screens of both, 2009 and 2010. The resistant accessions were selected for further screening against four isolates Fx 57, Fx 58, Fx 60 and Fx 62 of *M. grisea*.

Resistance to different isolates of *M. grisea*. REML analysis of the selected accessions screened in the greenhouse for leaf, sheath, neck and head blast resistance against four isolates indicated significant variation due to genotypes, isolates and their interactions (Table 2). Significant MS variance due to isolates indicated pathogenic variation among the isolates used in this study. This variation was further confirmed by the differential leaf blast reaction of 14 accessions against the four isolates. Susceptible check ISe 1118 recorded 6 to 9 leaf blast scores on a 1-to-9 scale, 3.6 to 4.9 sheath blast and 3.5 to 4.7 neck blast scores on a 1-to-5 scale, and 63–100% head blast incidence against test isolates, indicating adequate disease pressure and a reliable disease screen. ISe 1286 was also found highly susceptible to leaf, sheath, neck and head blast against all the four isolates.

Among the 28 accessions (including germplasm checks ISe 376 and -1541) screened against four *M. grisea* isolates, two (ISe 1181 and ISe 1547) were found to have leaf blast (seedling stage) resistance against all the four isolates (Table 3). Six accessions had leaf blast resistance against three, five against two and three against only one isolate. The remaining accessions recorded ≥ 5.0 score to *M. grisea* isolates.

Most of the accessions, except ISe 1286, selected from the core collection exhibited adult plant resistance (≤ 2.0 score for sheath/neck blast and $\leq 10\%$ head blast incidence) to at least one isolate of *M. grisea*. Sheath, neck and head blast resistance was observed in 15 accessions against all the four isolates. Two accessions, ISe 1181 and ISe 1547, were free from head blast and resistant to leaf, neck and sheath blast against all the four isolates. In addition, ISe 1067 and ISe 1575 exhibited seedling leaf blast resistance to three, Fx 57, Fx 58 and Fx 62, isolates, and sheath, neck and head blast resistance to all the four isolates (Table 3).

Agronomic performance and nutritional quality of blast resistant accessions.

Fifteen of the 28 selected accessions were early-flowering compared to the mean (54.75 days) days to 50% flowering of the 155 accessions of the core collection (Table 4). Among these, six (ISe 1201, -1258, -1286, -1320, -1335 and -1563) accessions took ≤ 40 days to 50% flowering. Blast resistant accessions ISe 1201 and ISe 1419 were the shortest (29.7 cm) and tallest (155.6cm), respectively, among the 155 accessions. The average plant height of the 28 selected accessions (79.2 cm) was less than the average height (83.79 cm) of the core collection. Significant variation for basal tiller number was also observed in the selected accessions. Ten accessions had more basal tillers than the average (2.21) of the core collection. However, only five accessions recorded higher grain yield than the average (1046.32 kg ha⁻¹) of the core collection. ISe 1541 recorded the maximum grain yield (1852.5 kg ha⁻¹) among the 28 selected accessions.

Significant variation for nutritional quality traits (Ca, Fe, Zn and protein%) was also observed in the blast resistant accessions. Sixteen of the 28 accessions had more Ca than the average (145.82 ppm) for the entire core collection. Similarly, 15, 11 and 13 accessions had more Fe, Zn and protein, respectively, compared to the mean of the core collection.

Discussion

Twenty-one accessions resistant to neck and head blast were selected from the field evaluation of foxtail millet core collection under artificial inoculation. Eleven of the 155 core accessions also had seedling leaf blast resistance in the greenhouse screening against Patancheru isolate (Fx 57) of *M. grisea*. Further evaluation of the selected 28 accessions including two germplasm checks (with neck and head blast resistance in the field and/or leaf blast resistance in the greenhouse) against four isolates of *M. grisea* led to the identification of 16 accessions with resistance to leaf, sheath, neck and head blast to at least one isolate. Though 12 of the 28 selected accessions exhibited seedling leaf blast susceptibility to all the four *M. grisea* isolates, most of these accessions had adult plant resistance to sheath, neck and head blast. A weak correlation ($r = 0.2-0.5$) was observed between seedling (leaf blast) and adult plant (sheath, neck and head blast) reaction; whereas correlation between sheath, neck and head blast screening was high ($r = 0.83-0.92$; $P < 0.001$). Contrasting responses between the vegetative stage and the reproductive stage resistance often occur. Differential expression for resistance to leaf, neck and/or finger blast infection in finger millet has been reported (1). Similarly, some gene(s) responsible for seedling leaf blast resistance in rice were not found effective at the reproductive stage (23). Thus, there could be different genes responsible for seedling and adult plant resistance to *M. grisea* in foxtail millet.

Many pathogenic races have been identified in *M. grisea* infecting rice, and this variability has been cited as the principal cause for the frequent breakdown of resistance in rice varieties (25). Although pathogenic variations in the *M. grisea* populations adapted to

rice, wheat, foxtail millet, finger millet, pearl millet and several weed hosts have been reported (12, 13, 21, 26), there is no information on the virulence structure of foxtail millet-infecting populations of the pathogen in India. Differential reactions to four isolates was observed in 14 accessions (ISe 375, -376, -1059, -1067, -1137, -1187, -1201, -1204, -1258, -1419, -1541, -1563, -1575 and -1685) indicating possible pathogenic variation in the *M. grisea* populations adapted to foxtail millet in India (Table 3). If confirmed, some of these accessions can be used as host differentials to elucidate pathogenic variation in the foxtail millet infecting *M. grisea* isolates collected from the crop growing areas in India and elsewhere.

Based on the comparative morphology, foxtail millet accessions have been classified into three races: *moharia*, *maxima* and *indica* (14). Eleven of the 24 (46%) accessions of race *maxima* included in the foxtail millet core collection exhibited resistance to at least one isolate of *M. grisea* in the greenhouse screen (Tables 3 and 4). However, none of the 29 accessions from race *moharia*, and only three of the 102 accessions of race *indica*, showed blast resistance. Two accessions, ISe 1547 and ISe 1181, of race *maxima* were found resistant to all the four isolates of *M. grisea* indicating a high level of resistance in race *maxima* to different populations of *M. grisea* adapted to foxtail millet. Therefore, it will be useful to evaluate the remaining 211 accessions of race *maxima* available at ICRISAT genebank (29) to identify multiple pathotype resistance in foxtail millet germplasm.

Wide variations for nutrient quality traits (protein, Ca, Fe and Zn content) was observed in the grains of blast resistant accessions selected from the foxtail millet core collection. ISe 1419, which is resistant to sheath, neck and head blast against all the four isolates and has leaf blast resistance to two isolates Fx 58 and Fx 60, was among 26 best accessions with three or more agronomic and nutritional traits (Ca, Zn and protein) combinations selected by Upadhyaya et al. (30) from the foxtail millet core collection. Blast

resistant accessions ISe 1059, -1181, and -1685, and ISe -1059 and -1187 were among the trait specific accessions identified for Ca and Fe content, respectively (30). ISe 1067 and germplasm check ISe 1541 were identified as best sources of protein among the 16 blast resistant accessions. Therefore, these accessions could be used for the development of blast resistant, nutritionally superior foxtail millet cultivars.

Breeding for improved blast resistant varieties is an important goal of foxtail millet improvement programs in India. Multiple pathotype resistant accessions identified in the core collection could be used in breeding programs. Among blast resistant accessions identified in this study, ISe 376 is an improved cultivar. This accession was found resistant to three of the four isolates tested. In addition, ISe 1685 and ISe 1541 recorded higher grain yields compared to the best control, ISe 1468 (30). Therefore, these agronomically superior blast resistant accessions can be directly released for cultivation in farmers' fields after thorough testing in yield trials in the relevant locations.

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Figure Captions

Fig. 1. Summary of blast reaction of 155 accessions (two accessions failed to germinate in the greenhouse screen and one in the 2009 field screen) of foxtail millet core collection under field (neck and head blast) and greenhouse (seedling leaf blast) conditions. Resistant = $\leq 10\%$ blast incidence in the field and ≤ 3.0 score on a 1-to-9 scale in the greenhouse; moderately resistant = 11 to 30% blast incidence in the field and 3.1 to 5.0 score in the greenhouse; susceptible = 31 to 50% blast incidence in the field and 5.1 to 7.0 score in the greenhouse; highly susceptible = $>50\%$ blast incidence in the field and >7.0 score in the greenhouse. Vertical bars indicate standard error.

Table 1. Variance components due to genotypes (σ^2_g), genotype \times environment (σ^2_{ge}), and their standard errors (s.e.) for blast reaction in the foxtail millet core collection

Disease screen	Season	σ^2_g	s.e.	σ^2_{ge}	s.e.	Wald statistics (season)	<i>F</i> prob
Field	2009	159.0	27.1	...	...	...	...
	2010	517.61	64.10	...	...	...	...
	Pooled	122.9	33.3	216.5	31.6	9.66	0.009
Greenhouse	...	4.8680	0.5610	...	...	...	...

Table 2. Variance components due to genotypes, isolates and their interactions for the leaf, sheath, neck and head blast in the selected foxtail millet accessions evaluated under greenhouse conditions during December 2011 to April 2012

Source of variation	Degree of freedom	Mean square			
		Leaf blast	Sheath blast	Neck blast	Head blast
Isolate (I)	3	38.54***	5.03***	6.49***	8.38***
Genotype (G)	28	325.86***	45.71***	94.23***	76.06***
I × G	84	37.9***	3.77***	5.04***	8.13***

***Significant at $P \leq 0.001$

Table 3. Leaf, neck, sheath and head blast scores of the selected foxtail millet accessions evaluated against four *Magnaporthe grisea* isolates under greenhouse conditions during December 2011 to April 2012

Accession (ISe) No	Leaf blast (1-9 scale)				Sheath blast (1-5 scale)				Neck blast (1-5 scale)				Head blast (%)			
	Fx 57	Fx 58	Fx 60	Fx 62	Fx 57	Fx 58	Fx 60	Fx 62	Fx 57	Fx 58	Fx 60	Fx 62	Fx 57	Fx 58	Fx 60	Fx 62
375	3.0	3.0	4.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	40.0	0.0	0.0
376	2.0	3.0	4.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	80.0	0.0	0.0
748	6.0	5.0	7.0	6.0	1.0	1.5	1.2	1.0	1.1	1.0	1.1	1.0	0.0	0.0	0.0	0.0
751	7.0	5.0	6.0	5.5	1.3	1.0	1.2	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
769	5.0	5.0	6.0	4.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
771	9.0	8.0	8.0	8.0	1.0	2.7	1.8	1.8	1.0	1.4	1.0	1.0	0.0	0.0	0.0	0.0
785	9.0	8.0	8.0	8.0	3.9	3.7	1.4	1.7	2.1	1.0	1.0	1.0	0.0	10.0	0.0	20.0
846	8.5	6.0	7.0	6.0	1.0	2.2	1.0	1.3	1.0	2.8	1.0	1.0	0.0	50.0	0.0	0.0
1059	3.0	5.0	5.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1067	2.0	3.0	4.0	2.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	1.0	0.0	0.0	0.0	0.0
1137	8.5	8.0	7.0	3.0	2.0	2.2	1.4	2.8	1.0	1.1	1.0	1.4	20.0	0.0	0.0	60.0
1181	1.0	2.0	3.0	3.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1187	3.0	3.0	3.0	4.0	1.0	1.0	1.0	1.5	2.0	1.0	1.0	1.0	0.0	0.0	0.0	50.0

1201	2.0	4.0	6.0	3.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1204	6.0	4.0	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1258	2.0	8.0	7.0	7.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	0.0	0.0	25.0	0.0
1286	6.0	7.0	6.0	5.0	4.5	4.4	4.2	3.0	4.4	3.7	3.7	2.0	100.0	83.3	80.0	40.0
1320	5.5	5.0	6.0	6.0	1.5	2.0	1.4	1.0	1.0	1.6	1.0	1.0	0.0	0.0	0.0	0.0
1335	9.0	7.0	6.0	5.0	2.4	2.8	3.3	1.9	1.0	1.1	1.2	1.0	12.5	0.0	20.0	0.0
1387	8.0	6.0	5.0	7.0	1.0	1.8	--	1.0	1.0	1.0	--	1.0	0.0	0.0	--	0.0
1419	4.0	3.0	3.0	7.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.1	0.0	0.0	0.0	0.0
1541	4.0	3.0	4.0	3.0	1.3	1.0	3.5	2.7	1.0	1.0	2.3	1.0	0.0	60.0	60.0	60.0
1547	3.0	3.0	2.0	3.0	2.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1563	3.0	4.0	2.0	3.0	2.0	1.6	3.0	1.1	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1575	2.0	3.0	4.0	3.0	1.2	1.0	1.0	1.1	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1593	4.0	5.0	5.0	5.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1685	3.0	9.0	8.0	8.0	1.2	1.4	1.6	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
1704	8.0	9.0	8.0	8.0	2.5	1.7	1.9	2.5	1.1	1.0	1.0	1.4	0.0	0.0	30.0	0.0
1118	9.0	8.0	7.0	6.0	4.5	4.9	4.0	3.6	4.7	4.6	3.5	3.7	100.0	100.0	62.5	100.0
Mean	4.88	5.14	5.25	4.77	1.52	1.59	1.51	1.37	1.34	1.21	1.17	1.07	4.73	11.55	7.96	8.21
LSD ($P < 0.01$) for Isolate			0.143					0.173				0.101			3.57	
LSD ($P < 0.01$) for genotype			0.385					0.467				0.272			9.52	

LSD ($P < 0.01$) isolate ×				
genotype	0.770	0.934	0.544	19.05
CV (%)	0.7	4.4	2.3	4.6

Resistant = $\leq 10\%$ head blast incidence, ≤ 3.0 score on a 1-to-9 scale and ≤ 2.0 score on a 1-to-5 scale.

Moderately resistant = 11 to 30% head blast incidence, 3.1 to 5.0 score on a 1-to-9 scale and 2.1 to 3.0 score on a 1-to-5 scale.

Susceptible = 31 to 50% head blast incidence, 5.1 to 7.0 score on a 1-to-9 scale and 3.1 to 4.0 score on a 1-to-5 scale.

Highly susceptible = $> 50\%$ head blast incidence, > 7.0 score on a 1-to-9 scale and > 4.0 score on a 1-to-5 scale.

Table 4. Origin, race, biological status, days to 50% flowering, plant height, basal tiller number, protein and minerals contents of the foxtail millet accessions selected from the core collection evaluated during rainy season 2008

Accession (Ise)	Origin	Race	Sub-race	Biological status	Days to 50% flowering	Plant height (cm)	Basal tiller (No.)	Grain yield (kg ha ⁻¹)	Ca (ppm)	Fe (ppm)	Zn (ppm)	Protein (%)
375	India	<i>Maxima</i>	<i>Assamense</i>	Improved Cultivar	60	85.91	1.52	666.7	126.7	40.1	42.0	11.3
376	India	<i>Maxima</i>	<i>Assamense</i>	Improved Cultivar	57	88.19	1.54	996.4	114.6	43.9	46.4	11.4
748	India	<i>Indica</i>	<i>Magna</i>	Landrace	97	132.5	2.47	693.5	154.2	43.1	60.1	16.8
751	India	<i>Indica</i>	<i>Glabra</i>	Landrace	101	103.33	2.24	561.0	221.3	49.5	55.2	16.1
769	India	<i>Moharia</i>	<i>Aristata</i>	Landrace	89	155.45	2.27	1012.7	187.3	45.2	48.8	12.6
771	India	<i>Indica</i>	<i>Nana</i>	Landrace	59	86.91	2.83	1683.7	130.9	52.2	46.2	12.4
785	India	<i>Indica</i>	<i>Nana</i>	Landrace	54	83.6	2.49	926.2	139.6	47.0	44.4	13.0
846	India	<i>Indica</i>	<i>Nana</i>	Landrace	57	92.27	2.68	1508.3	147.3	51.1	47.9	11.9
1059	India	<i>Maxima</i>	<i>Spongiosa</i>	Landrace	66	121.55	1.56	721.5	248.4	63.3	46.4	12.9
1067	Syria	<i>Maxima</i>	<i>Compacta</i>	Landrace	45	43.29	1.73	322.1	143.9	49.0	43.0	15.7

1137	Syria	<i>Indica</i>	<i>Nana</i>	Landrace	48	61.73	1.74	165.9	127.2	56.9	37.7	14.4
1181	China	<i>Maxima</i>	<i>Compacta</i>	Landrace	43	62.2	1.39	155.8	271.6	51.8	44.6	14.9
1187	China	<i>Maxima</i>	<i>Compacta</i>	Landrace	45	44.71	1.97	109.7	107.2	58.6	45.2	13.9
1201	China	<i>Maxima</i>	<i>Compacta</i>	Landrace	36	29.69	1.61	78.8	154.6	42.0	39.8	13.0
1204	Russia & CISs	<i>Maxima</i>	<i>Compacta</i>	Landrace	45	46.31	1.78	47.5	155.1	48.4	40.9	14.3
1258	Russia & CISs	<i>Maxima</i>	<i>Compacta</i>	Landrace	40	43.47	1.62	186.6	90.3	52.0	47.4	14.4
1286	Turkey	<i>Moharia</i>	<i>Glabra</i>	Landrace	36	33.07	2.55	232.5	181.5	66.0	74.2	13.5
1320	USA	<i>Moharia</i>	<i>Glabra</i>	Landrace	30	33.78	2.37	210.7	118.5	62.2	55.9	13.7
1335	Hungary	<i>Moharia</i>	<i>Glabra</i>	Landrace	35	37.95	1.74	77.8	154.8	55.0	50.2	16.2
1387	Sri Lanka	<i>Indica</i>	<i>Glabra</i>	Landrace	83	132.75	1.74	778.6	157.3	49.3	59.3	13.2
1419	India	<i>Indica</i>	<i>Glabra</i>	Landrace	94	155.59	1.93	883.9	241.0	52.2	57.2	15.7
1541	India	<i>Maxima</i>	<i>Compacta</i>	Landrace	75	114.79	1.97	1852.5	107.4	47.6	51.9	17.2
1547	Korea	<i>Maxima</i>	<i>Compacta</i>	Landrace	43	51.72	1.47	150.3	113.0	37.2	33.6	11.5
1563	Korea	<i>Maxima</i>	<i>Compacta</i>	Landrace	39	62.88	2.28	657.3	155.9	51.1	34.3	13.9
1575	Korea	<i>Maxima</i>	<i>Compacta</i>	Landrace	50	60.71	1.87	254.4	159.7	53.8	37.8	12.5
1593	Korea	<i>Maxima</i>	<i>Compacta</i>	Landrace	51	60.78	1.73	420.3	144.4	43.2	37.4	13.2

1685	India	<i>Indica</i>	<i>Profusa</i>	Landrace	80	115.73	2.11	1644.7	200.3	49.8	47.8	11.9
1704	India	<i>Indica</i>	<i>Nana</i>	Landrace	56	77.29	2.49	1531.7	148.6	58.8	55.5	12.6
1118	Syria	<i>Moharia</i>	<i>Glabra</i>	Landrace	42	30.02	2.63	411.5	113.6	39.7	38.4	16.0
Statistical parameters for 155 accessions of core collection												
Range					30-101	29.7- 155.6	1.4- 3.2	39.9-2349.5	90.3- 288.7	24.1- 68.0	33.6- 74.2	10.7- 18.5
ISe for min					1151	1201	1181	1227	1258	1129	1547	931
ISe for max					751	1419	909	1820	1227	1151	1286	1312
Trial mean					54.75	83.79	2.21	1046.32	145.82	49.78	47.85	13.50
LSD ($P = 0.05$)					8.23	18.87	1.05	915.82	50.79	16.57	13.65	2.26
CV (%)					7.75	11.66	35.54	50.54	17.76	16.89	14.42	8.55

