EPIDEMIOLOGY, VIRULENCE DIVERSITY AND HOST-PLANT RESISTANCE IN BLAST [*Magnaporthe grisea* (Hebert) Barr.] OF FINGER MILLET [*Eleusine coracana* (L.) Gaertn.]

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Title	**:**	**Epidemiology, Virulence Diversity and Host-Plant Resistance in Blast [*Magnaporthe grisea* (Hebert) Barr.] of Finger Millet [*Eleusine coracana* (L.) Gaertn.]**
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ABSTRACT

Studies were conducted on blast disease of finger millet that included cultural, morphological, pathological and molecular diversity, epidemiology and identification of host-plant resistance at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India and field trials were conducted at ICRISAT; ARS, Vizianagaram; RARS, Nandyal; ZARS, Mandya and OFRS, Naganahalli. A total of 125 blast disease specimens from finger millet, 6 from foxtail millet, 3 from rice and 5 from pearl millet were collected from major crop growing areas of India during 2008-2010. From these samples, a total of 70 monoconidial isolates of *Magnaporthe grisea*, 56 from finger millet, 6 from foxtail millet, 3 from rice and 5 from pearl millet were obtained. Of the 70 isolates, 15 each were from Patancheru and Vizianagaram, 13 from Nandyal, 14 from Mandya, 8 from Naganahalli and one each from Dholi, Aurangabad, Hissar, Jaipur and Solan.

In pathogenicity studies, considerable variation was found among the isolates from finger millet for leaf blast however, no significant differences were found among the isolates from foxtail millet and pearl millet. Diversity in cultural characters, such as colony colour, texture and growth pattern were noticed among the isolates, but no clear-cut groupings were observed between isolates from different hosts. The isolates that were grayish-green and sector-forming produced more spores than those having cottony and submerged growth. Variations in morphological characters, such as colony growth, size of the conidia and sporulation were observed within and between the isolates from the same location.

Five selected representative isolates (one isolate/location) were evaluated for pathogenicity (leaf blast) on Finger Millet Blast Resistance Stability Nursery (FMBRSN) consisting of 28 accessions and were found highly variable for virulence, disease severity and disease reaction. Among the five isolates, the isolate FMNg55 was found highly virulent and FMP1 the weakly virulent. A set of 10 putative host differentials were identified based on field evaluation of FMBRSN accessions over 2 years at five locations and greenhouse screening. Twenty isolates (4 isolates/location) evaluated for pathogenicity on the 10 host differentials, and one resistant and one susceptible check were found highly variable for virulence, disease severity and disease reaction. Among these, the isolates FMP5, FMV23, FMNg54 and FMNg55 were found highly virulent and FMV14 the weakly virulent. Based on leaf blast severity, *M. grisea* isolates were classified into four pathotype groups.

High degree of polymorphism was detected among the isolates from finger millet and foxtail millet using SSR analysis with 17 markers. The isolates were grouped on the basis of their host origins however, two isolates from finger millet and one from foxtail millet were grouped together indicating the occurrence of some genetic drift between the two populations. Based on similarity coefficient, the isolates from finger millet were classified into nine groups. The isolates from different plant parts (leaf and neck) were randomly distributed in the dendrogram. In contrast, the isolates from neck and finger

samples from the same genotype/plant were clustered in one group at 90% similarity matrix. No correlation was observed between pathogenicity data and SSR data. Model-based population structure analysis revealed three distinct populations based on their host origin with varying levels of ancestral admixtures among the 65 isolates.

Epidemiological studies showed maximum disease development after 48 h of leaf wetness and 1×10^5 and 1×10^6 conidia ml^{-1} inoculum concentration. Influence of temperature on sporulation showed that 27°C was optimum for sporulation of *M. grisea* lesions in finger millet. Maximum growth and sporulation of finger millet isolates occurred at 25°C and those of pearl millet at 30°C whereas, maximum growth of foxtail millet isolates occurred at 25°C and sporulation at 30°C.

Effective greenhouse and field screening techniques, and rating scales for neck blast (1–5 scale) and finger blast severity (%) were developed. From the resistance evaluation of 622 finger millet core collection, 402 accessions were found resistant to neck blast, 436 resistant to finger blast and 372 had combined resistance to both neck and finger blast in field under artificial inoculation at ICRISAT during the rainy season (*kharif)* 2009. Of the mini-core, 68 had combined resistance to all the three phases of blast in field during 2009 and 2010 at ICRISAT. A significant weak to moderate correlations were found between leaf blast with neck blast and finger blast whereas, significant strong positive correlation was found between neck and finger blast ratings. Of the mini-core, 58 accessions were found resistant to leaf blast in greenhouse to Patancheru isolate.

Of the mini-core, 68 accessions were resistant to both neck and finger blast at Patancheru, 57 at Vizianagaram, 56 at Naganahalli, 11 at Naganahalli and 10 at Mandya during 2009 field screening. Among the mini-core, 7 accessions were resistant to both neck and finger blast across the 5 locations during 2009. The FMBRSN-2010 comprising of 28 accessions including resistant and susceptible checks was constituted and evaluated at five locations during the *kharif* 2010. Of these, 17 were resistant to all the three phases of blast at Patancheru; 11 at Naganahalli; 10 at Vizianagaram; 8 at Mandya and 7 at Nandyal. Of the 7 resistant accessions during 2009, two were found susceptible to neck and finger blast in 2010 screening.

Analysis of resistance stability (2009 and 2010) using relative variation and GGE biplot technique showed that, five accessions (IE 2589, -2911, -4497, -6337 and -7018) were most resistant to all the three phases of blast across the five locations over two years. Of the five accessions, IE 2911 was found resistant to all three phases of blast against five isolates (one representative isolate/location) under greenhouse conditions and thus appears to be the best source of stable resistance.

Analysis of weather data from five locations over two years and neck, and finger blast severity on four highly susceptible accessions did not show any significant association between blast severity and weather variables (temperature and relative humidity) however, positive association was observed with amount and frequency of rainfall.

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%	:	per cent
C	:	Celsius
µm	:	micrometer
cm	:	centimetre
g	:	gram
h	:	hours
ha	:	hectare
i.e.,	:	that is
l	:	litre
µl	:	microlitre
µg	:	microgram
mg	:	milligram
ml	:	milliliter
OMA	:	Oat-Meal Agar
ANOVA	:	Analysis of Variance
REML	:	Residual maximum likelihood
CRD	:	Completely Randomized Design
DAI	:	Days After Inoculation
DI	:	Disease Incidence
DF	:	Days to 50% flowering
e.g.	:	for example
et al.	:	and others
etc.	:	etcetera
FMBHDS	:	Finger Millet Blast Host Differential Studies
FMBRSN	:	Finger Millet Blast Resistance Stability Nursery
LSD	:	Least Significant Difference
LWD	:	Leaf Wetness Duration
No.	:	Number
p. m.	:	Afternoon
RCBD	:	Randomized Complete Block Design
RH	:	Relative Humidity
SE (m)	:	Standard Error of mean
viz.,	:	Namely
YESB	:	Yeast Extract Glucose Broth
FYM	:	Farm Yard Manure
SSR	:	Simple Sequence Repeat

Chapter I

INTRODUCTION

The transformation of agriculture from a stable to more productive systems has been through crop distribution and diversification. Currently, the area and production of traditional crops are showing a declining trend in most developing countries. Yet, in many parts of the world, these traditional crops play a major role in both the dietary needs and incomes of many rural households. One such traditional group of cereal crops is the minor coarse cereals (small millets). Among the small millets, finger millet a widely grown traditional grain cereal cultivated in semi-arid areas of East and Southern Africa and South Asia, is a staple food and generates income for millions of poor people.

It is widely cultivated in India, Srilanka, Malaysia, China, Myanmar, Nepal and Japan in Asia, and Kenya, Uganda, Tanzania, Ethiopia, Eritrea, Rwanda, Democratic Republic of Congo, Zaire, Eritrea, and Somalia in Africa. Finger millet accounts for about 8% of the area and 11% of production of all millets, worldwide (Bennetzen *et al*., 2003). As production statistics for the nine cultivated millets are often combined by the FAO, reliable estimates of the areas sown to individual species are difficult to find. It was recently estimated that finger millet accounts for 10% of 38 m ha sown to millets globally (Mgonja *et al*., 2007). In India, the important finger millet growing states are Karnataka, Odisha, Maharashtra, Tamil Nadu, Andhra Pradesh, Uttarakhand, Uttar Pradesh and Bihar. It is cultivated from sea level in parts of Andhra Pradesh and Tamil Nadu in India to about 2,400 m above sea level in hilly areas in northern India (Upadhyaya *et al*., 2007). The total area under finger millet (called *Ragi* in Hindi) in India is about 2.8 m ha with an annual production of about 2.78 m t (Nagaraja *et al*., 2007) and nearly half of the area is in Karnataka (Nagaraja *et al*., 2008). Finger millet constitutes about 81% of the minor millets produced in India (Latha *et al*., 2005).

Finger millet [*Eleusine coracana* (L.) Gaertn.] belongs to the family Poaceae and the crop was known to be domesticated around 5000 years BC in the western Uganda and Ethiopian highlands and from there reached to the west cost of India around 3000 BC (Hilu and deWet, 1976a). Its wide adaptability to different rainfall zones, developmental plasticity and high nutritive value make it one of the most popular in small millets.

The grains are a rich source of seed protein, fiber, minerals (calcium, iron, and manganese) and amino acids (tryptophan, cystine and methionine), and are mostly used for making chapati, cakes, puddings, or porridge brewing beer (Hilu and deWet, 1976a), baking

bread and poultry feed. Finger millet is being increasingly recognized as highly nutritious for the weak and immuno-compromised (Takan *et al*., 2011). Nutritionally, finger millet is equal or superior to other staple cereals, especially in minerals. The nutritional quality of finger millet grain makes it an ideal food for expectant women, breast-feeding mothers, children, the sick, elderly and diabetics (National Research Council, 1996). It is a major component in the preparation of food for HIV patients in Eastern Africa. The main protein fraction (*eleusinin*) has high biological value with good amounts of tryptophan, cystine, methionine and total aromatic amino acids, which are crucial to human health and growth, and are deficient in most cereals. For this reason alone, finger millet is important in preventing malnutrition. Finger millet has also been used as a folk remedy for many diseases, such as leprosy, liver diseases. Though often known as a crop for the poor, it is fast becoming a popular food crop among health conscious people of all categories both in rural and urban areas.

In recent years, the overall production and productivity of finger millet has been declining due to several biotic and abiotic stresses. Of the biotic stresses, diseases caused by fungi, bacteria, viruses and MLOs are common. Among the fungal diseases, blast disease caused by *Magnaporthe grisea* (anamorph-*Pyricularia grisea* (Cooke) Sacc.) is a major problem in India and Africa causing substantial yield losses. In India, the disease was first reported from the Tanjore delta of Tamil Nadu by Mc Rae in 1920 with an estimated loss of 50% (Venkatarayan, 1946). The average loss due to blast has been reported to be around 28-36% (Vishwanath *et al*., 1986., Nagaraja *et al*., 2007), and in endemic areas, yield losses could be as high as 80-90% (Vishwanath *et al*., 1986., Bisht, 1987 and Rao, 1990). The blast pathogen *M. grisea* (Cooke) Sacc. (Rossman *et al*., 1990) is a heterothallic, filamentous fungus, pathogenic to almost 50 plant species in 30 genera of *Poaceae* including economically important crops like rice, wheat, barley and millets (Ou, 1985).

Finger millet blast is the most devastating disease affecting different aerial parts of the plant at all growth stages starting from seedling to grain formation. The symptom appears on leaf lamina with typical spindle shaped spots with gray or whitish centre and brown or reddish brown margin that enlarge and coalesce to give blasted appearance. Then most important stage of the disease is neck blast, when it attacks the neck region of the plant. Two to four inches of the neck almost immediately below the earhead turns initially brown, later turn black due to infection resulting in breaking of stem at the neck region. This results in severe blasting of florets in the fingers of the earhead and thus very poor grain development. The pathogen also attacks fingers usually from the apical portions which runs towards the base. The extent and

severity of infection depend on the stage of infection and weather conditions. Infected fingers in the earhead have blasted florets either with no grain or shriveled blackened grains, resulting in huge production losses.

Effective management of blast disease in finger millet can best be achieved through host-plant resistance. Growing disease resistant varieties is most relevant and cost effective for the resource-poor and marginal farmers, who cannot afford other method of disease control such as using expensive chemical fungicides. For a proper use of host-plant resistance to develop resistant cultivars, there is a need to have clear understanding of the biology of the pathogen, including pathogenic and genetic diversity; epidemiology; reliable resistance screening techniques to identify stable resistance sources and finally a strategy for utilization and deployment of resistant cultivars.

Magnaporthe grisea being an ubiquitous pathogen with many hosts, understanding the basis for host-specificity and host range will be useful in designing improved methods for disease management. It will also provide an insight into the role played by other hosts in the spread of the blast epidemic.

Levy *et al*. (1993), in case of rice blast pathosystem indicated that to understand the mechanisms of frequent breakdown of resistance in blast resistant cultivars, studies on the extent of genetic diversity present in the population of *M. grisea* in a specific geographical region is important. Development of durable blast resistance for environments highly conducive for the disease should be possible, if breeding programs are based on a complete understanding of pathogen diversity in the target area. Substantial work has been done with the rice-blast pathosystems on pathogenic and genetic diversity, epidemiology and disease management through host-plant resistance. However, such studies are very limited with the finger millet-blast pathosystems.

In order to measure genetic variability more precisely, molecular markers provide an unbiased estimate of total genomic variation and have the potential to minimize errors due to sampling variance (Spooner *et al*., 1996). DNA fingerprinting techniques have created new tools for the molecular analysis of *M. grisea* populations from rice (Levy *et al*., 1993). Various molecular techniques have been used for analysis of *M. grisea* population structure; Several SSR (Brondani *et al*., 2000., Kim *et al*., 2000., Kaye *et al*., 2003 and Suzuki *et al*., 2009) and minisatellite markers (Li *et al*., 2007) have already been developed and screened for *M. grisea* populations. Genetic diversity information, in addition to pathogenic diversity, would be useful in development of finger millet varieties with broad-spectrum stable resistance to blast.

Weather variables, particularly relative humidity, leaf wetness duration and temperature play a major role in influencing infection and disease development in any host-pathogen systems. Blast disease has the potential to cause severe crop losses in finger millet when environmental conditions are favorable for disease development and yield losses up to 90% have been recorded (Vishwanath *et al*., 1986., Bisht, 1987 and Rao, 1990). Therefore, information on relationship between weather variables and blast disease could be used to develop and improve techniques to screen for resistance. For example, the use of mist to provide high relative humidity and leaf wetness that are ideal for infection is already being used for screening pearl millet for blast resistance at ICRISAT (Thakur *et al*., 2009). Improved knowledge of the effect of interaction of host cultivar with weather, pathogenic strain and the crop growth stages would be helpful in understanding and predicting the disease epidemics. These factors are more relevant with a polycyclic, airborne pathogen like *Magnaporthe* spp. In general, long periods of leaf wetness, high relative humidity (>90%) and high temperatures of 17 to 28°C favor the blast disease development. Determination of quantitative relationship between the environmental conditions, such as temperature, humidity and leaf wetness duration on infection, sporulation and incidence is critical in the development of prediction models.

Development of effective screening technique based on the basic knowledge of pathogen biology and epidemiology, and identification of resistance in diverse germplasm accessions and breeding lines provides the basis for resistance utilization. When there is wide diversity in the pathogen population across geographical locations, multilocation evaluation of resistant lines, and greenhouse evaluation against diverse pathotypes help identify the stable resistance sources. Such resistance sources can be used for breeding cultivars with stable and likely durable resistance.

Growing cultivars with durable resistance is the best means of combating the blast disease of finger millet, which is predominantly grown by resource-poor and marginal farmers. Blast resistant breeding lines developed using resistance sources should be evaluated and selected at “hot spots” under pathogen populations representing all the diversity. An underlying assumption in this approach is that all pathotypes for the target production system present at the site, albeit some in very low frequency and that pathotypes do not arise *de novo*, or do so very infrequently.

Availability of adequate genetic variation is a prerequisite for genetic improvement of any crop species. ICRISAT’s genebank in Patancheru, India holds 5,949 accessions of finger millet from 23 countries. A finger millet mini-core collection (10% of core and 1% of entire

collection) consisting of 80 accessions (Upadhyaya *et al*., 2010) representing the core collection of 622 accessions (Upadhyaya *et al*., 2006) developed at ICRISAT in 2009 could be evaluated at key blast "hot spots" for identification of broad-spectrum stable resistance sources that could be utilized in disease resistance breeding programs.

Recognizing the importance of finger millet and the constraint posed by the blast disease, the present study was planned to characterize populations of *M. grisea* from diverse geographical locations with reference to cultural, morphological, pathogenic and genetic diversity in the pathogen; study epidemiology and identify host-plant resistance to the disease using mini-core collection with the following specific objectives.

1. Collection, purification and testing pathogenicity of *M. grisea* isolates from diverse geographical locations and cultivars.
2. Study cultural, morphological, pathogenic and molecular diversity among the *M. grisea* isolates.
3. Study epidemiology – influence of temperatures and leaf wetness duration on sporulation and infection, inoculum threshold and host susceptibility stage.
4. Identification of sources of blast resistance from mini-core collection of finger millet germplasm.

Chapter II

REVIEW OF LITERATURE

The available literature of work done on the blast disease of finger millet and the various aspects related to the present study of epidemiology, virulence diversity and host plant resistance have been reviewed in this chapter. The review of literature pertaining to this dissertation is presented in the following headings and sub-headings.

2.1 DISEASE

2.1.1 Distribution of the disease

Finger millet blast caused by *Magnaporthe grisea* (Hebert) Barr. is the most devastating disease distributed in almost all the growing regions of the world affecting different aerial parts of the plant at all stages of its growth starting from the seedling stage (causing lesions and premature drying of young leaves) to affecting the panicle causing neck and/or finger blast. The disease is known to occur in India (Mc Rae, 1920), Srilanka (Park, 1932), Nepal (Thompson, 1941), Malaya (Burnett, 1949), Tanzania (Kuwite and Shao, 1992), Somalia (Mohamed, 1980), Zambia (Muyanga and Danial, 1995), Ethiopia, Kenya, Uganda (Dunbar, 1969; Adipala, 1992). In India the disease is prevalent wherever finger millet is grown viz., Karnataka, Tamilnadu, Maharashtra, Andhra Pradesh, Orissa, Bihar, Uttaranchal etc. The disease was reported for the first time in India, from Tanjore delta of Tamilnadu by Mc Rae (1920).

2.1.2 Symptoms

The symptoms appear at all the stages of plant growth viz., germlings to earheads and even on seed. When the young healthy seedlings catch the disease, patches of seedlings give burnt appearance due to severe leaf blight and die which results in the gappy patches. Disease appears on leaf lamina with typical spindle-shaped spots with gray or whitish centre and brown or reddish brown margin enlarge, coalesce and give blasted appearance. Well developed lesions may measure 0.5 × 2 cm. The pathogen also attacks culms, especially at the nodal region results in blackening of that area. However, the most damaging stage of the disease is when it attacks neck region. Two to four inches of the neck almost immediately below the earhead, turns initially brown, later black due to fungal infection results in breaking at the infected area. Sporulation of the fungus may be noticed on this area. The pathogen also attacks fingers usually from the apical portions which run towards the base. The extent of infection depends on stage of infection and weather conditions. Neck infection causes significant loss in grain

number, grain weight and significant increase in spikelet sterility (Rath and Mishra, 1975). If the pathogen attacks the developing grains, it results in shriveled blackened seeds. Even in a resistant variety like GPU 28 some black seeds can be seen (Kumar, 2002).

2.1.3 Pathogen

Blast of finger millet (ragi) is caused by the fungus *Pyricularia grisea* (Cooke.) Sacc. (formerly *Pyricularia oryzae* Cavara.) anamorph of *Magnaporthe grisea* (Hebert) Brar. It is a heterothallic, filamentous fungus pathogenic to almost 40 plant species in 30 genera of Poaceae (Ou, 1980., Murakami *et al.,* 2000., Inukai *et al.,* 2006) including *Eleusine*. Initially, there was difference of opinion with regard to the nomenclature of the pathogen. Morphologically it is very close to *Pyricularia oryzae* (Ramakrishnan, 1948). The perfect stage of *Pyricularia grisea* was earlier named as *Ceratosphaeria grisea* (Hebert, 1971). Later Yaegashi and Nishihara (1976) suggested the genus *Magnaporthe*. Yaegashi and Udagawa (1978) finally proposed *M. grisea* as the perfect stage of *Pyricularia grisea* (Cke.) Sacc. instead of *Ceratosphaeria grisea*. Chauhan and Varma (1981) reported *P. grisea* on *Eleusine indica* from Kanpur, India.

Hyphae is hyaline and septate. However, as the fungus gets older, the hypha becomes brown. Generally, growth of the pathogen is relatively more on the upper surface which thus makes the spot more dark on that side. Conidiophores are simple, septate, basal portion being relatively darker. Conidia obpyriform in shape and hyaline in colour produced acrogenously, one after another. Conidium is three celled, the middle cell being much wider and darker, and end cell germinates giving out germtubes. Formation of intercalary or terminal chlamydospores is common, which are globose, thickwalled and olive brown. Under laboratory conditions the pathogen produces fertile perithecia (Viji and Gnanamanickam, 1998).

2.1.4 Losses due to blast

Mc Rae (1922) who reported the blast disease first time in India also gave an yield loss estimate could be over 50%. The yield losses estimated to be 10-50% in Kenya (Sreenivasaprasad *et al.,* 2007) and 10-80% in Uganda (Esele, 1982). In India, the average loss due to blast has been reported to be around 28-36% (Vishwanath *et al.,* 1986., Nagaraja *et al.,* 2007), and in endemic areas, yield losses can be as high as 80-90% (Vishwanath *et al.,* 1986., Bisht, 1987 and Rao 1990). Ragi blast in Himalayan region appears at lower elevation and it was recorded at <1600 m and caused 25-40% yield loss (Bisht *et al.,* 1997). Cent per cent yield reduction was recorded at Rampur, Nepal (Batsa and Tamang, 1983). Ramappa *et al.* (2002) observed 76% reduction in grain yield and 70% reduction 1000-grain weight when infection

occurred immediately after flowering while the reduction in grain yield was 52% and that of 1000-seed weight 50% when the disease occurred at milky stage. Quantification of losses in yield due to neck blast at different stages of earhead development revealed that the losses were drastic when disease appeared within 10 days of ear emergence and considerable losses were incurred even if infection occurred up to 20 days of ear emergence (Bisht *et al.,* 1987).

2.1.4 Cross-infectivity tests

Pathogenicity of blast fungus is largely restricted to its host species (Ramakrishnan, 1948., Todman *et al.,* 1994), although successful infection of a host by an isolate from a different species has been reported under experimental conditions. Some isolates of the blast from weeds in Uganda able to infect finger millet, which implicates weeds/wild grasses as "green bridges" for finger millet blast (Ekwamu, 1988).

Mackill and Bonman (1986) suggested that various weed hosts growing near cultivated plants could serve as potential sources of inoculum for the disease and thus provide alternate means of survival for the fungus. Hamer *et al.* (1989) and Valent *et al.* (1986) concluded that the *M. grisea* populations are strongly delimited by host range although blast is found to infect a range of sympatric flora. Inoculations of rice under experimental conditions with isolates of *P. grisea* from weeds resulted in successful (Mackill, 1986) and unsuccessful (Prabhu *et al.,* 1992) cross-inoculations.

Viji *et al.* (2000) reported that ten isolates of *M. grisea* from rice did not infect finger millet and *vice versa* in the laboratory and confirmed that the *M. grisea* populations in India were distinct. Similar results were reported by Kato *et al.* (1977) and Todman *et al.* (1994), who found that *Magnaporthe* isolates from *E. coracana* failed to infect rice and *vice versa*. On the contrary, Kumar and Singh (1995) reported contradictory results which may be due to the type of environmental condition provided during the experimentations and the nutrient status of the soil (Asuyama, 1965., Ou, 1985). From the above results it is clear that the gene flow between the pathogen infecting rice and finger millet has been restricted and these are genetically distinct populations of *M. grisea*.

Pathogenicity tests revealed that the isolates from weeds were pathogenic to finger millet, with some weed isolates being as aggressive as some of the finger millet isolates (Takan *et al.,* 2004).

2.2 VIRULENCE DIVERSITY

2.2.1 Cultural and morphological diversity among the *M. grisea* isolates

Ramakrishnan (1948) observed a positive correlation in the sporulating ability and aerial growth of *P. grisea*. Mutations of the SMO^{+} genetic locus were reported to cause a number of gross deviations from the normal process of conidiogenesis, resulting in conidia which exhibited a wide variety of unusual morphologies (Hamer *et al.,* 1989). Arase *et al.* (1994) reported that two mutant isolates of *Pyricularia oryzae* formed abnormal, longer, cylindrical spores with more septa than those of normal, obpyriform spores of wild isolates.

Viji and Gnanamanickam (2000) could distinguish *Pyricularia* isolates from different hosts based on cultural and conidial variation. Sonah *et al.* (2009) studied the cultural and morphological variability of *M. grisea* isolates collected from rice and non-rice hosts revealed that isolates that showed fast vegetative growth as grey-green or grey- white produced more number of spores than those with slower vegetative growth (submerged or subdued growth patterns). Isolates derived from non-rice hosts also showed abnormal spore morphology which were longer, cylindrical and obpyriform.

2.2.2 Pathogenic variability of *M. grisea* using a set of putative host differentials

Information on the pathogen population structure, such as the type of variants present in a location, the amount and distribution of variation assist plant breeders in developing for resistance breeding and deployment of resistant cultivars. Therefore, precise delineation of pathogenic variability in the target production area is a prerequisite for identifying finger millet genotypes with a stable resistance to the variable pathogen populations. It is important from an ecological, epidemiological and breeding perspective to know how genetic diversity is maintained and how new, well-adapted complex races arise in the pathogen population. For the finger millet blast there is limited information available (Kumar *et al.,* 2007) on development of a tentative set of differentials for assessing the racial differentiation. To know the virulence pattern of the finger millet blast pathogen, Kumar *et al.* (2007) pathotyped 12 isolates using finger millet genotypes IE 1012, IE 2912, IE 2885, Indaf-5, Indaf-9 and GPU 28 as a new set of differentials, identified genotype IE 1012 as a differential host and Indaf-5 and Indaf-9 as susceptible controls in the differential set. For a better understanding of the pathogen diversity it is important to have the right number of differentials, including local commercial cultivars and other sources of resistance. For example, in case of rice blast, there are several site- specific differential sets and an International differential set have been developed (Atkins *et al.,* 1967., Ling and Ou, 1969., Ou, 1972 and Bonman *et al.,* 1986), and these are being effectively used to

discern the races/biotypes in the rice blast pathogen. Extensive work has been done with rice blast and detailed pathogenic variation has been reported from single-spores originating from single lesions and monoconidal subcultures (Ou and Ayad, 1968., Ou *et al.,* 1970).

Chen *et al.* (2001) tested pathogenicity reactions of 792 *M. grisea* isolates of rice using 13 host differentials consisting of six *indica* and seven *japonica* near-isogenic lines (NILs) and identified that 48 pathotypes with the indica NILs, 82 pathotypes with the *japonica* NILs, and a total of 344 pathotypes with both *indica* and *japonica* NILs. It is concluded that large differences in distribution of the pathotypes among the different rice growing areas. Sharma *et al.* (2002) pathotyped 119 isolates of *M. grisea* from north-western Himalayan region were grouped into 52 pathotypes on the basis of disease reaction on international differential rice lines and proved the set was inadequate to characterize the pathogen population.

In finger millet blast, Kumar *et al.* (2007) studied 12 isolates using six finger millet genotypes IE 1012, -2912, -2885, Indaf-5, Indaf-9 and GPU 28 and identified IE 1012 as a differential host, and Indaf-5 and Indaf-9 as susceptible controls in the differential set. Thus, information on finger millet blast variability is very limited so far.

Takan *et al.* (2011) studied the compatibility of thirty-one isolates representing diverse sampling location and host range revealed that all isolates were compatible to the tested eight finger millet varieties and only showed differences in aggressiveness and over all differences between isolates and varieties were highly significant for lesion number and leaf area affected.

2.2.3 Genetic diversity in *Magnaporthe grisea* using SSR (simple sequence repeat) markers

To understand the mechanism of frequent breakdown of resistance in blast resistant cultivars, studies on the extent of genetic diversity present in the population of *M. grisea* in a specific geographical region is important (Levy *et al.,* 1993). In order to measure genetic variability more precisely, molecular markers provide an unbiased estimate of total genomic variation and have the potential to minimize errors due to sampling variance (Spooner *et al.,* 1996). Furthermore, determination of fungal genetic diversity based on molecular markers is reliable as it is independent of culture conditions. DNA fingerprinting techniques have created new tools for the molecular analysis of *M. oryzae* populations (Levy *et al.,* 1993) and this is equally applicable to *M. grisea* as well. Information on regional and global population diversity at the lineage level is useful to understand the epidemiological properties of the blast disease in neighboring areas (Le *et al.,* 2010).

Assessment of genetic diversity of *M. grisea* from different crops mostly relied on MGR-based restriction fragment length polymorphism (RFLP), which is an expensive and time-consuming technique. The most commonly used DNA-based markers includes, randomly amplified polymorphic DNA (RAPD; Williams *et al.,* 1990., Welsh and McClelland, 1990), amplified fragment length polymorphism (AFLP; Vos *et al.,* 1995) and sequence characterized amplified region (SCAR) markers (Soubabere *et al.,* 2001). These markers are PCR-based markers and do not need any sequence information, speedy means to generate molecular markers but provide several genomic fragments with a marker in the single experiment (Varshney *et al.,* 2007). However, these markers are not locus specific and RAPDs suffer with reproducibility. Microsatellites or SSR markers are tandemly repeat DNA sequences occur throughout the eukaryotic genome on the other hand represent the locus specific, highly polymorphic, multi-allelic and co-dominant marker systems which have been proved the markers of choice in plant genetics and breeding applications (Gupta and Varshney, 2000). Generation of SSR markers is a time consuming, labour intensive and expensive task. Several SSR (Brondani *et al.,* 2000., Kim *et al.,* 2000., Kaye *et al.,* 2003 and Suzuki *et al.,* 2009) and minisatellite markers (Li *et al.,* 2007) have already been developed for *M. grisea*.

2.2.3.1 *M. oryzae* from rice

A family of dispersed repetitive DNA sequences known as *Magnaporthe grisea repeat* (MGR) elements was reported by Hamer *et al.* (1989) and this has been used for analyzing the population structure of rice-infecting *M. grisea* in various countries (Levy *et al.,* 1991., Han *et al.,* 1993., Levy *et al.,* 1993., Shull and Hamer, 1994., Chen *et al.,* 1995., Sivaraj *et al.,* 1995., Zeigler *et al.* 1995., Shen *et al.,* 1996., Rouman *et al.,* 1997., Kumar *et al.,* 1999., Correll *et al.,* 2000 and Xia *et al.,* 2000). Xia *et al.* (1993) analyzed 113 isolates from a rice cultivar Newbonnet grown in two commercial fields of Arkansas, USA through RFLP technique using MGR586 probe and found seven distinct fingerprint groups (A to G) in the population and concluded that there is no distinct group causing only neck blast or leaf blast either. George *et al.* (1998) developed a pair of primers amplify *Pot* (*Pyricularia oryzae* transposable) elements (Kachroo *et al.,* 1994) present in the genome of *M. grisea* facilitated the characterization population into clonal lineages.

DNA fingerprint groups specific to a particular geographical region were obtained by Sharma *et al.* (2002) using the RAPD analysis of 250 *M. grisea* isolates collected from the north-western Himalayan region. The isolates were separated into 25 DNA fingerprint groups or lineages, in which, 13 were exclusive to isolates obtained from Himachal Pradesh, five from

Uttaranchal and one from Jammu and Kashmir, India and seven remaining groups were composed of isolates from different locations, and 26 isolates could not be classified. DNA fingerprinting analysis with MGR586 and MAGGY of 176 *M. grisea* isolates collected over 16 years did not show any clear lineage structure in Korea and genetic similarity was significantly greater ($P<0.001$) within years than between years, although the difference was small (Park *et al.,* 2003).

A study conducted by Rathour *et al.* (2004) reported the presence of high genotypic diversity and continuous DNA fingerprint variation in the *M. grisea* population in the north-western Himalayan region and that no correlation was found between RAPD patterns and virulence characteristics of the pathogen. Globally, random amplified polymorphic DNA (RAPD) markers have been used for population analysis of *M. grisea* (Sere *et al.,* 2007., Kumar *et al.,* 2010).

Genetic relationships among *M. oryzae* isolates from perennial ryegrass (prg) within and between the two countries (USA and Japan) were examined using the repetitive DNA elements MGR586, Pot2 and MAGGY as DNA fingerprinting probes and the parsimony tree obtained from combined data showed that 71 of the 82 isolates grouped into a single lineage, 5 isolates formed four different lineages, and the remaining 6 (from Japan) formed a separate lineage (Tosa *et al.,* 2007).

Suzuki *et al.* (2009) evaluated several SSR markers reported by Kaye *et al.* (2003) among contemporary *M. grisea* isolates from Japan, but polymorphisms were rarely observed except for a few markers and the main reason is probably that field isolates collected from Japan in recent years have a genetically similar relationship and belongs to a limited number of lineages (Sone *et al.,* 1997., Suzuki *et al.,* 2006).

Le *et al.* (2010) studied the population dynamics of 226 isolates of *M. oryzae* in the Mekong Delta in Vietnam based on the transposable elements *Pot2* and MGR586 in the genomes supported that the pathogenic races were critically variable in comparison with the genomic diversity.

2.2.3.2 *M. grisea* from millets and grasses

Dobinson *et al.* (1993) identified a retroelement in strains of *M. grisea* that infect finger millet and designated it as grasshopper (*grh*). *M. grisea* isolates of rice and finger millet collected from southern parts of India were characterized by MGR-DNA fingerprinting (Viji *et al.,* 2000) and they reported that the blast fungus collected from these two hosts did not cross-infect and also exhibited different fingerprint patterns. Takan *et al.* (2004) stated that isolates

causing leaf, neck and panicle blast on finger millet compared by AFLP analysis were genetically similar indicating that the same strains were capable of causing different expressions of blast under suitable conditions. High degree of sexual compatibility between rice and finger millet strains of *M. grisea* and strong possibility of gene flow among these two host-limited populations of the pathogen were also reported (Rathour *et al.,* 2004a).

Rathour *et al.* (2006) studied the population structure of rice, finger millet, jungle rice, goosegrass and crabgrass infecting isolates of *M. grisea* from the north-western Himalayan region of India using native protein and isozyme revealed a high level of genetic diversity among different host-limited populations of the pathogen including those infecting rice and clustered in accordance with their host specificity. Subpopulations of the pathogen attacking rice and weeds in the same field were genetically distinct and there was no gene flow among rice and non-rice isolates of the pathogen.

Zheng *et al.* (2008) developed 313 polymorphic SSR markers, based on the released genome sequence data of *M. grisea* (Dean *et al.,* 2005) and constructed a genetic map consisting of 176 SSR markers. Sonah *et al.* (2009) observed the high level of the genetic variability through PCR based RAPD analysis of *M. grisea* isolates from different non-rice and rice hosts stated that isolates from same location grouped together irrespective of the crop.

Tanaka *et al.* (2009) examined the population structure of *Eleusine* isolates of *M. oryzae* by DNA fingerprinting with three repetitive elements: MGR586, MGR583, and *grasshopper* resulted the isolates collected just after an outbreak of finger millet blast in Japan during 1970s had almost identical fingerprint profiles although they were collected in distant prefectures, supports the idea that the outbreak was caused by seed transmission of a particular strain of *Eleusine* isolates.

Fifteen RAPD markers were used by Singh and Kumar (2010) to find out genetic diversity in 45 *M. grisea* isolates of finger millet collected from three different geographical regions of Uttarakhand which depicted about 25 to 40% linkage distance and clustered in to two major groups. The dendrogram study revealed that the geographic origin of strains did not play crucial role in lineage formation, as in each lineage (group), there were mixed populations of the three geographical regions.

Takan *et al.,* (2011) reported that continuous genetic variation pattern and lack of clonal lineages, with a wide range of haplotypes in 328 isolates of *M. grisea* from finger millet, rice and *Dactylaria* spp. In East Africa.

2.3 EPIDEMIOLOGY

Information on relationships between weather variables and blast disease could be used to improve techniques to screen for resistance. For example, the use of mist to provide high relative humidity and leaf wetness that are ideal for infection is already being used for screening pearl millet for blast resistance at ICRISAT (Thakur *et al.,* 2009). A knowledge of the effect of the interaction of host variety with weather, pathogenic strain and of course the time factor would go a longway in understanding the disease build up in any situation. In general, long periods leaf wetness, high relative humidity and temperatures of 17 to 28°C favor the blast disease development. These factors are more relevant with a polycyclic, airborne pathogen like *Pyricularia* spp.

2.3.1 Rice Blast

A minimum leaf wetness duration of 7 to 14 h was found essential for infection of rice by *P. grisea* (Kahn and Libby, 1958., Kato and Kozaka, 1974., Yoshino, 1974 and Teng, 1994). Barksdale and Asai (1965) found that 12.2, 9.7, and 7.7 h of dew were required for infection at 15.6, 21.1 and 26.7°C, respectively. Kato and Kozaka (1974) reported that leaf blast lesion on rice continued sporulation more than 20 days after lesion appearance and also observed that it continued until 30 days after lesion appearance in rice (Kim and Yoshino, 1987). However, the sporulation capacity was decreased when the lesion was getting old.

As per the literature, most of the works on sporulation and conidial release from blast lesions on rice have been conducted during the leaf blast stage (Kato, 1974) and this was probably due to the importance of primary inoculum potential of leaf blast lesions to neck blast development. The pathogen from rice grows luxuriantly on oat-meal, potato dextrose, ragi-meal agar medium at pH of 6.9 and temperature 30°C (Sirkant Kulkarni and Govindu, 1976). Perezsendin *et al.* (1982) recorded 30°C as the optimum temperature for sporulation of *M. grisea* from rice. Sporulation of *M. oryzae* and disease progress was favored by high relative humidity (>89%), optimal temperature (25-28°C), and a minimum of 4 h of leaf wetness (Teng, 1994).

Moss and Trevathan (1987) found that blast infection of 3-wk-old plants of susceptible ryegrass cultivar 'Gulf' increased exponentially with increasing inoculum densities up to 8×10^5 conidia ml^{-1} and optimum temperature for infection was predicted to be 26°C, few lesions occurred at 35°C and none observed at 5°C. A continuous leaf-wetness of at least 24 h was

required for maximum infection and may be the critical factor in epidemic disease development.

Kim (1994) and Teng (1994) reported that conidiophores and first conidia were produced 4 to 6 h after dew formation and released shortly thereafter under optimal conditions. Sporulation of *P. grisea* from rice is favored relative humidity ≥89%, optimal temperatures of 25-28°C and a minimum of 4 h leaf wetness (Ou, 1985., Kim, 1994 and Teng, 1994). Studies by Kim and Yoshino (2000) on the sporulation pattern of rice blast fungus by detaching lesion-bearing leaves revealed that more conidia were produced on the adaxial than on the abaxial leaf surfaces and sporulation intensity was higher on the intact lesions than on those from which conidia and conidiophores were removed previously.

2.3.2 Millets and grasses

According to the Bisht *et al*, (1984) the climatic conditions that prevailed from 15th July were more favourable for blast development with average minimum and maximum atmospheric temperature of around 20 and 30°C respectively and relative humidity of >80%. The investigations on effect of temperature and relative humidity on finger millet blast incidence made by Chaudary and Vishwadhara (1988), Gowda and Gowda (1995) and Kumar *et al.* (2005) revealed that a temperature range of 18 to 24°C was more congenial for the development of neck and finger blast in ragi, than at other temperature ranges.

Kumar and Singh (1995) studied the response of *P. grisea* isolates from rice, finger millet and pearl millet to different temperatures and found that all the isolates exhibited maximum growth at 30°C though maximum sporulation in rice and finger millet isolates occurred at 25°C and pearl millet isolates at 30°C. Veena Hedge (1996) also found that a pH of 7.0 to be optimum while the temperature requirement was 28°C for finger millet blast pathogen. Madhukeshwara *et al.* (1997) working six isolates of *P. grisea* from finger millet found 28°C to be the optimum temperature for growth. Average minimum and maximum temperature between 22°C to 29°C with high relative between 85 to 99% during the growth period increased blast disease intensity in finger millet. The disease intensity also showed significant positive correlation with maximum and minimum temperature, rainfall and relative humidity (Patel and Tirupati, 1998).

A typical leaf wetness period of 14 h was more than sufficient for production of *M. grisea* conidia, however peak conidia release is typically at 6:00 a. m. and the length of the required leaf wetness period for infection is dependent upon the temperature in rice (Greer and

Webster, 2001). Uddin *et al.* (2002) studied the effects of temperature and leaf wetness duration on development of gray leaf spot of perennial turf grass (*Pyricularia grisea*) and stated that disease incidence and severity increased with increased leaf wetness duration (3 to 36 h at 3-h intervals) at all temperatures (20, 24, 28 and 32ºC).

The results of an epidemiological studies conducted by Kumar *et al.* (2005) concluded that, the increased neck and finger blast incidence in finger millet was due to reduced temperature (21.8°C) and increased relative humidity (93%). Ramappa *et al.* (2006) observed the highest leaf blast severity over 50% in finger millet nursery raised in October month probably due to high inoculum pressure coincides with favorable weather conditions *i.e*. more number rainy days (15 days), high relative humidity and low night temperature recorded during October as compared to June, July and August or November months.

A gradual increase of spore release of *M. grisea* from finger millet was recorded from 08.00 hours onwards whereas, mean maximum was 10.00 hours (1267.5) and as the day advances spore load was drastically reduced and marginal increase was recorded at 22.00 hours to midnight (Kumar *et al.,* 2007).

Thakur *et al.* (2009) developed the greenhouse and field screening technique for pearl millet blast by artificial inoculation. The field screening technique involved the use of a highly susceptible line as an infector row grown after every four test rows, artificial spray inoculation of 30-day-old plants using *P. grisea* spore suspension (1×10^5 spores ml^{-1}) and maintaining high humidity (>90% RH) through perfo-irrigation for 2 weeks following inoculation. The greenhouse screening technique involved spray inoculation of 15-day-old potted seedlings with *P. grisea* spore suspension and maintaining moderate temperature (25±1°C) and high humidity through a misting system for 10 days after inoculation.

Nagaraja *et al.* (2010a) evaluated core set of 520 finger millet accessions for blast resistance under prevailing weather conditions in field revealed that the incidence of neck and finger blast decreased significantly with increased temperature from 23.9 to 27.0°C and reduced rainfall from 303 to 83.4 mm during flowering period, however, the RH remained almost constant (88.34 to 88.90%).

2.4 HOST PLANT RESISTANCE

Finger millet is a low value crop and is generally grown as rainfed crop and most often on marginal soils. Development of varieties with genetic resistance is the best means of combating the disease problem and is more relevant in finger millet, which is predominantly

grown by resource-poor and marginal farmers who cannot afford controlling diseases using chemicals. The success of such programme depends on the identification of stable resistant sources and its subsequent utilization in breeding. As the germplasm is the basic raw material, one has to bank upon a broad genetic base now and in the future (Nagaraja *et al.,* 2007). As a result, the search continues for sources of high levels of host-plant resistance (HPR). However, large-scale evaluation of germplasm collections against various biotic or abiotic stresses is resource and time consuming. To overcome the need for a large scale evaluation of the entire germplasm collection of a species, Frankel and Brown (1984) proposed the concept of a core collection (10% of the entire collection) representing over 70% of the genetic variation available in the entire collection. Using 14 quantitative traits data, Upadhyaya *et al.* (2006) established a core collection in finger millet, which consists of 622 accessions representing geographical regions and biological races from the entire collection of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) germplasm, which is still large for multilocation evaluations and for systemic evaluation of traits of economic importance such as disease resistance would require large resources. To overcome this, Upadhyaya and Ortiz (2001) suggested a mini-core (10% of core collections and 1% entire collection) approach. In both stages, the intention is to ensure that over 80% of the variability from the entire collection (for developing core) or from the core collection (for developing mini core) is sampled. A finger millet mini-core consisting of 80 accessions, representing genetic diversity of the core collection and entire collection, was developed at ICRISAT by Upadhyaya *et al.* (2010) and multilocation evaluation for biotic and abiotic stresses is underway to identify new sources of variation for use in crop improvement programmes.

2.4.1 Rice Blast

Leaf blast susceptible varieties of rice have shown the resistance to neck blast and *vice versa* (Ono and Suzuki, 1960). Balal *et al.* (1977), Bhardwaj and Singh (1983) showed the positive correlation between leaf and neck blast infection. However, Koh *et al.* (1987) found some cultivars resistant in seedling stage appeared susceptible to neck infection. Bonman *et al.,* (1989) reported that two lines out of 27 were susceptible to leaf blast but resistant to neck blast and concluded that leaf and neck blast were not linked. Similar findings were obtained by Padmanabhan (1965), and Puri *et al.* (2009) concluded that resistance to neck blast might be expressed in some lines of rice independently to leaf blast. Ou (1985), Ou and Nuque (1963)

reported rice lines resistant to leaf blast to seedling stage, are completely resistant to neck blast and susceptible at the seedling stage are susceptible to neck blast.

Vingnanakulasingam (1991) and Puri *et al.* (2009) screened the rice lines for neck blast resistant under greenhouse conditions by injecting spore suspension of 10^5 spores ml^{-1} with syringe at photosynthetic leaf sheath base of the individual tillers at Booting stage (beginning with panicle initiation, growth stage 4 of IRRI growth scale of a 0 – 9) (IRRI, 2002). Bonman (1992) showed the correlation between leaf and neck blast incidence in most of lines of rice, Barkhe 3017, Masuli × MT4P # 137, Masuli × MT4 P # 168 and Masuli × MT P # 86 except IR 25604, which was susceptible to leaf blast but resistant to neck blast and concluded that genetic makeup and environmental parameter were the prominent factors for differential interaction.

Jia *et al.* (2003) developed novel spot method for evaluation of blast resistance in rice and indicated that no deleterious effects of Tween 20 to rice blast development and Tween-20 (0.02% vol/vol) was necessary for promoting adherence of spore suspensions to the detached leaves. Puri *et al.* (2009) assessed 182 rice lines for leaf and neck blast resistance, among them 77 were resistant, 43 were moderately resistant, 39 were moderately susceptible and 23 were susceptible to leaf blast while among the selected 31 lines evaluated for neck blast, each 4 lines were resistant and moderately resistant, 16 were moderately susceptible and 7 were susceptible. Leaf and neck infection was significant and positively correlated.

2.4.2 Finger millet blast

Ravikumar *et al.* (1990) evaluated 316 accessions of finger millet over four seasons under natural epiphytotic conditions at UAS, Bangalore. However, none were completely free from finger blast. Six genotypes GE 75, -669, -866, -1309, -1319, and 1407 showed resistance to both neck and finger blast and these were identified as source of stable resistance for resistance breeding programmes. Out of 25 finger millet cultivars tested in two fields evaluations, none of the cultivars were resistant to leaf blast bur HPB IE11-1 had small sized lesions. When scored for neck and finger blast IE 1012 was completely immune to infection and cultivars HPBIE11-1, indaf 15, MR 1, MR 2 and MR 3 had less than 5% infection (Somashekhara *et al.,* 1991).

Evaluation of 21 genotypes of ragi under natural epiphytotic conditions for three consequent years to know the stability of resistance to neck and finger blast showed that the genotypes VL 145, VL 149, PR1158-9, GPU 16 and RHRN82-Y84 to have stable resistance while HR8-19-1 and PR 202 exhibited moderate resistance and stability (Jain *et al.,* 1994).

Jain and Yadava (1999) found significant positive association of plant height, leaf angle, leaf area and number of stomata per unit area with blast disease. Hence, selection of a dwarf plant with narrow and vertical leaves coupled with reduced numbers of stomata per unit area should increase blast resistance in finger millet. Jain *et al.* (2002) concluded that leaf area, leaf angle, number of stomata, plant height and harvest index contributed most towards blast resistance in finger millet and GE 3022, 3024, 3058, 3060, VL 146 and IE 1012 exhibited real genetic diversity with high degree of blast resistance, appeared as promising donors for resistance breeding against blast disease.

Fakrudin *et al.* (2000) evaluated 15 selected accessions of finger under field conditions IE 2897, -2912, -2885 and -1012 were resistant while others were intermediate to highly susceptible for leaf blast whereas, IE 1012, -2885, GPU 28 and GPU26 were completely resistant to neck blast. Over the 2 years of evaluation under natural epiphytotic conditions, finger millet genotypes, GPU-26, GPU-28, AKE-1033, VL-149 and MR-2 were found to be moderately resistant to neck and finger blast (Rajanna *et al.,* 2000).

Mantur and Madhukeshwara (2001) and Mantur *et al.* (2001) screened 66 genotypes of finger millet over two seasons in field conditions under natural epiphytotic conditions revealed that neck blast incidence in susceptible check was >50% whereas, genotypes 2400, 4913, 4914, 4915, 4929, 4966, 5102, 5126, 5148 were completely free from blast while as many as 36 genotypes showed <2% incidence. Sunil (2002) screened 100 finger millet germplasm lines resistance to blast over two seasons, of these GE 632, -637, -659, -665, -669, -674, -676, -682, -696, -704, -705, -710, -728, -730 were found to posses partial resistance in the form of slow blasting.

Karmakar *et al.* (2002) identified finger millet blast tolerant cultivars, GPU 28, MR 20, VR 550, MR 19, GPU 34 and VR 687 during two years of evaluation under field conditions and also reported that sowing on 2nd July allowed the crop to escape the disease and obtained higher grain yield in comparison to 18th July sowing, where disease severity increased and reduced grain yields by 21.5% probably due to high inoculum pressure coincides with favorable weather conditions.

Mantur *et al.* (2002) evaluated 18 finger millet lines over the three rainy seasons from 1996 to 1999 under field conditions, genotypes 181E, GPU 28 were free of neck blast and GPU 28, VL 149, VL 253 were resistant. Ramappa *et al.* (2002) found MR1, GPU 56, GPU 53, GPU 58, VR 222, GPU 52, VL 317, VL 321, GPU 49, GPU 51, among varieties to be resistant to

blast in field screening during the rainy season 2000 at Zonal Agricultural Research Station, Mandya.

A total of 2950 finger millet genotypes were tested for resistance to neck and finger blast for three seasons under natural epiphytotic conditions revealed that 630 genotypes were resistant to neck blast, and 84 were resistant to finger blast. Three genotypes were completely free from disease and showed more than 20 g yield: IE 287, IE 976 and IC 43335 (Madhukeshwara *et al.,* 2004). The seeds of over 3000 finger millet genotypes screened by Madhukeshwara *et al.* (2004a) for blast resistance during the rainy season 2000-03 under field conditions at University of Agricultural Sciences (UAS), Bangalore and found 13 lines resistant to both neck and finger blast.

Ravishankar *et al.* (2004) studied the effect of different maturity groups on blast disease under field conditions at UAS, Bangalore and found that long duration (MR-33) and medium-duration (KMR-9 and KMR-3) cultivars were more tolerant than the early-maturing cultivars (KMR-7 and KMR-4). Sixty-five farmer varieties and 30 germplasm lines were evaluated by Takan *et al.* (2004) for blast resistance under natural infection at Alupe, Kenya revealed that ICRISAT germplasm lines KNE 620, -629, -688, -814 and -1149, and farmer variety accessions 14, 29, 32 and 44 were identified with low blast severity levels and good agronomic performance.

An attempt made to determine the mechanism of resistance to leaf, neck, and finger blast showed that smaller leaf area, narrow leaf angle, fewer stomata, dwarf plant with better conversion efficiency of photosynthates from source to sink (harvest index), thick epidermis and cuticle on the leaf and neck, fewer chlorenchymatous strands, higher total phenols, and low quantities of total and reducing sugars contributed toward blast resistance in finger millet (Jain and Yadava, 2004).

A field survey conducted by Kumar *et al.* (2005) reported that maximum neck (13-16%) and finger blast (42-55%) incidence in local varieties sown in July second fortnight with black seeds ranging from 64 - 96% and least of 0.1 - 1.0 in recently released varieties (GPU 28 and Indaf 5) in Tumkur district of Karnataka.

Kumar *et al.* (2006) reported that in finger millet epidermis and cuticle thickness was significantly higher in leaves of highly resistant cultivars (GPU 28 and GPU 45) compared to highly susceptible cultivars (KM 245, KM 252 and PR 202). However, the highly resistant cultivars had significantly less stomatal frequencies per mm and size when compared with highly susceptible cultivars. A study was conducted by Kumar *et al.* (2006a) to assess 78 long

duration finger millet genotypes against blast resistance under field conditions at UAS, Bangalore revealed that genotypes GE 253, -357 and -393 were immune to neck blast whereas, none of them were immune to finger blast.

Pande *et al.* (2006) screened a chickpea mini-core collection composed of 211 germplasm accessions for resistance against Ascochyta blight (AB), Botrytis gray mold (BGM), Fusarium wilt (FW) and dry root rot (DRR) under a controlled environment revealed that 21 were asymptomatic and 25 were resistant to Fusarium wilt whereas, 3, 55, and 6 accessions were moderately resistant to AB, BGM and DRR respectively. ICC 11284 was the only accession moderately resistant to both AB and BGM. Combined resistance was also identified for DRR and FW in 4 accessions, and for BGM and FW in 11 accessions.

Nagaraja and Mantur (2007) evaluated a set of 64-75 finger millet germplasm entries consequently for four year (2000-2003) under field conditions at UAS, Bangalore resulted 28, 23, 33, 16 entries were resistant showing <2.0% neck and finger blast. However, entries GE 5183, -5203, -5205, -5209, -5212, -5215, -5218, -5227 and -5230 showed stable resistance reaction. Thirty-six medium-duration finger millet genotypes evaluated for resistance to neck and finger blast during the rainy season 2003 under natural epiphytotic conditions, only GE-325 showed immune response to neck blast, and no genotype was immune to finger blast. GE-326 and GE-332 showed resistance to neck blast and moderate resistance to finger blast (Kumar *et al.,* 2007).

Nagaraja *et al.* (2007) found that ideal sowing time for medium to late maturing varieties was second fortnight of July for avoidance finger millet blast whereas, it could be stretched to first fortnight of August for early duration varieties. It may be due to that panicle emergence stage of the crop was more prone to pathogenic invasion which coincides with favourable conditions and virulent pathogen.

Sreenivasaprasad *et al.* (2007) reported that varieties producing dark coloured seeds and compact heads were more resistant compared to white-seeded and open-headed varieties in finger millet. It may be due to that air-borne pathogen inoculum readily entered on open-headed varieties than compact ones. Out of 47 genotypes of finger millet evaluated for blast resistance under natural epiphytotic conditions during *kharif*, 1999 as well as artificial epiphytotics conditions at Zonal Agricultural Research Station, Kolhapur during *kharif* 2000 revealed that 12 genotypes viz. KFM 41, -120, -150, -174, -177, -181, -228, -230, -243, and -253 of mid late group and KFM-183, -246 of late group were found resistant (Khot *et al.,* 2008).

Kumar *et al.* (2008) concluded that long duration finger millet genotypes are performing well against neck and finger blast disease under field conditions at (UAS), Bangalore most probably due to susceptible stage of the crop (panicle emergence stage) may not coincides with favourable weather conditions and virulent pathogen. A field study conducted at AICSMIP, UAS, Bangalore by Nagaraja and Gowda (2008c) during the rainy season 2005 revealed that of the 480 accessions of finger millet obtained from ICRISAT, 173 were resistant and 125 were moderately resistant to neck and finger blast under natural epiphytotic conditions.

From the results of Nagaraja *et al.* (2008a), the variety GPU 28 developed at AICRP small millets improvement, Bangalore during the 1990s remained highly resistant to neck and finger blast with only 2% incidence and occupied vast area of almost 75% under finger millet in Karnataka state. Nagaraja *et al.* (2008b) evaluated white seeded finger millet entries against blast disease under natural epiphytotic conditions at Zonal agricultural Research Station, UAS, Bangalore and found that overall incidence was low on white seeded entries in comparison with brown seeded ones and four entries (WRC 1-12, GPUW-1, GE 4971, GE 5153) were resistant to neck and finger blast with <2% incidence.

An attempt has been made by Kumar and Kumar (2009) revealed that out of 18 finger millet genotypes screened, nine genotypes (VL 234, SANJI 1, PRM 9802, VL 328, VL 333, ED 201-5A, ICM 401, VR 708 and VL 324) were completely free from neck and finger blast disease under natural epiphytotic conditions. Seedlings are more susceptible to leaf blast than are mature plants in finger millet (Rachie and Peters, 1977)., however, no relationship is known between the intensity of seedling infection and that of later head infection. Rather prevailing weather conditions at a particular stage of crop development determine the intensity of blast infection (Esele *et al.,* 2002).

A sorghum mini-core collection composed of 242 germplasm accessions evaluated for grain mold and downy mildew resistance at ICRISAT under natural epiphytotic and greenhouse conditions resulted 50 and 6 accessions were resistant to grain mold (≤10% mean severity) and downey mildew (mean incidence ≤10%) respectively. One accession, IS 23992, exhibited resistance to both the diseases. The morphologically and agronomically diverse accessions that are resistant to grain mold or downy mildew should be useful in sorghum disease resistance breeding programs (Sharma *et al.,* 2009).

Takahashi *et al.* (2009) developed a novel inoculation method, the ‘filter paper method’, for assay of grey leaf spot (GLS) in Italian ryegrass (*Lolium multoflorum* Lam.). Thakur *et al.*

(2009) developed field and greenhouse screening techniques for foliar blast disease of pearl millet and evaluated some elite hybrid parental lines to identify resistance to *P. grisea*.

Nagaraja *et al.* (2010) evaluated 120 recombinant inbred lines of finger millet for blast resistance under field conditions in different agro climatic conditions viz., Bangalore, Vizianagaram and Ranichauri during 2006 and 2007 revealed that low temperature, high RH (>80%) and high rainfall are conducive for blast development and MLC-29-5, 54-4, 63-4-1 and 89-4 were found blast resistant with 2% disease incidence.

Both neck and finger blast were positively correlated with glumes cover, seed protein content and peduncle length and negatively correlated with seed calcium content, days to flowering and yield, and no relationship between grain colour and blast resistance (Nagaraja *et al.,* 2010a)

CHAPTER III

MATERIAL AND METHODS

This chapter includes all the materials used and methods adopted in the investigation. All the techniques used are detailed under respective headings and their original references quoted. The present investigation was carried out at Plant Quarantine Laboratory (PQL), Cereals Pathology and Genomic Services Laboratory (GSL) of International Crops research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. The field experiments were conducted at ICRISAT; Agricultural Research Station (ARS), Gajularega, Vizianagaram (dt) and Regional Agricultural Research Station (RARS), Nandyal, Kurnool (dt) of Andhra Pradesh; Zonal Agricultural Research Station (ZARS), V.C. Farm, Mandya (dt) and Organic Farming Research Station (OFRS), Naganahalli, Mysore (dt) of Karnataka.

3.1 COLLECTION, PURIFICATION AND TESTING PATHOGENICITY OF *Magnaporthe grisea* ISOLATES

3.1.1 Collection of blast diseased specimens

Blast-infected tissue samples (leaf, node, neck and finger) of finger millet, foxtail millet, pearl millet and rice were collected from different locations from India in the during 2008, 2009 and 2010 rainy seasons (Figure 3.1). Sampling sites also included "hot spots" where blast occurs frequently. All collections were made from tissues infected in the field with naturally occurring inoculum. The samples separately bagged, air dried, and stored in a refrigerator at 4^{o}C for further studies.

3.1.2 Media and their composition

The following media were used in the present investigation.

Oat Meal Agar medium (OMA)

Oat-meal	: 25 g
Agar	: 16 g
Distilled water	: 1000 ml

Yeast extract sucrose broth (YESB)

Yeast extract	: 2 g
Sucrose	: 20 g
Distilled water	: 1000 ml

The pH was adjusted to 6.8–7.2 before autoclaving.

3.1.3 Isolation of mono-conidial isolates of *Magnaporthe grisea*

Blast-infected tissues (Leaf, node, neck and finger) from the refrigerator were cut into small bits. These bits were washed in sterilized distilled water twice, surface sterilized in 0.1% sodium hypochlorite for 2 min, rinsed three times in sterilized water, dried with sterilized filter paper, and plated onto OMA medium in petri dishes. Following incubation for 4 days at 26±1°C, a dilute spore suspension was prepared in sterilized distilled water and plated onto 0.8% water agar in petri plates. After 10–12 h incubation at 26±1°C, single germinating conidia were marked with help of a dummy objective lens under a microscope and transferred to fresh petridishes containing OMA medium, one conidium per plate. The petridishes were incubated at 26±1°C for 7 days and the identity of the fungal cultures developing from the single spores was established based on spore morphology (Ou, 1985).

3.1.4 Pathogenicity test

Plant material: Susceptible finger millet cultivar (VR 708) was used for testing the pathogenicity of each isolate. Seedlings of the susceptible cultivar were grown in 15 cm diameter plastic pots filled with sterilized soil-sand-FYM (farmyard manure) mix (2:1:1) and placed in a greenhouse bay maintained at 30°C with four replications. Seedlings were thinned at one-leaf stage to keep 10 plants per pot.

Inoculum preparation and inoculation: The 6 mm mycelial discs of each isolate were cut from 7 day-old-culture of *M. grisea* grown on OMA medium at 26±1ºC. Mass multiplication of spores for inoculation was achieved by growing each isolate (9 discs/plate) on OMA medium at 26±1ºC for 15 days. The plates were flooded with 10 ml of distilled water and the fungal growth containing mycelium and conidia was gently removed by scrapping with a sterile plastic inoculation loop. Approximately 30 ml of a spore suspension of each isolate was transferred into 100 ml conical flask, mixed thoroughly by vortexing for release of conidia into water. Harvested spores were filtered through a double-layer muslin cloth, the resultant concentration was adjusted to 1×10^5 conidia ml^{-1} and 0.02% (vol/vol) Tween 20 (polyoxylethylene sorbitan monolaurate) (Jia *et al*., 2003) was added to the suspension just before the inoculation. 15-day-old pot-grown seedlings were inoculated artificially by spraying the inoculum on the foliage using a hand-operated atomizer. Inoculated plants were allowed to partially dry for 30 min to avoid dislodging of the spores and the seedlings sprayed with water were maintained as control. All the inoculated seedlings were incubated at 23°C with >95% Relative Humidity (RH) and leaf wetness under 12 h photoperiod for 7 days.

Data recording: Leaf blast severity of each isolate was recorded on individual plant basis using a progressive 1–9 scale (Figure 3.4). To complete Koch's postulates, re-isolations of the each isolate from the artificially inoculated leaves were made following the protocol previously described.

3.1.5 Cross-infectivity tests

The pathogenicity of *M. grisea* isolates from finger millet, foxtail millet and pearl millet was determined by cross-infectivity tests (Viji *et al*., 2000) under greenhouse conditions. Three accessions from each crop (IE 860, CO 14 and VR 708 of finger millet; ISe 375, ISe 376 and ISe 1118 of foxtail millet and ICMB 95444, ICMB 96666 and ICMB 89111 of pearl millet) were grown in 15-cm diameter pots (10 seeds/pot) filled with sterilized soil-sand-FYM mix (2:1:1) with three replications. The pathogen multiplication, inoculum preparation and inoculation was similar as described in pathogenicity studies. Controls in each set included plants from each crop accessions sprayed with spore suspension. A set of water-sprayed plants was left uncovered to check for natural infection. All the inoculated seedlings were incubated at 23°C with >95% RH and leaf wetness under 12 h photoperiod for 7 days. Observations for the presence or absence of disease symptoms were made after 10 days.

3.1.6 Storage of fungal isolates

The fungus was grown on OMA medium slants in test tubes (15×150 mm) for 7 days at 26±1^{0}C in an incubator. The test tubes were filled up to active mycelia growth of fungus with mineral oil, sealed in plastic zippy bags and stored at 4°C for further studies as short-term preservation. Established cultures were also subsequently maintained according to the method of Valent *et al*. (1986), which involves growing the cultures in sterilized filter paper (Whatmann No. 3) discs (0.5 cm^2) overlaying OMA medium. The plates were incubated at 26±1^{0}C for 7 days by the time the filter papers were fully colonized by the fungus. After colonization, the filter paper discs were dried at 30°C and subsequently stored in sterilized glass vials at 4°C. The detached leaf blast lesions of each isolate collected from pathogenicity studies were air-dried and stored in plastic zippy bags at 4°C for further use.

3.2 STUDY CULTURAL, MORPHOLOGICAL, PATHOGENIC AND MOLECULAR DIVERSITY AMONG THE *M. grisea* ISOLATES

3.2.1 Cultural diversity among the *M. grisea* isolates

Cultural characters of all the monoconidal isolates of *M. grisea* were recorded by growing them on OMA medium for 15 days at 26±1^{0}C. Colony characters observed were color

of the mycelium, color of the metabolite produced in the media, growth of the fungus such as growth patterns – aerial, subdued, submerged or combination; appearance – ringed, sectored, uniform, rough, smooth. The cultural characteristics were photographed using a Sony digital still camera, DSC-H7 (Sony, Japan).

3.2.2 Morphological diversity among the *M. grisea* isolates

Morphological characteristics of *M. grisea* isolates collected from different crops were studied for radial growth (mm), size of conidia and sporulation. The size of conidia was measured (100 conidia) and microphotographed under high power objective (40X) using calibrated progRes CapturePro 2.7 microscope digital camera system (Jenoptik, Germany).

3.2.3 Pathogenic variability of *M. grisea* isolates using a set of putative host differentials

3.2.3.1 Evaluation of Finger Millet Blast Resistance Stability Nursery (FMBRSN)–2010 for leaf blast resistance

Tester lines: The FMBRSN–2010 consisted of 28 finger millet germplasm accessions as test entries including one susceptible (VR 708) and one resistant (GPU 28) checks (Table 3.1). Seed of FMBRSN-2010 accessions were sown in 15-cm diameter plastic pots and kept in a greenhouse bay at 30°C for 15 days. Seedlings were thinned at one-leaf stage to keep 10 plants per pot.

Inoculum preparation and Inoculation: Five highly virulent isolates of *M. grisea* (one isolate from each of the five locations *i.e*. Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli) were used for assessing leaf blast reaction on FMBRSN accessions. Stored cultures of *M. grisea* were revived and multiplied by subculturing on OMA medium for sporulation. After 15 days of incubation at 26±1°C, eight petriplates (90 mm) of each *M. grisea* isolate were washed each with 20 ml of sterile distilled water to produce spore suspension. Mycelium was filtered out with a double- layered muslin cloth. The concentration of the conidial suspension was adjusted to 1×10^5 conidia ml^{-1} using a hemocytometer, and the suspension was then ready to use for inoculation. Approximately 250–280 ml of the spore suspension containing Tween 20 (0.2%) was sprayed onto 15 day-old-seedlings using a hand-operated atomizer. All the inoculated seedlings were incubated at 23°C with >95% RH and leaf wetness under 12 h photoperiod for disease development for a week. The experiment was designed by following the completely randomized design (CRD) with two replications and 10 seedlings per replication.

Table 3.1. List of entries in the Finger Millet Blast Resistance Stability Nursery (FMBRSN – 2010)

Entry No.	Accession No.	Origin	Race	Sub-race
1	IE 2589	USA	*Plana*	*Seriata*
2	IE 2619	Malawi	*Vulgaris*	*Incurvata*
3	IE 2710	Malawi	*Plana*	*Confundere*
4	IE 2872	Zambia	*Vulgaris*	*Digitata*
5	IE 2911	Zambia	*Vulgaris*	*Incurvata*
6	IE 2957	Germany	*Vulgaris*	*Liliacea*
7	IE 3077	India	*Vulgaris*	*Incurvata*
8	IE 3392	Zimbabwe	*Vulgaris*	*Liliacea*
9	IE 3543	India	*Spontanea*	*
10	IE 4057	Uganda	*Plana*	*Seriata*
11	IE 4497	Zimbabwe	*Vulgaris*	*Digitata*
12	IE 4755	India	*Vulgaris*	*Stellata*
13	IE 4759	India	*Vulgaris*	*Stellata*
14	IE 4797	Maldives	*Vulgaris*	*Liliacea*
15	IE 5066	Senegal	*Vulgaris*	*Incurvata*
16	IE 5091	Zimbabwe	*Vulgaris*	*Digitata*
17	IE 5106	Zimbabwe	*Vulgaris*	*Incurvata*
18	IE 5817	Nepal	*Vulgaris*	*Incurvata*
19	IE 5870	Nepal	*Vulgaris*	*Digitata*
20	IE 6082	Nepal	*Plana*	*Confundere*
21	IE 6221	Nepal	*Vulgaris*	*Stellata*
22	IE 6240	Zimbabwe	*Vulgaris*	*Incurvata*
23	IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*
24	IE 6421	Uganda	*Vulgaris*	*Digitata*
25	IE 7018	Kenya	*Vulgaris*	*Incurvata*
26	IE 7079	Kenya	*Vulgaris*	*Liliacea*
27	GPU 28 (RC)	India	*	*
28	VR 708 (SC)	India	*	*

* Information not available; RC: Resistant Check; SC: Susceptible Check

Data recording: Leaf blast reaction of each finger millet line was recorded 7 DAI using a progressive 1–9 disease scoring scale developed for rice blast (IRRI, 2003). Finger millet lines exhibiting reaction types 0–3 were rated as resistant, while those showing reaction types 4–9 were considered as susceptible. All the lines were tested twice against each isolate and for a few lines were showing ambiguous reaction, the experiment was repeated until consistent reactions were obtained.

3.2.3.2 Finger Millet Blast Host Differential Studies (FMBHDS–2011)

Finger millet mini-core collections (80 accessions) were evaluated at several locations (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli) during the rainy seasons 2009 and 2010 under field conditions and also in the greenhouse at Patancheru using one representative isolate from each of the five locations. Some lines showed differential reactions under field and greenhouse conditions indicating possible variability in the pathogen population. Thus, a Finger Millet Blast Host Differential Studies (FMBHDS) – 2011 was constituted with finger millet germplasm accessions that showed variable disease reactions in field and greenhouse studies.

Plant materials: FMBHDS consisted of 12 accessions as test entries which included, 10 putative host differentials (IE 2619, -2911, -2957, -3392, -4057, -4497, -5097, -6240, -6337 and -7079), one resistant (GPU 28) and one susceptible (VR 708) checks. Seed of FMBHDS accessions were sown in 15-cm diameter plastic pots and kept in a greenhouse bay at 30°C for 15 days with two replications in completely randomized design. Seedlings were thinned at one-leaf stage to maintain 10 plants per pot.

Inoculum preparation and Inoculation: A total of 20 isolates of *M. grisea* (4 from each location *i.e*. Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli) were selected based on pathogenicity data and these were used for studying the pathogenic diversity on FMBHDS accessions. Stored cultures of *M. grisea* were revived and mass multiplication of fungal spores for inoculation was achieved by growing the each isolate on OMA medium at 26±1°C for 15 days. In case of less sporulating isolates, the detached infected lesions collected during the pathogenicity studies were surface sterilized in and 0.1% sodium hypochlorite for 2 min, placed upside down over petriplates containing OMA medium and incubated at 26±1°C for 7 days. Four petriplates (90 mm) of each *M. grisea* isolate were washed with 20 ml of sterile distilled water to produce spore suspension. Inoculum preparation, inoculation and favourable conditions were maintained as described in 3.2.3.1.

Data recording: Leaf blast severity was recorded using 1–9 scale. All the lines were tested twice against each isolate and the isolates were classified into different pathogenic groups using resistance factors and principal component analysis of severity data.

3.2.4 Genetic diversity in *Magnaporthe grisea* using SSR markers

Genetic diversity among the isolates of *M. grisea* collected from different crops and locations (Table 4.1) was studied using the SSR (simple sequence repeat) markers. A set of 24 SSR markers (Table 3.2) located across seven chromosomes of *M. grisea* were selected based on the *M. grisea* linkage map reported by Kaye *et al.* (2003).

3.2.4.1 Genomic DNA isolation: DNA was extracted from the single spore cultures of *M. grisea* isolates from finger millet, foxtail millet, pearl millet, rice using DNA extraction method as described by Viji *et al*. (2000) with minor modifications.

Reagents and Buffers used

- 3% CTAB (Cetyl Trimethyl Ammonium Bromide) buffer having 10 mM Tris, 1.4 M NaCl, 20 mM EDTA, pH 8.0.
- Chloroform-isoamyl alcohol mixture (24:1)
- Ice-cold isopropanol
- RNase-A (10 mg/ml) dissolved in solution containing 10 mM Tris (pH 7.5)
- 15 mM NaCl stored at –20°C; working stocks were stored at 4°C
- Phenol-chloroform-iso-amyl alcohol mixture (25:24:1)
- 3 M sodium acetate (pH 5.2)
- Ethanol (absolute and 70%)
- $T_1E_{0.1}$ buffer (10 mM Tris and 1 mM EDTA)
- $T_{10}E_1$ buffer (0.5 M Tris and 0.05 M EDTA)

Culturing of the fungus

- *M. grisea* isolates were grown in aliquots of 100 ml of Yeast Extract Sucrose Broth (YESB) were dispensed in 250 ml Erlenmeyer flasks under continuous shaking for 7-10 days.
- The mycelial mat was harvested by filtering through a sterilized Whatmann No. 3 filter paper.
- The mycelial mats were transferred to sterilized blotter papers for drying and stored at -20ºC.

Table 3.2. List of SSR primers and their sequences, source and type (Kaye *et al*., 2003)

S. No.	Primers	Primer sequence	Source	SSR type
1	Pyrms 7 and 8	gcaaataacataggaaaacg agaaagagacaaaacactgg	Full BAC (70-15)	CT/GA 29
2	Pyrms 15 and 16	ttcttccatttctctcgtcttc cgattgtggggtatgtgatag	EST (P12)	CT/GA 20
3	Pyrms 33 and 34	catttgttcaaggcggattt ctcgggaggttgctaacg	BAC end (70-15)	AGT/TCA
4	Pyrms 37 and 38	accctacccccactcatttc aggatcagccaatgccaagt	BAC end (70-15)	CA/GT 6 + CT/GA 12
5	Pyrms 39 and 40	cgcatacaggaaagccaaga ctgacgagggactcctgtgt	EST (Guy11)	CA/GT 19
6	Pyrms 41 and 42	aacgtgacaatgtgagcagc gccatgttctaaggtgctgag	BAC end (70-15)	CT/GA 16
7	Pyrms 43 and 44	tcagtaggcttggaattgaaaaa cttgattggtggtggtgttg	BAC end (70-15)	TA /AT 12
8	Pyrms 45 and 46	ccactttatagcccacccagt ctcttttctcgcaggaggtg	BAC end (70-15)	TA/AT 11
9	Pyrms 47 and 48	tcacatttgcttgctggagt agacagggttgacggctaaa	BAC end (70-15)	TA/AT 15
10	Pyrms 59 and 60	ttctcagtaggcttggaattga cttgattggtggtggtgttg	BAC end (70-15)	TA/AT 12
11	Pyrms 61 and 62	gaggcaacttggcatctacc tggattacagaggcgttcg	BAC end (70-15)	GA/CT 9
12	Pyrms 63 and 64	ttgggatcttcggtaagacg gccgacaagacactgaatga	BAC end (70-15)	CT/GA 15
13	Pyrms 67 and 68	agcaagcaggagatgcagac gtttggctggcaagacagtt	SSR library (Guy11)	CA/GT 17
14	Pyrms 77 and 78	gaagtattgcacacaaacac gctttcggcaagcctaatc	SSR library (Guy11)	CA/GT 24
15	Pyrms 81 and 82	ccttgttttccccctgtgta tagccaaatgcccattatcc	BAC end (70-15)	ACT/TGA 12
16	Pyrms 83 and 84	gtctgcctcgactccttcac agcccaaaaacagaaagcaa	BAC end (70-15)	TCA/AGT 13
17	Pyrms 87 and 88	agacttgttactcgggtcttga ccagatgtcactcccctgta	BAC end (70-15)	TGC/ACG 12
18	Pyrms 93 and 94	cctcgactccttcaccaaaa cggagagctcaggaagagg	Est (70-15)	ATC/TAC 12.5
19	Pyrms 99 and 100	caccactttatggcgcagt acctaggtaggtatacatgttgtt	BAC end (70-15)	ACC/TGG 20
20	Pyrms 101 and 102	ctgcgttcaacatgcctcta cttgatctgcggtatgagca	SSR library (Guy11)	TG/AC 25
21	Pyrms 107 and 108	gcagcaagcagcaatatcag gtggatatcgaaggccaagg	SSR library (Guy11)	GA/CT 10
22	Pyrms 109 and 110	tacagtgggagggcaaagag ccagatcgagaaggggtat	SSR library (Guy11)	TG/AC 12
23	Pyrms 115 and 116	ttcgttcacctttggctct ttgttaagtgagcggacgtg	SSR library (Guy11)	GA/CT 33
24	Pyrms 125 and 126	ctctccggccaagattga ggttgttgggagaaagaacg	Full BAC (70-15)	CAA/GTT 32

Grinding and extraction

- The 200 mg of dried frozen mycelium was ground in a mortar with a pestle in liquid nitrogen to a fine powder.
- The CTAB buffer was pre-heated in 65°C water bath before start of DNA extraction.
- The pulverized mycelium of each isolate then transferred to a 2-ml Eppendorf tube containing a volume of 750µl of pre-heated CTAB buffer and the contents were thoroughly vortexed (Scientific Industries Inc. USA) until evenly suspended.
- The samples were incubated at 65ºC in a water bath for 30 min with occasional shaking and then allowed to cool at room temperature.

Solvent extraction

- A volume of 750 µl of chloroform-isoamyl alcohol mixture (24:1) was added to each tube and the samples were centrifuged at 8000 rpm for 10 min (Sigma centrifuge model 4K15C).
- After centrifugation, the aqueous, viscous supernatant (approximately 400 µl) was transferred to a fresh eppendorf tube.

Initial DNA precipitation

- To the tube containing aqueous layer, 0.7 volumes (approximately 280 µl) of cold isopropanol (kept at –20ºC) was added to precipitate the nucleic acid. The solutions were carefully mixed and the tubes were kept at –20ºC for one hour.
- The samples were centrifuged at 8000 rpm for 15 min.
- The supernatant was decanted under a fume-hood and pellets were vacuum dried for 10 min.

RNase treatment

- In order to remove co-isolated RNA, 200 µl of low salt TE buffer ($T_1E_{0.1}$) and 3µl of RNase (stock 10 mg/µl) were added to each tube containing dry pellet and mixed properly.
- The solution was incubated room temperature overnight.

Solvent extraction

- After incubation, 200 µl of phenol-chloroform-isoamyl alcohol mixture (25:24:1) was added to each tube, carefully mixed and centrifuged at 8000 rpm for 10 min.

- The aqueous layer was transferred to fresh tubes and chloroform-isoamylalcohol (24:1) mixture was added to each tube, carefully mixed and centrifuged at 8000 rpm for 10 min. The aqueous layer was transferred to fresh tubes.

DNA precipitation

- To the tubes containing aqueous layer, 15 µl (approximately $1/10^{th}$ volume) of 3M sodium acetate (pH 5.2) and 300µl (2 volume) of absolute ethanol (kept at –20ºC) were added and the tubes were subsequently placed in a freezer (–20ºC) for 30 min.
- Following incubation, the tubes were centrifuged at 8000 rpm for 15 min.

Ethanol wash

- After centrifugation, supernatant was carefully decanted from each tube having ensured that the pellets remained inside the tubes and 200 µl of 70% ethanol was added to the tubes followed by centrifugation at 8000 rpm for 5 min.

Final re-suspension

- Pellets were obtained by carefully decanting the supernatant from each tube and then dried in vacuum for 10 min.
- Completely dried pellets were re-suspended in 100 µl of $T_{10}E_1$ buffer and incubated overnight at room temperature to allow them to dissolve completely.
- Dissolved DNA samples were stored at 4ºC.

3.2.4.2 DNA quality / quantity check: Qualitative analysis of DNA was performed by agarose gel electrophoresis as described below.

Reagents required

- TBE buffer: 109 g of Tris and 55 g of boric acid were dissolved one by one in 800 ml distilled water; then 40 ml of 0.5M EDTA (pH 8.0) was added for 10X TBE buffer. The volume was made up to one liter with distilled water and sterilized by autoclaving. This was stored at 4°C. To prepare working solution (1X), the stock solution was diluted 10 times.
- Ethidium bromide (10 mg/ml): A quantity of 100 mg ethidium bromide was dissolved in 10 ml of distilled water. The vessel containing this solution was wrapped in aluminium foil and stored at 4°C.
- Agarose
- Orange loading dye
    - 0.5 M EDTA (pH 8.0): 10 ml

- 5 M NaCl : 1 ml
- Glycerol : 50 ml
- Distilled water : 39 ml

Orange dye powder (Orange G, Gurr Certistain®) was added till the color became sufficiently dark.

Procedure: Agarose (0.8 g) was added to 100 ml of 1X TBE buffer and heated using microwave oven until the agarose was completely dissolved. After cooling the solution to about 60°C, 5 µl of ethidium bromide solution was added and the resulting mixture was poured into the gel-casting tray for solidification. Before the gel solidified, an acrylic comb of desired well number was placed on the agarose solution to form wells for loading the samples. Each well was loaded with 5 µl of sample aliquot having 3 µl distilled water, 1 µl orange dye and 1 µl of DNA sample. The DNA samples in known concentration (lambda DNA of 50 ng/µl, 100 ng/µl and 200 ng/µl) were also loaded on to the gel to estimate the DNA concentration of the experimental samples. The gel was run at 70 V for 20 min. After completing the electrophoresis run, DNA on the gel was visualized under UV light and photographed. If the DNA was observed as a clear and intact band, the quality was considered good, whereas a smear of DNA indicating poor quality was discarded and reisolated. Relative concentration of DNA present in the samples approximately derived by visual comparison with lambda DNA.

3.2.4.3 SSR genotyping: A set of 24 SSR markers described in Kaye *et al*. (2003) were used for studying the genetic diversity of *M. grisea* isolates (Table 3.2). These primer sequences were synthesized at MWG-biotech (Bangalore). The forward primers of these markers were synthesized by adding M13-forward primer sequence 5'CACGACGTTGTAAAACGAC3' at the 5'end of each primer. All the 24 primer pairs were initially tried on four representative isolates.

Genomic DNA of all the isolates were diluted to 5 ng μl^{-1} and used as template for amplification of SSR loci. The PCR reactions were performed in 5 µl volume consisting of 2 µl of 5 ng DNA template, 1 µl of 2mM dNTPs, 0.4 µl of 50 mM $MgCl_2$, 0.7 µl of primer containing 1:5:1 ratio of 100 pmole/µl M13 tailed forward primer, 100 pmole/µl reverse primer and 100 pmole/µl of M13-Forward primer labeled with either 6-Fam or Vic or Ned or Pet (Applied Biosystems), 1.0 µl of 10X PCR buffer and 0.04 U of *Taq* DNA polymerase (SibEnzymes Ltd, Russia). The reaction mixture was vortexed and briefly centrifuged. PCR amplification was performed in a ABI thermal cycler (GeneAmp, PCR system 9700, PE

Applied Biosystems) with the following temperature profiles: 94ºC for 5 min of initial denaturation cycle, followed by 35 cycles of denaturation at 94ºC for 30 seconds, with constant annealing temperature (45˚C) for 30 sec and extension at 72˚C for 30 sec, followed by a final extension at 72˚C for 20 min. The PCR products were tested for amplification on 1.2% agarose.

3.2.4.4 Capillary electrophoresis: After confirming the PCR amplification on 1.2% agarose gel, the PCR products were size-separated by capillary electrophoresis using an ABI Prism 3730 DNA analyzer (Applied Biosystems Inc.). A set of 20 PCR multiplex sets were constructed based on the allele size range estimates and the type of forward primer label of the markers. Each set consisted of four SSR markers with different labels and allele size. For post PCR multiplexing, 1µl PCR product of each of 6-FAM, VIC, NED and PET-labeled products were pooled (according to above mentioned criteria) and mixed with 7 µl of Hi-Di formamide (Applied Biosystems, USA), 0.2 µl of the LIZ-500 size standard (Applied Biosystems, USA) and 2.8 µl of distilled water. The pooled PCR product were denatured 5 min at 95°C and cooled immediately on ice.

3.2.4.5 SSR fragment analysis: Raw data produced from ABI 3730*xl* Genetic Analyser was analysed using Genemapper® software version 4.0 (Applied Biosystems, USA) and fragment size was scored in base pairs (bp) based on the relative migration of the internal size standard.

3.2.4.6 Molecular data analysis: The fragment sizes for all markers were used to analysis basic statistics using PowerMarker version 3.25 (http://www.powermarker.net) (Liu and Muse, 2005) including the polymorphic information content (PIC), allelic richness as determined by total number of the detected alleles and number of alleles per locus, gene diversity and occurrence of unique, rare, common, and most frequent alleles, and average heterozygosity (%).

Polymorphic Information Content (PIC): The polymorphic information content (PIC) values measure the informativeness of a given a given DNA marker. The PIC value for each SSR loci was measured as given by Anderson *et al*. (1993).

$$\widehat{PIC}_l = 1 - \sum_{u=1}^{k} \tilde{p}_{lu}{}^2 - \sum_{u=1}^{k-1} \sum_{v=u+1}^{k} 2\tilde{p}_{lu}^2 \tilde{p}_{lv}^2$$

where k is the total number of alleles detected for a given marker locus and *Pi* is the frequency of the *i*th allele in the set of genotypes investigated.

Gene diversity: Gene diversity often referred to as expected heterozygosity, is defined as the probability that two randomly chosen alleles from the population are different. An unbiased estimator of gene diversity at the l^{th} locus is

$$\hat{D}_l = (1 - \sum_{u=1}^{k} \tilde{p}_{lu}{}^2) / (1 - \frac{1+f}{n}),$$

Heterozygosity: Heterozygosity is simply the proportion of heterozygous individuals in the population. At a single locus and it was estimated as

$$\hat{H}_l = 1 - \sum_{u=1}^{k} \tilde{P}_{luu}$$

Allele frequencies: The sample allele frequencies are calculated as $\tilde{p}_u = n_u / (2n)$, with the variance estimated as

$$\text{var}(\tilde{p}_u) \triangleq \frac{1}{2n}(\tilde{p}_u + \tilde{P}_{uu} - 2\tilde{p}_u^2)$$

Where

where $\triangleq$ means "estimated by".
The sample genotype frequencies $\tilde{P}_{uv}$ are calculated as n_{uv} / n. Both the $\tilde{p}_u$ s and $\tilde{P}_{uv}$ s are unbiased maximum likelihood estimates (MLEs) of the population frequencies. Confidence intervals for allele and genotype frequencies are formed by resampling individuals from the data set.

Unweighted Neighbor-joining tree: A similarity matrix was generated from the binary data using similarity coefficient in the SIMQUAL program of the NTSYS-pc package (Rohlf, 1993). Unweighted neighbor-joining tree was constructed based on the simple matching dissimilarity matrix of SSR markers genotyped across the *M. grisea* isolates as implemented in DARwin 5.0.156 programme (http://darwin.cirad.fr/darwin).

3.4.4.7 Determination of correlation between SSR and virulence data: The leaf blast severity data of 25 *M. grisea* isolates on 12 finger millet accessions was used to derive similarity matrix based simple matching coefficient using SIMQUAL program of the NTSYS-pc package (Rohlf, 1993). Dissimilarity matrix of pathogenicity and SSR data was obtained using DARwin software. Correlation of SSR and virulence data of 25 isolates was determined by comparison of SSR and virulence data was determined by matrix comparison technique was used (Mantel, 1967). Mantel test in GenAlEx software version 6.4 (Peakall and Smouse, 2006) for matrix comparison was carried out to see the goodness of fit among the pathogenicity and SSR data with 999 permutations of the datasets.

3.2.4.8 Population structure analysis: Analysis of population structure among *M. grisea* isolates from different hosts performed using the software package STRUCTURE (Pritchard *et al.,* 2000) in its revised version 2.2 (Falush *et al*., 2007). This method uses multilocus genotypes to infer the fraction of an isolates genetic ancestry that belongs to a population for a given number of populations (*K*). The optimum number of populations (K) was selected after five independent runs of a burn-in of 1,00,000 iterations followed by 1,00,000 iterations for each value of *K* (testing from *K* = 2 to *K* = 10). The posterior probabilities were estimated using a Markov Chain Monte Carlo method (MCMC). The MCMC chain was run multiple times, using a correlated allele frequency model (prior mean = 0.01, prior SD = 0.05 and Lambda = 1.0 in the advance option of the STRUCTURE 2.2 programme (http://pritch.bsd.uchicago.edu/software/structure).

3.3 STUDY EPIDEMIOLOGY– INFLUENCE OF TEMPERATURES AND LEAF WETNESS DURATION ON SPORULATION AND INFECTION, INOCULUM THRESHOLD AND HOST SUSCEPTIBILITY STAGE

3.3.1 Determination of inoculum threshold and host susceptibility stage of finger millet to blast

Leaf Blast: Seedlings of the susceptible accession (IE 501) was raised in 15-cm diameter plastic pots (10 seeds/pot) filled with sterilized soil-sand-FYM mix (2:1:1) in a greenhouse with four replications and maintained at 30°C and a 12-h photoperiod was used to study the inoculum threshold concentration required for leaf blast development. 15-day-old-seedlings were spray-inoculated with aqueous conidial suspension of different concentrations (0, 1×10^3, 1×10^4, 1×10^5 and 1×10^6 conidia ml^{-1}) of *M. grisea* isolate (FMP1) grown on OMA medium at 25ºC for 7 days. All the inoculated seedlings were incubated at 23°C with >95% RH and leaf wetness under 12 h photoperiod for 7 days. The observations on leaf blast severity were recorded in 10 randomly selected plants after 7 days of inoculation in each replication.

Neck and finger blast: Seedlings of the susceptible accession (IE 501) was raised in 30-cm diameter plastic pots (5 seeds/pot) in a greenhouse bay at 30°C were used for assessment of inoculum threshold required for neck and finger blast. Individual tillers were inoculated at booting stage (beginning with panicle initiation) by injecting the aqueous conidial suspension of different concentrations (0, 1×10^3, 1×10^4, 1×10^5 and 1×10^6 conidia ml^{-1}) of *M. grisea* Patancheru isolate (FMP1) with syringe at photosynthetic leaf sheath base

(Vingnanakulasingam, 1991., Puri *et al*., 2009). In each replication, control was maintained by injecting water in to photosynthetic leaf sheath. All the inoculated and control tillers were labeled with yellow and red ribbon for observation. Inoculated plants were covered with pre-wetted polythene bags for 48 h at 23°C with >95% RH and leaf wetness in incubation chamber and then pots were transferred to greenhouse benches at 25±2°C and >95% RH under misting for disease development during the next four weeks.

The observations on individual plants were recorded 30 DAI using a 1–5 scale for neck blast (Figure 3.5) and finger blast severity (%) estimate across all the inoculated panicles/all inoculated tillers in each replication. For neck and finger blast, total number of infected neck and finger were scored, counted and disease incidence (DI) percentage was calculated using formula, DI% = (number of infected tillers/total number of tillers inoculated in each replication) × 100.

3.3.2 Influence of leaf wetness duration ((LWD) on infection

Influence of leaf wetness duration (0, 12, 24, 36, 48, 60 h) on the development of leaf blast was studied under greenhouse conditions with four replications. Seedlings of the susceptible accession (IE 501) was raised in 15-cm diameter plastic pots filled with sterilized soil-sand-FYM mix (2:1:1) in a greenhouse, maintained at 30°C and a 12 h photoperiod. 15-day-old-seedlings were spray-inoculated with aqueous conidial suspension of $1\times x10^5$ conidia ml^{-1} of *M. grisea* Patancheru isolate (FMP1) grown on OMA medium at 25ºC for 7 days. Inoculated plants, except those exposed to 0 h of leaf wetness, were covered immediately with pre-wetted polyethylene bags for different durations (12, 24, 36, 48, 60 h) and incubated at 23°C with >95% RH and leaf wetness under 12 h photoperiod for 7 days. After completion of each wetness duration, the bags were removed and incubated at above mentioned conditions. To serve as controls, one pot of inoculated plants was left uncovered and one pot of noninoculated plants was covered with a bag. Observations on lesion size (mm), number of lesion per leaf and leaf blast severity using a 1–9 scale were recorded 7 DAI. The entire experiment was repeated once.

3.3.3 Influence of temperatures on sporulation of *M. grisea* on foliage

The effect of different temperature regimes (18, 21, 24, 27, and 30ºC) for different durations (24, 48 and 72 h) on sporulation of *M. grisea* was studied on foliage using blotter paper method. The experiment was repeated once. Inoculum preparation and inoculation were similar as described in 3.3.1. Tissues of young lesions of uniform size (10 mm) were brought to

the laboratory and incubated at different temperatures (18, 21, 24, 27, and 30ºC) and at different durations (24, 48 and 72 h) in a petridish lined with sterilized blotter paper with four replications. After completion of incubation at different temperatures and durations, the lesions were thoroughly scraped to harvest the conidia with 1 ml hypodermic syringe (Kim and Yoshino, 2000) by adding 0.1 ml of 0.02% Tween-20 solution. Collected spore suspension was placed in a vial, mixed thoroughly by vortexing for complete harvesting of conidia from leaf tissues and the conidia were immediately counted using a hemocytometer. The observations on visual sporulation rating and spore density were also recorded at 24, 48 and 72 h of incubation at different temperatures.

3.3.4 Influence of temperatures on sporulation of *M. grisea* on OMA medium

The growth and sporulation of the *M. grisea* was studied at different temperatures (10, 20, 25, 30 and 35ºC) on OMA medium (Kumar and Singh, 1995) with three replications, repeated twice. A 6 mm mycelial disc was cut from the margin of a 7-day-old culture and placed aseptically at the centre of each petridish (90 mm) containing 20 ml OMA medium and incubated at given temperatures for 7 days. The colony diameter was recorded 7 days after incubation. Four discs (6 mm) were scoped out from each replication and transferred to 5 ml sterilized distilled water in a test tube. The test tubes were agitated to detach the conidia from the mycelial surface and filtered through a cheese cloth. The quantification of conidia in a given suspension was done using a hemocytometer.

3.4 IDENTIFICATION OF SOURCES OF BLAST RESISTANCE FROM MINI-CORE COLLECTION OF FINGER MILLET GERMPLASM

3.4.1 Development of field screening technique

Seed source: Seed of the 622 germplasm accessions of the finger millet core collection including 80 mini-core collection and four checks (VL 149, VR 708, RAU 8, PR 202) were obtained from ICRISAT, Genebank, Patancheru, India.

Planting and agronomic practices: Six hundred twenty-two accessions of the finger millet core collection with standard national checks (VL 149, VR 708, RAU 8, PR 202) were evaluated during the 2009 rainy season (August to December) at ICRISAT, Patancheru, India under artificial inoculation. Each accession was grown in one row of 2 m length with row-to-row spacing of 60 cm and plant-to-plant spacing within the row of 10 cm with two replications in completely randomized block design. Plants were thinned to 20 plants/row 15 days after

emergence. In order to increase disease pressure, the check varieties were planted on every 5th row alternatively, as these varieties are being as used standard checks for varietal evaluation. The fertilizers, 50:40:25 (N:P:K) were applied, in which N was applied in two equal doses as basal and topdressing at 30 days after sowing. Experiment was kept free from weeds and insect pests. Irrigation was applied as and when necessary (Figure 3.6).

Inoculum preparation: A 6 mm mycelial discs were cut from a 7- day-old-culture of *M. grisea* Patancheru isolate (FMP1) grown on OMA medium at 26±1ºC. Mass multiplication of fungal spores for inoculation was achieved by growing the fungus (9 discs/plate) on OMA medium at 26±1ºC for 15 days. The plates were flooded with 20 ml of distilled water and fungal growth containing mycelium and conidia was gently removed by scrapping with a sterile plastic inoculation loop (Figure 3.6). The suspension was transferred to 100 ml conical flask, mixed thoroughly by vortexing for release of conidia into water and filtered through a muslin cloth. The conidial concentration in the suspension was adjusted to 1×10^5 spore ml^{-1} and Tween 20 (0.02%) (Jia *et al*., 2003) was added to the suspension just before the inoculation.

Inoculation and favorable weather conditions: Thirty day-old-seedlings were inoculated artificially by spraying the inoculum on the foliage using a Knapsack power sprayer during the evening for leaf blast. High humidity and leaf wetness was provided for 20 days post inoculation by perfo-irrigation of test plots twice a day for 30 min each between 10:00 a.m. and 12:00 noon, and 4:00 p.m. and 6:00 p.m. to promote disease development. For neck and finger blast, plants were spray-inoculated at pre-flowering stage with an aqueous conidial suspension and inoculation was continued upto end of flowering in the nursery. High humidity and leaf wetness was provided through sprinkler irrigation twice a day following inoculation to physiological maturity on rainy free days (Figure 3.6).

Collection of weather data: Weather parameters such as, temperature (minimum and maximum) and relative humidity (minimum and maximum) and rainfall (mm) from date of inoculation to the hard-dough stage was obtained from meteorological station, ICRISAT, Patancheru, India.

Disease assessment: The leaf blast severity was recorded at 10 DAI using a 1–9 scale developed at International Rice Research Institute (IRRI), Philippines for rice blast (Figure 3.4). Accessions screened were classified based on their response to the leaf blast as Highly Resistant (HR: 1.0), Resistant (R: 2.0–3.0), Moderately Resistant (MR: 3.1–5.0), Susceptible (S: 5.1–7.0) and Highly Susceptible (HS: 7.1–9.0) (Figure 3.4).

The neck and finger blast severity in finger millet was recorded (10 individual plants in each replication) at dough stage using newly developed 1–5 scale (Figure 3.5) for neck blast based on lesion size (cm) on the neck region and per cent finger blast severity across all tillers in selected individual plants in a row. Based on the neck blast rating, the accessions were categorized as Highly Resistant (HR: 1.0), Resistant (R: 1.1–2.0), Moderately Resistant (MR: 2.1–3.0), Susceptible (S: 3.1–4.0) and Highly Susceptible (HS: 4.1–5.0) (Figure 3.5). Similarly, based on finger blast severity (%), the accessions were categorized as Highly Resistant (HR: 1.0%), Resistant (R: 2–10%), Moderately Resistant (MR: 11–20%), Susceptible (S: 21–30) and Highly Susceptible (HS: >30%).

3.4.2 Development of greenhouse screening techniques

Planting: Seed of test lines along with susceptible check (VR 708) were planted in 15-cm diameter pots (10 seeds/pot) filled with sterilized soil-sand-FYM mix (2:1:1) and placed in a greenhouse bay maintained at 30ºC for 15 days. For neck and finger blast, five mini-core accessions, one resistant and susceptible checks were planted in 30-cm diameter pots (5 seeds/pot). The experiment was conducted in completely randomized design with four replications. Soil moisture in the pot was regulated by daily irrigation (Figure 3.2).

Inoculum preparation: Pathogen multiplication and inoculum preparation were similar as described in field screening technique. The conidial concentration in the suspension was adjusted to 1×10^5 conidia ml^{-1} for leaf blast and 1×10^6 conidia ml^{-1} for neck and finger blast. Tween 20 (0.02%) was added to the suspension just before the inoculation.

Inoculation and optimum conditions: The 15 day-old seedlings were spray-inoculated using a hand-operated atomizer. Inoculated plants were partially dry for 10 min to avoid dislodging of spores. Control plants were maintained by spraying the water on foliage. All the inoculated seedlings were incubated at 23°C with >95% RH and leaf wetness under 12 h photoperiod for 7 days (Figures 3.2, 3.3).

For neck and finger blast screening, individual tillers of each plant was inoculated at booting stage (beginning with panicle initiation) by injecting the aqueous conidial suspension (1×10^6 conidia ml^{-1}) of *M. grisea* Patancheru isolate with syringe at photosynthetic leaf sheath base (Vingnanakulasingam, 1991., Puri *et al*., 2009). In each replication, eight tillers were inoculated with pathogen and four tillers was maintained as control by inoculating water in to photosynthetic leaf sheath. All the inoculated and control tillers were labeled with yellow and red ribbon for observation. Inoculated plants were covered with pre-wetted polythene bags for

48 h at 24ºC in incubation chamber and then exposed to high humidity (> 90% RH) under misting for one month (Figure 3.3).

Disease assessment: Leaf blast severity was recorded using 1–9 scale. Neck and finger blast severity on individual tillers were recorded at dough stage using newly developed 1–5 scale for neck blast and finger blast severity (%) estimate across all the inoculated panicles/all inoculated tillers in each replication. The total number of infected neck and finger were scored, counted and disease incidence (DI) % was calculated using formula DI % = (number of infected tillers/total number of tillers inoculated in each replication) × 100.

3.4.3 Evaluation of mini-core collection of finger millet for blast resistance under field conditions during 2009 rainy season at five locations

Locations and seed source: Mini-core collection of finger millet (Table 3.3) consisting of 80 accessions (Upadhyaya *et al*., 2010) along with four standard national checks (VL 149, VR 708, RAU 8 and PR 202) were obtained from Genebank, ICRISAT, Patancheru, India and evaluated for blast resistance under natural epiphytotic conditions at Vizianagaram, Nandyal, Mandya and Naganahalli and under artificial inoculation at ICRISAT during the 2009 rainy season (Table 3.4).

Planting and agronomic practices: The experiment was conducted in a randomized complete block design with two replications at Patancheru with one of the four checks were repeated after every four test entries and α-design at other locations with local susceptible check was repeated after every 21 test entries. Each accession was grown in one row of 2 m length with row-to-row spacing of 60 cm at Patancheru and two rows of 4 m length with 30 cm row-to-row spacing at other locations. Plant-to-plant spacing within the row was fixed at 10 cm at all locations. Plants were thinned to 20 plants/row 15 days after planting at all locations. Other agronomic practices were followed as per the local practices. The fertilizers, 50:40:25 (N:P:K) were applied, in which N was applied in two equal doses as basal and topdressing at 30 days after sowing. The nurseries were well managed and properly labeled. Multiplication of the pathogen, inoculum preparation, inoculation and favorable weather conditions were similar as described under field screening technique.

Collection of weather data: Weather variables, such as, temperature (minimum and maximum), relative humidity (minimum and maximum) and rainfall (mm) from the date of sowing to the hard-dough stage were collected from meteorological station of the respective location.

Disease assessment: Leaf blast scoring was done at 10 DAI using a progressive 1–9 scale. Neck and finger blast severity was recorded on 10 randomly selected plants at dough stage using a 1–5 scale for neck blast and finger blast severity (%) estimate across all

Table 3.3. List of finger millet mini-core collection (80 accessions + 4 checks) evaluated for blast resistance at five locations and their passport information

Entry No	Accession No	Source country	Race	Sub-race
1	IE 501	India	*Vulgaris*	*Stellata*
2	IE 518	India	*Vulgaris*	*Incurvata*
3	IE 1055	Unknown	*Vulgaris*	*Digitata*
4	IE 2034	India	*Vulgaris*	*Incurvata*
5	IE 2042	India	*Vulgaris*	*Incurvata*
6	IE 2217	India	*Vulgaris*	*Stellata*
7	IE 2296	India	*Vulgaris*	*Digitata*
8	IE 2312	India	*Elongata*	*Sparsa*
9	IE 2430	Kenya	*Vulgaris*	*Digitata*
10	IE 2437	Kenya	*Plana*	*Confundere*
11	IE 2457	Kenya	*Compacta*	*
12	IE 2572	Kenya	*Plana*	*Grandigluma*
13	IE 2589	USA	*Plana*	*Seriata*
14	IE 2606	Malawi	*Vulgaris*	*Incurvata*
15	IE 2619	Malawi	*Vulgaris*	*Incurvata*
16	IE 2710	Malawi	*Plana*	*Confundere*
17	IE 2790	Malawi	*Elongata*	*Laxa*
18	IE 2821	Nepal	*Compacta*	*
19	IE 2871	Zambia	*Compacta*	*
20	IE 2872	Zambia	*Vulgaris*	*Digitata*
21	IE 2911	Zambia	*Vulgaris*	*Incurvata*
22	IE 2957	Germany	*Vulgaris*	*Liliacea*
23	IE 3045	India	*Vulgaris*	*Liliacea*
24	IE 3077	India	*Vulgaris*	*Incurvata*
25	IE 3104	India	*Vulgaris*	*Incurvata*
26	IE 3317	Zimbabwe	*Vulgaris*	*Digitata*
27	IE 3391	Zimbabwe	*Vulgaris*	*Digitata*
28	IE 3392	Zimbabwe	*Compacta*	*
29	IE 3470	India	*Vulgaris*	*Stellata*

30	IE 3475	India	*Vulgaris*	*Incurvata*
31	IE 3614	Unknown	*Plana*	*Confundere*
32	IE 3721	Uganda	*Compacta*	*
33	IE 3945	Uganda	*Plana*	*Confundere*
34	IE 3952	Uganda	*Plana*	*Confundere*
35	IE 3973	Uganda	*Vulgaris*	*Stellata*
36	IE 4028	Uganda	*Vulgaris*	*Incurvata*
37	IE 4057	Uganda	*Plana*	*Seriata*
38	IE 4073	Uganda	*Elongata*	*Reclusa*
39	IE 4121	Uganda	*Plana*	*Confundere*
40	IE 4329	Zimbabwe	*Vulgaris*	*Incurvata*
41	IE 4491	Zimbabwe	*Elongata*	*Reclusa*
42	IE 4497	Zimbabwe	*Vulgaris*	*Digitata*
43	IE 4545	Zimbabwe	*Compacta*	*
44	IE 4565	Zimbabwe	*Elongata*	*Reclusa*
45	IE 4570	Zimbabwe	*Plana*	*Confundere*
46	IE 4622	Zimbabwe	*Compacta*	*
47	IE 4646	Zimbabwe	*Plana*	*Grandigluma*
48	IE 4671	India	*Vulgaris*	*Digitata*
49	IE 4709	Burundi	*Africana*	*
50	IE 4734	India	*Vulgaris*	*Digitata*
51	IE 4757	India	*Vulgaris*	*Stellata*
52	IE 4795	Zimbabwe	*Vulgaris*	*Digitata*
53	IE 4797	Maldives	*Vulgaris*	*Liliacea*
54	IE 4816	India	*Elongata*	*Reclusa*
55	IE 5066	Senegal	*Vulgaris*	*Incurvata*
56	IE 5091	Zimbabwe	*Vulgaris*	*Digitata*
57	IE 5106	Zimbabwe	*Vulgaris*	*Incurvata*
58	IE 5201	India	*Vulgaris*	*Digitata*
59	IE 5306	Zimbabwe	*Vulgaris*	*Digitata*
60	IE 5367	Kenya	*Vulgaris*	*Liliacea*
61	IE 5537	Nepal	*Vulgaris*	*Stellata*
62	IE 5817	Nepal	*Vulgaris*	*Incurvata*
63	IE 5870	Nepal	*Vulgaris*	*Digitata*
64	IE 6059	Nepal	*Vulgaris*	*Digitata*
65	IE 6082	Nepal	*Plana*	*Confundere*
66	IE 6154	Nepal	*Vulgaris*	*Incurvata*

67	IE 6165	Nepal	*Vulgaris*	*Incurvata*
68	IE 6221	Nepal	*Vulgaris*	*Stellata*
69	IE 6240	Zimbabwe	*Vulgaris*	*Incurvata*
70	IE 6294	Zimbabwe	*Vulgaris*	*Incurvata*
71	IE 6326	Zimbabwe	*Vulgaris*	*Digitata*
72	IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*
73	IE 6350	Zimbabwe	*Vulgaris*	*Incurvata*
74	IE 6421	Uganda	*Vulgaris*	*Digitata*
75	IE 6473	Uganda	*Plana*	*Confundere*
76	IE 6514	Zimbabwe	*Vulgaris*	*Incurvata*
77	IE 6537	Nigeria	*Vulgaris*	*Incurvata*
78	IE 7018	Kenya	*Vulgaris*	*Incurvata*
79	IE 7079	Kenya	*Vulgaris*	*Liliacea*
80	IE 7320	Kenya	*Vulgaris*	*Digitata*
81	VR 708 - Check	India	*	*
82	PR 202 - Check	India	*Vulgaris*	*Incurvata*
83	RAU 8 - Check	India	*Vulgaris*	*Incurvata*
84	VL 149 - Check	India	*Compacta*	*

* Information not available

panicles/all tillers in a row. Blast infected leaf, neck, node and finger samples were collected from Vizianagaram, Nandyal, Mandya and Naganahalli for isolation of pathogen.

3.4.4 Evaluation of core collection of finger millet germplasm for blast resistance under field conditions during 2009 rainy season at Patancheru

Finger millet core collection consisting of 622 accessions (Upadhyaya *et al*., 2006) along with systematic national checks for blast screening (VL 149, VR 708, RAU 8 and PR 202) were evaluated for blast resistance in field under artificial inoculation during the rainy season 2009 at ICRISAT, Patancheru, India. Planting, pathogen multiplication, inoculum preparation, inoculation, optimum weather conditions and disease assessment were similar as described under section 3.4.2.

3.4.5 Finger Millet Blast Resistance Stability Nursery (FMBRSN) – 2010

Finger millet germplasm accessions (core and mini-core) were evaluated at Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli in India during the rainy season 2009 and accessions exhibiting resistance to neck and finger blast were identified. Some other finger

millet lines that exhibited differential reactions at these locations were also included. Isolates of *M. grisea* collected from these locations were analyzed at ICRISAT for pathogenic variability. A Finger Millet Blast Resistance Stability Nursery (FMBRSN) – 2010 was constituted with finger millet accessions that showed resistant and variable disease reactions at the above locations. The nursery was coordinated by ICRISAT and conducted with the help of collaborating scientists at the above locations (Table 3.4) during the rainy season 2010.

Table 3.4. Geographical characteristics and experimental conditions of finger millet blast resistance screening at five locations in India during 2009 and 2010 rainy seasons

Location	**Patancheru**	**Vizianagaram**	**Nandyal**	**Mandya**	**Naganahalli**
Abbreviation	Pat	Viz	Nan	Man	Nag
State	Andhra Pradesh	Andhra Pradesh	Andhra Pradesh	Karnataka	Karnataka
Name of the Institute	International Crops Research Institute for Semi-Arid Tropics (ICRISAT)	Agricultural Research Station (ARS)	Regional Agricultural Research Station (RARS)	Zonal Agricultural Research Station (ZARS)	Organic Farming Research Station (OFRS)
Coordinates	17º 53'N, 78º 27'E	18º 7'N, 83º 25'E	15° 28'N, 78° 29'E	12º 52'N, 76º 9'E	12° 3'N, 76° 64'E
Altitude (m)	522	127	216	678	754
Rainfall (mm)	997.59	1131	800	700	800
Plot size (m^2)	1 row × 2 m long in 2009 2 rows × 2 m long in 2010	Two rows of 4 m length	Two rows of 4 m length	Two rows of 4 m length	Two rows of 4 m length
No. of reps	2	2	2	2	2
Inoculation method	Artificial spray inoculation at 30 DAS and pre-flowering stage	Natural epiphytotic conditions	Natural epiphytotic conditions	Natural epiphytotic conditions	Natural epiphytotic conditions
Inoculum	*M. grisea* single spore isolate from Patancheru (1×10^5 conidia ml^{-1})	No artificial inoculation	No artificial inoculation	No artificial inoculation	No artificial inoculation
Humidity control	Mist irrigation	Irrigation	Irrigation	Irrigation	Irrigation

Entries: The FMBRSN–2010 consisted of 28 finger millet accessions as test entries including one susceptible (VR 708) and one resistant (GPU 28) checks. Details of the lines and their randomization are given in Table 3.1.

Locations: The FMBRSN–2010 was evaluated for blast resistance under natural epiphytotic conditions at Vizianagaram, Nandyal, Mandya and Naganahalli and under artificial inoculation at Patancheru during the 2010 rainy season (Table 3.4).

Planting and other agronomic practices: The nursery was conducted in a RCBD with 2 replications and each entry was grown in two rows, 2 m long in each replication according to plot numbers *i.e.* 1001 to 1028 in replication 1, and 2001 to 2028 in replication 2. In order to increase disease pressure, the varieties (VL 149, VR 708, RAU 8 and PR 202) were planted in boarder rows and also on every 5th row alternatively at Patancheru and a local susceptible check was planted as boarder rows, repeated after every 5th row at other locations. Row-to-row spacing was maintained as 60 cm at Patancheru location and 30 cm at other locations. Plants were thinned to 40 plants/row with 5 cm spacing between plants per row while thinning 2 weeks after seedling emergence.

The required fertilizers, 50:40:25 (N:P:K) were applied, in which N was applied in two equal doses as basal and topdressing at 30 days after sowing except Naganahalli where, the crop was grown under organic farming conditions (application of well decomposed farm yard manure @ 50 t/ha at the time of land preparation). The other agronomic practices followed were as per the local practices. Multiplication of the pathogen, inoculum preparation, inoculation and favorable weather conditions followed at Patancheru were similar as described in the section 3.4.1.1

Disease assessment and collection of weather data: The data were recorded for leaf, neck and finger blast severity as described in the section 3.4.1.1. Weather data also collected.

3.4.6 Evaluation of mini-core collection of finger millet germplasm for blast resistance in field conditions during 2009 rainy season at Patancheru

Finger millet mini-core collection (Table 3.3) consisting of 80 accessions (Upadhyaya *et al*., 2010) along with systematic national checks for blast screening (VL 149, VR 708, RAU 8 and PR 202) were evaluated for blast resistance under field conditions during *khariff* 2010 at ICRISAT, Patancheru, India under artificial inoculation. The

experimental design followed was randomized complete block design with two replications. Planting, pathogen multiplication, inoculum preparation, inoculation, optimum weather conditions were similar as described in the section 3.4.2.

Disease assessment: The data were recorded for leaf, neck and finger blast severity as described in 3.4.2. Data were also recorded for agronomic traits, such as days to flowering (time of full panicle emergence in 50% if the plants in a row), plant height (measured from the base of the plant to the tip of the panicle at maturity), and inflorescence compactness (compactness of the panicle at maturity) by following the finger millet descriptors (IBPGR, 1985).

3.4.7 Evaluation of mini-core collection of finger millet for leaf blast resistance using FM-Patancheru isolate (FMP1) under greenhouse conditions

Mini-core collection was evaluated for leaf blast resistance under greenhouse conditions using Patancheru isolate (FMP1). Planting, pathogen multiplication, inoculum preparation, inoculation, optimum weather conditions were similar as described in greenhouse screening technique.

3.4.8 Evaluation of selected entries against location specific isolates for neck and finger blast resistance under greenhouse conditions

Test entries: Five resistant accessions across the five locations for both the years (2009 & 2010) under field conditions along with resistant check (GPU 28) and susceptible check (VR 708) were used for assessment of neck and finger blast resistance under greenhouse conditions. The experiment was conducted in completely randomized design with three replication.

Isolates: One highly virulent *M. grisea* isolate from each location (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli) was used for assessment stability of neck and finger blast resistance in selected germplasm accessions. Planting, pathogen multiplication, inoculum preparation, inoculation and favourable conditions were similar as described in the section 3.4.1.2.

Disease assessment: The observations on individual tillers were recorded after 30 days of inoculation using 1–5 scale for neck blast and finger blast severity (%) estimate across all the inoculated panicles/all inoculated tillers in each replication. For neck and finger blast incidence, total number of infected neck and finger were scored, counted and

disease incidence (DI) % was calculated using formula DI % = (number of infected tillers/total number of tillers inoculated in each replication) × 100.

3.5 STATISTICAL ANALYSIS

3.5.1 Pathogenic variability of *M. grisea* isolates using a set of putative host differentials

The experiments to detect pathogenic variability among the isolates of *M. grisea* were conducted in factorial completely randomized design under greenhouse conditions. The data on leaf blast severity studies were subjected to Analyses of variance using GENSTAT statistical package (version 13.0., Rothamsted Experiment Station, Herpenden Herts AL52JQ, UK) to determine significant differences among the isolates, locations, accessions and their interaction (Payne, 2002). Principal component analysis was done to determine the similarity among the isolates and to classify them to pathotype groups based on leaf blast severity.

3.5.2 Epidemiology

A completely randomized design was used for all the epidemiology experiments. An analysis of variance (ANOVA) was performed to determine statistical significance of the main factors and their interactions using PROC GLM (General Linear Model) in SAS 9.2 (Statistical Analysis Systems Institute Inc., Cary, NC). When ANOVA showed significant differences among the treatments at $P < 0.01$, separation of means was conducted using the least significant difference (LSD) at $P<0.01$ (LS MEANS DUNCAN). Regression procedures were performed using MINITAB statistical package (trail version 15.1.30.0, USA; www.minitab.com) to determine the relationship between the environmental factors (independent variable x) and disease incidence, severity (leaf, neck and finger blast), sporulation, lesion size and number of lesions (dependent variable y).

In evaluating leaf wetness duration (LWD), the linear regression of the log of the standard deviation of lesion number across 24 observations (6 LWD × 4 replications) on the log of the mean of Y at each level of wetness duration was significant, with a slope near 1, suggesting a logarithmic transformation would provide the most homogeneous error variance. One was added to the raw Y value to prevent the occurrence of log10(0).

3.5.3 Identification of sources of blast resistance from mini-core collection of finger millet germplasm

3.5.3.1 Evaluation of mini-core collection at ICRISAT during 2009 and 2010

Statistical analysis was performed following the Residual Maximum Likelihood (REML) on GENSTAT statistical package (edition 4.0; Rothamsted Experiment Station, Herpenden, Herts AL52JQ, UK) for both years separately and on the combined data. Variance components due to genotype (σ^2g), genotype × environment (years) ((σ^2ge), residual (σ^2e) and their standard errors were estimated. In the combined analysis, years were considered as fixed and genotypes as random. Best linear unbiased predictors (BLUPs) were obtained for each trait. The Bartlett's test of homogeneity was done using GENSTAT, which indicated that the error variances were homogeneous except for leaf blast. The associations between pairs of variables such as – leaf, neck and finger blast, plant height, days to flowering and panicle compactness were determined in terms of Pearson's correlation coefficients using the PROC CORR procedure in SAS (version 9.2, USA).

A correlation analysis (CORR procedure, SAS 9.2) was performed between leaf, neck and finger infection for all the experiments. Regression procedures were performed using MINITAB statistical package (Minitab trail version 15.1.30.0, USA; www.minitab.com) to determine the relationship between finger infection (independent variable *x*) and neck blast infection (dependent variable *y*).

3.5.3.2 Evaluation of mini-core collection at five locations during 2009

The random model of residual maximum likelihood (REML) (Patterson and Thompson, 1971) in GenStat 14.0 was used to analyze data of three phases of blast for individual locations. Meta-analysis of the combined data from all five locations was performed and variance components of the random effects were estimated using maximum likelihood. Environments were considered fixed and the significance was evaluated using Wald statistic. Variance components owing to genotype (σ^2g) and its standard errors (SE) were estimated for individual and combined (meta) analysis.

3.5.3.3 Analysis of resistance stability

Evaluation of finger millet mini-core collection for blast resistance was conducted in 2009 at five locations and the selected resistance accessions were further evaluated at above locations during the rainy season 2010 for confirmation of stability of resistance. The data on these 23 accessions and one susceptible check (VR 708) were obtained across the five locations over two years were combined for statistical analysis. The analysis of variance of finger blast severity (%) data was done on both original and arsine transformed scales using fixed-effects models. Since the results of the analyses on both scales were similar, the mean severity data were presented on the original scale. Leaf blast (1–9 scale) and neck blast (1–5

scale) severity data collected at five locations were used directly for analysis. The statistical analysis includes an analysis of variance for each environment and a combined analysis across environments using PROC GLM in SAS (version 9.2). The combined analysis of variance served as basis to estimate components of variance attributable to accessions (genotype), location/environment, year and their interaction with blast severity. For partitioning of total variation into different sources, mixed model was followed, where accession (A) effects were considered as fixed, while location (L) and years (Y) effects as random. The year factor was nested with a total of 10 environments (5 locations × 2 years). In the present studies, two types of analysis were conducted for stability of resistance, one is relative variation method and another one is GGE biplot analysis. As the variation in the disease severity on a accession at different over time can be considered as an indicator for the stability of resistance in the cultivars, variation was compared among the finger millet accessions. Because standard deviation in disease severity is linearly related to the square root of [mean severity × (1 – mean severity)], relative variation was calculated by dividing the standard variation was calculated by dividing the standard deviation with [mean severity × (1 – mean severity)]. Variance analysis was then conducted on the relative variation and the means were compared among the 24 finger millet accessions using GLM procedure in SAS. Similarly, disease severity variation among different finger millet accessions at each location was also analyzed to test if it changed significantly across locations.

GGE biplot analyses for blast severity were conducted using GENSTAT (Yan and Kang, 2002) statistical package (version 13.0; Rothamsted Experiment Station, Herpenden Herts AL52JQ, UK) to determine stability and to identify genotypes of interest for disease resistance. Five environments (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli), two years (2009 and 2010) and the 23 finger millet mini-core accessions tested across these environments were used in this analysis, with finger millet national check (VR 708) as the susceptible check. A performance line passing through the origin of the biplot is used to determine mean performance of a genotype. The arrow on the performance line represents increasing mean disease severity (i.e., increase susceptibility to blast). A stability line perpendicular to the performance line also passes through the origin of the biplot; the two arrows in opposite directions represent a decrease in stability. A genotype distanced farther from the biplot origin on either side on the stability line represents relatively lower stability. All biplots presented in this experiments are direct outputs of

GENSTAT software. A genotype closer to the performance line is considered more stable than the one placed farther.

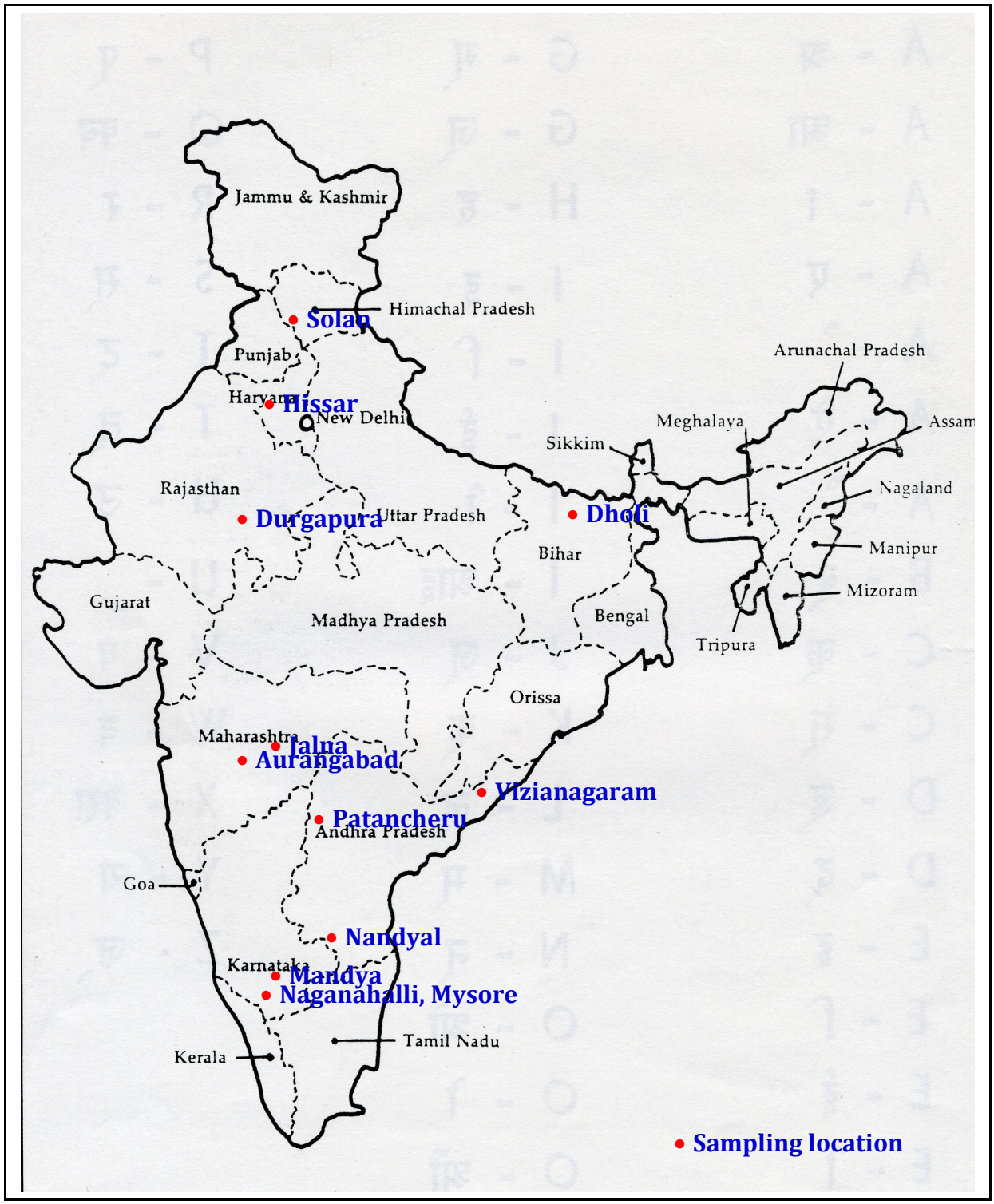

Figure 3.1. Map showing the collection sites of isolates of *Magnaporthe grisea* in India from different hosts.

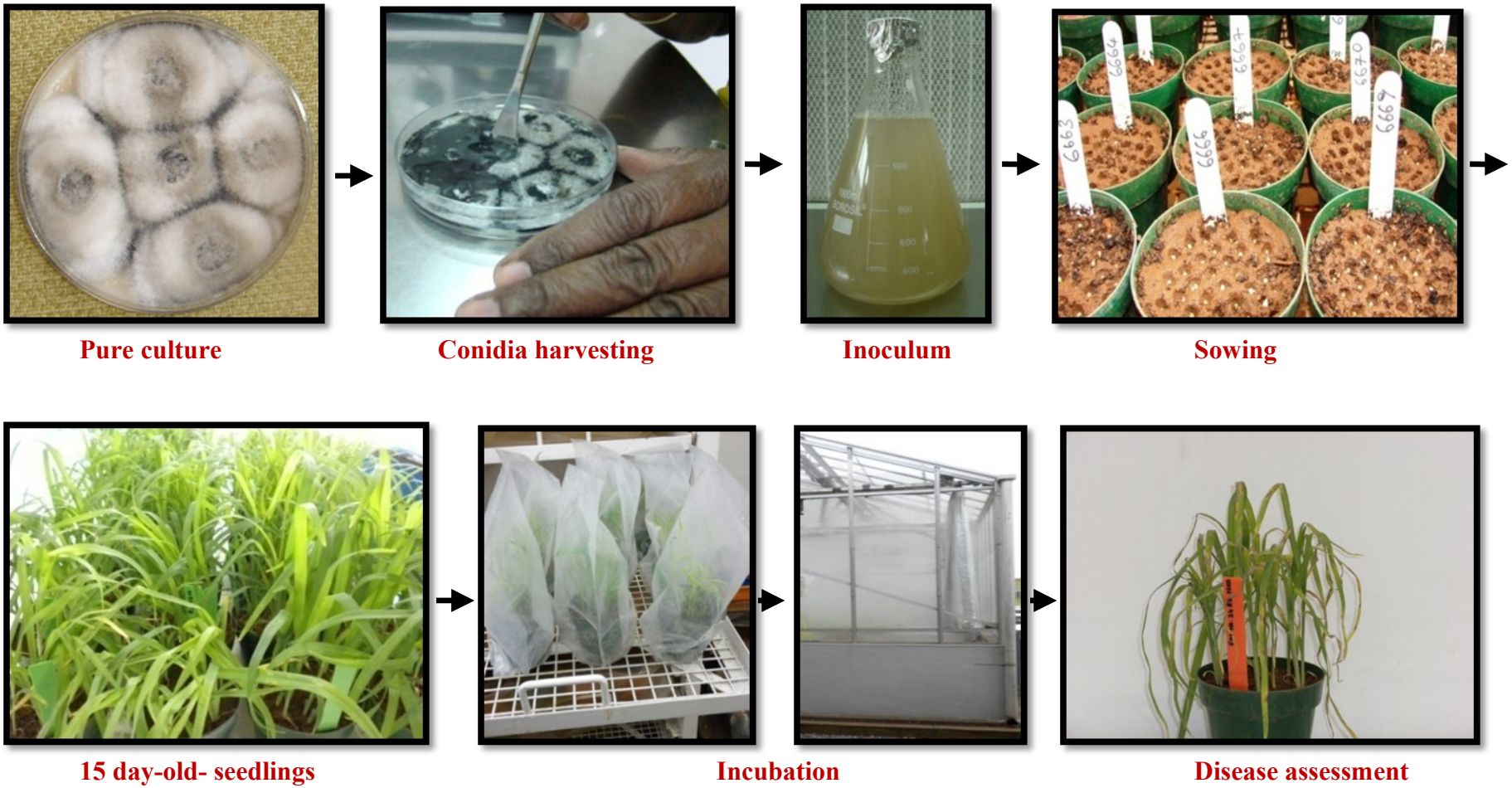

Figure 3.2. Greenhouse screening technique for leaf blast.

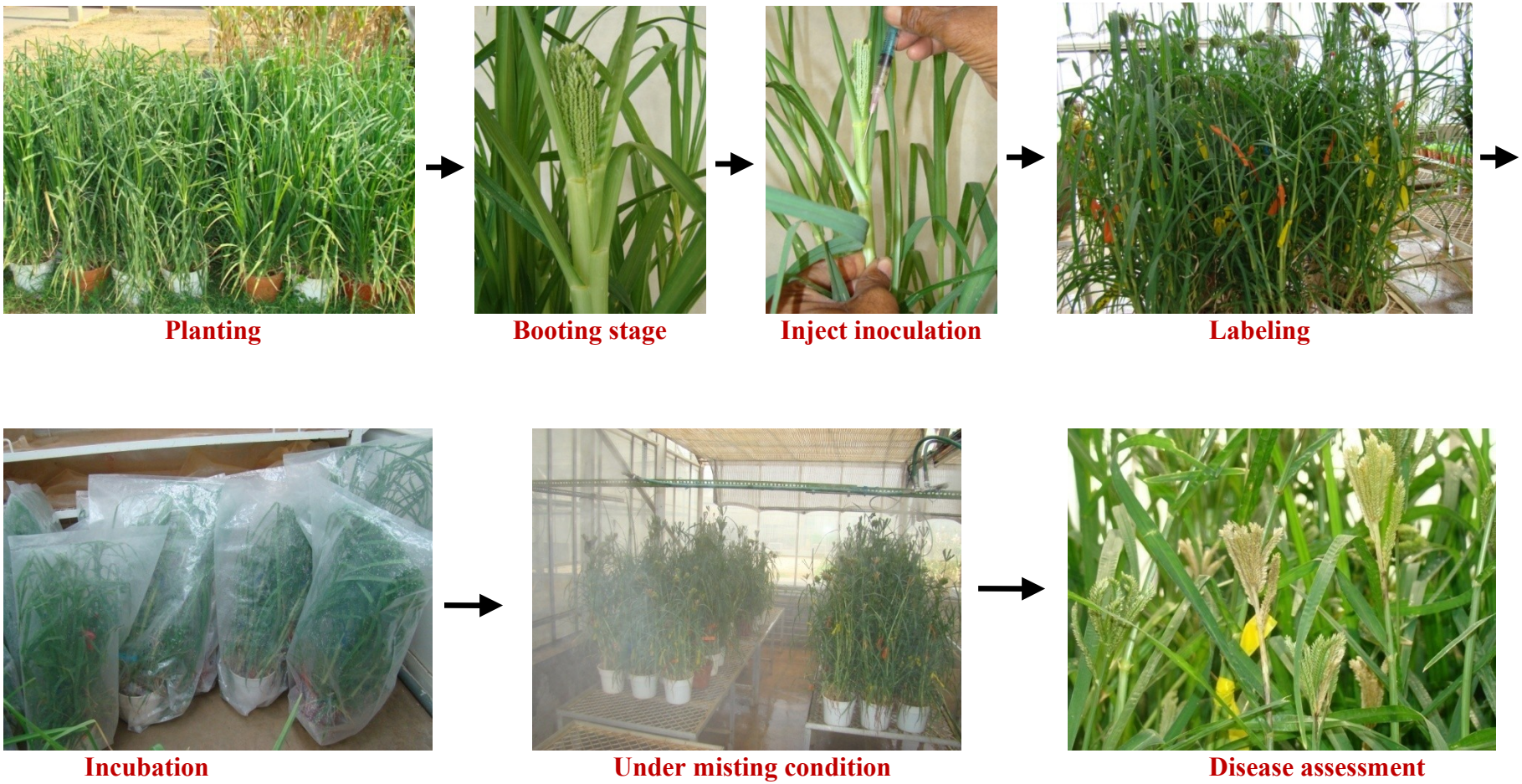

Figure 3.3. Greenhouse screening technique for neck and finger blast.

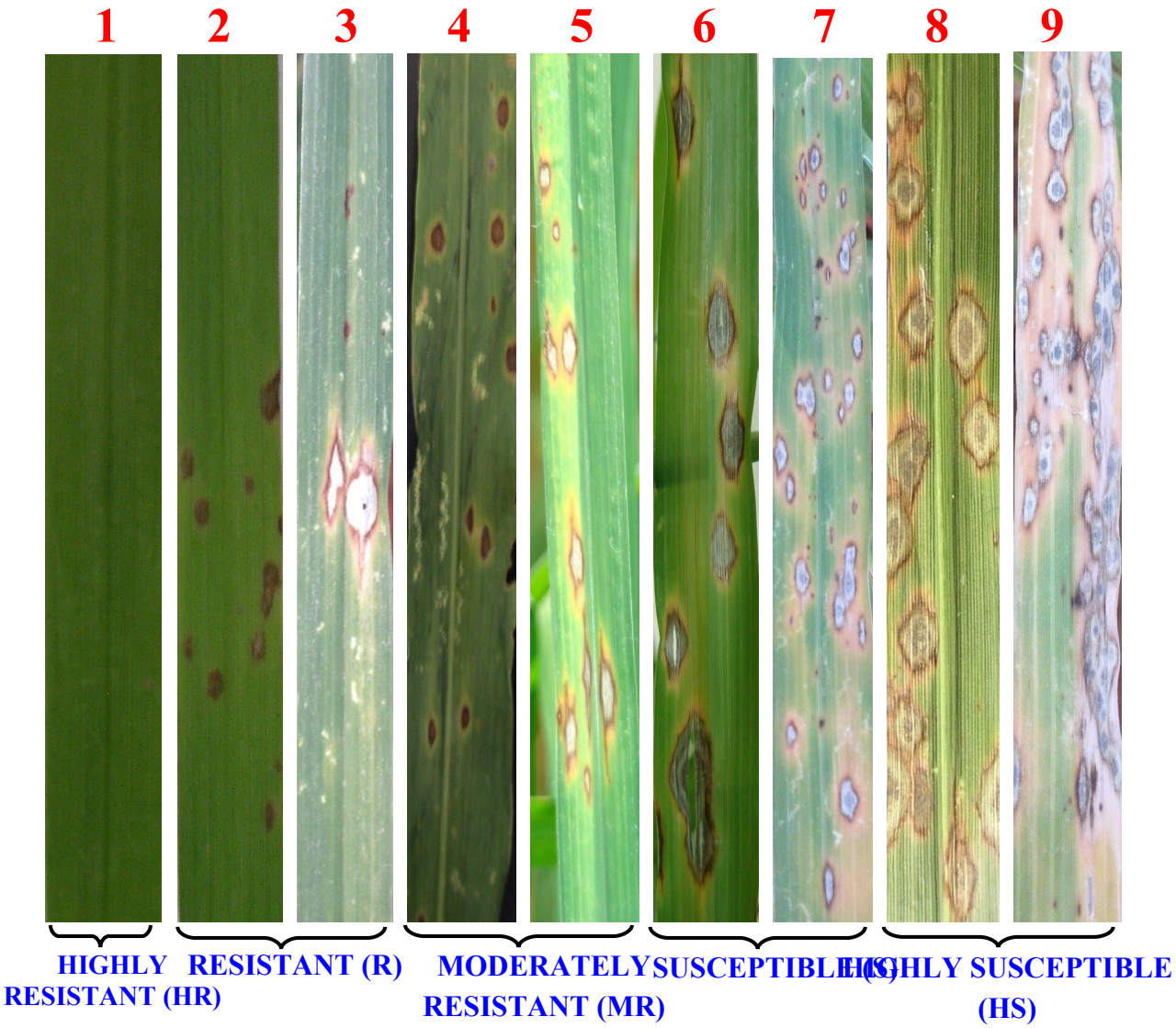

Figure 3.4. A 1–9 rating scale for recording leaf blast severity in finger millet seedlings infected with *Magnaporthe grisea.*

Score	Disease
1	No lesions to small brown specks of pinhead size
2	Larger brown specks covering 1-5% of the leaf area
3	Small, roundish to slightly elongated, necrotic gray spots, about 1–2 mm in diameter with brown margins covering 6-10% of the leaf area
4	Typical blast lesions, elliptical, 1–2 cm long, usually confined to area between main veins, covering 11-20% of the leaf area
5	Typical leaf blast covering 21-30% of the leaf area
6	Typical blast lesions covering 31-40% of the leaf area
7	Typical blast lesions covering 41-50% of the leaf area
8	Typical blast lesions covering 51-75% of the leaf area and many leaves dead
9	>75% leaf area covered with lesions or all the leaves dead

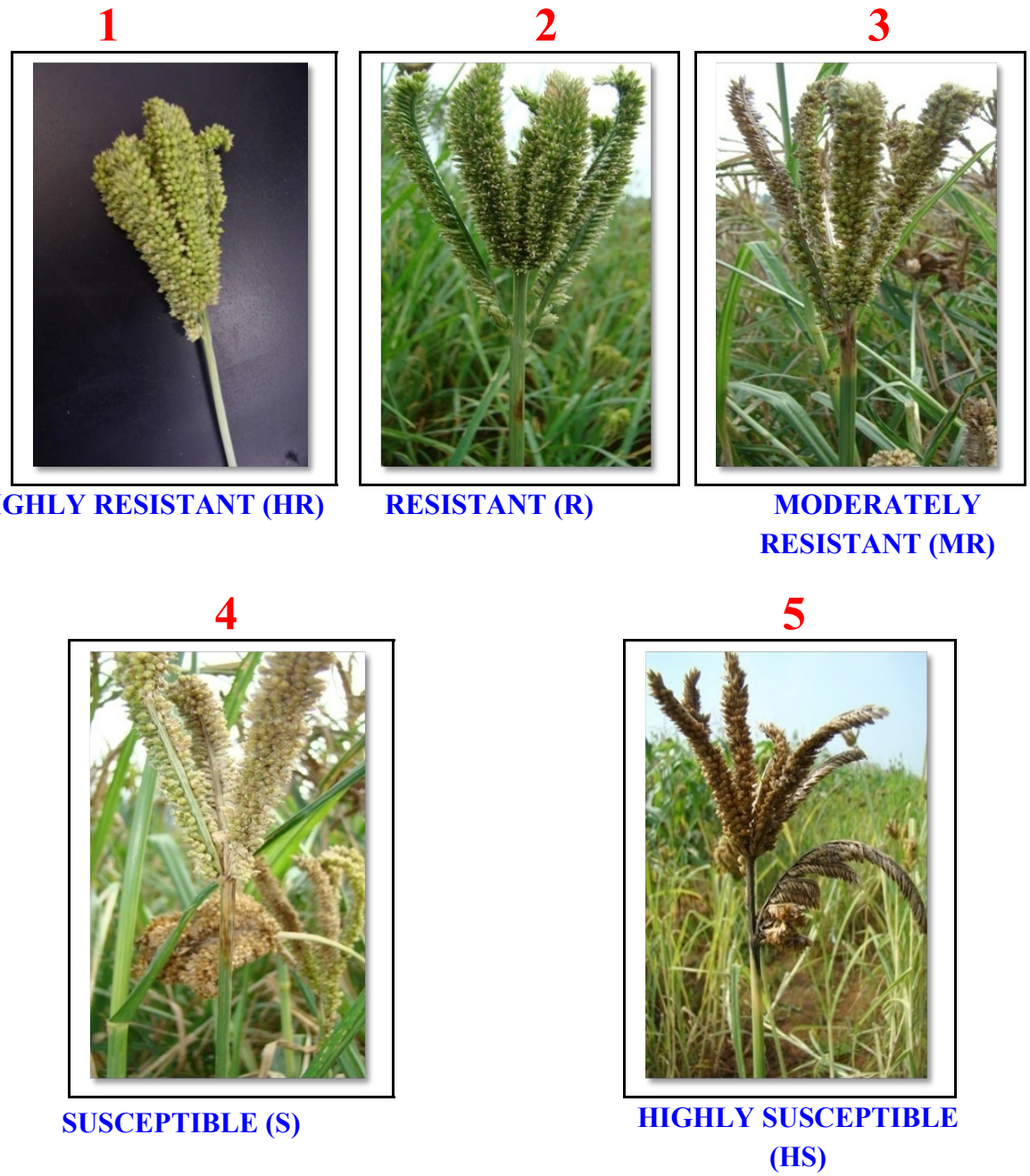

Figure 3.5. A 1–5 rating scale based on lesion size on neck region for recording neck blast severity in finger millet infected with *Magnaporthe grisea*

Score	Neck blast
1	No lesions to pin head size of lesions on the neck region
2	0.1–2.0 cm of lesions on the neck region
3	2.1–4.0 cm of lesions on the neck region
4	4.1–6.0 cm of lesions on the neck region
5	> 6.0 cm of lesions on the neck region

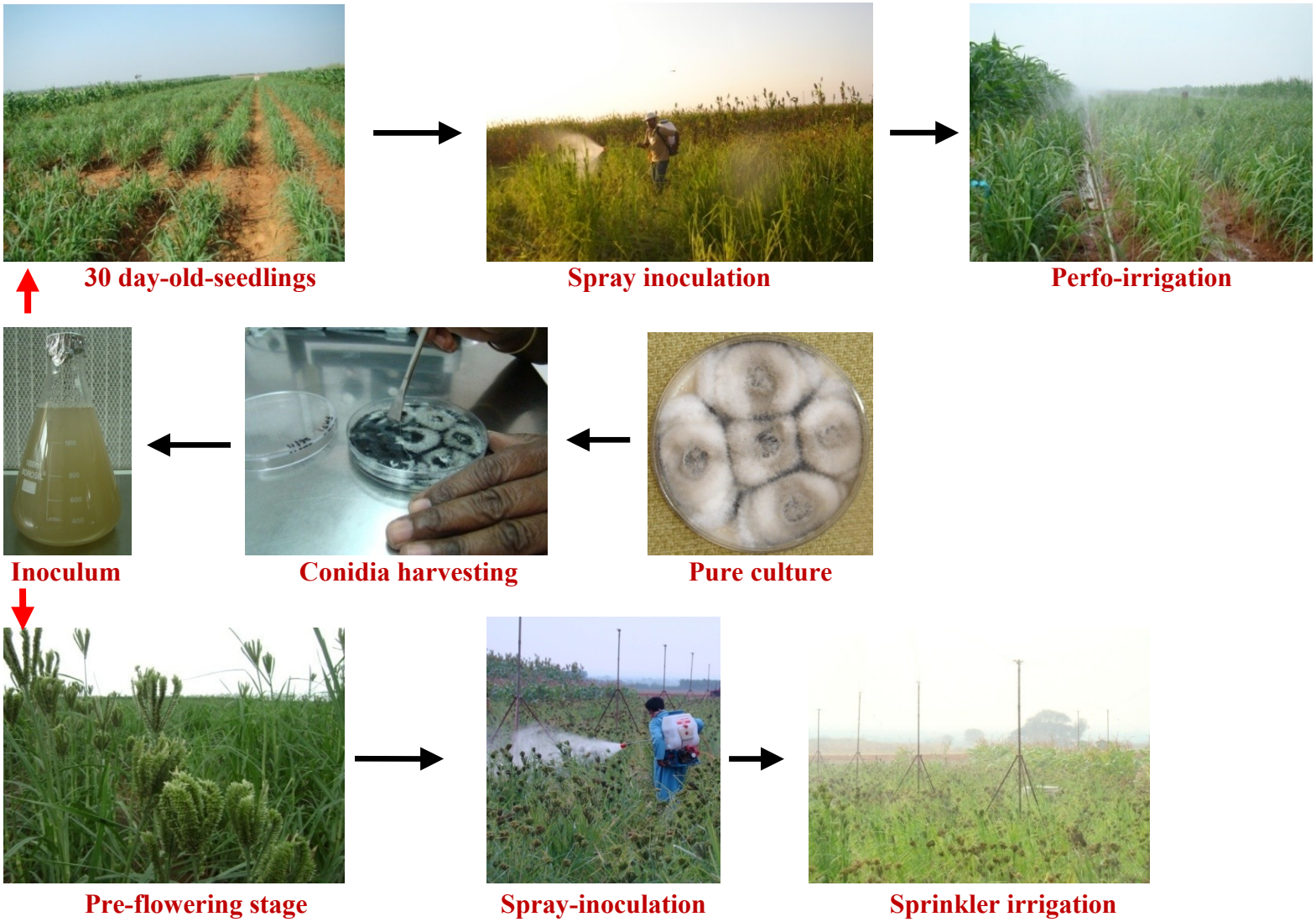

Figure 3.6. Steps in field screening technique for leaf, neck and finger blast.

CHAPTER IV

RESULTS AND DISCUSSION

Results of the experiments conducted in the present investigation on virulence diversity, epidemiology and host-plant resistance in finger millet for blast disease are presented in detail below. The results were critically examined and discussed in the light of past information available on these aspects.

4.1 COLLECTION, ISOLATION, PURIFICATION AND TESTING PATHOGENICITY OF *Magnaporthe grisea* ISOLATES

4.1.1 Collection, isolation and purification of *M. grisea* isolates

A total of 125 blast disease samples (leaf, neck, node and finger) from finger millet, six from foxtail millet and 3 from rice were collected from six locations (Patancheru, Vizianagaram, Nandyal, Mandya, Naganahalli and Dholi) during the 2008, 2009 and 2010 rainy seasons. Five pearl millet blast disease samples representing major growing areas of India were collected from Cereals Pathology, ICRISAT, Patancheru. The pathogen was identified as *Magnaporthe grisea* (Hebert) Barr. (anamorph = *Pyricularia grisea* Sacc.) based on microscopic studies of conidia. A total of 70 monoconidial isolates of *M. grisea*, 56 from finger millet, 6 from foxtail millet, 3 from rice and 5 from pearl millet were obtained from the samples collected from different locations of India (Tables 4.1 to 4.3). Of the total *M. grisea* isolates, 15 each from Patancheru and Vizianagaram, 13 from Nandyal, 14 from Mandya, 8 from Naganahalli and one each from Dholi, Aurangabad, Hissar, Jaipur and Solan (Table 4.2). Of the 70 isolates, 22 from leaf samples, one from node, 27 from neck and 20 from finger samples were isolated from samples collected from different locations and years (Table 4.3).

The isolates were named tentatively with 3-part code such as FMP1, FxMV59, RM63 and PMA66 and so on. The first part of the letters represented the crop name (e.g. FM: Finger millet, FxM: Foxtail millet, R: Rice and PM: Pearl millet). The next alphabet letter represented the location name (P: Patancheru, V: Vizianagaram, N: Nandyal, M: Mandya, N: Naganahalli, D: Dholi, A: Aurangabad, H: Hissar, J: Jaipur and S: Solan) and final numeral number indicated isolate serial number. The identity was assigned to each isolate based on state from which sample collected. The identity consists of 2 parts code such as A1, K1, M1, B1, H1, HP1 and R1. The first alphabet letter represented the name of the state (e.g. A: Andhra Pradesh, K: Karnataka, M: Maharashtra, B: Bihar, H: Haryana, HP: Himachal Pradesh, R: Rajasthan)

followed by numeral number indicated the serial number of isolate from that state. A total of 43 isolates of *M. grisea* were from Andhra Pradesh, 22 from Karnataka and one each from Bihar, Maharashtra, Haryana, Himachal Pradesh and Rajasthan (Table 4.1).

4.1.2 Pathogenicity test

Pathogenicity tests were performed with all *M. grisea* isolates from different crops and locations except rice isolates. A finger millet variety VR 708, foxtail millet accession ISe 1118 and pearl millet line ICMB 95444 known susceptible based on previous field and greenhouse observations were used in these assay under controlled conditions in the greenhouse. Highly significant differences were observed among the finger millet isolates for leaf blast severity on a 1–9 scale. No significant differences were observed among the foxtail and pearl millet isolates for leaf blast on their respective susceptible checks. Pathogenicity tests revealed that all *M. grisea* isolates from finger millet caused moderately resistant (3.1–5.0 on 1–9 scale) to highly susceptible (7.1–9.0) reactions on VR 708 with variations in aggressiveness whereas, highly susceptible reaction caused by foxtail and pearl millet isolates on their respective accessions (Table 4.5).

Among the 56 finger millet isolates from six locations, the highest leaf blast severity was recorded on VR 708 for FMNd33 (score 8.7 on a 1–9 scale) followed by FMM42 (8.6), FMNg55 (8.25), FMV20 (8.1), FMD56 (7.8), FMM47 (7.75), FMP4 (7.55), FMNd28 (7.1), FMP1 (7.05) and FMM43 (7.0) and the least in FMM44 (3.05) followed by FMNd27 (3.15), FMV15 (3.25), FMNd38 (3.25) and FMNd34 (3.3) (Table 4.5).

Similar variations in aggressiveness of *M. grisea* isolates on a particular variety were reported by Sreenivasaprasad *et al*. (2007) and Takan *et al*. (2011) in finger millet and Yamagashira *et al*. (2008) in foxtail millet. The variation in leaf blast reaction in isolates collected from the same location and years could be due to collection from different plant parts (neck and fingers) were tested against vegetative stage. Variation in leaf blast reaction in isolates collected from the same field (intra-population variability) in two years are in agreement with Silva *et al*. (2009), who found that diversity in *M. oryzae* population was greater within the same field and between cultivars rather than between sub-populations of leaf and panicle.

4.1.3 Lesion morphology of *M. grisea* on finger millet, foxtail millet and pearl millet

All the isolates from different crops produced blast lesions 3–4 DAI. In general, all the *M. grisea* isolates from different crops showed a continuous array of symptoms from very minute brown specks to large elliptical lesions, with large, grey necrotic centers and brown to grey margins (Figure 4.1). Field isolates collected from different hosts showed variation in the lesion morphology. The lesion morphology commonly observed with the finger millet isolates were the typical spindle shaped spots with gray or whitish centre and brown or reddish brown margin that enlarge and coalesce to give blasted appearance**.** The aged spots did not show water soaking symptoms, where as the lesions were small on the foxtail millet and generally showed water soaked lesions; while symptoms were intermediate in pearl millet between finger millet and foxtail millet. Sporulating lesions were also observed in foxtail millet. In pearl millet, the disease appeared as grayish, water-soaked foliar lesions that enlarged and became necrotic, resulting in extensive chlorosis and premature drying of young leaves.

M. grisea isolates from different crops show a continuous array of symptoms to the infection on different crops such as very minute brown specks (resistant) to roundish lesions a few millimeters in diameter with small grey necrotic centers and brown to gray margins (susceptible). The lesion morphology varied on different hosts. On all the hosts, it was observed that the lesions were coalescent this covering the large area thereby reducing the photosynthetic area of the leaves. It is understood that lesion types are the results of genetically controlled interaction between the pathogen and the host plants. Tremendous variation in virulence has been documented in field population of the rice blast fungus (Bonman *et al*., 1986., Correa-Victoria and Zeigler, 1993., Lee and Chao, 1990., Ou, 1980., Zeigler *et al*., 1995) and to some degree among asexual derivatives of single spore isolates (Valent *et al*., 1991).

4.1.4 Cross-infectivity studies

Cross-inoculation tests using one selected isolate each from finger millet, foxtail millet and pearl millet showed that the isolates of *M. grisea* from finger millet did not infect foxtail and pearl millet, foxtail millet isolate did not infect finger and pearl millet and pearl millet isolate did not infect finger and foxtail millet. The isolates produced characteristic symptoms on their respective hosts. This investigation supported the overall suggestion that finger, foxtail and pearl millet-infecting isolates of *M. grisea* exist as genetically isolated and distinct host-

specific populations. These results broadly agree with Viji *et al*. (2000) who found that *M. grisea* isolates from *E. coracana* failed to infect rice and *vice versa*. Several workers have reported that the pathogenicity of the blast fungus is largely restricted to its host species of origin (Ramakrishnan, 1948., Kato *et al*., 1977., Todman *et al*., 1994), although successful infection of a host by an isolate from a different species has been reported under experimental conditions. However, Kumar & Singh (1995) have reported contradictory results regarding the ability of the pathogens from rice and finger millet to cross-infect. Kulkarni and Govindu (1977) reported that ragi isolates infected *Setaria italica* and *vice versa* whereas, both did not infect rice. The reasons for this variation appears to be the environmental conditions provided during experimentation in addition to the nutritional status of soil (Asuyama, 1965., Ou, 1985). Contradictory reports might also be due to some variability in host range involving a small number of isolates within a population. Our results support the conclusion of Hamer *et al*. (1989) and Valent *et al*. (1986) that the *M. grisea* populations are strongly delimited by host range although blast is found to infect a range of sympatric flora.

4.2 STUDY CULTURAL, MORPHOLOGICAL, PATHOGENIC AND MOLECULAR DIVERSITY AMONG THE *M. grisea* ISOLATES

4.2.1 Cultural diversity among the *M. grisea* isolates

Variation in colony characteristics *viz*., growth type, pigmentation, colour of the vegetative growth, and surface appearance among the isolates of *M. grisea* from different hosts are presented in Table 4.4. Based on characteristics of single-spored colonies, *M. grisea* isolates did not group into distinct colony types. Cultural characteristics varied greatly with isolates and with the medium used. A range of colour variation was observed among the field isolates. Observation were recorded for the mycelial colour , colour of the metabolite produced in the medium, growth types (cottony, subdued, tufted, submerged, sectored or non-sectored, radiating sectored or ringed or concentric ringed sectored growth), and colony surface smooth or rough (Table 4.4).

The sporulating ability of the field isolates varied. The degree of sporulation was compared with the growth patterns of the pathogen. It was observed that progenies that were grayish green and sector forming produced more spores. The isolates with cottony and submerged growth were poor spore producers with some exceptions (FMV20). The undersurface of the colonies were usually brown or black. Colony texture or surface of all the isolates was rough to smooth with trace to abundant sporulation. In majority of the isolates, the

maximum sporulation was confined to sectored region. In general, among all the *M. grisea* isolates from different crops, maximum sporulation was observed in foxtail millet isolates followed by rice, pearl millet and finger millet (Table 4.4).

Diversity in cultural characters such as colony colour, texture, and growth pattern were noticed among the isolates, but there was no clear-cut grouping between isolates from different hosts. The present investigation indicated a close correlation between the sporulation ability with colour and sector formation. Correlation between sporulating ability and aerial growth was also observed as reported by Ramakrishnan (1948). The present observation regarding sporulation are in support to the earlier reports (Sonah *et al*., 2009). The isolates showed vegetative growth as grayish green colour groups produced more spores and those with poor vegetative growth (submerged) were poor spore producers.

4.2.2 Morphological diversity among the *M. grisea* isolates

Isolates significantly varied in spore morphology. It was observed on water agar medium under light microscope that a single bottle-shaped conidiogenous cell produced 3–5 conidia arranged in cluster at the active apical tip or they were formed successively and sympodially in a characteristic pattern, *i.e.* the active apical tip moves to the side to produce next conidium, resulting 3–5 conidia borne sympodially on mature conidiophore. The successive and sympodial bearing of spores was commonly observed with the isolates derived from the infected rice, finger millet and foxtail millet. Mature conidia of *M. grisea* generally pyriform, almost hyaline to pale olive, 2-septate, 3-celled, the middle cell being more wider and darker, and exhibit a basal appendage at the point of attachment to the conidiophore. End cells and middle cells germinate giving out germtubes.

The results presented in the Table 4.5 on colony growth of *M. grisea* isolates on Oat-meal agar medium revealed that significant differences within and between isolates from different hosts. Maximum radial growth was recorded in finger millet isolates and minimum was in pearl millet isolates. Colony diameter ranged from 49–84 mm in finger millet isolates, 61–77 mm in foxtail millet, 59–63.5 mm in rice and 49–54.5 mm in pearl millet isolates. Among the isolates, maximum radial growth was recorded in FMP1 (84 mm) and FMV24 was showed the least radial growth (49 mm). The results are in agreement with Kumar and Singh (1995) and Meena (2005), who reported the variability in aerial mycelial growth of *M. grisea* isolates from different hosts.

With regard to sporulation (Index 0–4), excellent sporulation (index 4) was noticed in foxtail and pearl millet isolates (Table 4.5). Variation in sporulation capacity was noticed within the isolates from the same location and between the isolates in finger millet and rice isolates. Conidial measurements did not reveal any specific pattern for isolates from four crops. However, the conidial size ranged from 15.2–24 × 4.2–8 µm in rice, 12–36.7 × 6–12 µm in pearl millet, 10–35 × 5–12 µm in foxtail millet and 10.2–30.5 × 2–10 µm in finger millet (Table 4.5). In general, it was observed that the size of the conidia was larger in rice isolates followed by pearl millet isolates. Diversity in conidial size was recorded with isolates from finger and foxtail millet.

The size and shape of spores are important criteria for classification and identification of *Pyricularia* species. The present observations on the collected field isolates from rice, finger millet, foxtail millet and pearl millet isolates indicated morphological variation in terms of radial growth, size and sporulation. Studies on morphological variation of the spores, however have been limited although many observations have been made on spore morphology. Existence of variability among the isolates of *M. grisea* with respect to conidial size is well documented (Yamanaka and Kobayashi, 1962 and McKenzie *et al*., 2010).

4.2.3 Pathogenic variability of *M. grisea* isolates on a set of putative host differentials

In the host-pathogen systems where near-isogenic lines with known resistance genes are available, use of host differentials has been very successful in monitoring and identifying new virulence or races of the pathogens, *viz.,* rice–*Magnaporthe oryzae*, flax–*Melamspora lini*, wheat–*Puccinia graminis*, Potato–*Phytophthora infestans* and several others. In finger millet–*M. grisea*, the resistance genes are not yet identified and confirmed (Reddy *et al*., 2010) and near isogenic lines are not available, thus virulence monitoring has been less accurate and effective.

4.2.3.1 Finger Millet Blast Resistance Stability Nursery (FMBRSN)– 2010

An attempt was made to identify finger millet lines having stable resistance to blast disease. This was done by evaluating the finger millet mini-core collection at five locations (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli) during the rainy season 2009 and the accessions exhibiting resistant reactions at these locations were selected to constitute a Finger Millet Blast Resistance Stability Nursery (FMBRSN–2010) with 28 accessions including one resistant and susceptible checks. The nursery was evaluated during the rainy

season 2010 at the above locations. However, the resistant check (GPU 28) was included only during 2010 screening and pooled data of 27 entries are presented in Table 4.6. This study identified stable resistant accessions across five locations over 2 years and results also provided information on pathogenic variability based on differential reactions of host lines.

This study identified five finger millet accessions IE 2589, IE 2911, IE 4497, IE 6337 and IE 7018 highly resistant to all three phases/types of blast across the locations and years (Table 4.6) exhibiting high stability of resistance for utilization in resistance breeding programms. Several other accessions (IE 2619, -2710, -2872, -2957 and -5106) that were stable at specific locations could be utilized in resistance breeding at those locations. The remaining 16 accessions developed varying reaction types for leaf, neck and finger infection over 2 years of evaluation at the five locations. These accessions exhibited differential reactions showing the variations in the *M. grisea* populations and could be used to identify new pathotypes. However, these need to be characterized for *R*-genes involved. Correlation between leaf, neck and finger infection were similar, refer as reported earlier under section 4.4.5.3.

Eight accessions recorded susceptible (S) reaction to leaf blast at Mandya, while 4 at Patancheru. Based on the S reaction to leaf blast, Mandya isolate was most virulent followed by Naganahalli, Nandyal and Vizianagaram, and the Patancheru isolate was least virulent. 16 and 21 accessions recorded S reaction to neck and finger blast at Mandya, while seven for neck blast at Vizianagaram and 9 for finger blast at Patancheru. Based on the neck and finger blast, Mandya isolate was most virulent and the Patancheru isolate was least virulent (Table 4.6).

In finger millet-blast system some efforts have been made towards genetic diversity in the blast pathogen using MGR-DNA fingerprinting (Viji *et al*., 2000., Tanaka *et al*., 2009), RAPD (Singh and Kumar, 2010), AFLP markers (Sreenivasaprasad *et al*., 2007., Takan *et al*., 2011). However, very limited information available (Kumar *et al*., 2007) on attempts for identification of host differentials in finger millet blast for race identification.

4.2.3.2 Evaluation of *M. grisea* isolates for pathogenicity on FMBRSN accessions under greenhouse conditions

The data on leaf blast severity of five isolates (one representative isolate/location) of *M. grisea* on FMBRSN accessions are presented in Table 4.7 to 4.9.

Variation in virulence: All the isolates induced symptoms on host genotypes/accessions were considered virulent on these genotypes, although they induced different levels of disease severity (Table 4.7). Two isolates (FMNg55 and FMM42) were more virulent than other three isolates as it induced susceptible reaction on 27 and 25 accessions

respectively indicating the range of resistance/ and or virulence genes available in the accessions and isolates.

Variation in aggressiveness: Considerable variation was found among the isolates of *M. grisea* across accessions for leaf blast severity ranging from 1.1 on a 1–9 scale with the Patancheru isolate (FMP1) on IE 2872 to 8.6 with the Mandya isolate (FMM42) on IE 6082 (Table 4.7). Among the five isolates evaluated, highest mean leaf blast severity was recorded with the FMM42 (5.2) followed by FMNg55 (5.1) and the lowest was observed with the isolate FMP1 (2.8), across the accessions. Vizianagaram isolate (FMV20) and Nandyal isolate (FMNd33) had mean severity score 3.4 and 4.5 across the 28 accessions. All the isolates were highly aggressive on VR 708, IE 4755, IE 5870, IE 4797, IE 4759, IE 3543 and IE 3077, and least aggressive on IE 2957, IE 4497 and IE 6337. However on other accessions, the leaf blast severity was highly variable within and across the isolate-accession combinations. The highest mean severity developed on VR 708 (6.5) followed by IE 6082 (6.3), IE 4755 (6.0) and the least on IE 2911 and IE 2957 (2.4).

The analysis of variance indicated highly significant (P<0.001) effect of isolates, accessions and their interactions on disease severity, but the mean sum squares for accession and interaction with isolate were much less than that of the isolates (Table 4.8). The greatest differences were observed among the isolates, showing that virulence of isolates was the major factor that contributed to the variance. Similar findings have been reported by Takan *et al*. (2011) who found that effect isolates, varieties and their interaction were highly significant for lesion numbers and leaf area affected.

Variation in disease reaction: All the five isolates showed susceptible reaction on accessions VR708, IE 5870, -4797, -4759, -4755, -3543 and -3077 and none of them shown resistant reaction. Except isolate FMV20 on IE 6337, all other isolates gave differential reactions on these accessions. However among the 28 accessions, isolates had clear differential disease reactions on 21 accessions and remaining were uniformly susceptible to all the five isolates (Table 4.9).

Table 4.8. Analysis of variance for leaf blast severity of five isolates of *M. grisea* on 28 FMBRSN accessions

Source of variation	df	Sum squares	Mean sum of squares	F pr.
Replication	1	0.276	0.276	-
Isolate (I)	4	253.81	60.87	<.001
Accession (A)	27	316.39	12.70	<.001
I × A	108	248.96	2.27	<.001
Residual	139	42.757	0.30	-

The results indicated differential interaction for virulence, aggressiveness and disease reaction among the 5 isolates on 28 finger millet accessions. Significant host × pathogen interactions (Table 4.8) indicated existence of specificity in the finger millet-blast pathosystems as hypothesized by Vanderplank (1984). These results further support the findings of on pathogenic variation among *M. grisea* isolates (Kumar *et al*., 2007). The variations in virulence and aggressiveness of the isolates on accessions indicated the presence of a range of resistance genes in the accessions to the corresponding virulence genes in isolates. The host genotype GPU 28, which was included in the study as a resistant genotype (Nagaraja *et al*., 2007), unexpectedly showed differential reaction to isolates evaluated. This suggest the evolution of virulence factor(s) specific to host resistant factor (s) in finger millet–blast system. The findings are in agreement with Madhukeshwara *et al*. (2005) who reported that all the existing resistant varieties are only resistant against ear and finger blast, but invariably susceptible to leaf blast.

The main objective of this study was to characterize pathogen populations from Andhra Pradesh and Karnataka states and to select putative host differentials for determining finer level of variability by screening against more number of isolates would further add to the knowledge of race structure of *M. grisea.* A set of 10 putative host differentials were selected based on FMBRSN field screening over 2 years at five locations and greenhouse screening against 5 isolates (one isolate/location) were further evaluated for pathogenicity using 4 isolates from each location.

4.2.3.2 Finger millet Blast Host Differential Studies (FMBHDS) – 2011

The FMBHDS consisting of 12 accessions (10 putative differentials and one resistant and susceptible check) were evaluated for pathogenicity of 20 isolates of *M. grisea.* The data on leaf blast severity of five highly virulent isolates of the earlier experiment (4.1.7.2), 20 isolates in the present experiment were combined and presented in Tables 4.10 to 4.12. The isolates

were selected based on pathogenicity reaction on susceptible check (VR 708). The experiment was repeated twice.

Variance components: Analysis of variance showed that significant differences (P<0.001) between location, isolate, accession and their interactions for leaf blast severity indicating the pathogenic variability among the test isolates (Table 4.11). Although there was significant interaction between accession and isolate, the MS variance for accession was high, indicating that differences in the leaf blast severity were mainly contributed by accessions followed by isolate. Similar findings were obtained by Takan *et al*. (2011) who found that overall differences between isolates, accessions and their interaction were highly significant for the lesion numbers and leaf area affected.

Table 4.11. Analysis of variance for leaf blast severity of 25 isolates of *M. grisea* from five locations on 12 host differential accessions

Source of variation	df	Mean sum of squares	F pr.
Replication	1	0.0	-
Location (L)	4	49.5	<.001
Residual	4	0.1	-
Isolate (I)	24	20.4	<.001
Residual	16	0.3	-
Accession (A)	11	65.4	<.001
L × A	44	3.8	<.001
I × A	264	2.0	<.001
Residual	231	0.3	-

Variation in aggressiveness: All the test isolates induced blast symptoms on the susceptible variety VR 708. However, considerable variation was found among the isolates of *M. grisea* from different locations across the host differentials for leaf blast severity, ranging from 1.0 on a 1–9 scale with the isolate FMM40 on GPU 28 to 9.0 with isolate FMV23 on IE 3392 and VR 708. Finger millet variety GPU 28 considered as resistant check was found susceptible to leaf blast with the isolates FMP1, FMP5, FMV19 and FMNg55 with the mean severity ranging from 3.1 to 3.5 (Table 4.10).

Among the 25 isolates, FMV23 recorded the highest mean leaf blast severity (6.5) across the accessions, followed by FMNd35 and FMNg51 (5.4), while FMP1, FMNd30 and FMM40 recorded the lowest (2.6) disease severity. All the isolates were highly aggressive on

the susceptible genotype VR 708 and least aggressive on GPU 28, while low to moderate aggressiveness was observed for all the isolates on the remaining 10 host differential accessions and also highly variable within and across the isolate-genotype/accession combinations (Table 4.10). Similar findings have been reported by Takan *et al*. (2011) who found that 31 isolates were compatible to the eight finger millet varieties but, differences were observed in aggressiveness. The host variety GPU 28, which was included in the study as a resistant genotype (Nagaraja *et al*., 2007), unexpectedly showed differential reaction to isolates evaluated. This suggest the evolution of virulence factor(s) specific to host resistant factor (s) in finger millet–blast system. The findings are agreement with Madhukeshwara *et al*. (2005) who reported that all the existing resistant varieties are only resistant against ear and finger blast, but invariably susceptible to leaf blast.

Variation in virulence: All the 25 isolates of *M. grisea* were found virulent on 12 putative host differentials, although they induced different levels of leaf blast severity. However, isolate FMM40 did not produce symptoms on resistant check (GPU 28) and thus were avirulent on this genotype. The isolates, FMP5, FMV23, FMNg54 and FMNg55 were most virulent infecting 11 out of 12 host differentials, while FMV14 was the least virulent and could infect only two accessions (Table 4.12).

Among the five isolates from Patancheru, FMP5 was virulent on all the accessions except IE 2911 while the remaining isolates were avirulent on IE 2911 and exhibited varied reactions on the remaining 11 accessions. Of the five isolates from Vizianagaram, FMV23 were virulent on all the accessions except resistant check GPU 28; FMV20 avirulent on 8 of the 12 accessions. Among the five isolates from Nandyal, FMNd35 was virulent on all the accessions except IE 7079 and resistant check GPU 28. Among the isolates from Mandya, FMM42 was virulent on all the accessions except IE 4497 and GPU 28 whereas, FMNg54 and 55 from Naganahalli were virulent on all the accessions except resistant check. All isolates from Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli were virulent on susceptible check (VR 708) suggesting without any major resistance genes against finger millet blast fungus (Table 4.12).

The variation in virulence of isolates from the same location to these specific accessions under controlled conditions indicated to some extent existence of intra-population variability due to heterogeneity and also the significant isolate × genotype interactions. Evidences also exist for evolution of intra-population variability in pathogenicity from single lesion and monoconidial cultures of *P. oryzae* (Ou and Ayad, 1968., Silva *et al*., 2009 and Le *et al*., 2010).

The possible mechanism of genetic changes within population of *P. oryzae* have been demonstrated due to parasexuality and heterocytosome (Fatemi and Nelson, 1977).

Variation in disease reaction: Most of the isolate-genotype combinations yielded susceptible reaction although they had different levels of disease severity. Based on leaf blast severity (1–9 scale), reaction of the differential hosts to the individual isolate was categorized as resistant (≤3.0) or susceptible (>3.0). All the isolates showed susceptible reaction on susceptible check VR 708, similarly resistant reaction was observed for all the isolates on resistant check GPU 28 except the isolates FMP1, FMP5, FMV19 and FMNg55. None of the accessions found resistant to all the 25 isolates tested. However, clear differential reactions were obtained on the remaining ten accessions (Table 4.12).

A similar study on pathogenic diversity in finger millet blast system reported by Kumar *et al*. (2007) and Takan *et al*. (2011). This study has shown clear differences in the host interaction patterns between the blast pathogen populations adapted to finger millet. In the finger millet blast system, compatibility between the various isolates from different locations and the accessions tested with only quantitative differences in disease levels, suggests that polygenic quantitative resistance is more common than qualitative resistance conditioned by major R genes (Pande *et al*., 1995., Takan, 2007., Takan *et al*., 2011).

Pathotype grouping: A dendrogram generated by the principal component analysis of leaf blast severity of the test isolates clustered the 25 isolates into four major pathotype groups (Figure 4.2). Isolates FMNd28, FMNd30, FMV20, FMNd 31 and FMNg48 were in group I; FMM39, FMM40, FMV14, FMM43, FMM47 and FMNg50 in group II; FMNd35, FMV25, FMM42, FMNg51, FMNg54 were in group III. FMNd35, FMNg51 and FMNg54 in group IV. Group IV had all the five isolates from Patancheru and also FMV19, FMNd33 and FMNg55 (Figure 4.2). This indicated significant variability among the populations of *M. grisea*. Grouping of isolates based on leaf blast severity, to some extent, supported the location-specific grouping of isolates. 3 of the 5 isolates from Nandyal were clustered in group I. Similarly, group II contained all the isolates from Mandya except FMM42 and group IV included all the five isolates from Patancheru. However, variance analysis based on pathogenicity using differential host lines seems useful than molecular analysis in determining race structures of plant pathogens (Casela and Ferreira, 1995). In contrast, international differential lines do not fully describe the entire pathogenic variability of the pathogen but merely a subset of this variability (Correa-Victoria *et al*., 1993; Sharma *et al*., 2002). Occurrence of four pathotype groups in the populations of 25 isolates further supports the

presence of differences in virulence in the pathogen and the presence of different resistance gene candidates (Reddy *et al*., 2010) or QTLs in the differential hosts. Besides, composition of land races and cultivars of finger millet grown in this geographic region can also play a crucial role in structuring the pathogen populations. Similar findings were reported by Sharma *et al*. (2002) who found that 119 *M. grisea* isolates from north-western Himalayan region were grouped into 52 pathotypes on the basis of disease reaction on international differential rice lines. Similar observations have been reported by Chen *et al*. (2001) and Le *et al*. (2010) in rice blast.

In summary, the results clearly showed that the pathotype composition of the fungal pathogen populations in Andhra Pradesh and Karnataka was very complex in finger millet and 10 accessions identified in the present study could be used to identify new pathotypes. However, these need to be characterized for *R*-genes involved. More work should be done by screening the identified host differentials in the present study against representative isolates from India for race identification. Knowledge about the pathotype composition of the pathogen population is crucial for the development of strategies for manipulating the disease resistance genes for crop protection.

4.2.4 Genetic diversity of *M. grisea* isolates using SSR markers

4.2.4.1 Polymorphic markers among the *M. grisea*

For assaying allelic diversity in *M. grisea* isolates, a total of 24 SSR markers were used. However, only 17 (70.8%) SSR markers showed polymorphism among *M. grisea* isolates from different hosts and locations. The genomic DNAs of five *M. grisea* isolates from pearl millet were amplified with only three SSR markers, eliminated from the SSR analysis. A high level of polymorphism was obtained with SSR analysis using 17 primer combinations among the 65 isolates of *M. grisea* (Table 4.1) from finger millet, foxtail millet and rice.

In the past, several studies for assessing molecular diversity in *M. grisea* were conducted using MGR-based fingerprinting (Viji *et al*., 2000., Tosa *et al*., 2007., Tanaka *et al*., 2009., Le *et al*., 2010), native protein and isozyme analysis (Rathour *et al*., 2006), RAPD (Sere *et al*., 2007., Sonah *et al*. 2009., Singh and Kumar, 2010., Kumar *et al*., 2010) and AFLP markers (Tanaka *et al*., 2011., Thuan *et al*., 2006). However, these markers are not locus specific and RAPDs suffer with lack of reproducibility. SSRs have been used only in few studies (Brondani *et al*., 2000., Kaye *et al*., 2003., Zheng *et al*., 2008 and Suzuki *et al*., 2009) to assess the molecular diversity in *M. grisea* that provided more informative than rep-PCR

analysis (Kaye *et al*., 2003). We evaluated SSR markers reported by Kaye *et al*. (2003) for assaying the molecular diversity in *M. grisea* isolates in the present study.

Similar observations on polymorphism were made by Kaye *et al*. (2003) and Zheng *et al*. (2008) who found a high degree of polymorphism (73 & 70%) with SSR markers among the *M. grisea* isolates from rice. In contrast to the present study and earlier reports, Suzuki *et al*. (2009) evaluated several SSR reported by Kaye *et al*. (2003) among contemporary isolates in Japan, but polymorphisms were rarely observed except for a few markers and concluded that field isolates collected from recent years probably had a genetically similar relationship and belonged to limited number of lineages (Sone *et al*., 1997 and Suzuki *et al*., 2006).

4.2.4.2 Allelic richness and diversity in *M. grisea*

The details of allelic richness, size range (bp), rare, common and most frequent alleles, PIC (Polymorphic Information Content), gene diversity and average heterozygosity (%) are presented in Table 4.13. The polymorphic SSR markers in the present study detected a total of 105 alleles among the 65 *M. grisea* isolates assayed. The number of alleles ranged from 2 (Pyrms 37) to 13 (Pyrms 15) with an average of 6.18 alleles per locus. The PIC value varied from 0.217 (Pyrms 37) to 0.805 (Pyrms 67) with an average of 0.486 per marker. Three markers (Pyrms15, Pyrms61 and Pyrms67) were highly polymorphic. Gene diversity is defined as the probability that two randomly chosen alleles from the population are different. It varied from 0.232 (Pyrms 37) to 0.827 (Pyrms 67), with an average of 0.517. A very low level of heterozygosity (%) was detected in the *M. grisea* isolates from different host, 0.000% to 0.586%, with an average of 0.048%. seven SSR loci detected no heterozygosity while nine and one loci detected <0.05% and <0.6% heterozygosity in 65 isolates (Table 4.13).

The allelic composition revealed the predominance of common alleles (79%) followed by most frequent alleles (20%) while the rare alleles are represented by 1% of the total number of alleles detected in the *M. grisea* isolates. Of the 105 alleles detected in the 65 isolates, one was rare, 83 common and 21 were most frequent alleles. Common and most frequent alleles were detected at all the 17 SSR loci, the former ranged from 1 (Pyrms37) to 12 (Pyrms15) with an average of 4.88 common alleles per locus while the latter from 1 to 2 with an average of 1.23 most frequent alleles per locus (Table 4.13). One unique allele was detected at one SSR loci (Pyrms41) restricted to three single spore isolates (FMV23, FMV26 and FxMM61) in a size of 191 bp. In terms of host-specific alleles among the isolates, one SSR marker (Pyrms15) showed unique allele for the isolates of finger millet and one SSR marker (Pyrms41) detected

unique allele for the isolates of foxtail millet. These markers can be used as diagnostic markers to identify a host-specific isolate from a group of isolates.

The polymorphic SSR markers in the present study showed 2 to 13 alleles with an average of 6.18 alleles per locus. In contrast to the present study, Kaye *et al*. (2003) reported that 2–6 with average of 2.9 alleles per locus. Similar observations were made by Zheng *et al*. (2008) with nine isolates. It is noteworthy here that Kaye *et al*. (2003) analyzed a small collection of *M. grisea* isolates. Variation in allele number in the present study could be due to the population size (Varshney *et al*., 2009). Similarly, Suzuki *et al*. (2009) reported up to 18 alleles per locus among the 48 field isolates of *M. grisea* from two natural populations from Japan. However, up to 9 alleles per locus were reported among the 96 isolates from central Brazil (Brondani *et al*., 2000). The difference in the number of alleles detected in *M. grisea* isolates was significant and could be related to the sampling strategy used to recover isolates in these areas.

The PIC value ranged from 0.27 to 0.80 with an average of 0.49 per marker. Similar observations were made by Brondani *et al*. (2000) who found PIC value for the Central Brazilian *M. grisea* populations were 0.54 for MGM-1 and 0.44 for MGM-21 markers. Similar observations on PIC value was reported by Zheng *et al*. (2008). The higher gene diversity value of the present study can be attributed to the diverse nature of *M. grisea* isolates as analyzed in the study of Kaye *et al*. (2003). Nevertheless, the reported PIC values for three SSR primer pairs may be useful for selecting comparatively more informative markers in future for assessment of molecular diversity of *M. grisea* isolates from India or elsewhere.

4.2.4.3 Genetic variability among the isolates

In the present study, the DNA polymorphism did not reflect the geographical distribution of isolates. Similar observations were reported by Xia *et al*. (2000) in rice blast, Takan *et al*. (2011) in case of *M. grisea* in finger millet, though in some cases importance of geographical regions were correlated (Sharma *et al*., 2002).

Cluster analysis classified the isolates into three major groups that corresponding with the host specificity of the isolates with low similarity value around 0.15 (Figure 4.3). However, there was an exception to this correspondence in that two isolates from finger millet (FMP1 and FMV20) were placed in group constituted by isolates from foxtail millet. Overall topology of the dendrogram indicated the presence of three lineages in *M. grisea* species complex infecting different hosts. Several groups were observed for subpopulations from finger and foxtail millet indicating high genetic variability within and between different host-limited forms of *M .grisea*.

Of the 56 isolates from finger millet, fifty-three isolate were clustered together in one group, whereas the other two isolates were grouped together with foxtail millet isolates and remaining one isolate FMP7, although appeared separately, but close to finger millet group. Nine sub-groups were observed within this group at 70% similarity level and classification presented as dendrogram (Figure 4.3). Eight isolates were clustered in group I, nine isolates in group II, 11 isolates in the group III, 6 in group IV, 7 in group V, 2 in group VI, 5 in group VII, 2 in group VIII and 3 isolates in group IX. However, one isolate FMP7 could not be assigned to any of these sub-groups. Three isolates from rice clustered in one group and exhibited identical haplotype. Isolates FMP1 and FMV20 from finger millet and FxMV60 from foxtail millet exhibited identical haplotype (Figure 4.3).

A lack of distinct genetic groups or lineages for any of the isolate clusters observed with the finger millet blast system clearly supported a continuous genetic variation pattern of the pathogen population. Few isolates did not share any of these groups as they had very distinct SSR profiles. SSR analysis of 56 isolates of *M. grisea* from the finger millet did not yield robust grouping based on their geographical origin.

High degree of variation was observed within the isolates from the same host, especially in the isolates from finger millet. Several clusters of the isolates from finger millet were observed in the dendrogram depicting a high genetic variation among the isolates from same host. Similar results have been documented by Singh and Kumar (2010). However, the two finger millet isolates shared SSR profile and clustered along with foxtail millet isolates indicating some gene flow occurring between populations of the pathogen from two different hosts. The findings are in agreement with Rathour *et al*. (2004) who suggested the possibility of gene flow between the *M. grisea* isolates infecting rice and finger millet. Evidences also exist for genetic recombination between the *M. grisea* that infect rice and finger millet in the Indian Himalayas (Kumar *et al*., 1999 and Zeigler, 1998) where both the hosts have been grown sympatrically for centuries. Similar observations were made by Rathour *et al*. (2006) between the isolates from finger millet and jungle rice. In contrast, Viji *et al*. (2000) reported that the blast fungus collected from rice and finger millet did not cross-infect and also gave different fingerprint patterns based MGR-DNA fingerprinting.

4.2.4.4 Genetic variability among the isolates from different plant parts

In this dendrogram, *M. grisea* isolates from different plant parts (leaf and neck) were randomly distributed among the overall population (Figure 4.3). For instance, the isolates FMM45 and FMM46 were from leaf and neck blast sample the of same genotype or plant were

grouped in different cluster. In contrast, the isolates from neck and finger samples (FMNg51 and FMNg52) of the same genotype and location were clustered in one group at 90% similarity matrix suggesting that there may not be any specific isolate causing only neck blast or finger blast either. The results of the present study agree with earlier reports in rice (Ou, 1972., Xia *et al*., 1993), where they did not find any distinct group causing only neck or leaf blast.

M. oryzae isolates from different types of blast revealed that an isolate is capable of causing different forms of disease (Pande *et al*., 1995). Finger millet varieties show a consistent reaction to different types of blast, with limited exceptions (Somasekhara *et al*., 1991., Takan *et al*., 2004 and Takan *et al*., 2007). Silva *et al*. (2009) reported that diversity in pathogen population was greater within each field and between cultivars rather than between sub-populations of leaf and panicle. Migration from leaf to panicle and recombination may be important factors in shaping the genetic structure of the *M. grisea* populations.

4.2.4.5 Association between pathogenicity and SSR pattern of *M. grisea* finger millet isolates

To determine the association between pathogenicity and SSR data of 25 *M. grisea* isolates from finger millet, the dissimilarity matrices based on pathogenicity and SSR data were compared by correlation analysis. Very poor correlation (r = 0.03) was observed following matrix comparison of SSR data with pathogenicity data. Therefore, no association between grouping of the isolates based on molecular data and pathogenicity data could be established. However, three isolates from Patancheru (FMP3, FMP5 and FMP9) shared the same virulence as well as DNA fingerprinting group. Sharma *et al*. (2002), Rathour *et al*. (2004) made similar observations with *M. grisea* isolates and concluded that molecular polymorphism is largely independent of virulence polymorphism. This is expected because gene(s) controlling a particular character is most likely to be present in a small fraction across the genome, whereas the molecular banding pattern obtained from the total DNA reflects diversity in the entire genome (Andebrhan and Furtek, 1994). In contrast, a direct correlation was observed between DNA fingerprint groups and pathotypes (Levy *et al*., 1991) although, considerable pathotype diversity also exists within DNA fingerprint groups (Zeigler *et al*., 1995).

4.2.4.6 Genetic structure of *M. grisea* isolates

On analysis of 65 *M. grisea* isolates for population structure using a model-based approach (Pritchard *et al*., 2000). We identified three genetically distinct groups or admixtures thereof within the *M. grisea* isolates from different hosts. The model-based simulation of population structure using SSRs showed the estimated likelihood values were variable among

different runs (K = 2–10), se we choose K = 3 for final analysis as the log likelihood function was increase up to K = 3 and deto crease thereafter. According to the membership pattern when K = 3, all the *M. grisea* isolates from finger millet except two isolates (FMNd31 and FMNg50) were unambiguously divided in Group 1 whereas five isolates (two from finger millet and three from foxtail millet) belonged to group 2 and six isolates (three each from rice and foxtail millet) were assigned to group 3, but with much smaller membership probability. Group 1 was the largest with 54 (83%) isolates representing only finger millet from different locations (red colour in figure 4.4). Group 2 was represented by five isolates which include 2 from finger millet (FMNd31 and FMNg50) and 3 isolates (FxMV59, FxMV60 and FxMM62) from foxtail millet (green colour in figure 4.4). Of the six isolates grouped in group 3 (blue colour in figure 4.4), three isolates from rice (RM63, RM64 and RM65) and remaining three (FxMP57, FxMNd58 and FxMM61) from foxtail millet

Insights into the structure of *M. grisea* populations from different hosts and locations will prove to be valuable in enhancing our understanding of the biology of blast epidemics and potentially adaptive genotype diversity in the species. Model-based population structure analysis did not revealed any location/region specific grouping of isolates however, most of the isolates were grouped based on their host origin with few exceptions. Group 1 consisting of isolates from finger millet did not show any admixture, suggesting that there is no gene flow among these populations although the isolates were collected from Andhra Pradesh and Karnataka are separated by short geographic distance. However, the other two groups were found to possess a varying degree of admixture percent of the alleles among these populations. Among the 56 isolates studied from finger millet, 54 isolates were in group 1 (with no admixture) and remaining 2 isolates were found to share with group 2. Three isolates from rice were found to share with foxtail millet isolates in group 3. Similar observations were made by Tosa *et al*. (2006) who found that *Oryza* and *Setaria* isolates shared two avirulence genes *PWT1* and *PWT2* and genetically closer to each other. These differences in population structure among the isolates within the same species and geographic regions are likely related to differences in evolutionary history and ecology. Similar observations were made on model-based population structure analysis by Varshney *et al*. (2009) revealed four distinct populations with varying levels of ancestral admixtures were observed among 64 *Ascochyta rabiei* isolates from chick pea from different states of India.

The overall results indicated that *M. grisea* populations infecting different hosts were genetically distinct and there was no gene flow among rice, finger and foxtail millet, however,

the recovery of two finger millet isolates shared SSR profile and clustered along with foxtail millet isolates, indicate that at least some gene flow is occurring between the different populations. SSR as well as pathotyping successfully detected the spatial and temporal variation in the *M. grisea* populations from different hosts and locations. However, association of DNA fingerprinting groups with the pathotyping could not be clearly established. Therefore, markers designed for pathogenicity genes may be used to establish the relationship between pathotyping and molecular analysis.

4.3 STUDY EPIDEMIOLOGY– INFLUENCE OF TEMPERATURE AND LEAF WETNESS DURATION ON SPORULATION AND INFECTION, INOCULUM THRESHOLD AND HOST SUSCEPTIBILITY STAGE

Blast disease (caused *Magnaporthe grisea*) has the potential to cause severe crop losses in finger millet when environmental conditions are favorable for disease development and yield losses up to 90% have been reported (Vishwanath *et al*., 1986., Bisht, 1987 and Rao, 1990). Average yield losses in individual fields have been reported in the range of 28–50% (Vishwanath *et al*., 1986., Nagaraja *et al*., 2007). The pathogen infects most aboveground parts of the plant, but neck and finger blast are the most damaging phases of the disease (Nagaraja *et al*., 2007) and also attacks seeds resulting in shriveled blackened seeds (Kumar, 2002). Improved knowledge of the effects of weather variables on host-pathogen interaction at different crop growth stages would be helpful in predicting the disease epidemics. Sporulation of *M. grisea* is favored by relative humidity ≥89%, optimal temperatures of 25 to 28°C, and a minimum of 4 h of leaf wetness (Ou, 1985., Teng *et al*., 1994). Information on relationships between weather variables and blast disease could be used to improve techniques to screen for resistance. The objective of this research was to determine the effects of weather variables, such as temperature and leaf wetness duration on infection, sporulation and severity of blast disease in finger millet for developing efficient and effective screening techniques.

4.3.1 Determination of inoculum threshold and host susceptibility stage of finger millet to blast

4.3.1.1 Leaf blast

Disease severity increased with increasing inoculum concentrations and higher concentrations produced severe infection. Inoculation was done on 15 day old seedlings. Leaf blast severity in IE 501 increased from 4.05 to 8.5 and 3.5 to 7.5 (on a 1–9 scale) with

increasing levels of inoculum concentrations from 1×10^3 to 1×10^6 conidia ml^{-1} at 7 and 15 days after inoculation, respectively (Table 4.14). Two higher concentrations (1×10^5 and 1×10^6 conidia ml^{-1}) produced significantly higher disease severity than the lower concentrations in both the observations. Spore concentrations of 1×10^5 and 1×10^6 conidia ml^{-1} after 7 days of inoculation caused similar levels of severe infection. Therefore, we used an inoculation concentration of 1×10^5 conidia ml^{-1} for the remaining experiments.

Similar findings of inoculum concentration have also been reported by Takahashi *et al*. (2009) in Italian ryegrass with *P. oryzae* and Thakur *et al*. (2009) in pearl millet. The leaf blast severity 7 days after inoculation increased with increasing concentration and then corresponding decrease in severity was recorded in 15 days after inoculation. Because leaves become increasingly resistant to infection with time, the total number of successful infections resulting in sporulating lesions for a certain amount of inoculum will depend on the initial level of susceptibility of newly emerging leaves and the rate of increase in resistance of aging leaves. Susceptibility of leaves declined rapidly with increasing leaf age but initial level of susceptibility of new leaves differed greatly among the cultivars (Puri *et al*., 2009). This result is supported by the finding of Rouman (1992), who reported that susceptibility of leaves declined rapidly with increasing leaf age in rice blast and a rapid buildup of age-related resistance was found in IR 36. In contrast, Moss and Trevathan (1987) found that infection of 3-week-old ryegrass plants increased exponentially with increasing inoculum densities up to 8×10^5 conidia ml^{-1} and began to decline at 5–6 week age.

Table 4.14. Effect of different inoculum concentrations of *M. grisea* on leaf blast development in the finger millet

Inoculum concentration	Leaf blast severity on 1–9 scale[2]	
	7 days after inoculation[1]	15 days after inoculation[3]
1×10^3 conidia ml^{-1}	4.05 b	3.5 c
1×10^4 conidia ml^{-1}	4.3 b	3.7 c
1×10^5 conidia ml^{-1}	8.3 a	6.2 b
1×10^6 conidia ml^{-1}	8.5 a	7.5 a
Control	1.0	1.0
Mean	5.3	4.4

[1] Mean of 4 replications and 10 plants/replication
[2] Leaf blast severity on a 1–9 scale where 1= no infection and 9= >75% leaf area covered with lesions
[3] Figures followed by same letters are not significantly different according to least significant difference test (P> 0.01)

4.3.1.2 Neck and finger blast

The effect of different inoculum concentrations on neck and finger blast incidence and severity were assessed under greenhouse conditions using *M. grisea* fm strain of Patancheru isolate. Neck and finger incidence and severity increased with increasing inoculum concentrations. Neck and finger blast severity in IE 501 increase from 3.9 to 5.0 (on a 1–5 scale) and 32.7 to 83.3% with increasing levels of inoculum concentration from 1×10^3 to 1×10^6 conidia ml^{-1} (Table 4.15). No significant differences were observed in neck and finger blast incidence (%) between different concentrations. However, significant differences were observed between 1×10^6 and 1×10^4 conidia ml^{-1} for neck blast severity, and between two higher (1×10^5 and 1×10^6 conidia ml^{-1}) and two lower concentrations (1×10^3 and 1×10^4 conidia ml^{-1}) for finger blast severity. The results also indicated the significant positive correlation (r = 0.95, P<0.001) between neck and finger blast severity suggesting the same gene(s) playing role in resistance to both neck and finger blast. A linear relationship was found between inoculum density and neck and finger blast incidence and severity. Inoculum concentration explained the 76% of the variation in neck and finger blast incidence (R^2 = 0.76) (Figure 4.5), and 71.2 and 90% of the variation in neck and finger blast severity (R^2 = 0.71 and 0.90; P<0.05) respectively (Figures 4.6, 4.7).

Table 4.15. Effect of different inoculum concentrations of *M. grisea* on neck and finger blast development in the finger millet

Inoculum concentration	Neck blast incidence (%)[a]	Neck blast severity (1–5 scale)[c]	Finger blast incidence (%)	Finger blast severity (%)[d]
1×10^3 conidia ml^{-1}	71.4 (62.7)	3.9	71.4 (62.7)[b]	32.7 (34.8)
1×10^4 conidia ml^{-1}	83.3 (70)	4.2	83.3 (70)	45.7 (42.5)
1×10^5 conidia ml^{-1}	100 (90)	4.6	100 (90)	78.8 (62.9)
1×10^6 conidia ml^{-1}	100 (90)	5.0	100 (90)	83.3 (65.9)
Control	0 (0)	1.0	0 (0)	0 (0)
Mean	71 (62.5)	3.8	71 (62.5)	48.1 (41.2)
SE (m)±[e]	7.8	0.14	7.8	3.2
LSD (P<0.01)[f]	37	0.7	37	15.3

[a] Mean of 4 replications and 7 plants/replication
[b] Values in parentheses are angular transformed values
[c] Neck blast severity on 1–5 scale where 1= no infection and 5= >6 cm lesions on the neck region
[d] Finger blast severity (%) across all panicles/all tillers in a row
[e] Trail Standard error mean
[f] Trial least significant difference

The two higher concentrations produced the same high levels of neck and finger blast severity compared to other concentrations therefore, 1×10^6 conidia ml^{-1} was used for the remaining experiments. These findings are in conformity with the observations made by Vingnanakulasingam (1991), Puri *et al*. (2009) successfully screened rice germplasm lines for neck and panicle blast resistance by injecting the spore suspension of 10^5 conidia/ml with syringe at photosynthetic leaf base. For finger millet blast, this is the first report on effect inoculum concentrations on incidence and severity of neck and finger blast by inject inoculation method.

The results revealed that significant infection could develop even at low concentrations as low as 1×10^3 conidia ml^{-1} (Figures 4.6, 4.7). Similar results were obtained for the *P. oryzae*-rice system (Moss and Trevathan, 1987). This suggests that under favorable environment even few conidia may cause disease in the field and that only diseased lesions are needed to spread the disease to other plants.

4.3.2 Influence of Leaf Wetness Duration (LWD) on infection of blast in finger millet

There was an overall trend for leaf blast severity, lesion size (mm) and number of lesions per plant to increase as hours of leaf wetness duration (LWD) increased with the exception of decrease in number of lesions for 60 h of wetness duration (Table 4.16). The leaf wetness duration of 48 and 60 h produced significantly higher blast severity than the duration of 12 and 24 h. Significant positive correlations were found between leaf blast severity and lesion size (r = 0.88 P<0.001) and number of lesions/plant (r = 0.93) and also between lesion size and number of lesions (r = 0.88).

The number of lesions was statistically similar in plant in which the duration of leaf wetness was 24 and 36 h, but increased significantly in response to the 48 h leaf wetness and decreased in duration of 60 h. It could be due to that lesions formed in wetness duration 60 h were elongated, coalesced and enlarge to necrotic spots leading to decreased number of lesions/plant. It may also be supported by corresponding significant increase in lesion size in duration of 60 h however, there may not be any change in disease severity. These results are broad agreement with earlier studies which have shown that lesion number increased exponentially with increased wetness duration up to 24 h in gulf ryegrass and did not increased beyond 24 h (Moss and Trevathan, 1987).

Linear regression was used to quantify the relationship between LWD and infection efficiency for the linear portion of this curve and LWD explained the 87 and 96% of the variation in blast severity (R^2 = 0.87) and lesion size (R^2 = 0.96) (Figures 4.8, 4.9). A polynomial model provided the best-fit for the wetness duration and number lesions per plant (Figure 4.10). Similar results have been reported in earlier studies by Moss and Trevathan (1987) in rice. These regression results show a high degree of fit of the model to the data (R^2 = 0.98). The model predicted optimum wetness duration of 48 h for formation of maximum number lesions per plant, however there is no significant difference in number lesions per plant between 48 and 60 h duration.

To our knowledge, this is the first systematic study to demonstrate the effect of leaf wetness duration on development of leaf blast in finger millet. Leaf wetness of 7 to 14 h is essential for infection of rice by *P. grisea* (Barksdale and Asai, 1965., Kato, 1974., Yoshino, 1974., Kingsolver *et al*., 1984., Teng, 1994., Greer and Webster, 2001) and similar results were obtained in the present studies that 12 h leaf wetness caused blast infection in finger millet. The length of required wetness period for infection depends upon the temperature. If leaf wetness ends before infection is completed, the process is terminated (Teng, 1994). The effect of leaf wetness duration on leaf blast development in finger millet was consistent with the findings of Green *et al*. (2004) who found 25°C temperature and 32 and 48 h leaf wetness were optimum conditions for infection of *P. setariae* in green foxtail. Similar findings on leaf wetness duration and *Pyricularia* spp. have been reported in earlier studies by Uddin *et al*. (1998) in tall fescue and Uddin *et al*. (2002) in perennial ryegrass turf.

In our experiments, leaf blast severity, lesion size and number of lesions increased with LWD. A severe outbreak of this disease seems to require 48 h of leaf wetness duration and a linear relationship was found between wetness and blast severity, although low level of disease appeared in 24 h wetness duration as well. Further, more critical experiments are needed to better understand the interaction of LWD and temperature for blast (leaf, neck and finger) infection for development of disease prediction models.

4.3.3 Influence of temperature on sporulation of *M. grisea* on foliage

The influence of temperatures on sporulation potential of *M. grisea* in lesion was investigated by incubating the blast lesions (approx. 10 mm size) at different temperatures. It is evident from Table 4.17 that, out of 5 temperatures (18°C, 21°C, 24°C, 27°C and 30°C) tested, maximum sporulation was detected on blast lesions incubated at 27°C for 48 h and minimum

at 21°C for 24 h (Figure 4.11). Sporulation occurred in all the temperatures and incubations. Significant variations were also recorded in sporulation at different temperatures and incubation periods. The sporulation of *M. grisea* was significantly higher at 30°C (8.1×10^4 conidia ml^{-1}) followed by 27°C (4.6×10^4 conidia ml^{-1}) in 24 h of incubation however, sporulation was less in 24 h of incubation when compared to 48 and 60 h. Significantly highest sporulation occurred at 27°C in 48 h of incubation (13.4×10^4 conidia ml^{-1}) followed by 9.8×10^4 conidia ml^{-1} at 30°C and other temperatures were non-significant in 48 h of incubation of lesions. There is was no significant difference between the sporulation of *M. grisea* at 24°C, 27°C and 30°C in 60 h of incubation. It is clear from the data that an increased incubation period from 24 to 60 h also resulted in significant increase in the sporulation at different temperatures (Table 4.17). The highest mean sporulation (7.7×10^4 conidia ml^{-1}) was recorded at 60 h incubation followed by 48 h (6.0×10^4 conidia ml^{-1}).

Sporulation potential decreased with time in the higher temperature regimes. The highest potential for accumulative spore production was detected in lesions incubated at 27°C for 48 h. All conidia are not produced at the same time, therefore, a very small percentage may be produced early enough to allow low-level of infection. Most of the works on sporulation and conidial release of *M. grisea* have been conducted in rice blast (Kim and Yoshino, 2000). The results in the present studies are in agreement with that of Kato and Kozaka (1974), who reported that blast fungus in the lesions sporulate between 12 to 34°C with optimum at 28°C and sporulation decreases sharply above 28°C. Optimal conditions for *P. grisea* conidial germination were 92 to 96% relative humidity at 25 to 28°C (Kim, 1994., Ou, 1985). Observations on the effect of temperatures on sporulation indicated that the increase in temperature from 24°C to 27°C in 48 h of incubation period resulted in a sharp increase in sporulation. The results of the present findings are in accordance with the observations Castejon-munoz (2008) who reported that relative humidity of 95% and an average temperature of 26 to 27°C were optimum for infection and substantially favoured spore release of *M. grisea*. Similarly, Teng (1994), Veena Hedge (1996) and Madhukeshwara *et al*. (1997) also reported the 25 to 28°C temperature as optimum for sporulation and disease progress of *M. grisea*. Kim and Yoshino, (2000) reported that sporulation was in proportion with the length of infected parts and we included almost uniform size (10 mm) of blast lesions. The significant difference in sporulation of *M. grisea* among different temperatures, indicates the strong influence of temperature on sporulation. According to earlier work (Castejon-Munoz *et al*., 2007), an accurate examination of the colour and size of blast lesions could be sufficient to determine the

severity of disease. Sporulation of *M. grisea* was associated with many factors, such as weather conditions, plant age, presence of inoculum, size, type and age of the lesion. This study suggests that 27°C was the optimum temperature for sporulation of *M. grisea* lesions in finger millet.

Table 4.17. Influence of temperature on sporulation[1] of *M. grisea* on foliage

Temperature	Sporulation ($\times 10^4$ conidia ml^{-1})[2]		
	24 hours after incubation	48 hours after incubation	60 hours after incubation
18°C	1.7 c	1.4 c	5.7 c
21°C	1.2 c	1.4 c	6.3 bc
24°C	2.1 c	4.0 c	8.2 ab
27°C	4.6 b	13.6 a	9.2 a
30°C	8.1 a	9.8 b	9.1 a
Mean	3.5	6.0	7.7

[1]Mean of 3 replications and 10 lesions/replication
[2]Figures followed by same letters are not significantly different according to least significant difference test ($P>0.01$)

4.3.4 Influence of temperature on sporulation of *M. grisea* isolates on oat-meal agar medium

To study the different aspects of disease, determination of nutritional and physiological conditions required for growth and sporulation of the fungus is necessary. Isolates of the fungus from different hosts differ in their response to temperature in relation to growth and sporulation. Therefore, the effect of different temperature treatments on growth and sporulation was studied using eight isolates, six from finger millet (one from each location), and one each from foxtail millet and pearl millet.

All the isolates showed growth at all the temperatures except 10°C with FMV20 and 35°C with FMM42, FMNg55 and FMD56 (Table 4.18). Maximum growth (colony diameter) was observed in finger millet isolates followed by foxtail millet and rice isolates. Among the different temperatures tested, maximum colony growth occurred at 25°C and 30°C, however there was a significant difference between these two temperatures for all the isolates tested except finger millet isolate FMD56. In terms of average growth among the different isolates, maximum mean radial growth (67.98 mm) was recorded at 25°C followed by 66 mm at 30°C and minimum (1 mm) at 35°C. All the isolates sporulated at 20°C, 25°C and 30°C, but did not sporulate at 0 and 35°C (Table 4.18). Among the different isolates, maximum sporulation was recorded for foxtail

millet isolates followed pearl millet and finger millet isolates. Variations in terms of sporulation of each isolate at different temperature were recorded. Maximum sporulation of all the isolates were observed at 25°C and 30°C however, there was a significant difference in sporulation between these two temperatures was observed except for FMV20 and FMM42. The maximum mean sporulation was recorded at 30°C (3.3×10^4 conidia ml^{-1}) followed by 2.8×10^4 conidia ml^{-1} at 25°C (Table 4.18).

Among the different temperatures, maximum colony diameter of finger millet blast isolates were observed at 25°C except two isolates (FMV20 and FMD56) at 30°C (Figure 4.12). Similar results were also obtained in sporulation and exception with FMD56 isolate. Variations in colony diameter were observed within the isolates and between temperatures suggesting that the some isolates adapted better to slightly higher temperatures than others. Among the different isolates from finger millet at 25°C, maximum radial growth was recorded for FMM42 (73.6 mm), which was statistically on par with FMNd33 (73 mm) followed by FMNg55 (72.1 mm) and minimum for FMV20 (52.8 mm). All the isolates of finger millet sporulated well at 25°C except FMNg55 and maximum sporulation occurred in FMP1 (3.4×10^4 conidia ml^{-1}) which was statistically on par with FMNd33 (3.1×10^4 conidia ml^{-1}) (Figure 4.13). The results obtained in the present study are similar to those of Awoderu *et al*. (1991) who found minimum, optimum and maximum temperatures for growth and conidia production of *P. grisea* to be 10°, 25° and 37°C, respectively. And also of Veena Hegde (1996) and Madhukeshwara *et al*. (1997) who found that 28°C was optimum for growth of finger millet blast isolates.

The maximum colony diameter (69.5 mm) of foxtail millet blast isolate was recorded at 25°C and sporulation (9×10^4 conidia ml^{-1}) at 30°C. However, the pearl millet isolate grew (70.3 mm) and sporulated (5.2×10^4 conidia ml^{-1}) well at 30°C (Figures 4.12, 4.13). The observations in the present study broadly supported by Perezsendin *et al*. (1982) recorded 30°C as the optimum temperature for sporulation in the *M. oryzae* from rice.

Pearl millet isolate sporulated better at 30°C which was 5°C higher than the optimum temperature needed for sporulation of finger millet isolates. This may be due to the adaptation of the former to a slightly higher temperature since pearl millet is grown under rainfed conditions in warmer climate. Similar results were also obtained by Kumar and Singh (1995), who reported that maximum growth of fungus occurred at 30°C though maximum sporulation in rice and finger millet isolates occurred at 25°C and in pearl millet isolate at 30°C.

The present studies show that the intra- and inter-host isolates of the fungus showed differential response in the preference of temperatures. This further indicates that the finger and foxtail millet isolates are more close than the pearl millet isolate.

4.4 IDENTIFICATION OF SOURCES OF BLAST RESISTANCE FROM MINI-CORE COLLECTION OF FINGER MILLET GERMPLASM

4.4.1 Evaluation of core collection of finger millet germplasm for blast resistance during the rainy season 2009 at ICRISAT, Patancheru

Generally, only few germplasm accessions have been utilized in crop improvement. One of the reasons for their low use is, the large size of collection which makes it difficult to accommodate in a replicated field experiment for any trait evaluation/and thus for utilization in a breeding programme. The ICRISAT genebank at Patancheru holds 5,949 accessions of finger millet originating from 23 countries. To screen this large number for any biotic and abiotic stresses would take an exorbitant amount of time and resources. To increase the efficiency of germplasm screening, a core collection consisting of 622 accessions (about 10% of total collection) was developed (Upadhyaya *et al*., 2006), which was evaluated for identification of sources of resistance to blast. The experiment consisting of 622 accessions (3 accessions could not get established) was conducted in field by artificial inoculation with the blast pathogen at appropriate stage of the crop during the rainy season 2009 at ICRISAT, Patancheru, and blast severity was recorded on 619 accessions.

Neck blast scores ranged from 1.0 to 5.0 on a 1–5 scale in core collection compared to the 4.7 and 4.9 on the susceptible checks, VR 708 and VL 149, and 1.7 and 1.9 on resistant checks PR 202 and RAU 8 respectively. Finger blast severity ranged from 0 to 64% compared to 30.7 and 30.1% on the susceptible checks, VL 149 and VR 708, and 8.5 and 10.5% on resistant checks PR 202 and RAU 8 respectively (Table 4.19; Appendix–A). Under favourable conditions, foliar blast occurred in a number of accessions at the seedling stage, which did not correlate well with crop growth stages and maturity of the plants, probably because of buildup of adult plant resistance. Hence, neck and finger blast that are more destructive were considered as measures of blast resistance.

Resistance to neck blast: Of the 619 accessions, 11 were found highly resistant (score 1.0 on a 1–5 scale), 391 resistant (score 1.1–2.0), 171 moderately resistant (score 2.1–3.0), 35 susceptible (score 3.1–4.0) and the remaining 11 highly susceptible (score 4.1–5.0) to neck blast (Figure 4.14).

Resistance to finger blast: Of the 619 accessions, 57 were highly resistant (0–1%), 379 resistant (2.0–10%), 133 moderately resistant (11–20%), 30 susceptible (21–30%) and 20 highly susceptible (>30%) to finger blast. (Figure 4.15).

Resistance to both neck and finger blast: A total of 372 accessions had combined resistance to both neck and finger blast. The resistant accessions belongs to five basic races of finger millet, *compacta* 53 out of 75, *plana* 76 of 102, *vulgaris* 212 out of 379, *elongata* 26 out of 50, *africana* 5 out of 16 (Table 4.20). Among the 76 resistant accessions in race *plana* belongs to three subraces, *confundere* (62), *grandigluma* (2), *seriata* (12). Of the 212 accessions in race *vulgaris* represented four subraces, *digitata* (80), *incurvata* (91), *liliacea* (14), *stellata* (27). Of the 26 resistant accessions in race *elongata* belongs to 3 sub-races, *laxa* (12), *reclusa* (11), *sparsa* (3).

Blast resistant accessions in the core collection originated from 19 countries indicating the wide geographical diversity among resistant accessions (Table 4.20). Among the 402 neck-blast resistant accessions, 290 of the 365 accessions (79.5%) from Africa, 85 of the 223 accessions (38.1%) from Asia, 4 of the 5 (80%) from America, 6 of the 7 (85.7%) were of the European origin and the remaining 17 were of unknown origin. Of the 436 finger blast resistant accessions, 314 of the 365 accessions (86%) from Africa, 92 of the 223 (41.2%) from Asia, 4 of the 6 (66.6%) from America, 6 of the 7 (85.7%) were from Europe and the remaining 20 of unknown origin. Most of the accessions from Asian origin were susceptible to neck and finger blast. A total of 372 accessions (60%) had combined resistance to neck and finger blast originating from Burundi, Ethiopia, Germany, India, Italy, Kenya, Malawi, Mozambique, Nepal, Nigeria, Senegal, Srilanka, Tanzania, United Kingdom, Uganda, United States of America, Zaire, Zambia and Zimbabwe (Table 4.20).

A significant strong positive correlation ($r = 0.85$, $P<0.0001$) was found between neck blast and finger blast ratings (Figure 4.16). Recording the blast severity using these two scales provided realistic data under field and greenhouse conditions at the right stage of the crop (physiological maturity) and also possible ability of the same gene(s) to induce resistance to both neck and finger blasts. It could be suggested that there is no isolate or strain specificity for causing neck or finger blast. This is an important finding on the significant role of neck infection to the finger blast development. Thus for rapid evaluation of finger millet lines either of the two recordings should suffice for preliminary resistance evaluation. Significant positive correlation ($r = 0.90$; $P<0.01$) was found between neck and finger blast have been reported by Nagaraja *et al*. (2010) and Nagaraja *et al*. (2010a).

There are several reports, where core or mini-core collections (10% core or 1% entire collection; Upadhyaya and Ortiz, 2001) have successfully been used to identify resistance to diseases (Holbrook and Anderson, 1995., Franke *et al*., 1999., Neill and Bauchan, 2000., Grunwald *et al*., 2003., Pande *et al*., 2006., Silvar *et al*., 2009., Damicone *et al*., 2010 and Sharma *et al*., 2010). Xia *et al*. (2010) identified 188 rice blast resistant accessions from primary core collection of Chinese rice germplasm. Utilizing a core collection enables a subset of accessions to be screened more efficiently for disease resistance (Franke *et al*., 1999). The core collection can be used as a starting point to screen accessions for resistance to a particular disease. It would be desirable to screen the core collection at different locations in India and elsewhere and confirm the resistance under greenhouse conditions. A subsample of the core collection possessing stable resistance to blast can be useful for finger millet breeding programs.

4.4.2 Field and greenhouse screening techniques

Development of efficient and effective screening techniques based on the basic knowledge of pathogen biology and epidemiology for evaluation of germplasm is critical to a successful breeding program for blast resistance.

In this study both field and greenhouse screening methods involved artificial inoculation of plants at appropriate stages and favourable conditions (temperature and relative humidity) were provided for disease development that greatly minimized the chances of escape from infection. We developed both field screening and greenhouse techniques for leaf, neck and finger blast. These techniques allowed screening of germplasm lines in the field and their resistance confirmation through greenhouse screen.

4.4.2.1 Field screening technique

The field screening technique involved: use of systematic susceptible checks after every four test rows, artificial spray inoculation at tillering and pre-flowering stages with an aqueous conidial suspension (1×10^5 conidia ml^{-1}) of *M. grisea* fm strain multiplied on oatmeal agar medium at 27±1ºC for 7 days. The high humidity and leaf wetness was provided through sprinkler irrigation twice a day for 4 weeks following inoculation and recording leaf blast severity 10 days after inoculation using a 1–9 scale, and neck blast on a 1–5 scale and finger blast as severity percentage across all tillers in a row at physiological maturity.

4.4.2.2 Greenhouse screening technique for leaf blast

The greenhouse screening technique involved: spray inoculation of 15-day-old potted seedlings with aqueous conidial suspension as mentioned above and incubated at 23°C with >95% RH and leaf wetness under 12 h photoperiod for 7 days and recording foliar blast severity 7 DAI using a 1–9 scale.

4.4.2.3 Greenhouse screening technique for neck and finger blast

The greenhouse screening technique involved: inoculation of individual tillers of each plant at the booting stage (beginning with panicle initiation) by injecting the aqueous conidial suspension (1×10^6 spores ml^{-1}) of *M. grisea* isolate with a syringe at photosynthetic (top most) leaf sheath base, labeling the inoculated and control tillers, covering them with pre-wetted polythene bags for 48 h at 25ºC in incubation chamber and then exposing them to high humidity (>90% RH) under misting for one month and recording neck and finger blast severity at physiological maturity.

4.4.3 Evaluation of finger millet mini-core collection for blast resistance under field conditions during the rainy season 2009 and 2010 at ICRISAT, Patancheru

Of the 80 finger millet mini-core collection (Upadhyaya *et al*., 2010) evaluated for blast resistance (leaf, neck and finger) under artificial inoculation condition during the rainy season 2009, blast severity was recorded on 78 accessions (2 accessions could not get established) are presented in Table 4.22. The mini-core collection was again evaluated during the 2010 rainy season. Four systematic checks (VR708, VL 149, RAU 8 and PR 202) were included in both the years of screening. The results of statistical analysis permitted to combine the two experiments data, and mean disease score of each genotype for both the years separately and pooled data are given in Tables 4.23

4.4.3.1 Variance components

Residual maximum likelihood (REML) analysis exhibited significant ($P<0.001$) variation among the mini-core accessions for blast resistance during the 2009 and 2010 rainy seasons and in the pooled data (Table 4.23). Estimates genotypic variance (σ^2g) were highly significant for all the three phases of blast (leaf, neck and finger blast) in 2009 and 2010 separately, indicating that the entries included in the mini-core displayed high variation among the genotypes for blast resistance. However, in the pooled analysis, variance component due to genotype (σ^2g) was non-significant for leaf blast whereas, highly significant for neck and finger blast (Table 4.23).

The significant effect of year, as detected by Wald statistics that occurred in leaf, neck and finger blast infection levels between two years of experiment could be due to variable weather conditions. Such differences in weather conditions between two years could influence disease level is a known fact (Koutroubas *et al.,* 2009). Environmental conditions, especially relative humidity and temperature could strongly affect the sporulation, release and germination of blast conidia (Ou, 1985). In this study, a highly significant and strong positive correlation for neck and finger blast severity were found between 2009 and 2010 (r = 0.93) suggesting that the significant year effect didn't cause much impact on disease severity and reaction in both the years.

Table 4.23. Estimates of variance due to genotype (σ^2g) and genotype × year (σ^2ge) for blast resistance in the finger millet mini-core collection during 2009 and 2010 rainy seasons, ICRISAT, Patancheru, India

Trait	2009	2010	Pooled		Wald statistics	*P*
	σ^2g	σ^2g	σ^2g	$\sigma^2g \times e$		
Leaf blast	0.09**	0.90**	0.03	0.51**	11.07	0.002
Neck blast	0.80**	0.99**	0.85**	0.03*	61.00	<0.001
Finger blast	180.35**	141.28**	155.10**	4.55**	14.99	<0.001

*Significant at $P < 0.05$; **Significant at $P < 0.001$

4.4.3.2 Weather data

At Patancheru, the mean maximum temperature during the crop period (2009) was 30.5°C (July to October) and it was 29.6°C in 2010 (September to November) whereas, mean minimum temperature recorded 20.9°C and 19.9°C during 2009 and 2010, respectively. The mean maximum relative humidity was recorded as 89.5% and 94.4% during 2009 and 2010, respectively. Total rainfall during 2009 and 2010 was 197.3 mm and 69.7 mm, respectively. Rainfall pattern, the total amount of rainfall and their distribution, and relative humidity varied considerably over the years. However, use of perfo and or sprinkler irrigation on test plots twice a day for 30 min each between 10:00 a.m. and 12:00 noon, and 4:00 p.m. and 6:00 p.m. for 30 days post inoculation in both the stages provided favourable conditions for blast development. This facilitated fair assessment of genotypic responses to blast infection and development. Association of weather parameters with finger millet blast was well documented by Nagaraja *et al*. (2010a).

4.4.3.3 Leaf, neck and finger blast severity under field conditions

In 2009, leaf blast severity rating ranged from 1.2 to 4.5 with mean of 1.5 on a 1–9 scale, neck blast severity ranged from 1.1 to 4.7 with mean of 2.0 on a 1–5 scale and the corresponding levels of disease severity based on finger blast (% florets blasted) ranged from 0.2 to 62.8% with a mean of 9.3%. In 2010, mean disease severity based on leaf, neck and finger blast was 2.0 (range 1.1 to 6.0), 1.6 (1.0 to 4.8) and 7.4% (0.2 to 53%) respectively (Table 4.22).

Although plants were inoculated at tillering in the 2009, leaf blast development was low whereas, severe leaf blast developed in 2010. In addition to differences in weather between the two years, the lower disease development in 2009 could have been due to less initial inoculum and differences in crop development. It could also be due to that leaf blast scored on a per plot basis, individual susceptible plants may have gone undetected in the mini-core collection. Similar findings have been reported by Bonman *et al*. (1991) in case of rice blast. Mini-core accessions showed severe neck and finger blast in both the years. However, the differences in mean neck and finger blast severity among the two years were relatively small, although finger blast severity in 2009 showed slightly higher (9.3%) over 2010 (7.4%) could be due to variation in dates of flowering of the min-core collection was the primary cause of this inconsistency. Variable reactions of rice lines to neck blast resistance has been recorded in several studies reviewed by Bonman *et al*. (1989) and this is mainly due to different dates of flowering and maturity, may have been differed in neck blast scores because of inoculum or weather during flowering.

Pearson's correlation coefficient for 2009 versus 2010 neck blast severity ratings for mini-core in both the experiments was highly significant (r = 0.91 at P <0.0001) *i.e.* the accessions with lower severity rating in 2009 tended to show low severity ratings and/or similar severity in 2010, and *vice versa*. Pearson's correlation coefficient for mean finger blast severity (%) in 2009 versus 2010 for mini-core was highly significant (r = 0.93 at P<0.0001).

Of the 80 mini-core accessions evaluated for blast resistance over two years (2009 & 2010), 70 accessions were highly resistant (1.0 score on 1–9 scale), 6 resistant (2.0–3.0), and 2 moderately resistant (3.1–5.0) to leaf blast. Based on mean neck blast severity in two experiments, 67 accessions were found to be resistant (1.1–2.0 on a 1–5 scale), 5 moderately resistant (2.1–3.0), 2 susceptible (3.1–4.0) and 4 highly susceptible (4.1–5.0) compared to scores 4.6 and 4.4 in susceptible checks VR 708 and VL 149, and 1.5 and 2.0 in resistant checks PR 202 and RAU 8, respectively. Of the mini-core, 19 were highly resistant (severity ≤1.0%), 51 resistant (2 to 10%), 4 moderately resistant (11 to 20%), 2 susceptible (21 to 30%)

and 4 highly susceptible (≥30%) to finger blast (Table 4.24) compared with 52.4 and 40.7% in susceptible checks VR 708 and VL 149, and 7.0 and 9.6% in resistant checks PR 202 and RAU 8, respectively.

Sixty eight accessions were found to have combined resistance to leaf, neck and finger blast in both the experiments, indicating stability of resistance in these accessions. These resistant accessions belong to four cultivated races of finger millet, *vulgaris* (43 out of 51), *plana* (11 out of 13), *compacta* (7), *elongata* (6) and wild race *africana* (1) (Table 4.24). The finger millet mini-core accessions originated from 13 countries, which is an ideal pool of geographical diversity of resistance sources. Of the 68 resistant mini-core accessions, 21 accessions originated from Zimbabwe, 12 from India, 10 from Uganda, 6 from Kenya, 5, 4 and 3 from Nepal, Malawi and Zambia, respectively, and one each from Burundi, Germany, Nigeria, Senegal and United States of America (USA) and 2 accessions were of unknown origin (Table 4.25).

Of the 68 resistant accessions, nine (IE 1055, -2821, -2872, -4121, -4491, -4570, -5066, -5091, and -5537) had desirable agronomic traits, such as early flowering (<65 days to flowering), medium plant height (105–125 cm), semi-compact to compact inflorescence. It is also important to identify blast resistant accessions with farmers preferred traits (early maturity, large heads, resistant to blast and lodging). These accessions would be of immense value to the breeders in development blast resistant varieties.

Among the 80 mini-core accessions, IE 4709 was only *africana* type finger millet included in the experiment (Table 4.24), which is highly resistant to blast and also good source of several economic traits, such as early flowering, plant height, basal tillers, number of culm and panicle branches, peduncle length, inflorescence length and length of longest finger (Upadhyaya *et al*., 2007). Therefore, it would be desirable to screen more *africana* type accessions, which are distinct from other races in the core collection to identify blast resistance. This mini-core can be used very effectively as a starting point of research by screening them for sources of desirable traits, such as resistance to diverse blast pathotypes. There are several reports where mini-cores of different crops have successfully been used to identify resistance sources for diseases (Pande *et al*., 2006., Sharma *et al*., 2010), drought (Upadhyaya, 2005., Kashiwagi *et al*., 2005., Gaur *et al*., 2008 and Krishnamurthy *et al*., 2010) and salinity (Serraj *et al*., 2004., Vadez *et al*., 2007).

The pathogen is highly variable, with strains are specialized in their host range and thus strains from finger millet, foxtail millet and pearl millet cannot infect each other (Todman *et*

al., 1994., Viji *et al*., 2000 and Thakur *et al*., 2009). There is less chance of development of new genetic recombinants, because of this pathogen is not known so far to have a sexual stage in order to survive from season to season. However, it would be desirable to test the resistance stability of these lines through multilocation testing in India and elsewhere. Identification of blast resistant accessions from the finger millet mini-core collection would permit use of diverse sources for future breeding efforts and ensure a better chance of success in improving the disease resistance in finger millet.

4.4.3.4 Correlation between disease severity and agronomic traits

The blast resistant accessions exhibited wide diversity for agronomical traits such as days to 50% flowering (DF), plant height and spike type (Table 4.22). Agronomic traits, such as DF and plant height of mini-core collection varied depending on the variation in weather variables over the years. However a general pattern remained consistent. The significant differences were observed in DF and plant height between mini-core accessions. The DF ranged between 45 to 92 (mean 70.2 days) and plant height between 70 to 137 cm (mean 105.8 cm). Diversity for spike type such as top curved, incurved and long open was also observed in mini-core accessions (Table 4.22).

Leaf, neck and finger blast severity was negatively correlated with plant height (r = –0.21, –0.26 and –0.27) and DF (r = –0.19, –0.55 and –0.57) whereas, it was weakly positively correlated with spike type (r = 0.17, 0.06 and 0.07). The negative correlations between blast severity and plant height indicates that tall and late maturing plant might escape blast infection due to less favourable microclimatic conditions (Thakur *et al*., 2009). The results were in agreement with Jain *et al*. (2002) who reported that the roles of leaf area, leaf angle, number of stomata, plant height and harvest index towards the blast resistance in finger millet. These results are consistent with Torres and Teng (1993) and Koutroubas *et al*. (2009), who reported that plant height had negative effect on blast in rice.

A significant negative correlation was found between blast severity and DF suggesting that early flowering accessions seemed to be more susceptible than late ones. A similar results were found by Sreenivasaprasad *et al*. (2007) and Nagaraja *et al*. (2010a). For instance, the accessions (IE 501, -3104, -4734, -5870 and -6082) were earliest to flower (mean 54.2 days and range 48 to 62 days) except IE 4097, but also had the highest neck blast severity (3.5 to 4.9 on a 1–5 scale and mean 4.5) and finger blast (30 to 55% and mean 46%) as compared to highly resistant accessions in which DF ranged from 60 to 92 with the mean of 72.5 days (Table 4.22). The variation in blast reaction of early maturing accession (IE 4097) mainly due to inoculum

and weather during flowering. In early maturing varieties, more disease incidence may be due to higher peduncle length providing more surface area for infection (Nagaraja *et al*., 2010a). Similar results were obtained in earlier studies (Pande *et al*., 1995., Takan *et al*., 2004 and Mgonja *et al*., 2007).

In this study, no association between spike type and blast severity was found. However, in one study it was reported that, accessions producing dark coloured seeds and compact heads were more resistant compared to white seeded and open headed varieties (Takan *et al*., 2004).

4.4.3.5 Relation between leaf infection with neck and finger infection

A significant weak to moderate correlation was found between leaf blast with neck (r = 0.25, $P \leq 0.001$) and finger blast (r = 0.30, $P \leq 0.001$) probably suggest that a high level of leaf blast achieved by early inoculation may not result in severe neck or finger blast during the later stages of plant development. The results are in agreement with Koutroubas *et al*. (2009) who found positive correlation between leaf and neck blast in rice. Similar observations have been reported by Somashekhara *et al*. (1991) who found poor correlation between leaf and neck blast (r = 0.04), leaf and finger blast (r = 0.27) infection. It was reported that seedlings of finger millet are more susceptible to leaf blast than mature plant (Rachie and Peters, 1977). However, no relationship is known between the intensity of seedling infection and that of later neck and finger infection. Rather, the prevailing weather conditions at a particular stage of crop development determine the intensity of blast infection (Esele, 2002).

Contrasting responses between the vegetative stage and reproductive stage often occur, indicating different genes may be needed for resistance to leaf and neck blast infection and some genes responsible for leaf blast resistance were not effective at reproductive stage in rice (Zuuang *et al*., 1997., Wu *et al*., 2004). Similar observations were made by Sirithunya *et al*. (2002) who mapped QTLs for leaf blast on chromosomes 7 and 9, while those for neck blast on chromosomes 5 and 6 in rice. The present findings on correlation between leaf blast with neck blast are in agreement with Puri *et al*. (2009), Hossain *et al*. (2004) and Bonman *et al*. (1989) in rice and they concluded both are not linked. So that, resistant to neck blast may be expressed in some lines of rice independently of that leaf blast (Padmanabhan, 1965) supports our findings in finger millet.

In this study, few accessions shown differential reactions to leaf, neck and finger blast. The genetic makeup and environmental parameters were prominent factors for differential interaction (Bonman, 1992). He showed correlation between leaf and neck blast in most of the lines of rice except IR 25604, which was susceptible to leaf blast but resistant to neck blast.

Similar type of reactions were also reported by Ou (1985) and Koutroubas *et al*. (2009) in case of rice blast. But Filippi and Prabhu (1997) found negative correlations between leaf and panicle blast (r = -0.50, P= 0.001). However, further histological and physiological studies on finger millet plants at different disease development stages are needed to elucidate the nature of adult-plant resistance to leaf, neck and finger blast. Findings also reflect the need of separate screening to both of leaf and neck or finger blast before releasing the resistance sources. Further, most virulent blast isolate could be for evaluation of both quantitative and qualitative resistance to blast.

4.4.3.6 Relation between neck and finger infection:

A significant strong positive correlation (r = 0.92, $P \leq 0.001$) was found between neck blast severity and finger blast severity suggested that the accessions resistant to neck blast could be resistant to finger blast and also possible ability of the same genes inducing resistance to both neck and finger blast. A linear relationship was found between neck blast (1–5 scale) and finger blast severity (%) (R^2 = 0.83) among the mini-core collection (Figure 4.17). The accessions resistant to neck blast were also resistant to finger blast with few exceptions in intermediate reaction types. This could be due to inoculum and weather conditions during flowering (Bonman *et al*., 1989). The present studies are in agreement with Nagaraja *et al*. (2010) and Nagaraja *et al*. (2010a), who reported that the significant positive correlation between neck and finger blast.

4.4.3.7 Confirmation of leaf blast resistance under greenhouse conditions

The finger millet mini-core collection screened under field condition were further evaluated under greenhouse condition to confirm their leaf blast resistance. The leaf blast severity ranged from 1.0 to 6.55 score on 1–9 scale compared to 8.0 on susceptible check (VR 708) and 2.4 on resistance check (RAU 8) at 7 days after inoculation (Table 4.26). Of the 80 finger millet mini-core accessions, the maximum foliar blast was recorded on IE 4794 (score 6.55 on a 1–9 scale) followed by IE 6082 (score 5.2), IE 3475 (score 4.65) and IE 7320 (score 4.45) and minimum was recorded on IE 2911, IE 6154, IE 6421 (score 1.0).

Among the mini-core collection, 29 accessions were highly resistant (score 1.0 on 1–9 scale), 29 resistant (2.0–3.0), 20 moderately resistant (3.1–5.0) and two accessions were susceptible (5.0–7.0) to leaf blast (Table 4.26). Analysis of variance showed that significant effect of accession (P<0.001) suggested that the mini-core accessions exhibited different resistance against Patancheru isolate (FMP1) and possess different resistance gene(s). All the

accessions found resistant to foliar blast in greenhouse screen also had field resistance (score ≤3.0).

In this study, we developed field and greenhouse screening techniques for finger millet blast where by germplasm can be effectively screened in the field and resistance confirmed through greenhouse screening. Plants were inoculated in the seedling stage were observed till the dough stage for neck and finger blast under greenhouse conditions. However, no neck and finger infection was seen in this experiment suggesting that prevailing weather conditions and availability of pathogen inoculum at a particular stage of crop development determine the intensity of blast infection.

4.4.3.8 Comparison of field and greenhouse screening for leaf blast

Blast severity ratings were generally higher in greenhouse than in the field. The susceptible check VR 708 scored 5.8 in field and 8.0 in greenhouse. Significant and moderate to low level of correlation ($r = 0.44$, $P<0.0001$) between greenhouse and field screening for leaf blast suggest that resistance to leaf blast can be more precisely determined under greenhouse conditions. Large scale screening at seedling stage for leaf blast resistance could be more economical and rapid in greenhouse than in the field. Leaf blast severity in mini-core was quite variable in field and greenhouse, but the severity levels on the susceptible control VR 708 indicated adequate disease pressure in both the tests. The differences in leaf blast reaction in few accessions between field and greenhouse evaluations against the same isolate could be attributed to several variable factors operating in the field. Environmental conditions and inoculum are more variable in field nurseries than in the greenhouse.

4.4.3.9 Disease assessment

Proper and precise disease assessment and evaluation procedures are critical for identification of resistant genotypes. Artificial inoculation usually generates high disease pressure that allows easy distinction of genotypes into different groups and it is important to develop a rating method that fully describes the range of infection responses. The neck and finger blast were routinely assessed at dough stage of the crop based on percentage of ears showing infection on the neck and fingers over total number of neck and fingers in a row (Madhukeshwara *et al*., 2005., Nagaraja *et al*., 2007., Nagaraja *et al*., 2008 and Kumar and Kumar, 2009).

We developed a more precise 1–5 rating scale for neck blast and estimation of finger blast severity (%) based on severity under field conditions to categorize accessions into highly resistant, resistant, moderately resistant, susceptible and highly susceptible. These scales were

very effective, easy, and convenient and provided good correlation between neck and finger blast severity. This is a significant step towards simplifying the screening process in terms of improving precision of disease scoring and economizing on time and resources. This procedure would also increase the pace of screening germplasm accessions and improve efficacy of blast resistance breeding in finger millet.

4.4.4 Evaluation of mini-core collection of finger millet germplasm for blast resistance under field conditions during 2009 rainy season at five locations

To overcome the need for large-scale evaluation of germplasm collection, Upadhyaya *et al*. (2010) developed a finger millet mini-core collection consisting of 80 accessions. These were evaluated for blast resistance at five locations and results obtained are presented in Tables 4.27 to 4.32.

Of the 80 accessions, two could not get established at Patancheru and Mandya, and nine at Vizianagaram. Most of the accessions recorded leaf blast of <2.0 score across locations compared to a range of 3.5 to 4.5 score on the susceptible check (VR 708) across locations. The average neck blast severities across the locations was generally low to moderate (Table 4.27), but varied widely, ranging from 1 to 5 scores across the locations. Among the locations, the highest neck blast was obtained in Mandya (score 2.3 on 1–5 scale) and the lowest at Vizianagaram and Naganahalli (1.5) whereas, highest finger blast severity (%) occurred at Nandyal (27.9%) followed by Mandya (26.6%) and the lowest at Vizianagaram (5.7%) (Table 4.27). The variations in the mean neck and finger blast severity at different locations suggest that the pathogen population was highly variable and host genotype-specific and also weather conditions were more conducive to the some locations over others. However, the selected test locations in the present study were identified as lead centers for finger millet blast research and 'hot spot' for blast screening except Patancheru (AICRP small millet report, 2002–2007; Ram *et al*., 2007). The relative effect of weather conditions at Patancheru was minimized by artificial inoculation of *M. grisea* at appropriate stage of the crop and use of perfo and/or sprinkler irrigation for maintenance of blast-conducive weather conditions (Thakur *et al*., 2009). This facilitated fair assessment of genotypic response to blast infection and development at Patancheru location.

Table 4.27. Experiment mean, accession mean with highest and lowest blast severity and least significant difference (LSD) observed on mini-core collection of finger millet evaluated for blast resistance during 2009 at five locations

	Neck blast severity 1 – 5 scale					Finger blast severity (%)				
	Pat*	**Viz**	**Nan**	**Man**	**Nag**	**Pat**	**Viz**	**Nan**	**Man**	**Nag**
Mean	1.9	1.5	2.2	2.3	1.5	8.9	5.7	27.9	26.6	9.8
Min.	1.0	1.0	1.0	1.0	1.0	0	0	0	1	0
Max.	4.9	4.9	5.0	5.0	5.0	64	66	86	64	46
LSD 5%	0.6	0.45	1.57	0.89	0.64	5.7	4.7	21.0	8.35	5.8

*Locations: Pat = Patancheru; Viz = Vizianagaram; Nan = Nandyal; Man = Mandya; Nag = Naganahalli

4.4.4.1 Variance components

Residual maximum likelihood (REML) analysis of individual locations indicated that the genotypic variance for all the three phases of blast except leaf blast at Nandyal were significant in all five environments (Table 4.28). In pooled analysis, both genotypic (Accession) effect and genotype × environment interaction effects were significant for all the three phases of blast. Highly significant ($P < 0.001$) Wald statistics revealed that the environments (locations) differed significantly. The significant effect of environment, as detected by Wald statistics that occurred in leaf, neck and finger blast infection levels between five environments could be due to variable weather conditions or pathogen populations might be variable across the environments. The significant effect of genotype and environment interaction might suggest that genotypes posses different resistant gene(s), and the structures of the pathogen populations, in terms of virulence genes varied across different locations (Kulakarni and Chopra,1982).

4.4.4.2 Blast resistance at individual locations

Patancheru: Most of the accessions in the mini-core had leaf blast severity score <2.0 on a 1–9 scale compared score of 4.5 on the susceptible check (VR 708). Neck blast severity ranged from 1.0 to 4.9 score on a 1–5 scale with a mean of 1.9, while for finger blast, it was from 0 to 64% with an average of 8.9% compared to score 4.9 and 51% of neck and finger blast severity on susceptible check (VR 708), respectively indicating the adequate disease pressure under artificial inoculation conditions (Table 4.29). One accession was highly resistant (score 1.0 on 1–5 scale), 59 resistant (1.1–2.0), 12 moderately resistant (2.1–3.0) and 3 susceptible (3.1–4.0) and 3 highly susceptible (4.1–5.0) to neck blast, whereas, 14 were highly resistant (0–1.0%), 50 resistant (2–10%), 8 moderately resistant (11–20%) and 6 highly susceptible (>30%) to finger blast (Table 4.30). The variations in blast reaction were also recorded in some

accessions *i.e.* the accessions (IE 4545 and IE 6514) were resistant to neck blast and moderate resistant to finger blast whereas, the accessions (IE 1055, -2042, -2217, -2437, -4795 and -5106) were resistant to finger blast and moderately resistant to neck blast suggesting that prevailing weather conditions at particular stage of the crop might have played role in neck and finger infection.

Vizianagaram: Neck blast severity ranged from 1 to 4.9 with an average severity of 1.5, whereas, 5.7% of the mean finger blast severity was recorded at Vizianagaram with a range of 0-57% compared to score 4.2 and 51% of neck and finger blast on susceptible check (Table 4.29). Among the mini-core collection, 39, 20, 7, 3 and 2 accessions were highly resistant, resistant, moderately resistant, susceptible and highly susceptible to neck blast, respectively, while for finger blast, 54 were highly resistant, 4 resistant, 6 moderately resistant, 3 susceptible and 4 accessions highly susceptible (Table 4.30).

Nandyal: Mean neck blast severity e was 2.2 (range 1 to 5) whereas, finger blast severity ranged from 0 to 86% with the mean of 27.9% compared to susceptible check (VR 708) with score 4.1 for neck blast severity and 47% of finger blast severity (Table 4.30). Of the 80 mini-core collection, 10 accessions were highly resistant (score 1.0 on 1–5 scale), 35 resistant (1.1–2.0), 18 moderately resistant (2.1–3.0), 9 susceptible (3.1–4.0) and 8 highly susceptible (4.1–5.0) to neck blast whereas, only 11 accessions were resistant (2–10%), 15 moderately resistant (11–20%), 24 susceptible (21–30%) and 30 highly susceptible (>30%) to finger blast (Table 4.30). Most of the accessions (86.25%) were found susceptible to finger blast at Nandyal. Of the 45 neck blast resistant accessions at Nandyal, 14 were moderately resistant, 20 susceptible and the remaining 11 accessions were resistant to finger blast.

Table 4.30. Performance of finger millet mini-core collection (80 accessions) for blast resistance under field conditions at five locations, 2009 rainy season, India

Location	No.	Neck blast (1–5 scale)					Finger blast severity (%)				
		HR	R	MR	S	HS	HR	R	MR	S	HS
Patancheru*	78	1	59	12	3	3	14	50	8	-	6
Vizianagaram**	71	39	20	7	3	2	54	4	6	3	4
Nandyal	80	10	35	18	9	8	-	11	15	24	30
Mandya*	78	11	33	11	13	10	1	9	24	17	27
Naganahalli	80	41	25	6	7	1	14	42	14	6	4

No.: Total number of accessions
*Two entries data not available
**Nine entries data not available

Mandya: Most of the accessions were free from leaf blast, whereas, neck blast severity ranged from score 1.0 to 5.0 with a mean of 2.3 and finger blast severity ranged from 1.0 to 64% with an average of 26.6%. compared to a score of 4 and 43.5% neck and finger blast severity on susceptible check respectively (Table 4.29). In the 80 mini-core collection, 11 were highly resistant, 33 resistant, 11 moderately resistant, 13 susceptible and the remaining 10 were highly susceptible to neck blast whereas, one accession was highly resistant, 9 resistant, 24 moderately resistant, 17 susceptible and 27 highly susceptible to finger blast (Table 4.30).

Naganahalli: In the 80 mini-core collection, neck blast severity ranged from 1 to 4.8 with a mean of 1.5 score and corresponding level of finger blast severity ranging from 0 to 64% with a mean severity of 9.8%. At Naganahalli, 41 accessions were highly resistant, 25 resistant, 6 moderately resistant, 7 susceptible and one highly susceptible to neck blast whereas, 14 were highly resistant, 42 resistant, 14 moderately resistant, 6 susceptible and 4 highly susceptible to finger blast (Table 4.30).

In the present study, finger millet mini-core collection consisting of 80 accessions, evaluated at five locations provided differential reactions, and the blast severities of these accessions varied greatly across the geographical locations. The study has identified accessions with resistance to multiple isolates under field environments. Similar observations were reported by Pande *et al*. (2006) who identified multiple disease resistance in mini-core collection of chick pea. Genetic diversity for blast resistance in mini-core collection was evident from the variable severities and reactions at five different locations. Neck and finger blast severity was quite variable, but the severity levels on the susceptible check VR 708 indicated high and adequate disease pressure in all the tests. In addition, to genetic differences in mini-core, there are several weather factors that influence blast infection and symptom expression under field conditions (Ou, 1985., Patel and Tripathi, 1998., Kumar *et al*., 2007 and Koutroubas *et al*., 2009). Differential reactions of the finger millet mini-core collection to blast require not only differential resistance among these lines, but also differential virulence in the pathogen population. The differential reactions within the accessions to neck and finger blast in the present study are in agreement with Kumar *et al*. (2009), who reported that, the genotypes (HR

374, ICM 808, PES 400, OEB 87, RAU 8 and VR 708) were resistant to neck blast and found susceptible to finger blast under natural epiphytotic conditions.

4.4.4.3, Blast resistance across the locations

The mean leaf, neck and finger blast severity of the mini-core across five environments varied from 1 to 4.1 score on a 1–9 scale, 1.1 to 4.8 score on a 1–5 scale and 2.5 to 58.3%, respectively compared to 4.1, 4.3 and 45.3% on the susceptible check (VR 708) (Table 4.29). Based on the mean neck blast severity scores of 2 as cut-off point for resistance, 60 accessions were resistant at Patancheru, 59 at Vizianagaram, 45 at Nandyal, 44 at Mandya and 66 at Naganahalli. We considered a accession resistant, if it had ≤ 10% finger blast severity. Of the 80 accessions, 64 were resistant at Patancheru, 58 at Vizianagaram, 11 at Nandyal, 10 at Mandya and 56 at Naganahalli (Table 4.31). However, the largest number accessions (58 out of 78) were resistant to both neck (score ≤3.0 on 1–5 scale) and finger blast (≤10%) at Patancheru followed by 57 at Vizianagaram, 56 at Naganahalli, and the lowest number of accessions (10 out of 78) at Mandya followed by (11 out of 80) at Nandyal (Table 4.31). This differences in the number of resistant accessions among the locations might arise either from differences among the dominant genotypes in the pathogen populations or from the environmental differences or from a combination of both factors. It could be also because existence of more virulent pathotype at Nandyal and Mandya locations. Among the mini-core collection, 36 accessions were found resistant to all the three blasts (leaf, neck and finger) across the three environments (Patancheru, Vizianagaram and Naganahalli) suggesting that these accessions may possess similar resistance gene(s) or near uniform blast conducive-weather conditions in the above locations whereas, 29 of the 35 resistant accessions were found susceptible to blast at Nandyal and Mandya confirming that the existence more virulent pathogen population at these locations than at Patancheru, Vizianagaram and Naganahalli.

Of the 80 mini-core accessions, 21 showed high neck blast resistance (score ≤2.0 on 1–5 scale) whereas, 7 are found resistant to finger blast across the five environments. Seven accessions (IE 2589, -2619, -2911, -2957, -4497, -6337 and -7018) had combined resistance to neck and finger blast across five environments with a mean of 1.0 to 1.4 score on 1–5 scale for neck blast and 2.5 to 7.7% for finger blast severity (Table 4.32).. The neck and blast severity of these accessions were consistent at all the locations except IE 2619 at Mandya, where the finger blast severity was relatively higher than other accessions and locations. Of these seven accessions, 2 originated from Zimbabwe (IE 4497 and IE 6337) and each one from USA (IE 2589), Malawi (IE 2619), Zambia (IE 2911), Germany (IE 2957) and Kenya (IE 7018). Among

these resistant accessions, IE 2589 belongs to race *plana* and sub-race *seriata,* whereas, the remaining 6 accessions represented race *vulgaris* and sub-races: *incurvata* (4)*, liliacea* (1) and *digitata* (1). These lines have desired days to flowering (70 to 82 days) and medium plant height (91 to 137 cm). Besides, all the accessions have semi-compact panicles (Table 4.32). It would be desirable to test blast resistance stability of these accessions through Finger Millet Blast Resistant Stability Nursery (FMBRSN) at above locations and at others across India or elsewhere.

4.4.4.4 Differential reactions across the locations

Differential host varieties are useful in the analysis of pathogen variability (Vanderplank, 1984., Wolfe and Knott, 1982., Wolfe and Schwarzback, 1975). Based on mean neck blast severity score of 2.0 on a 1–5 scale as resistant whereas, we considered a accession resistant if it had ≤10% finger blast severity. However, in case of variable reactions *i.e.* accessions resistant to neck blast and susceptible to finger blast and *vice versa* were considered as susceptible to both the infections for identification of differential host. In mini-core collection, differential reaction across the locations was evident in 54 accessions *i.e.* resistant at one location and susceptible at another and these variable reactions were categorized into different groups for identification of putative host differentials. The differential reactions to blast disease in mini-core accessions were categorized into seven major groups and 9 accessions were not included in differential groups due to unavailability of data from all the locations. The selected differential accessions from the mini-core were further evaluated through Finger Millet Blast Resistance Stability Nursery (FMBRSN) at same five locations.

Group I: IE 2710 - resistant at Patancheru, Vizianagaram, Mandya and Naganahalli; susceptible at Nandyal.

Group II: 28 accessions - resistant at Patancheru, Vizianagaram and Naganahalli; susceptible at Nandyal and Mandya.

Group III: 6 accessions - resistant at Patancheru and Naganahalli; susceptible at Vizianagaram, Nandyal and Mandya.

Group IV: 7 accessions - resistant at Patancheru and Vizianagaram; susceptible at Nandyal, Mandya and Naganahalli.

Group V: 3 accessions (IE 4545, -4671 and -5106) - resistant at Vizianagaram and Naganahalli; susceptible at Patancheru, Nandyal and Mandya.

Group VI: IE 5817 - resistant at Vizianagaram and Nandyal; susceptible at Patancheru, Mandya and Naganahalli.

Group VII: 8 accessions - resistant at Vizianagaram; susceptible at other four locations.

A total of 16 putative host differentials were selected (Table 4.31) from the above groups to confirm their reaction through Finger Millet Blast Resistance Stability Nursery (FMBRSN) during 2010.

4.4.4.5 Correlation studies

A significant and poor positive correlation was found between leaf blast in seedling stage with neck (r = 0.20, P<0.0001, and finger blast (r = 0.17; P= <0.0001). Significant poor correlation between leaf blast with neck and finger blast supported the earlier results (Somashekhara *et al*., 1991). However, in this study leaf blast infection at seedling stage did not contribute directly to the neck and finger blast in the later stages as indicated by low correlation between leaf blast scores with neck and finger blast severity, which needs further confirmation. This suggested that some genes responsible for leaf blast resistance were not effective at reproductive stage (Zuuang *et al*., 1997 and Wu *et al*., 2004). A strong significant positive correlation was found between neck blast and finger blast (r = 0.81; P<0.0001, Figure 4.18) suggested that recording the blast severity using these two scales provides more realistic data under field and greenhouse conditions at the right stage of the crop (physiological maturity) and also possible ability of the same gene(s) to induce resistance to both neck and finger blast. The R^2 value also supports the correlation between neck and finger blast (Figure 4.18). Similar results were reported by Nagaraja *et al*. (2010) and Nagaraja *et al*. (2010a)

This study identified seven finger millet mini-core accessions (IE 2589, -2619, -2911, -2957, -4497, -6337 and -7018) as resistant to blast disease across multiple locations with desirable agronomic traits, which needs further confirmation for stability of resistance. The study also identified 54 differentials, which were categorized into seven groups and selected 16 differentials and their reactions further confirmed at the above locations.

Further, it also demonstrated the variability of resistance in the finger millet mini-core collection against blast disease among geographical locations. Future research will focus on confirmation of stability of resistance and also better understanding of variability in the pathogen.

4.4.5 Finger Millet Blast Resistance Stability Nursery (FMBRSN) – 2010

Identification of sources of stable resistance is important in a disease resistance breeding program. Finger millet mini-core collection of 80 germplasm accessions were evaluated at Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli during the rainy

season 2009 and accessions exhibiting resistance to leaf, neck and/or finger blast were identified. Some other lines exhibited differential reactions at these locations indicating possible variability in the pathogen population. Proper understanding of the nature and mechanism of variation in the pathogen population will lead to identification and characterization of stable resistance genes that can be utilized in resistance breeding programs. With the above objectives in view a Finger Millet Blast Resistance Stability Nursery (FMBRSN) comprising of 28 finger millet accessions (7 resistant and 16 differential accessions and 3 early maturing accessions from the mini-core collection) including resistant and susceptible checks was constituted and evaluated at the above five locations during the rainy season 2010, and the results obtained are presented in Tables 4.33 to 4.36.

Disease severity scores for leaf, neck and finger blast were high in all five test locations with mean of scores 5.0 on 1–9 scale, 4.6 on 1–5 scale and 46% on the susceptible check (VR 708) respectively indicating adequate disease pressure and reliable evaluation at each test location (Table 4.33). Similarly, resistant check (GPU 28) found to be resistant across the locations except Nandyal, which needs confirmation. Among the locations, Mandya recorded the highest average leaf blast severity (score 3.4) on the test accessions, while the mean leaf blast severity was lowest (score 2.6) at Patancheru. The highest average neck blast severity was recorded at Mandya (3.0 on a 1–5 scale) followed by Nandyal (2.8) and lowest at Patancheru (1.8) whereas, the highest finger blast severity was at Nandyal (28%) followed by Mandya (25.1%) and lowest at Patancheru (11%).

4.4.5.1 Analysis of variance

In the present study, 28 accessions evaluated in five environments provided stable and differential reactions. Analysis of variance (ANOVA) showed that the effects of location (L), accession (A) and interaction between them were all significant (P<0.0001) (Tables 4.34). The mean squares due to location and L × A interaction components were lower than those due to accessions (A) for leaf blast severity. The mean squares due to accession and L × A interaction components were lower than those due to location components for neck and finger blast severity. Significant effects of accession suggested that certain accessions exhibited differential resistance and probably posses different resistance gene(s). Significant effects of location suggested that the weather conditions were more conducive for blast at some locations than at others.

Table 4.34. Analysis of variance of FMBRSN – 2010 for blast resistance at five locations during 2010 rainy season, India

Source of variation	df	Leaf blast		Neck blast		Finger blast	
		MS	F-value	MS	F-value	MS	F-value
Location (L)	4	5.89	28.96***	782.78	782.78***	509.84	509.84***
Replication (Loc)	5	0.18	0.9	1.38	1.38	1.67	1.67
Accession (A)	27	24.69	121.48***	149.06	149.06***	137.34	137.34***
L × A	108	2.11	10.39***	25.12	25.12***	18.62	18.62***
Residual	135	0.20		1.00		1.00	

*** Significant at $P<.0001$

However, the present test locations were identified as 'hot spots' for blast screening and these, except Patancheru, are being used by the national program (AICRP small millet reports, 2002–2007). In 'hot spots', the inoculum pressure remains high during the crop season and the pathogen population more diverse (Correa-Victoria and Zeigler, 1993 and Cuevas-perez *et al.,* 1989). However, the relative effect of the weather condition at Patancheru were minimized by the artificial inoculation at appropriate stages of plant growth, and relative humidity and temperature were maintained by the use of perfo and/or sprinkler irrigation twice a day in between 10:00 a.m. to 12:00 noon and 4:00 p.m. to 6:00 p.m. (Thakur *et al.,* 2009).

4.4.5.2 Blast resistance in early maturing accessions

Of the three early maturing accessions, 2 (IE 4755 and IE 4759) showed susceptible reaction during the rainy season 2009 and in FMBRSN–2010 (Table 4.33) confirming the relationship between early maturity and blast susceptibility. Similar results were found by Sreenivasaprasad *et al*. (2007) and Takan *et al*. (2007), who reported that early maturing varieties are more susceptible to blast than late ones.

4.4.5.3 Correlation between leaf with neck and finger blast

Significant and positive correlations were found between leaf blast at seedling stage with neck (r = 0.70; $P<0.0001$) and finger blast (r = 0.70; $P<0.0001$) in FMBRSN – 2010 across the locations indicating the significant role of leaf infection to the neck and finger

infection, which needs further confirmation. It could be also because, 7 out of 26 tested accessions were stable resistant to three blasts (leaf, neck and finger) across the locations during the rainy season 2009 and these accessions remained consistently resistant to all three types of blast in the present studies. For instance, the accessions (IE 2589, IE 2911 and IE 7018) were stable resistant across the locations during the year 2009 with mean leaf and neck blast severity <2.0 score and finger blast severity <5.0% and similar reactions were recorded in FMBRSN–2010. The higher correlation coefficient obtained (r = 0.70) between leaf blast with neck and finger blast may be explained as the same gene/()s inducing resistance at both vegetative and reproductive stages. In rice-blast system, similar results were reported by Balal *et al.* (1977), Bonman *et al.* (1989), Bhardwaj and Singh (1983) and Hossain *et al.* (2004). In contrast, significant poor correlation between leaf blast with neck and finger blast in finger millet were reported by Somashekhar *et al.* (1991), Takan *et al*. (2004) and Takan (2007). Similarly, Filippi and Prabhu (1997) found negative correlation between leaf and neck blast in the field under high disease pressure and also moderate to low positive correlation reported by Puri *et al.* (2009) in rice. Teng *et al.* (1991) mentioned that leaf and neck blast in rice were two different pathosystems due to time discontinuity, and the relationship between the two was yet to be defined.

There was a significant and strong positive correlation between neck and finger blast severity (r = 0.95, P<0.0001) in FMBRSN – 2010 (Figure 4.19). Correlation between neck and finger infection were similar, refer as discussed earlier under section 4.4.3.6.

4.4.5.4 Differential reactions

Of the 28 FMBRSN accessions, 21 showed differential reactions to leaf, neck and finger blast, 5 stable resistance across locations and the remaining two were resistant and susceptible checks (Table 4.37). Among the 21 differential accessions, 6 (IE 3543, -4755, -4759, 5817, -5870 and -6082) were susceptible to neck and finger blast at all locations with exceptions. These accessions may not serve as differential host could be due to uniform susceptibility to neck and finger blast in most of the locations. Of the 6 susceptible accessions, IE 5870 and IE 6082 were uniformly susceptible to all the three types of blast across five locations except at Vizianagaram for leaf blast and the remaining showed moderate to highly susceptibility to leaf, neck and finger blast. The detailed results on identification of host differentials based leaf, neck and finger blast in field conditions were discussed under section 4.2.3.1.

4.4.5.5 Blast resistance across the locations

Based on the mean leaf blast severity scores of 3.0 on a 1–9 scale as cut-off point for resistance, 23 accessions were resistant at Patancheru, 16 at Vizianagaram, 14 at Nandyal, 13 at Mandya and 14 at Naganahalli. We considered an accession resistant, if it had ≤2.0 score on a 1–5 scale for neck blast severity and ≤10% for finger blast severity. Of the 26 accessions, 18 were resistant at Patancheru, each 14 were resistant at Vizianagaram and Nandyal, 11at Mandya and 14 Naganahalli whereas, for finger blast 17 were resistant at Patancheru, 13 at Vizianagaram, 7 at Nandyal, 8 at Mandya and 13 at Naganahalli (Table 4.35). However, the largest number of accessions (17 out of 26) were resistant to all three phases of blast at Patancheru; 11 at Naganahalli; 10 at Vizianagaram; 8 at Mandya and 7 at Nandyal (Table 4.36). These accessions will be useful for location-specific blast resistance breeding.

Table 4.35. Performance of Finger Millet Blast Resistance Stability Nursery (26 accessions) for leaf, neck and finger blast resistance under field conditions at five locations during 2010 rainy season, India

Location	Leaf blast					Neck blast					Finger blast				
	HR	R	MR	S	HS	HR	R	MR	S	HS	HR	R	MR	S	HS
Patancheru	2	21	-	3	-	10	8	6	2	-	9	8	5	2	2
Vizianagaram	6	10	8	-	2	6	8	6	3	3	3	10	3	5	5
Nandyal	8	6	7	5	-	5	9	2	-	10	-	7	4	5	10
Mandya	8	5	8	4	1	2	9	1	4	10	1	7	6	1	11
Naganahalli	8	6	7	5	-	-	14	3	3	6	3	10	4	2	7

HR: Highly Resistant; **R**: Resistant; **MR**: Moderately Resistant; **S**: Susceptible; **HS**: Highly Susceptible

Of the 7 stable resistant accessions during 2009 (IE 2589, -2619, -2911, -2957, -4497, -6337 and -7018), two (IE 2619 and IE 2957) were found susceptible to neck and finger blast in the present studies. The accession IE 2619 was consistently recorded less severity across 5 locations during 2009 and 2010 except Mandya. In 2009, the finger blast severity in IE 2619 at Mandya was relatively higher than at other locations and accessions. In 2010, IE 2619 was found susceptible to finger blast at Mandya confirming the results of 2009, whereas, IE 2957 was found stable resistant across 5 environments during 2009 and it was found susceptible to neck and finger blast during 2010 at Mandya and Naganahalli (Table 4.36).

This study identified 5 accessions (IE 2589, -2911, -4497, -6337 and -7018) as highly resistant across locations and years, exhibiting high stability, and thus could be ideal sources of

resistance for utilization in breeding programms. The blast resistant accessions identified in mini-core accessions in this study could be used as potential seed parents for the developing blast resistant varieties.

4.4.6 Analysis of blast resistance stability of 24 finger millet mini-core accessions over 2 years at five locations

4.4.6.1 Analysis of variance

The analysis of variance for blast severity across the five locations over two years indicated highly significant (P<0.0001) effects of genotype/accession (A), location (L), Year (Y), and interactions of A x L and A x Y except Y × L component of leaf blast (Table 4.37). The mean squares of leaf blast severity due to year and Y × A interaction components were higher than location, L × A components. The mean squares of leaf blast severity due to Y × L × A and Y × L components were lower than all other factors. The mean squares for neck blast severity due to year were higher than all other factors whereas, mean squares due to accession was higher than location and other interaction components. The MS variances for finger blast due to location was very high indicating the differences in finger blast severity mainly contributed by location followed by year and accessions. Significant effects of genotype for leaf, neck and finger blast suggested that the 24 tested accessions exhibited differential resistance, and probably possess different resistance genes. The significant effects of location and year suggested that the weather conditions were more conducive for disease development at some locations than at others and varied over locations or due to the likely existence of variable populations at these locations. The significant effects of A × L and A × Y interactions suggested that the tested accessions probably posses different resistant genes, and that the structure of pathogen populations, in term of virulence genes was different across locations and over years (Table 4.37).

In this study, the significant mean squares due to A × L interaction supports breeding for specific adaptation (characterized by predictable variability), while those due to A × Y interaction suggests breeding for stability over temporal (unpredictable) variability. In the present study, both A × L and A × Y interaction mean square components are although significant for leaf, neck and finger blast, their magnitude are much lower than that of genotypic variance.

4.4.6.2 Variance analysis

Leaf, neck and finger blast severity was high in all five tests in disease nurseries over years with mean score of 5.1 on a 1–9 scale, 4.5 on a 1–5 scale and 44.9% on the susceptible check (VR 708), respectively, is an indicative of good disease pressure at all test locations over years (Table 4.38).

Table 4.37. Analysis of variance of 24 tested finger millet mini-core accessions for blast resistance under field conditions at five locations during the 2009 and 2010 rainy seasons

Source of variation	df	Leaf blast		Neck blast		Finger blast	
		MS	F-value	MS	F-value	MS	F-value
Year (Y)	1	270.51	1237.52***	22.9	160.9***	2611.3	183.2***
Location (L)	4	2.88	13.19***	12.7	89.3***	4449.5	312.2***
Replication (Y × L)	10	0.16	0.75	0.1	0.7	32.3	2.3
Accession (A)	23	15.88	72.64***	17.7	124.3***	2549.8	178.9***
A × Y	23	8.28	37.89***	2.7	18.9***	339	23.8***
L × Y	4	0.37	1.68	4.7	32.9***	831.2	58.3***
A × L	92	1.01	4.63***	2.0	13.9***	320.7	22.5***
Y × L × A	92	0.63	2.87***	1.0	7.3***	136.6	9.6***
Error	230	0.22		0.1		14.3	

*** Significant at $P<0.0001$

Among the 5 locations, Mandya (score 2.5 on a 1–9 scale) and Naganahalli (2.4) in Karnataka recorded the highest average leaf blast severity on the tested finger millet accession over the 2 years, while the mean leaf blast severity was lower at Patancheru (score 2.1) and Vizianagaram (score 2.2) in Andhra Pradesh (Table 4.39). Variance analysis of the blast severity among the different finger millet accession showed this variation in blast severity changed significantly changed across locations. This variation was greater at Naganahalli than at Mandya, and larger at Vizianagaram than at Patancheru (Table 4.39) suggesting that the pathogen population was highly host genotype-specific with high virulence on some accessions at Naganahalli and Vizianagaram, but had low genotype specificity at Mandya and Patancheru.

The highest neck blast severity recorded at Mandya (2.6 on 1–5 scale) and Nandyal (2.3) and lowest was at Vizianagaram (1.7) and Patancheru (1.9) across 5 locations and over 2 years. The mean neck blast severity among the different finger millet accessions at five

locations were statistically significant to each other except Naganahalli and Patancheru (Table 4.39). Variance analysis on neck blast severity among the different finger millet accessions showed that the variation was larger at Nandyal (0.87) than at Mandya (0.78) and Vizianagaram (0.99) than at Patancheru (0.88) suggesting that the pathogen population was highly host genotype-specific at Nandyal and Vizianagaram and low genotype-specific at Mandya and Patancheru (Table 4.39).

Amongst the locations, the highest mean finger blast severity occurred at Mandya (24.2%) followed by Nandyal (23%), while the mean lowest finger blast severity was recorded at Vizianagaram (10.3%) and Patancheru (10.6%). The mean finger blast severity across the locations over 2 years were statistically significant except Patancheru and Vizianagaram. The variance analysis showed that the variation was greater at Mandya than at Nandyal, and larger at Vizianagaram than at Nandyal (Table 4.39) suggesting that the pathogen population was highly host genotype-specific with high virulence on some accessions at Mandya and Vizianagaram, but had low genotype specificity at Nandyal and Patancheru.

Differences in disease severity among genotypes occur not only because of the innate resistance in genotypes, but because of the frequency of virulence genes in pathogen population. Assuming that the finger millet–*M. grisea* host-pathosystem is governed by the gene-for gene hypothesis (Flor, 1971), genotypes exposed to pathogen populations possessing the matching virulence genes will develop greater disease severity. Some locations, such as Mandya in Karnataka and Nandyal in Andhra Pradesh, had much higher average blast severity on almost all tested finger millet accessions over 2 years.

At all the locations, blast severity in a highly susceptible variety VR 708 was adequate as an indicative of good disease pressure. The analysis of the weather variables across these locations over the study period, particularly relative humidity, temperature and leaf wetness duration, indicated that conditions for blast development were favorable. However, the variations in severity on tested accessions at Naganahalli were higher than at Mandya for leaf blast; Mandya and Nandyal for neck and finger blast suggesting that the pathogen populations at Naganahalli, Nandyal and Mandya were probably genotype-specific. The low variation on tested accessions at Vizianagaram could be due to diverse and highly virulent pathotypes.

Table 4.39. Comparison of the mean leaf, neck and finger blast severity on 24 finger millet mini-core accessions tested for two years among different locations

Location	Average severity[1]	Relative variation[2]

	Leaf blast (1-9 scale)	Neck blast (1-5 scale)	Finger blast severity (%)	Leaf blast[3]	Neck blast	Finger blast
Patancheru	2.1 b	1.9 c	10.6 d	0.80 a	0.88 a	1.48 a
Vizianagaram	2.2 b	1.7 d	10.3 d	0.93 a	0.99 a	2.53 a
Nandyal	2.3 a	2.3 b	23.0 b	0.69 a	0.87 a	0.71 a
Mandya	2.5 a	2.6 a	24.2 a	0.61 a	0.78 a	0.79 a
Naganahalli	2.4 a	2.0 c	13.1 c	0.74 a	0.97 a	1.16 a

[1] Average severity on 24 tested accessions over years.
[2] Standard deviation of the severity on 24 tested accessions at five locations over two years divided by square root of [mean severity × (1 – mean severity)].
[3] Figures followed by same letters are not significantly different according to least significant difference test ($P > 0.05$)

In contrast, average blast severity was the lowest at Patancheru and Vizianagaram. Similarly, low variations were observed at Patancheru, which could be due to either the pathogen populations lacked highly virulent genes or the lower frequency of highly virulence genes in the pathogen population. However, the lower variation at Patancheru location could be due to the fact that screening was conducted under artificial inoculation of a single-spore culture of *M. grisea*.

Among the 23 finger millet accessions, IE 2589, -2911, -4497, -6337 and -7018 were most resistant to leaf, neck and finger blast with average severity ranging from score 1.3 to 1.83, 1.03 to 1.37 and 3.0 to 5.6%, respectively (Table 4.40). However, finger millet accessions, IE 2619, -2710, -2872, -2957 and -5106 were also resistant to leaf, neck and finger blast with mean severity ranging from score 1.4 to 1.9, score 1.25 to 1.72 and 6.3 to 10.6% respectively, but these accessions showed variable reactions at some locations. (Table 4.40). For instance, IE 2957 was found resistant across all locations during 2009 but it was susceptible to neck and finger blast during 2010 at Mandya and Naganahalli.

In the present studies, we found several accessions possessing resistance to leaf blast under field condition at all five locations over 2 years. However, it has been reported that, all the existing resistant varieties are resistant only against ear and finger blast, but invariably susceptible to leaf blast. Analysis of relative variation showed that the variation in the leaf blast severity was smaller in all accessions and also non-significant. Among the several resistant accessions to leaf blast, the average leaf blast severity of the accessions IE 4497, IE 2957, IE 2872, IE 2911 and IE 5066 were much lower and most resistant, but these accessions showed

highest relative variation across the location and years, indicating their resistance varied to certain blast isolates. In contrast, although the average severity levels of accessions IE 2710, IE 6337 and IE 7018 were slightly higher, these lines showed lower variation across locations and years.

Analyses of the relative variation for neck and finger blast showed that the variation in the severity was smaller on certain accessions (Table 4.40) indicating that IE 2710 and IE 2872 may possess resistance only against certain populations of the pathogen, as they varied significantly among the locations over time. In contrast, accessions IE 2589, -2911, -4497, -6337 and -7018 may possess resistance against a wide range of the pathogen populations with stable resistance across locations and years. The relative variation of these accessions varied between leaf, neck and finger blast, but there is no significant difference between the relative variations of these accessions. Accessions VR 708, IE 6082 and IE 5870 showed high average susceptibility across locations and over years. When VR 708 showed small variation across locations over years, IE 6082 and IE 5870 demonstrated modest relative variation, suggesting that this line posses pathogen-specific resistance gene(s) even though their resistance level is very low for the genes(s), and that VR 708 may not posses any specific resistance gene(s).

This study identified finger millet accessions -2589, -2911, -4497, -6337 and -7018 highly resistant to all three phases of blast across the locations and years exhibiting high stability of resistance for utilization in resistance breeding programms. Several other accessions (IE 2619, -2710, -2872, -2957 and -5106) that were stable at specific locations could be utilized in resistance breeding at those locations. It would be desirable to confirm the stability of resistance of these accessions under greenhouse conditions using representative pathogen isolates from the same locations.

4.4.6.3 Correlation between leaf, neck and finger blast

A significant and positive correlations were found between leaf blast at seedling stage with neck (r = 0.43; P<0.0001) and finger blast (r = 0.44; P<0.0001) in 24 finger millet accessions across the locations. The present correlation could also be due to that the most of the accessions were uniformly resistant to all the three types with low average disease severity scores during 2009 and 2010 with some exceptions. For instance, the accessions (IE 2589, IE 2911 and IE 7018) were resistant across locations during 2009 with mean leaf and neck blast severity <2.0 score and finger blast severity <5.0% and similar reactions were recorded across the locations in FMBRSN–2010. In contrast, the accessions (IE 3392, IE 4057, IE 5091, IE

5106, IE 5817 and IE 6421) were found resistant to leaf blast at seedling stage, but susceptible to neck and finger blast at Nandyal location while none had opposite reaction (Table 4.38). Significant and strong positive correlation was found between neck and finger blast severity (r = 0.90, P<0.0001) indicated the neck blast shares 82.1% variability with finger blast (Figure 4.20). The detailed discussion on correlation between leaf, neck and finger infection were similar, refer as discussed earlier under sections 4.4.3.5 and 4.4.3.6.

4.4.6.4 Genotype main effect and Genotype × Environment (GGE) biplot analysis leaf blast resistance stability

The GGE biplot analysis were conducted separately for each type of blast and represented in three separate scatter and rank biplots. The principal components of the GGE biplot for leaf blast severity explained 87.17% (72.53% and 14.64% by PC1 and PC2 respectively) of total variation of the genotype-centered data, as indicated on top of the biplot (Figure 4.21).

The scatter plot in Figure 4.21 facilitates visual identification mega-environment groups that are 'hot spots for disease screening and most virulent to each of the accessions. There was a clear-cut grouping of environments based on year of screening to the leaf blast except Vizianagaram 2010 and repeatedly same site grouped differently in two years indicating the significant effect of year factor and G×E interaction. The first mega-environment consists of locations during 2009 and second mega-environment consists of locations during 2010 except Vizianagaram 2010. It is evident from the biplot (Figure 4.21) that, the location Vizianagaram during 2010 lay separately on biplot from other locations and far away from biplot origin due to variation in leaf blast severity compared to other locations and over years. It could be either due to existence of highly virulent pathogen population at Vizianagaram during 2010.

The GGE biplot analysis of the 24 finger millet mini-core accessions and the susceptible control (VR 708) for leaf blast resistance revealed that the accessions, IE 4497, IE 2957, and IE 2872 had the lowest level of neck blast severity across the locations by being farthest to the left of the biplot origin compared with all other the accessions (Figure 4.22). In addition, 10 finger millet mini-core accessions (IE 7079, -2589, -2710, -2911, -2619, -5066, -7018, -6337, -3392 and -5106) were just away from the left of the biplot origin as well as being lower mean performance considered as stable resistant accessions. The susceptible variety VR 708 consistently more susceptible across the locations and over years by being farthest on the right side of the biplot origin (Figure 4.22).

4.4.6.5 Genotype main effect and Genotype × Environment (GGE) biplot analysis neck blast resistance stability

The first two principal components of the GGE biplot explained 72.46% (59.34% and 13.12% by PC1 and PC2 respectively) of total variation of the genotype-centered data (Figure 4.23). The biplot analysis showed that the sectors displayed 3 mega-environments for neck blast severity across locations over years (Figure 4.23). The genotypes IE 5870 and VR 708 were most susceptible at Patancheru, Vizianagaram, Naganahalli and Mandya for 2 years except Mandya 2009 (first mega-environment) whereas, IE 4057 was most susceptible at Nandyal for two years (second mega-environment) and IE 5091, IE 6082 and IE 6240 were also susceptible at Nandyal and other locations. The accession IE 5066 was highly susceptible at Mandya 2009 (third mega-environment).

Two years of screening at Patancheru (2009&2010) are located closely in Figure 4.23, indicating that more consistent severity over two years and similar virulence of pathogen population to finger millet accessions. It could be due to that the experiment was conducted under artificial inoculation conditions using Fm-strain of Patancheru isolate (FMP1). In contrast, the test environment (Mandya) was highly diverse, and repeatedly same site grouped differently in two years indicating the significant effect of genotype × environment interaction (Figure 4.23). Among the five locations, Mandya seemed to support highest disease expression either due to the existence of highly virulent pathogen population or the prevailing blast-conducive weather conditions over two years. The accessions located at the vertices are either the most or the least susceptible at some or all the locations. VR 708 is the vertex for all locations except Nandyal and Mandya during 2009. Opposite to VR 708, IE 2911 located on the other side of the biplot origin, seems to be most resistant across the locations.

The GGE biplot analysis for neck blast resistance revealed that the accessions, IE 2911, IE 2589, IE 7018, IE 4497, IE 6337, IE 2710 and IE 2619 had the lowest level of mean neck blast severity across all the locations by being farthest to the left of the biplot origin compared with all other the accessions (Figure 4.24). In addition, the finger millet mini-core accession, IE 5106 was closer to performance line, just away from the left of the biplot origin and above accessions as well as being lower mean performance considered as stable resistant accession. Two finger millet mini-core accessions (IE 6082 and IE 5870) and susceptible check (VR 708) were consistently highly susceptible by being farthest on the right side of the origin of the biplot on the performance line (Figure 4.24).

4.4.6.6 Genotype main effect and Genotype × Environment (GGE) biplot analysis finger blast resistance stability

The first two principal components of the GGE biplot for finger blast severity explained 71.84% (59.15% and 12.69% by PC1 and PC2 respectively) of total variation of the genotype-centered data (Figure 4.25). All the locations were fell into one mega-environment for finger blast except Nandyal 2009 implying that the relationship among the locations is more complex. The remaining location (Nandyal 2009) fell into another distinct mega-environment. However, Mandya and Naganahalli 2009 were grouped as separate cluster in one mega-environment (Figure 4.25). The two years of screening at Patancheru (PATAN9 and PATAN10) lay very closely each other on biplot in Figure 4.25, indicating that more consistent finger blast severity occurred over two years. The test environments (Mandya and Naganahalli) during 2009 were highly diverse, and repeatedly same site grouped differently in two years indicating the significant effect of genotype × environment interaction.

The GGE biplot analysis for finger blast resistance revealed that the accessions, IE 2911, IE 7018, IE 4497, IE 6337 and IE 2589 had the lowest level of mean finger blast severity across all the locations by being farthest to the left of the biplot origin compared with all other the genotypes (Figure 4.26). In addition, the finger millet mini-core accessions, IE 2710 and IE 5106 were closer to performance line, near to biplot origin and just away from the stable resistant accessions as well as being lower mean performance indicating that these accessions were stable at some locations. The accessions IE 2619, IE 7079, IE 2957 and IE 2872 were lay near to the origin of biplot revealed that these accessions had lower level finger blast severity, but variations were found in disease reaction at Nandyal and Mandya. Two finger millet mini-core accessions IE 6082 and IE 5870 and susceptible check variety VR 708, were consistently the more susceptible by being farthest on the right side of the origin of the biplot on the performance line (Figure 4.26).

Based on GGE biplot analysis, 13 accessions (IE 2589, -2619, -2710, -2872, -2911, -2957, -3392, -4497, -5066, -5106, -6337, -7018 and -7079), seven (IE 2589, -2619, -2710, -2911, -4497, -6337 and -7018) and five accessions (IE 2911, -7018, -4497, -6337 and -2589) were found stable resistant to leaf, neck and finger blast across the locations and over years by being farthest to the left of the biplot origin compared with all other the accessions. Among the five locations, the highly responsive locations, Mandya and Nandyal could be considered as good sites for germplasm screening for blast resistance.

Analysis of the blast resistance stability of finger millet mini-core accessions using GGE biplot technique showed that five accessions (IE 2911, -7018, -4497, -6337 and -2589) by being farthest to the left of the biplot origin, could be considered as stable resistant to three phases (leaf, neck and finger) across the locations and over years. These accessions could be of value for breeding programs attempting to improve finger millet blast resistance. Identification of genotypes/accessions that possess high stability for low disease severity is a key component that ensures the selection of useful sources of high resistance for breeding programs (Sharma and Duveiller, 2007). A regular stability analysis often does not provide relative ranking of superior accessions each and across the locations, which results in a subjective judgment when selecting a cultivar (Yan *et al.,* 2000). The GGE biplot approach used in this study could help breeders better prioritize genotypes to use. The combined visual assessment of the level of resistance and its stability is a big advantage, and adds confidence in the decision to promote a superior genotype. The GGE biplot approach has been used in selection of superior genotypes that have stable resistance to spot blotch in wheat (Sharma and Duveiller, 2007), rust in soybean (Twizeyimana *et al.,* 2008), anthracnose and virus disease of water yam (Egesi *et al.,* 2009). However, it would be desirable to confirm their resistant stability using highly virulent and geographically diverse pathotypes under greenhouse conditions.

4.4.7 Confirmation of stability of blast resistance

The finger millet mini-core accessions (IE 2589, -2911, -7018, -4497, and -6337) found stable resistant to blast across five locations and over two years in the field screen were further evaluated under greenhouse conditions using the isolates from geographically diverse origin (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli), to confirm their stability of resistance. One highly virulent isolate from each location was selected based on pathogenicity scores.

4.4.7.1 Analysis of variance

Variability in leaf, neck and finger blast severity due to genetic differences among finger millet mini-core accessions, due to isolate, and due to accession × isolate interaction were all highly significant (P<0.001) (Table 4.41). The largest proportion of variability for all the three phases of blast severity was accounted by accession, followed by accession × isolate interaction and isolate. The main effect of the pathogen is notably small whereas, the accession × isolate interaction is larger, indicating that the isolates differ primarily in specific virulence to different finger millet accessions (Table 4.41).

Disease pressure (leaf, neck and finger blast) with all five isolates was quite high, with the scores of 5.8 on 1–9 scale, 4.95 on 1–5 scale and 79.5% of leaf, neck and finger blast respectively on susceptible check (VR 708) indicating adequate disease pressure for an effective greenhosue screening. As in field tests, the resistant check (GPU 28) found susceptible to neck and finger blast with Nandyal isolate (FMNd39) (Table 4.42).

Table 4.41. Analysis of variance (ANOVA) for leaf, neck and finger blast severity of selected finger millet accessions against five *M. grisea* isolates under greenhouse conditions

Source of variation	d.f.	Leaf blast		Neck blast		Finger blast	
		MS	F-value	MS	F- value	MS	F- value
Replications	2	0.09	0.70	0.06	0.58	19.2	0.68
Isolate (I)	4	11.0	89.6**	8.3	86.4**	1277.7	45.3**
Accession (A)	6	20.8	169.6**	38.5	403**	14681.2	520.7**
I × A	24	4.0	32.9**	3.7	38.3**	618.4	22.0**
Residual	68	0.13	-	0.09	-	28.2	-

** indicates significant at $P < 0.001$

All the accessions were resistant to leaf blast with Patancheru isolate (FMP1), two to Vizianagaram isolate (FMV25), each three to the Nandyal isolate (FMND31) and Mandya isolate (FMM39) and none of them to Naganahalli isolate (FMNg54). For neck blast, two accessions were resistant to FMP1 and FMV25, three to the FMNd31 and four to FMM39 and FMNg54 while for finger blast, two to the FMP1, one to the FMV25, three to the FMNd31, each four to the FMM39 and FMNg54. Of the five accessions evaluated for blast resistance, IE 2911 was found resistant to all three types/phases of blast against five isolates, but variation was found in leaf blast reaction with FMV25 and FMNg54. IE 2957 was resistant to all the three phases of blast except leaf blast to FMNg54, and neck and finger blast to FMV25 (Table 4.43). The apparent susceptibility of the finger millet accessions to neck and finger infection, appeared to differ from that in the seedling assays (leaf blast). For example, IE 6337 which was relatively resistant in the seedling experiments appeared more susceptible to neck and finger blast. The results are in agreement with Puri *et al*. (2009) who reported that the leaf blast resistant accessions were found susceptible to neck blast in rice.

The differences in results between field and greenhouse evaluations against the same isolate from that location could be attributed to several variable factors operating in the fields. Environmental conditions and inoculum are more variable in field nurseries than in the greenhouse. In the field, infection to plants occurs by variable spore types of different pathogen populations while in the greenhouse it is due to single spore type. The fact that stable field resistance of two of the five tested mini-core accessions was confirmed in greenhouse tests indicates the value, effectiveness, and usefulness of the greenhouse evaluation. Similar observations were made by Thakur *et al*. (2001).

Greenhouse evaluation of accessions for leaf blast resistance with isolates from the five locations showed a differential pattern, with the largest number of accessions (5) being resistant to FMP1 and none of them to FMNg54, confirming that FMNg54 is more virulent than others. However, it cannot be claimed that these four isolates are necessarily more virulent than the Patancheru isolate. This could result from chance fixation of genes responsible for resistance against isolates from other locations; or a Patancheru isolate may consist of a low frequency of those pathogen genotypes dominant at other locations, permitting simultaneous selection for resistance to multiple pathotypes. The largest number (four out of five) of accessions were resistant neck and finger blast with FMM39 and FMNg54 and lowest number of accessions to the FMP1 and FMV25 with FMNd31 falling between the two in that order. This difference in the number of resistant accessions between isolates might arise from differences among the dominant genotypes in the pathogen populations or differences virulence in pathogen population and or from a combination both factors (Table 4.44).

4.4.7.2 Correlation studies

A significant and moderate positive correlations were found between leaf blast at seedling stage with neck (r = 0.36; P<0.0001) and finger blast (r = 0.37; P<0.0001) in seven finger millet accessions under greenhouse. There was significant and strong positive correlation between neck and finger blast severity (r = 0.89, P<0.0001) under greenhouse conditions (Figure 4.27). The detailed discussion on correlation between leaf, neck and finger infection were similar, refer as discussed earlier under sections 4.4.3.5 and 4.4.3.6.

Shared haplotypes representing *M. oryzae* isolates from different types of blast revealed that genetically similar isolates are capable of causing different forms of the disease (Pande *et al*., 1995., Takan *et al*., 2011). Finger millet varieties in general show a consistent reaction to different types of blast, with limited exceptions (Somasekhara *et al*., 1991., Takan *et al*., 2004 and Takan, 2007).

Identification of one mini-core accession (IE 2911), which was found to be resistant across multiple locations and years and also to five representative isolates from same locations in greenhouse condition provides ample opportunity for their direct use in development blast resistant cultivars with resistance to multiple pathotypes of *M. grisea*. The blast resistant accession identified in this study have relative earliness, medium plant height and top curved type of spike, and originated from Zambia, representing the race *Vulgaris* and sub-race *Incurvata.* This study also identified another accession IE 2957 as resistant across multiple locations and years and moderately resistant under greenhouse conditions to multiple isolates, exhibiting high stability and could be ideal source of resistance for utilization in breeding programms. Furthermore, the responses of IE 4497 and IE 7018 varied differently from location specific isolates, therefore, may be used as good resistance sources in location-specific breeding programms.

Most of the blast resistant sources reported so far were screened under natural epiphytotic conditions and there is limited information available on neck and finger blast screening techniques under greenhouse conditions. Screening under natural infection condition may provide escapes and true resistance may not be identified. However, in this study identified stable resistance mini-core accessions across the multiple locations over years in the field screen were further confirmed their stability of resistance using greenhouse screening technique against the isolates from geographically diverse locations. Several workers have been identified blast resistance sources in finger millet (Nagaraja *et al*., 2005., Nagaraja *et al*., 2007 and Kumar *et al*., 2009), but none of them confirmed their resistance stability through greenhouse screening. In the present study, sources of stable, durable resistance to blast were identified through multilocation testing at 'hot spot' locations and also under artificial inoculation conditions, and confirmed their stability under greenhouse conditions. This study, first of its kind reports the greenhouse screening technique for neck and finger blast resistance in finger millet.

4.4.8 Association of weather parameters with finger millet blast severity

The purpose of this study was to understand the relationship between weather parameters such as RH and temperature, and blast severity for identifying disease risk environments with an ultimate objective of developing decision-making tools for disease management. The most vulnerable crop stage for leaf blast infection is up to 30 days after emergence and at pre-

flowering of stage for neck and finger blast. In the present studies, neck and finger blast data four susceptible accessions (IE 3543, IE 4755, IE 4759 and VR 708) were used.

There was considerable variation in RH across locations and years. The mean maximum RH (RHmax) ranged from 79.4% (Nandyal) to 92% (Patancheru) and the mean minimum RH (RHmin) ranged from 50.1% (Mandya) to 65.3% (Vizianagaram) across two crop seasons (Table 4.44). However, the range of RHmax was 71.5–95.7% and that of RHmin was 44.8-79.7%. The mean maximum temperature (Tmax) ranged from 29.2°C (Naganahalli) to 32.2°C (Nandyal) and the mean minimum temperature (Tmin) ranged from 18.1°C (Naganahalli) to 25.1°C (Vizianagaram). Among the two years, low variation in Tmax and Tmin were observed compared to RH. The range of Tmax was 27.3–33.4°C and that of Tmin was 13.2–28.2°C. The mean maximum and minimum temperature measurements did not deviate more than 0 to 1.1°C at five locations.

The mean neck and finger blast severity of four susceptible accessions varied from score 3.3 to 3.9 on 1–5 scale and 26.8 to 40.6% respectively across locations and over years. The neck and finger blast severity of four susceptible accessions ranged from score 2.0 to 5.0 and 18 to 64% respectively across locations and over years (Table 4.44). A significant positive correlation (r = 0.80, P<0.0001) were found between neck and finger blast severity across the locations and over years. Considerable year-to-year variations at and across locations were found on these accessions.

The average loss due to blast has been reported to be around 28-36% (Vishwanath *et al.,* 1986., Nagaraja *et al.,* 2007), and in endemic areas, yield losses could be as high as 80-90% (Vishwanath *et al.,* 1986., Bisht, 1987 and Rao, 1990). In the present studies, we designated score >3.5 and >30% of neck and finger blast severity respectively to classify the location as high risk and low risk environments.

The finger millet accessions (IE 3543, IE 4755 and IE 4759) were showed high mean neck blast severity (>3.5) in half of the 10 locations, susceptible check VR 708 was in 6 of the 10 while, IE 3543 was found high mean finger blast severity (>30%) in half of the 10 locations, IE 4755 and IE 4759 in 4 of the 10 and VR 708 in 7 out of 10 locations respectively. Individual accessions were classified based on neck and finger blast severity as high and low risk environments, however this was not consistent in all the four accessions even for a single year at a particular location because of variable disease severity in the accessions due to differences in level of susceptibility in the accessions and differences in virulence pattern of pathogen populations among the locations and over years or combination from both the factors. Similar

finding on variable disease severity were reported by Kumar *et al*. (2009) in finger millet blast Thakur *et al*. (2001) and Thakur *et al*. (2004) in downy mildew of pearl millet.

In 2009, positive correlation was observed between RHmax with neck and finger blast severity across the locations and years whereas, negative correlation with RHmin. The relationships between temperature (both maximum and minimum) and neck and finger blast were not significantly correlated in the rainy season 2009 across locations. A strong and significant positive correlation was found between rainfall and neck (r = 0.96, P<0.05) and finger blast severity (r = 0.96, P<0.05) whereas, positive correlation was observed with frequency of rainfall and neck (r = 0.83) and finger (r = 0.54) blast severity. In 2010, positive correlation was observed with Tmax, Tmin, RHmin and rainfall with neck and finger blast severity. Two years of weather data revealed that, positive correlation was found between RHmin, RHmax, rainfall and frequency of rainfall with neck and finger blast. The relationships between temperature (both maximum and minimum) and neck and finger blast severity were not significantly correlated across locations and over years. The neck and finger blast severity was positively associated with rainfall and frequency of rainfall with the range of r = 0.36 to 0.58 suggesting the role of leaf wetness duration in blast disease development. Similar findings on correlation between rainfall and finger millet blast was reported by Nagaraja *et al*. (2010) and Nagaraja *et al*. (2010a).

The present findings on association weather parameters and blast severity are in agreement with Ramappa *et al.* (2006) who reported that high relative humidity, low night temperature and more number of rainy days (15 days) were resulted high leaf blast severity. Kumar *et al.* (2005) showed that a temperature of 18–24°C was more congenial for development neck and finger blast. Whereas, less than and more than would not favor the disease (Gowda and Gowda, 1995., Patel and Tripathi, 1988). Association of weather parameters with finger millet blast was studied by Nagaraja *et al.* (2010a), who reported that neck and finger blast incidence decreased significantly with increased temperature from 23.9 to 27.0°C and decreased rainfall from 303 to 83.4 mm during flowering period, however, the RH remained almost constant (88.34 to 88.90%).

In the present studies, year to year and location to location variations in disease severity especially in 3 finger millet accessions, the causes for such variations were not well understood. However, the selected finger millet accessions are early maturing accessions, which were highly susceptible to blast. We believe the main reason for such insignificant correlations between weather variables and disease severity could be the lack of weather data from the

experimental plots. Because all weather data reported here were collected from the meteorological observatory of the research stations, these may not be representative of the field microclimate data. It would be desirable that, microclimate data on RH, temperature, leaf wetness be collected from the experimental plots at the crop canopy level. For wider application of weather data-based disease forecasting, it would be necessary to obtain the data both from the meteorological observatory and microclimate conditions in the field, and determine correlations of these with the disease severity data. It is often not easy to obtain microclimate data, so it would be necessary to understand the correlation between meteorological observatory data and microclimate data and then with disease severity data.

Table 4.1. Sources of *Magnaporthe grisea* isolates collected from different crops and different states of India

Isolate No.	Identity	Host of origin	Year	Cultivar	Plant Part	Site of collection (Location/District/State)
A1	FMP1	*E. coracana*	2008	VL 149	Neck	ICRISAT/Patancheru/Medak/A.P.
A2	FMP2	*E. coracana*	2009	VR 708	Neck	ICRISAT/Patancheru/Medak/A.P.
A3	FMP3	*E. coracana*	2009	IE 518	Finger	ICRISAT/Patancheru/Medak/A.P.
A4	FMP4	*E. coracana*	2009	IE 588	Neck	ICRISAT/Patancheru/Medak/A.P.
A5	FMP5	*E. coracana*	2009	IE 2322	Finger	ICRISAT/Patancheru/Medak/A.P.
A6	FMP6	*E. coracana*	2009	IE 2323	Finger	ICRISAT/Patancheru/Medak/A.P.
A7	FMP7	*E. coracana*	2008	IE 2354	Finger	ICRISAT/Patancheru/Medak/A.P.

A8	FMP8	*E. coracana*	2008	IE 2517	Neck	ICRISAT/Patancheru/Medak/A.P.
A9	FMP9	*E. coracana*	2009	IE 3038	Neck	ICRISAT/Patancheru/Medak/A.P.
A10	FMP10	*E. coracana*	2009	IE 3470	Finger	ICRISAT/Patancheru/Medak/A.P.
A11	FMP11	*E. coracana*	2009	IE 4545	Neck	ICRISAT/Patancheru/Medak/A.P.
A12	FMP12	*E. coracana*	2009	IE 6154	Finger	ICRISAT/Patancheru/Medak/A.P.
A13	FMP13	*E. coracana*	2009	IE 6473	Finger	ICRISAT/Patancheru/Medak/A.P.
A14	FMV14	*E. coracana*	2009	VL 149	Neck	ARS/Vizianagaram/A. P.
A15	FMV15	*E. coracana*	2009	PSE 110	Finger	ARS/Vizianagaram/A. P.
A16	FMV16	*E. coracana*	2009	VR 708	Finger	ARS/Vizianagaram/A. P.
A17	FMV17	*E. coracana*	2009	VR 943	Neck	ARS/Vizianagaram/A. P.
A18	FMV18	*E. coracana*	2009	IE 196	Finger	ARS/Vizianagaram/A. P.
A19	FMV19	*E. coracana*	2009	IE 501	Neck	ARS/Vizianagaram/A. P.
A20	FMV20	*E. coracana*	2008	IE 1299	Neck	ARS/Vizianagaram/A. P.
A21	FMV21	*E. coracana*	2009	IE 2322	Neck	ARS/Vizianagaram/A. P.
A22	FMV22	*E. coracana*	2009	IE 3270	Neck	ARS/Vizianagaram/A. P.
A23	FMV23	*E. coracana*	2009	IE 3470	Finger	ARS/Vizianagaram/A. P.
A24	FMV24	*E. coracana*	2009	IE 4750	Leaf	ARS/Vizianagaram/A. P.
A25	FMV25	*E. coracana*	2008	IE 4759	Neck	ARS/Vizianagaram/A. P.
A26	FMV26	*E. coracana*	2009	IE 5736	Neck	ARS/Vizianagaram/A. P.
A27	FMNd27	*E. coracana*	2009	VR 708	Finger	RARS/Nandyal/A. P.
A28	FMNd28	*E. coracana*	2009	IE 501	Neck	RARS/Nandyal/A. P.
A29	FMNd29	*E. coracana*	2009	IE 518	Neck	RARS/Nandyal/A. P.
A30	FMNd30	*E. coracana*	2009	IE 588	Finger	RARS/Nandyal/A. P.
A31	FMNd31	*E. coracana*	2008	IE 3270	Neck	RARS/Nandyal/A. P.
A32	FMNd32	*E. coracana*	2009	IE 3470	Finger	RARS/Nandyal/A. P.
A33	FMNd33	*E. coracana*	2009	IE 4545	Neck	RARS/Nandyal/A. P.
A34	FMNd34	*E. coracana*	2008	IE 5525	Leaf	RARS/Nandyal/A. P.
A35	FMNd35	*E. coracana*	2008	IE 5788	Leaf	RARS/Nandyal/A. P.
A36	FMNd36	*E. coracana*	2008	IE 5843	Leaf	RARS/Nandyal/A. P.

A37	FMNd37	*E. coracana*	2008	IE 6055	Leaf	RARS/Nandyal/A. P.
A38	FMNd38	*E. coracana*	2008	IE 6165	Leaf	RARS/Nandyal/A. P.
K1	FMM39	*E. coracana*	2009	MR 6	Neck	ZARS/Mandya/Karnataka
K2	FMM40	*E. coracana*	2009	IE 518	Finger	ZARS/Mandya/Karnataka
K3	FMM41	*E. coracana*	2009	IE 588	Neck	ZARS/Mandya/Karnataka
K4	FMM42	*E. coracana*	2009	IE 2790	Neck	ZARS/Mandya/Karnataka
K5	FMM43	*E. coracana*	2009	IE 3470	Finger	ZARS/Mandya/Karnataka
K6	FMM44	*E. coracana*	2008	IE 5177	Finger	ZARS/Mandya/Karnataka
K7	FMM45	*E. coracana*	2009	IE 6165	Leaf	ZARS/Mandya/Karnataka

K8	FMM46	*E. coracana*	2009	IE 6165	Finger	ZARS/Mandya/Karnataka
K9	FMM47	*E. coracana*	2009	IE 6337	Node	ZARS/Mandya/Karnataka
K10	FMNg48	*E. coracana*	2009	MR 6	Leaf	OFRS/Naganahalli/Mysore/Karnataka
K11	FMNg49	*E. coracana*	2009	IE 518	Neck	OFRS/Naganahalli/Mysore/Karnataka
K12	FMNg50	*E. coracana*	2009	IE 2572	Leaf	OFRS/Naganahalli/Mysore/Karnataka
K13	FMNg51	*E. coracana*	2009	IE 2572	Neck	OFRS/Naganahalli/Mysore/Karnataka
K14	FMNg52	*E. coracana*	2009	IE 2572	Finger	OFRS/Naganahalli/Mysore/Karnataka
K15	FMNg53	*E. coracana*	2009	IE 4545	Neck	OFRS/Naganahalli/Mysore/Karnataka
K16	FMNg54	*E. coracana*	2009	IE 6154	Leaf	OFRS/Naganahalli/Mysore/Karnataka
K17	FMNg55	*E. coracana*	2009	IE 6154	Neck	OFRS/Naganahalli/Mysore/Karnataka
B1	FMD56	*E. coracana*	2008	IE 2857	Neck	RAU/Dholi/Bihar
A39	FxMP57	*S. italica*	2009	ISe 376	Leaf	ICRISAT/Patancheru/Medak/A. P.
A40	FxMNd58	*S. italica*	2008	ISe 1541	Leaf	RARS/Nandyal/A. P.
A41	FxMV59	*S. italica*	2008	ISe 376	Leaf	ARS/Vizianagaram/A. P.
A42	FxMV60	*S. italica*	2009	ISe 376	Leaf	ARS/Vizianagaram/A. P.
K18	FxMM61	*S. italica*	2009	ISe 376	Leaf	ZARS/Mandya/Karnataka
K19	FxMM62	*S. italica*	2009	ISe 1541	Leaf	ZARS/Mandya/Karnataka
K20	RM 63	*O. sativa*	2009	Vijaya	Leaf	ZARS/Mandya/Karnataka
K21	RM 64	*O. sativa*	2010	Vijaya	Leaf	ZARS/Mandya/Karnataka
K22	RM 65	*O. sativa*	2010	Vijaya	Leaf	ZARS/Mandya/Karnataka
M1	PMA 66	*P. typhoides*	2009	Great 555	Leaf	Farmers field/Aurangabad/Maharashtra
H1	PMH 67	*P. typhoides*	2009	ICMB 95222	Leaf	Farmers field/Hissar/Haryana
R1	PMJ 68	*P. typhoides*	2009	ICMB 95444	Leaf	ARS/Durgapura/Jaipur/Rajasthan
A43	PMP 69	*P. typhoides*	2009	ICMB 89111	Leaf	ICRISAT, Patancheru/Medak/A.P.
HP1	PMS70	*P. typhoides*	2010	Local	Leaf	Farmers field/Solan/Himachal Pradesh

ICRISAT: International Crops research Institute for the Semi-Arid Tropics; A.P: Andhra Pradesh; ARS: Agricultural Research Station; RARS: Regional Agricultural Research Station; ZARS: Zonal Agricultural Research Station; OFRS: Organic Farming Research Station

Table 4.2. Number of *M. grisea* isolates from different plant parts and locations

S. No.	Location	State	Leaf	Node	Neck	Finger	Total
1	ICRISAT, Patancheru	Andhra Pradesh	2	-	6	7	15
2	ARS, Vizianagaram	Andhra Pradesh	3	-	8	4	15
3	RARS, Nandyal	Andhra Pradesh	6	-	4	3	13
4	ZARS, Mandya	Karnataka	5	1	4	4	14
5	OFRS, Naganahalli	Karnataka	2	-	4	2	8
6	RAU, Dholi	Bihar	-	-	1	-	1
7.	Aurangabad	Maharashtra	1	-	-	-	1
8.	Hissar	Haryana	1	-	-	-	1
9.	ARS, Durgapura, Jaipur	Rajasthan	1	-	-	-	1
10.	Solan	Himachal Pradesh	1	-	-	-	1
		Total	22	1	27	20	70

Table 4.3. Number of *M. grisea* isolates from different crops and plant parts

S. No.	Crop	Location	Leaf	Node	Neck	Finger	Total
1.	Finger Millet	ICRISAT, Patancheru	-	-	6	7	13
		ARS, Vizianagaram	1		8	4	13
		RARS, Nandyal	5	-	4	3	12
		ZARS, Mandya	-	1	4	4	9
		OFRS, Naganahalli	2	-	4	2	8
		RAU, Dholi	-	-	1	-	1
						Total	**56**
2.	Foxtail Millet	ICRISAT, Patancheru	1	-	-	-	1
		ARS, Vizianagaram	2	-	-	-	2
		RARS, Nandyal	1	-	-	-	1
		ZARS, Mandya	2	-	-	-	2
						Total	**6**
3.	Rice	ZARS, Mandya	3	-	-	-	**3**
4.	Pearl Millet	Aurangabad	1	-	-	-	1
		Hissar	1	-	-	-	1
		ARS, Durgapura, Jaipur	1	-	-	-	1
		ICRISAT, Patancheru	1	-	-	-	1
		Solan	1	-	-	-	1
						Total	**5**
Total			**22**	**1**	**27**	**20**	**70**

Table 4.4. Cultural characteristics of the isolates of *M. grisea* collected from different hosts and locations

Isolate No.	Origin	Growth pattern	Colour on media	Colour of the vegetative growth	Texture/surface appearance
FMP1	Finger millet	Subdued + tuft + small radiating sectors	Brown	Grayish brown	Rough surface and sporulation was abundant in the radiating sectors
FMP2	Finger millet	Submerged + no sector formation	Brown	Grayish brown	Smooth surface
FMP3	Finger millet	Submerged + no sector formation	Brown	Grayish green	Smooth surface
FMP4	Finger millet	Subdued + tuft + radiating sectors	Brown	Grayish green	Rough surface
FMP5	Finger millet	Subdued + compact + sector formation	Brown	Grayish brown	Rough surface
FMP6	Finger millet	Submerged + no sector formation	Black	Grayish green	Smooth surface
FMP7	Finger millet	Compact + tuft + no sector formation	Brown	Grayish white	Rough surface
FMP8	Finger millet	Compact + tuft + no sector formation		Grayish brown	Smooth surface
FMP9	Finger millet	Subdued + compact + radiating sectors + growth in concentric rings	Brown	Grayish brown	Rough surface and sporulation was abundant in the sectors
FMP10	Finger millet	Subdued + tufted growth	Black	Grayish brown	Smooth surface
FMP11	Finger millet	Cottony + no sector formation	Black	Grayish brown	Smooth surface
FMP12	Finger millet	Subdued + compact + single tufted sector	Brown	Grayish white	Smooth surface
FMP13	Finger millet	Cottony growth + small tufted growth forming sectors	Black	Grayish green in sectored region and remaining white	Rough surface and sporulation only in sectored region
FMV14	Finger millet	Subdued + radiating sector	Brown	Grayish brown	Rough surface
FMV15	Finger millet	Cottony growth + radiating sector	Black	Grayish white	Smooth surface and sporulation was abundant in the sector
FMV16	Finger millet	Cottony growth + compact + ringed sector formation	Black	Grayish white	Smooth surface

FMV17	Finger millet	Cottony + tuft + sector formation	Brown	Grayish brown	Rough surface
FMV18	Finger millet	Cottony + subdued + sector formation	Brown	Grayish white	Rough surface
FMV19	Finger millet	Compact + sector in concentric rings	Brown	Grayish brown	Rough surface and sporulation was abundant in rings
FMV20	Finger millet	Submerged scanty aerial mycelium + tufted growth + no sector formation	Brown	Grayish brown	Rough surface and sporulation was uniform
FMV21	Finger millet	Submerged scanty aerial mycelium + no sector formation	Brown	Grayish white	Smooth surface
FMV22	Finger millet	Submerged + compact + no sector formation	Black	Grayish white	Smooth surface
FMV23	Finger millet	Subdued + tuft + no sector formation	Black	Grayish brown	Smooth surface
FMV24	Finger millet	Subdued + sector formation	Brown	Grayish white	Smooth surface
FMV25	Finger millet	Subdued +compact + no sector formation	Brown	Grayish green	Rough surface and sporulation was uniform
FMV26	Finger millet	Submerged scanty aerial mycelium + no sector formation		Grayish white	Smooth surface
FMNd27	Finger millet	Submerged scanty aerial mycelium + sector formation	Black	Grayish brown	Rough surface
FMNd28	Finger millet	Compact aerial mycelium + sectors in concentric rings	Brown	Grayish green	Rough surface and sporulation was abundant in sectors
FMNd29	Finger millet	Cottony + no sector formation	Brown	Grayish white	Smooth surface
FMNd30	Finger millet	Compact + tuft + ringed sectors	Brown	Grayish brown	Rough surface
FMNd31	Finger millet	Subdued + compact growth + ringed sector	Black	Grayish green	Smooth surface and sporulation was abundant in the sector
FMNd32	Finger millet	Submerged + sector formation	Brown	Grayish white	Smooth surface
FMNd33	Finger millet	Subdued + radiating sectors	Brown	Grayish brown	Rough surface

FMNd34	Finger millet	Subdued + compact + sectors in concentric rings	Brown	Grayish green in sector and white in periphery	Smooth surface and sporulation was abundant in the sector
FMNd35	Finger millet	Subdued + tufted growth + ringed sector	Brown	Grayish green	Rough surface and sporulation was abundant in the ringed sector
FMNd36	Finger millet	Submerged scanty aerial mycelium + no sector formation	Black	Grayish white	Rough surface
FMNd37	Finger millet	Submerged scanty aerial mycelium + no sector formation	Brown	Grayish green	Rough surface and sporulation was abundant in the center
FMNd38	Finger millet	Cottony white growth + small tufted sector formation	Brown	Grayish white	Smooth surface
FMM39	Finger millet	Cottony + subdued + no sector formation	Black	Grayish white	Rough surface
FMM40	Finger millet	Subdued + ringed sector formation	Brown	Grayish green	Rough surface and sporulation was abundant in the ring
FMM41	Finger millet	Submerged scanty aerial mycelium + no sector formation	Brown	Grayish brown	Rough surface
FMM42	Finger millet	Cottony + sectors in concentric rings + two radiating sectors	Black	Grayish green	Rough surface and sporulation was abundant in first sector
FMM43	Finger millet	Cottony growth + tuft + sector formation	Brown	Grayish white	Rough surface
FMM44	Finger millet	Cottony growth, no sector formation	Brown	Grayish white aerial mycelium	Smooth surface
FMM45	Finger millet	Subdued + compact + no sector formation	Brown	Grayish green	Rough surface and sporulation was abundant in the center
FMM46	Finger millet	Subdued + compact + no sector formation	Brown	Grayish green	Rough surface and sporulation was abundant in the center

FMM47	Finger millet	Cottony growth + compact + radiating sectors	Brown	Grayish green	Rough surface and sporulation was abundant in the first ring of the sector
FMNg48	Finger millet	Cottony + tufted growth + ringed sector formation	Brown	Grayish green	Smooth surface
FMNg49	Finger millet	Submerged + sector in concentric rings	Brown	Grayish green	Smooth surface
FMNg50	Finger millet	Subdued + tuft + no sector formation	Grayish white	Grayish white aerial mycelium	Smooth surface
FMNg51	Finger millet	Subdued + tuft + no sector formation	Grayish white	Grayish white	Smooth surface
FMNg52	Finger millet	Subdued + tuft + no sector formation	Grayish white	Grayish white	Smooth surface
FMNg53	Finger millet	Cottony aerial mycelium + radiating sector formation	Brown	Grayish white	Smooth surface and sporulation was abundant in the sectored region
FMNg54	Finger millet	Cottony + tufted growth + growth in concentric circles + radiating sectors	Brown	Grayish white	Smooth surface
FMNg55	Finger millet	Cottony + tufted growth + sector formation	Brown	Grayish green	Smooth surface and sporulation was abundant in the sectored region
FMD56	Finger millet	Subdued + aerial mycelium + radiating sector, brown in colour	Brown	Grayish brown	Rough growth and sporulation was abundant in the center
FxMP57	Foxtail millet	Subdued + compact + no sectoring	Black	Grayish white	Smooth growth and sporulation was uniform
FxMNd58	Foxtail millet	Subdued + submerged + sector in concentric rings	Brown	Grayish white	Smooth growth
FxMV59	Foxtail millet	Submerged + compact scanty aerial mycelium + no sectoring	Black	Grayish white	Smooth growth and sporulation was uniform
FxMV60	Foxtail millet	Submerged + compact scanty aerial mycelium + no sectoring	Black	Grayish white	Smooth growth and sporulation was uniform

FxMM61	Foxtail millet	Compact + ringed sector (grayish brown colour)	Brown	Grayish green	Rough surface and sporulation was abundant in the sectored region
FxMM62	Foxtail millet	Compact + ringed sector (golden brown colour)	Brown	Grayish green	Rough surface and sporulation was abundant in the sectored region
RM 63	Rice	Cottony + no sector formation	Brownish black	Grayish white	Smooth surface
RM 64	Rice	Subdued + tuft + no sector formation	Black	Grayish green	Rough surface
RM 65	Rice	Subdued + tuft + no sector formation	Black	Grayish green	Rough surface
PMA 66	Pearl millet	Submerged + compact + no sector formation	Brown	Grayish brown	Smooth surface and sporulation was uniform
PMH 67	Pearl millet	Submerged + compact + no sector formation	Brown	Grayish brown	Smooth surface
PMJ 68	Pearl millet	Submerged + tufted growth + no sector formation	Brown	Grayish brown	Smooth surface
PMP 69	Pearl millet	Subdued + submerged + no sector formation	Brown	Grayish brown	Smooth surface and sporulation was uniform
PMS 70	Pearl millet	Subdued + tuft + no sector formation	Brown	Grayish brown	Smooth surface

Table 4.5. Pathogenicity, colony diameter (mm), conidia size (µm) and sporulation (index 0–4)[a] of *M. grisea* isolates from different crops

Isolate No.	Origin	Leaf blast (1-9 scale)	Colony dia. (mm)	Conidia size (µm)		Sporulation
				Range	Average	
FMP1	Finger millet	7.05	84	14 – 28×6–9	20.9 ×7.7	4
FMP2	Finger millet	5.25	73	12.2–18.1×2–3	15.15×2.5	2
FMP3	Finger millet	6.2	73	13–20×3–5	15.2 ×3.5	4
FMP4	Finger millet	7.5	78	11.1–15.5×2–3	13.3 ×2.5	4
FMP5	Finger millet	5.7	77	10.2–20×5–6	13.8 ×4.2	4
FMP6	Finger millet	3.95	76	15.2–21.5×4.2–6	18.35×5.1	2
FMP7	Finger millet	5.55	79	17.2–25×6–8	20.2 ×6.8	1
FMP8	Finger millet	4.75	81	14.5–20.5×3–6	17.5×4.5	1
FMP9	Finger millet	5.7	76	14–28×5–9	20.9 ×7.7	4
FMP10	Finger millet	4.15	76	11.3–22.1×5–9	15.15× 7.5	2
FMP11	Finger millet	4.75	81	13–20×3–5	15.2×3.5	2
FMP12	Finger millet	3.85	79	11.8–15.9×4 –5	14.2×4.5	2
FMP13	Finger millet	3.65	82	10.2–21.1×6–10	17.1×7.2	3
FMV14	Finger millet	6.75	70.5	15.2–21.5×4.2–6	18.35× 5.1	4
FMV15	Finger millet	3.25	71	17.2–25×6–8	20.2×6.8	2
FMV16	Finger millet	4.85	71	12.8–25.7×5–7	18.5×6.5	2
FMV17	Finger millet	3.95	73	14.5–20.5×3–6	17.5×4.5	1
FMV18	Finger millet	4.6	72	14–28×6–9	20.9×7.7	2
FMV19	Finger millet	6.2	75	12.2–18.1×2–3	15.15× 2.5	4
FMV20	Finger millet	8.1	68.5	15.2–21.5×4.2–6	18.35× 5.1	4
FMV21	Finger millet	4	65	17.2–25×6–8	20.2×6.8	3
FMV22	Finger millet	4.1	55	14.5–20.5×3–6	17.5×4.5	1
FMV23	Finger millet	6.95	73	15.2–21.5×4.2–6	18.35× 5.1	4
FMV24	Finger millet	5	49	15–29.5×6–10	20.8×8.2	2
FMV25	Finger millet	6.85	74	10.8–22.1×3–8	17.5×5.5	4
FMV26	Finger millet	4.65	79	14–28×6–9	20.9×7.7	2
FMNd27	Finger millet	3.15	67	12.2–18.1×2–3	15.15×2.5	1
FMNd28	Finger millet	7.1	66.5	13–20×3–5	15.2×3.5	4
FMNd29	Finger millet	4.2	57	11.1–15.5×2–3	13.3×2.5	1
FMNd30	Finger millet	5.9	77	10.3–21×5.1–6	13.8×5.4	4
FMNd31	Finger millet	6.85	81	14.2–22.5×5.2–8	18.35× 6.1	4
FMNd32	Finger millet	5.8	75	17.2–25×6–8	20.2×6.8	4
FMNd33	Finger millet	8.7	75	14.7–25.1×3 –6	18.5×4.8	4
FMNd34	Finger millet	3.3	79	14.5–20.5×3–6	17.5×4.5	1
FMNd35	Finger millet	4.55	74	14–28×6–9	20.9×7.7	3
FMNd36	Finger millet	6.6	76	12.2–18.1×2–3	15.15×2.5	2
FMNd37	Finger millet	4.45	83	14.3–27.2×5–7	21.9×6.7	2

FMNd38	Finger millet	3.25	81	13.5–29.1×4–8	20.1×5.5	2
FMM39	Finger millet	5.6	65	13.2–20.4×3–6	14.2×4.5	2
FMM40	Finger millet	4.7	69	11.1–15.5×2–3	13.3×2.5	1
FMM41	Finger millet	3.35	69	10.2–20×5–6	13.8×4.2	1
FMM42	Finger millet	8.6	69	15.2–21.5×4.2–6	18.35×5.1	4
FMM43	Finger millet	7	73	17.2–25×6–8	20.2×6.9	4
FMM44	Finger millet	3.05	76	14.5–20.5×3 –6	17.5×4.5	3
FMM45	Finger millet	6.2	72	11.1–15.5×2–3	13.3×2.5	3
FMM46	Finger millet	3.95	71	10.2–20×5–6	13.8×5.7	2
FMM47	Finger millet	7.75	70	15.2–21.5×4.2–6	18.35× 5.1	2
FMNg48	Finger millet	5.35	81	17.2–25×6–8	20.2×6.7	2
FMNg49	Finger millet	3.75	70	14.5–20.5×3–6	17.5×4.5	1
FMNg50	Finger millet	3.6	73	11.2–20×5–6.5	13.8×5.8	1
FMNg51	Finger millet	6.3	77	17.5–25.6×4–8	20.5×6.5	3
FMNg52	Finger millet	5.05	59	14.2–23.5×4.9–6	19.35× 5.0	3
FMNg53	Finger millet	4.9	61	16.2–27.2×5–8	23.2×6.4	2
FMNg54	Finger millet	5.5	77	13.5–27.5×5–9	18.5×6.5	2
FMNg55	Finger millet	8.25	69	17.6–25.1×6–9	21.2×6.9	3
FMD56	Finger millet	7.8	70	18.8–30.5×6.2–10	21.5×8.5	3
FxMP57	Foxtail millet	8.55	62	14–35×5–12	20×7.5	4
FxMNd58	Foxtail millet	8.9	62.5	12–30×6–10	22×8.2	4
FxMV59	Foxtail millet	8.95	65	13–32×6–10	19×7.8	3
FxMV60	Foxtail millet	8.95	77	15–30×7–10	20×8	4
FxMM61	Foxtail millet	9	65	12–28×6–10	19×7	4
FxMM62	Foxtail millet	8.85	61	10–29×8–12	24×9	4
RM 63	Rice	-	59	17.6–22.5×5–7	20.0×6.0	3
RM 64	Rice	-	63.5	17.5–24×6.5–8	20.7×7.25	3
RM 65	Rice	-	61	15.2–21.5×4.2–6	18.35× 5.1	2
PMA 66	Pearl millet	8.15	49.5	18.4–36.7×7.4–11	27.5×9.2	4
PMH 67	Pearl millet	7.5	50.5	17.2–35×8–10	25.2×8.2	3
PMJ 68	Pearl millet	7.2	49	16–32×7–12	24.1×9.1	4
PMP 69	Pearl millet	8.55	54.5	12–31×6–10	21.5×7.5	4
PMS 70	Pearl millet	7.75	51	15–28×7–9.1	24.3×8.2	3
	Mean	5.8	70			
	SE (m)±	0.36	1.19			
	LSD (*P*>0.001)	1.35	4.5			

Sporulation	**No. of spores / microscopic field**	**Index[a]**
Excellent	>30	4
Good	20–30	3
Fair	10–20	2
Poor	<10	1
Nil	0	0

Table 4.6. Mean blast severity on tested FMBRSN accessions at five locations during the 2009 and 2010 rainy seasons

Entry No	Accession No.	Leaf blast reaction and severity[a]					Neck blast severity (1-5 scale)[b]					Finger blast severity (%)[c]				
		Pat[d]	Viz	Nan	Man	Nag	Pat	Viz	Nan	Man	Nag	Pat	Viz	Nan	Man	Nag
1	IE 2589	R/2.0	R/1.9	R/1.8	R/1.8	R/1.8	R/1.2	R/1.1	R/1.5	R/1.0	R/1.2	R/3.0	R/0.3	R/5.3	R/4.3	R/4.6
2	IE 2619	R/1.5	R/1.6	R/1.4	R/1.9	R/1.9	R/1.4	R/1.1	R/1.1	R/1.4	R/1.3	R/3.0	R/2.3	R/7.6	S/15.6	R/7.4
3	IE 2710	R/1.5	R/1.6	R/2.0	R/2.0	R/1.8	R/1.1	R/1.4	R/1.3	R/1.6	R/1.1	R/1.3	R/3.4	S/16.2	R/7.8	R/3.0
4	IE 2872	R/1.5	R/1.4	R/1.6	R/1.6	R/1.4	R/1.3	R/2.0	R/1.3	S/2.2	R/1.1	R/1.8	S/12	S/15.6	S/19.4	R/4.5
5	IE 2911	R/1.8	R/1.6	R/1.5	R/1.5	R/1.5	R/1.1	R/1.0	R/1.1	R/1.0	R/1.0	R/0.8	R/2.4	R/9.0	R/1.4	R/1.5
6	IE 2957	R/1.8	R/1.2	R/1.3	R/1.5	R/1.3	R/1.5	R/1.0	R/1.4	S/2.7	S/2.1	R/1.3	R/0.3	R/9.3	S/25.5	S/12.8
7	IE 3077	R/1.3	R/3.0	R/3.0	S/3.5	R/3.0	R/1.4	R/2.0	R/2.0	S/2.6	S/2.5	R/7.5	S/23.8	S/26.9	S/18.9	S/16.9
8	IE 3392	R/1.5	R/2.4	R/1.5	R/2.0	R/1.5	R/1.4	R/1.3	S/3.4	R/1.2	R/1.2	R/1.8	R/3.4	S/37	S/13.8	R/4.5
9	IE 3543	R/2.0	S/3.4	S/3.4	S/4.3	S/4.0	S/2.6	S/4.3	S/3.5	S/3.3	S/3.7	S/17.9	S/41.5	S/34.3	S/24.8	S/34.3
10	IE 4057	R/2.0	R/2.9	R/2.6	R/2.7	R/2.4	R/1.1	R/1.5	S/4.8	R/1.5	R/1.1	R/2.3	R/3.3	S/60.8	S/13.3	R/2.3
11	IE 4497	R/1.5	R/1.4	R/1.2	R/1.2	R/1.2	R/1.5	R/1.2	R/1.5	R/1.0	R/1.2	R/4.4	R/0.9	R/9.8	R/6.9	R/6.0
12	IE 4755	R/2.1	S/4.9	R/4.2	S/4.1	S/3.6	S/3.2	S/3.5	S/3.1	S/3.0	S/3.5	S/18.5	S/39.8	S/30.5	S/35	S/48.5
13	IE 4759	R/2.4	S/5.2	R/2.8	R/2.8	R/2.7	S/3.3	S/3.5	S/3.2	S/4.0	S/4.0	S/20	S/37	S/30.5	S/47.5	S/50
14	IE 4797	S/3.5	R/2.3	R/2.5	R/2.2	R/2.2	S/2.7	R/1.6	R/1.8	S/4.0	S/2.3	S/25.6	R/6.3	R/18	S/44.5	S/20.5
15	IE 5066	R/1.5	R/2.0	R/1.7	R/1.5	R/1.5	R/1.2	R/1.6	R/1.2	S/4.1	S/3.5	R/2.0	S/11.3	R/18	S/37.6	S/25
16	IE 5091	R.1.5	R/1.4	R/2.3	R/2.7	R/2.5	R/1.8	R/1.7	S/4.4	S/4.7	R/1.9	R/8.9	S.10.6	S/39.8	S/42.5	S/11.9
17	IE 5106	R/1.5	R/1.1	R/2.2	R/2.5	R/2.2	R/1.6	R/1.2	S/2.1	R/1.7	R/1.2	R/3.6	R/3.4	S/23	S/11.9	R/4.6
18	IE 5817	R/1.8	R/1.8	R/2.8	R/2.8	S/3.3	S/2.7	S/2.2	S/3.0	S/4.6	S/4.1	S/19	S/15.5	S/25.8	S/53.8	S/28.3
19	IE 5870	S/3.5	R/2.7	S/4.4	S/4.2	S/4.9	S/3.8	S/2.3	S/4.3	S/4.8	S/4.5	S/33.5	S/19.3	S/37.5	S/52.5	S/46.5
20	IE 6082	S/4.3	R/1.1	S/4.4	S/4.4	S/4.1	S/5.0	S/3.0	S/4.1	S/3.5	S/3.4	S/56	S/26	S/33.3	S/37	S/31.5
21	IE 6221	R/2.0	R/2.9	S/3.4	S/3.5	S/3.6	S/2.2	R/2.0	R/1.5	S/3.4	R/1.7	S/14.6	S/10.3	S/18.3	S/41.3	S/14.3
22	IE 6240	R/2.0	S/3.2	S/3.1	S/3.1	R/2.9	R/1.6	R/1.2	S/3.0	S/3.1	R/2.0	R/9.1	R/6.0	S/32.8	S/28.3	S/11
23	IE 6337	R/2.0	R/2.0	R/1.3	R/1.8	R/1.8	R/1.4	R/1.3	R/1.4	R/1.4	R/1.2	R/2.3	R/2.5	R/9.0	R/7.3	R/5.4
24	IE 6421	R/1.5	R/1.7	R/2.3	R/2.3	R/2.3	R/1.5	R/1.8	R/3.2	R/1.9	R/1.1	R/4.9	S/12	S/30.3	S/16.3	R/3.8
25	IE 7018	R/2.0	R/1.5	R/1.6	R/1.9	R/1.9	R/1.4	R/1.0	R/1.0	R/1.4	R/1.0	R/4.0	R/2.0	R/9.8	R/6.1	R/1.8
26	IE 7079	R/2.0	R/1.5	R/2.0	R/2.2	R/2.0	R/1.2	R/1.0	R/1.0	S/2.9	R/1.2	R/3.5	R/5.3	S/16.3	S/28.5	R/6.3
27	VR 708 (SC)	S/5.2	S/6.3	S/4.5	S/4.5	S/5.1	S/4.4	S/4.3	S/4.4	S/4.5	S/4.7	S/39.3	S/55.3	S/42.3	S/45.5	S/42
	Mean	2.1	2.1	2.3	2.5	2.4	1.9	1.6	2.3	2.6	2.0	10.6	9.9	22.6	24.2	13.2
No. of lines with S reaction		4	5	6	8	7	9	7	12	16	11	9	13	18	21	14

[a]Leaf blast severity on a 1–9 scale where 1= no infection and 9= >75% leaf area covered with lesions, R: Resistant reaction (≤3.0); S: Susceptible (>3.0), [b]Neck blast severity on a 1–5 scale where 1= no infection/pinhead size lesions and 5= >6 cm lesions on the neck region, R: Resistant reaction (≤2.0 on 1–5 scale); S: Susceptible (>2.0), [c]Finger blast severity (%) across all panicles/all tillers in a row, R: Resistant reaction (≤10%); S: Susceptible (>10%), [d]**Pat** = Patancheru; **Viz** = Vizianagaram; **Nan** = Nandyal; **Man** = Mandya; **Nag** = Naganahalli;

Table 4.7. Leaf blast severity (1–9 scale)[1] of five *M. grisea* isolates (one isolate / location) on 28 Finger Millet Blast Resistant Stability Nursery (FMBRSN-2010) accessions

Entry No.	Accession No	Leaf blast caused by *M. grisea* isolates[2]					Mean
		FMP1	FMV20	FMNd33	FMM42	FMNg55	
1	IE 2589	3.0	3.1	5.5	6.7	6.5	5.0
2	IE 2619	2.0	3.0	5.0	6.2	5.3	4.3
3	IE 2710	2.0	2.5	3.1	5.8	3.7	3.4
4	IE 2872	1.1	3.0	3.5	5.7	5.0	3.7
5	IE 2911	1.2	1.8	2.2	3.5	3.2	2.4
6	IE 2957	1.5	2.0	2.2	3.0	3.2	2.4
7	IE 3077	3.9	5.2	4.7	4.5	5.6	4.8
8	IE 3392	1.9	3.7	2.8	4.6	7.3	4.0
9	IE 3543	4.4	5.2	7.3	4.8	4.6	5.2
10	IE 4057	3.0	3.3	4.5	5.9	4.4	4.2
11	IE 4497	2.5	2.2	2.2	3.0	4.4	2.8
12	IE 4755	5.4	7.5	5.4	6.7	5.3	6.0
13	IE 4759	3.8	5.0	4.1	4.2	4.7	4.4
14	IE 4797	4.0	4.0	4.6	7.6	7.2	5.5
15	IE 5066	2.0	2.5	3.5	4.6	4.2	3.3
16	IE 5091	2.3	2.5	4.4	4.0	5.5	3.7
17	IE 5106	2.4	3.2	5.2	4.0	6.2	4.2
18	IE 5817	2.1	2.5	5.5	3.4	4.5	3.6
19	IE 5870	3.4	4.6	7.2	6.8	7.9	5.9
20	IE 6082	5.1	2.0	7.3	8.6	8.4	6.3
21	IE 6221	2.0	3.7	5.2	4.9	4.2	4.0
22	IE 6240	1.2	3.6	5.0	5.8	5.3	4.2
23	IE 6337	1.7	3.0	2.5	5.9	3.0	3.2
24	IE 6421	2.2	2.6	4.0	4.8	4.9	3.7
25	IE 7018	1.5	2.9	3.9	6.3	4.3	3.7
26	IE 7079	4.0	2.2	7.5	5.2	5.4	4.8
27	GPU 28	3.3	2.6	2.3	2.8	3.1	2.8
28	VR 708	6.6	7.5	6.1	5.9	6.5	6.5
	Mean	2.8	3.4	4.5	5.2	5.1	4.2

[1] Mean of two replications
SE (m)± for isolate (I) means = 0.07; for accession (A) means = 0.17; for I × E means = 0.40
LSD (P<0.01) for isolate (I) means = 0.21; for entry means = 0.6; and for I × E means = 1.5

[2] **FMP1**: FM isolate from Patancheru and isolate no. 1; **FMV20**: FM isolate from Vizianagaram and isolate no. 20; **FMNd33**: FM isolate from Nandyal and isolate no. 33; **FMM42**: FM isolate from Mandya and isolate no. 42; **FMNg55**: FM isolate from Naganahalli and isolate no. 55

Table 4.9. Leaf blast reaction of five isolates of *M. grisea* (one isolate/location) on 28 Finger Millet Blast Resistant Stability Nursery (FMBRSN-2010) accessions

	Leaf blast reaction caused by *M. grisea* isolates[a]

Accession No.	FMP1	FMV20	FMNd33	FMM42	FMNg55	Mean	Reaction
IE 2589	R	S	S	S	S	S	1R:4S
IE 2619	R	R	S	S	S	S	2R:3S
IE 2710	R	R	S	S	S	S	2R:3S
IE 2872	R	R	S	S	S	S	2R:3S
IE 2911	R	R	R	S	S	R	3R:2S
IE 2957	R	R	R	R	S	R	4R:1S
IE 3077	S	S	S	S	S	S	0R:5S
IE 3392	R	S	R	S	S	S	2R:3S
IE 3543	S	S	S	S	S	S	0R:5S
IE 4057	R	S	S	S	S	S	1R:4S
IE 4497	R	R	R	R	S	R	4R:1S
IE 4755	S	S	S	S	S	S	0R:5S
IE 4759	S	S	S	S	S	S	0R:5S
IE 4797	S	S	S	S	S	S	0R:5S
IE 5066	R	R	S	S	S	S	2R:3S
IE 5091	R	R	S	S	S	S	2R:3S
IE 5106	R	S	S	S	S	S	1R:4S
IE 5817	R	R	S	S	S	S	2R:3S
IE 5870	S	S	S	S	S	S	0R:5S
IE 6082	S	R	S	S	S	S	1R:4S
IE 6221	R	S	S	S	S	S	1R:4S
IE 6240	R	S	S	S	S	S	1R:4S
IE 6337	R	R	R	S	R	S	4R:1S
IE 6421	R	R	S	S	S	S	2R:3S
IE 7018	R	R	S	S	S	S	2R:3S
IE 7079	S	R	S	S	S	S	1R:4S
GPU 28	S	R	R	R	S	R	3R:2S
VR 708	S	S	S	S	S	S	0R:5S
Reaction	R	S	S	S	S	S	1R:4S
R:S ratio	18R:10S	15R:13S	6R:22S	3R:25S	1R:27S	4R:24S	-

R : Resistant reaction (≤3.0 on 1–9 scale)
S : Susceptible reaction (>3)

[a] **FMP1**: FM isolate from Patancheru and isolate no. 1; **FMV20**: FM isolate from Vizianagaram and isolate no. 20; **FMNd33**: FM isolate from Nandyal and isolate no. 33; **FMM42**: FM isolate from Mandya and isolate no. 42; **FMNg55**: FM isolate from Naganahalli and isolate no. 55.

Table 4.10. Leaf blast severity (1–9 scale)[a] of 25 isolates of *M. grisea* from five locations on 12 host differential accessions

Location	Isolate No.	Differential accessions												Mean
		IE 2619	IE 2911	IE 2957	IE 3392	IE 4057	IE 4497	IE 5091	IE 6240	IE 6337	IE 7079	GPU 28	VR 708	
Pat	FMP1	2.0	1.2	1.5	1.9	3.0	2.5	2.3	1.2	1.7	4.0	3.3	6.6	2.6
Pat	FMP3	4.2	1.4	3.5	2.2	2.4	2.5	2.3	2.8	2.2	2.4	2.9	6.4	2.9
Pat	FMP4	3.6	2.2	3.4	2.5	2.9	3.0	2.2	3.1	2.1	4.4	2.7	6.1	3.2
Pat	FMP5	5.3	1.8	3.4	5.1	4.5	4.6	4.2	7.5	4.7	4.4	3.3	6.8	4.6
Pat	FMP9	3.0	1.9	2.1	2.9	3.0	2.2	2.3	3.1	1.9	3.0	3.0	5.7	2.8
Viz	FMV14	5.0	2.5	2.0	2.3	3.0	4.0	2.0	4.0	4.5	2.9	1.7	7.0	3.4
Viz	FMV19	5.6	4.0	4.0	5.5	6.0	7.7	2.0	6.5	2.5	6.5	3.5	7.0	5.1
Viz	FMV20	3.0	1.8	2.0	3.7	3.3	2.2	2.5	3.6	3.0	2.2	2.6	7.5	3.1
Viz	FMV23	5.5	4.8	4.8	9.0	8.5	5.7	8.0	7.3	5.2	7.5	2.3	9.0	6.5
Viz	FMV25	6.0	3.6	2.9	4.6	7.2	5.6	6.1	7.7	4.8	5.9	2.3	6.7	5.3
Nan	FMNd28	3.0	2.9	1.8	4.0	4.5	3.2	5.5	5.3	5.5	4.0	2.0	6.9	4.1
Nan	FMNd30	2.2	1.4	1.4	3.4	2.0	2.0	4.5	2.3	2.4	2.1	1.5	6.2	2.6
Nan	FMNd31	4.5	2.2	2.0	5.5	5.0	2.7	7.7	5.3	5.5	3.0	3.0	7.1	4.5
Nan	FMNd33	5.0	2.2	2.2	2.8	4.5	2.2	4.4	5.0	2.5	7.5	2.3	6.1	3.9
Nan	FMNd35	5.4	3.4	3.9	7.4	6.0	6.6	5.3	8.0	7.0	2.6	2.0	7.6	5.4
Man	FMM39	4.5	2.6	2.5	2.4	4.0	3.5	2.7	2.5	2.2	2.0	1.1	5.0	2.9
Man	FMM40	1.2	2.0	3.0	2.0	4.5	2.0	2.0	3.5	2.0	3.5	1.0	4.4	2.6
Man	FMM42	6.2	3.5	3.1	4.6	6.0	3.0	4.1	5.8	5.9	5.2	2.8	5.9	4.7
Man	FMM43	5.0	2.7	2.3	5.5	5.6	1.8	3.7	6.7	3.5	4.5	1.7	7.0	4.2
Man	FMM47	4.1	1.7	1.8	5.5	3.0	1.7	2.0	3.5	2.3	3.8	1.3	6.3	3.1
Nag	FMNg48	4.2	2.5	2.5	4.2	3.0	3.2	5.1	7.4	5.0	6.4	2.5	8.3	4.5
Nag	FMNg50	4.4	2.7	2.3	2.9	2.2	3.3	2.9	2.7	4.4	4.2	2.0	5.2	3.3
Nag	FMNg51	3.5	3.2	2.5	7.2	5.7	6.7	7.7	7.5	6.0	5.4	2.5	6.5	5.4
Nag	FMNg54	3.4	4.6	3.4	6.3	6.3	5.2	8.0	8.5	3.5	4.3	2.5	5.2	5.1
Nag	FMNg55	5.3	3.2	3.1	7.3	4.4	4.4	5.5	5.3	3.0	5.4	3.1	6.5	4.7
	Mean	4.2	2.6	2.7	4.4	4.4	3.7	4.2	5.0	3.7	4.3	2.4	6.5	4.0

[a]Mean of 2 replications, 10 plants/replication

	Location (L)	Isolate (I)	Accession (A)	L × A	I × A
SE (m)±	0.02	0.11	0.08	0.17	0.40
LSD (*P*>0.01)	0.17	0.46	0.29	0.63	1.47

Table 4.12. Disease reaction of 25 isolates of *M. grisea* from five locations on 12 host differential accessions

Isolates and location	Differential accessions												Reaction
	IE 2619	IE 2911	IE 2957	IE 3392	IE 4057	IE 4497	IE 5091	IE 6240	IE 6337	IE 7079	GPU 28	VR 708	
FMP1 (Pat)	R	R	R	R	R	R	R	R	R	S	S	S	9R:3S
FMP3	S	R	S	R	R	R	R	R	R	R	R	S	9R:3S
FMP4	S	R	S	R	R	R	R	S	R	S	R	S	7R:5S
FMP5	S	R	S	S	S	S	S	S	S	S	S	S	1R:11S
FMP9	R	R	R	R	R	R	R	S	R	R	R	S	10R:2S
FMV14 (Viz)	S	R	R	R	R	S	R	S	S	R	R	S	7R:5S
FMV19	S	S	S	S	S	S	R	S	R	S	S	S	2R:10S
FMV20	R	R	R	S	S	R	R	S	R	R	R	S	8R:4S
FMV23	S	S	S	S	S	S	S	S	S	S	R	S	1R:11S
FMV25	S	S	R	S	S	S	S	S	S	S	R	S	2R:10S
FMNd28 (Nan)	R	R	R	S	S	S	S	S	S	S	R	S	4R:8S
FMNd30	R	R	R	S	R	R	S	R	R	R	R	S	9R:3S
FMNd31	S	R	R	S	S	R	S	S	S	R	R	S	5R:7S
FMNd33	S	R	R	R	S	R	S	S	R	S	R	S	6R:6S
FMNd35	S	S	S	S	S	S	S	S	S	R	R	S	2R:10S
FMM39 (Man)	S	R	R	R	S	S	R	R	R	R	R	S	8R:4S
FMM40	R	R	R	R	S	R	R	S	R	S	R	S	8R:4S
FMM42	S	S	S	S	S	R	S	S	S	S	R	S	2R:10S
FMM43	S	R	R	S	S	R	S	S	S	S	R	S	4R:8S
FMM47	S	R	R	S	R	R	R	S	R	S	R	S	7R:5S
FMNg48 (Nag)	S	R	R	S	R	S	S	S	S	S	R	S	4R:8S
FMNg50	S	R	R	R	R	S	R	R	S	S	R	S	7R:5S
FMNg51	S	S	R	S	S	S	S	S	S	S	R	S	2R:10S
FMNg54	S	S	S	S	S	S	S	S	S	S	R	S	1R:11S
FMNg55	S	S	S	S	S	S	S	S	R	S	S	S	1R:11S
Reaction	S	R	R	S	S	S	S	S	S	S	R	S	3R:9S
R:S ratio	6R:19S	17R:8S	16R:9S	9R:16S	9R:16S	12R:13S	11R:14S	5R:20S	12R:13S	8R:17S	21R:4S	0R:25S	

R : Resistant reaction (≤3.0 on 1 – 9 scale)
S : Susceptible reaction (>3)

Table 4.13. Allele composition, polymorphic information content (PIC), gene diversity and heterozygosity (%) of the 17 SSR loci in 65 isolates of *M. grisea* from rice, finger millet and foxtail millet

Marker	Allele composition					PIC	Gene diversity	Average heterozygosity (%)
	Allelic richness	Size range (bp)	Rare allele (1%)	Common allele (1– ≤ 20%)	Most frequent allele (>20%)			
Pyrms 7	7	137	0	6	1	0.558	0.593	0.000
Pyrms 15	13	175	0	12	1	0.785	0.803	0.031
Pyrms 37	2	215	0	1	1	0.205	0.232	0.018
Pyrms 41	6	168	1	4	1	0.286	0.300	0.015
Pyrms 45	4	220	0	2	2	0.473	0.554	0.586
Pyrms 47	6	190	0	4	2	0.647	0.700	0.031
Pyrms 59	3	201	0	2	1	0.217	0.238	0.000
Pyrms 61	10	260	0	9	1	0.760	0.780	0.000
Pyrms 63	4	174	0	3	1	0.316	0.341	0.031
Pyrms 67	9	211	0	7	2	0.805	0.827	0.046
Pyrms 77	8	194	0	7	1	0.606	0.636	0.000
Pyrms 87	4	186	0	3	1	0.483	0.529	0.000
Pyrms 93	5	222	0	4	1	0.373	0.392	0.000
Pyrms 99	4	208	0	3	1	0.357	0.385	0.031
Pyrms 107	8	360	0	6	2	0.558	0.596	0.015
Pyrms 109	8	203	0	7	1	0.611	0.640	0.016
Pyrms 125	4	168	0	3	1	0.225	0.237	0.000
Total	105	-	1	83	21	-	-	-
Mean	6.18	-	0.05	4.88	1.23	0.486	0.517	0.048
Range	2–13	137–360	0–1	1–12	1–2	0.217–0.805	0232–0.827	0.000–0.586

Table 4.16. Effect of leaf wetness duration on leaf blast severity[a], lesion size and number of lesions per plant in finger millet

Leaf wetness duration (hours)	Leaf blast severity (1–9 scale)[b]	Lesion size (mm)	Number of lesions/plant
12	1.75	1.9	3.8
24	5.85	5.55	14.5
36	6.02	8.4	15.5
48	7.55	8.67	21
60	7.55	11.25	18.5
Control	1.0	0	0
Mean	4.94	6.0	12.1
SE (m)±[c]	0.54	0.84	1.66
LSD (P<0.01)[d]	0.49	1.5	4.12

[a] Mean of 4 replications and 10 plants/replication
[b] Leaf blast severity on a 1–9 scale where 1= no infection and 9= >75% leaf area covered with lesions
[c] Standard error mean
[d] Trial least significant difference.

Table 4.18. Influence of temperature on sporulation of *M. grisea* isolates on oat-meal agar medium

Isolate[b]	Radial growth (mm)[a]						Sporulation ($\times 10^4$ conidia ml^{-1})[a]					
	10°C	20°C	25°C	30°C	35°C	Mean	10°C	20°C	25°C	30°C	35°C	Mean
FMP1	2.7	46.5	71.5	66.5	0.4	37.5	0	1.3	3.4	2.1	0	1.3
FMV20	0	33.8	52.8	60.6	1.5	29.7	0	1.7	2.8	2.4	0	1.4
FMNd33	3.8	48.2	73	67.5	0.5	38.6	0	1.2	3.1	1.3	0	1.1
FMM42	2.1	54.7	73.6	66.0	0	39.3	0	1.6	2.6	2.2	0	1.3
FMNg55	5.6	54.2	72.1	66.3	0	39.6	0	0.8	1.7	3.0	0	1.1
FMD56	1.9	44.2	64.8	65.5	0	35.3	0	1.1	1.7	1.0	0	0.8
FxMP57	4.2	46.6	69.5	65.8	2.6	37.7	0	3.1	4.9	9.0	0	3.4
PMP69	4.1	47.2	66.3	70.3	3.0	38.2	0	1.0	2.3	5.2	0	1.7
Mean	3.0	46.9	67.98	66.0	1.0	37.0	0	1.5	2.8	3.3	0	1.5

[a] Mean of 4 replications

[b] **FMP1** = Finger millet isolate from Patancheru and isolate no.1; **FMV20** = Finger millet blast isolate from Vizianagaram and isolate no. 20; **FMNd33** = Finger millet blast isolate from Nandyal and isolate no. 33; **FMM42** = Finger millet blast isolate from Mandya and isolate no. 42; **FMNg 55** = Finger millet blast isolate from Naganahalli and isolate no. 55; **FMD56** = Finger millet isolate from Dholi and isolate no. 56; **FxMP57** = Foxtail millet blast isolate from Patancheru and isolate no. 57 and **PMP69** = Pearl millet blast isolate from Patancheru and isolate no. 69.

Factors	Radial growth		Sporulation	
	SE (m)±	LSD (*P*<0.01)	SE (m)±	LSD (*P*<0.01)
Temperature	0.5	1.9	0.12	0.46
Isolate	0.6	2.4	0.12	0.58
Temperature × Isolate	1.4	5.3	0.34	1.3

Table 4.20. Race/subrace of finger millet core collection and their reaction to blast under field conditions during 2009 rainy season, ICRISAT, Patancheru

Race/subrace	No. of accessions[a]	Neck Blast reaction[b]					Finger blast reaction[c]				
		HR	R	MR	S	HS	HR	R	MR	S	HS
Compacta	75	1	54	17	2	1	9	54	11	-	1
Elongata	50	5	29	13	2	0	3	26	14	3	3
Laxa	16	2	11	3	-	-	1	11	4	-	-
Reclusa	21	3	9	7	1	-	2	12	1	2	3
Sparsa	13	-	9	3	1	-	-	3	9	1	-
Plana	102	1	79	18	1	1	18	70	11	-	1
Confundere	81	1	64	15	-	-	15	58	7	-	-
Grandiglum a	5	-	3	1	-	-	1	2	1	-	-
Seriata	16	-	12	2	1	1	2	10	3	-	1
Vulgaris	379	4	224	115	28	8	27	221	92	26	13
Digitata	122	2	83	27	10	-	7	82	22	10	1
Incurvata	163	2	95	60	4	2	16	96	43	6	2
Liliacea	34	-	16	11	7	-	2	13	11	6	2
Stellata	60	-	30	17	7	6	2	30	16	4	8
Africana	16		5	8	2	1	1	7	5	1	2
Total	622	11	391	171	35	11	57	379	133	30	20

[a] Three entries data not available

[b] Neck blast reaction based on 1-5 scale: 0-1.0: Highly resistant **(HR)**; 1.1-2.0: Resistant **(R)**; 2.1-3.0: Moderately Resistant **(MR)**; 3.1-4.0: Susceptible **(S)**; 4.1-5.0: Highly Susceptible **(HS)**

[c] Finger blast severity (%): 0-1.0: Highly resistant **(HR)**; 2.0-10: Resistant **(R)**; 11-20: Moderately Resistant **(MR)**; 21-30: Susceptible **(S)**; >30: Highly susceptible **(HS)**

Table 4.21. Origin of finger millet core collection and their reaction to blast disease under field conditions during 2009 rainy season, ICRISAT, Patancheru

Country of origin	No. of accessions	Neck blast severity (1-5 scale)		Finger blast severity (%)	
		Range[a]	No.[b]	Range[a]	No.[b]
Africa	**365**	**-**	**290**	**-**	**314**
Burundi	3	1.2- 4.7	2	1.1-42.7	1
Cameroon	1	3.0	-	40	-
Ethiopia	3	1.0-3.0	1	1.5-22.5	1
Kenya	107	1.0-3.4	78	0-20.5	94
Malawi	25	1.0-2.5	21	1.5-12.5	21
Mozambique	1	1.7	1	7	1
Nigeria	5	1.0-1.8	5	0-12	4
Senegal	1	1.4	1	4	1
South Africa	1	2.4	-	18.5	-
Tanzania	3	1.2-2	3	3-12.5	2
Uganda	81	1.0-3.0	68	0-19.5	75
Zaire	1	2.0	1	4.5	1
Zambia	21	1.0-2.6	17	0-18.5	19
Zimbabwe	112	1.1-2.6	92	0-18.5	94
Asia	**223**	**-**	**85**	**-**	**92**
India	149	1.2-4.9	50	0.5-64	58
Maldives	1	2.8	-	31	-
Nepal	70	1.1-4.9	34	2.0-60	32
Pakistan	1	2.5	-	11	-
Sri Lanka	2	1.5-2.1	1	3.2-10.5	2
Americas (USA)	**5**	**1.3-2.2**	**4**	**3.5-11**	**4**
Europe	**7**	**-**	**6**	**-**	**6**
Germany	1	2.0	1	1.5	1
Italy	3	1.5-1.9	3	1-7.5	3
United Kingdom	3	1.8-2.2	2	4.5-11	2
Unknown	**22**	**1.3-2.3**	**17**	**1-13**	**20**
Total	622	-	402	-	436

[a] Based on the mean of two replications
[b] No. = Number of resistant accessions

Table 4.22. Evaluation of finger millet mini-core collection for blast resistance under field conditions during the 2009 and 2010 rainy seasons at ICRISAT, Patancheru and their variable agronomic traits

Entry No.	Accession No.	Leaf blast severity[b]			Neck blast severity[c]			Finger blast severity (%)[d]			Agronomic traits[e]		
		2009	2010	Pooled[a]	2009	2010	Pooled	2009	2010	Pooled	DF	Height (cm)	Spike type
1	IE 501	1.5	2.0	1.7	4.6	4.8	4.8	62.8 (51.3)	46.1 (41.4)	55.0 (47.2)	48	81	TC
2	IE 518	1.7	2.4	2.1	2.8	3.1	2.9	18.3 (24.8)	23.1 (27.7)	20.9 (26.6)	60	110.8	TC
3	IE 1055	1.5	1.6	1.5	2.1	1.4	1.8	6.6 (14.7)	3.4 (10.3)	4.9 (12.5)	62	121.2	TC
4	IE 2034	1.5	2.4	1.9	1.5	1.0	1.3	7.5 (15.8)	1.2 (6.1)	4.3 (10.9)	89	85	TC
5	IE 2042	1.7	2.0	1.9	2.1	1.9	2.0	9.0 (17.3)	9.0 (16.8)	9.0 (17.2)	60	105	TC
6	IE 2217	1.5	2.0	1.7	2.1	1.7	1.9	4.1 (8.5)	12.4 (20.2)	8.3 (14.4)	64	90	TC
7	IE 2296	1.5	1.6	1.5	1.9	1.1	1.5	1.7 (5.5)	6.8 (14.1)	4.2 (9.7)	72	93	TC
8	IE 2312	1.5	2.0	1.7	1.9	1.2	1.6	5.1 (13)	5.5 (13.5)	5.3 (13.2)	82	110	LO
9	IE 2430	1.2	2.0	1.5	1.6	1.1	1.3	2.2 (8.2)	2.4 (8.5)	2.2 (8.2)	74	130	TC
10	IE 2437	1.2	2.0	1.5	2.6	2.2	2.4	7.1 (15.3)	5.5 (13.5)	6.3 (14.4)	75	123	TC
11	IE 2457	1.5	2.0	1.7	2.0	1.1	1.5	2.6 (9.3)	0.2 (0.7)	1.3 (4.8)	78	115	TC
12	IE 2572	*	2.9	2.9	*	1.0	1.0	*	1.2 (4.5)	1.2 (5.5)	92	83	LO
13	IE 2589	1.2	2.0	1.5	1.4	1.0	1.2	4.1 (11.6)	0.4 (2.6)	2.2 (6.9)	71	137	TC
14	IE 2606	1.5	2.0	1.7	1.6	1.0	1.3	3.6 (10.2)	4.6 (11.9)	4.1 (11)	80	95	TC
15	IE 2619	1.2	2.0	1.5	1.7	1.3	1.5	2.2 (8.5)	3.4 (9.3)	2.7 (8.8)	82	105	TC
16	IE 2710	1.2	2.0	1.5	1.2	1.0	1.1	2.6 (6.9)	0.4 (2.6)	1.5 (4.5)	78	110	I
17	IE 2790	1.2	1.6	1.3	1.8	1.0	1.4	5.1 (12.8)	3.8 (8.2)	4.4 (10.4)	79	70	LO
18	IE 2821	1.2	2.4	1.7	1.1	1.0	1.1	2.2 (8.5)	3.6 (10.9)	2.8 (9.4)	62	113	I
19	IE 2871	1.5	1.6	1.5	1.4	1.0	1.2	0.7 (3.4)	0.2 (0.7)	0.3 (1.8)	83	106	I
20	IE 2872	1.2	1.6	1.3	1.5	1.0	1.3	3.6 (10.7)	1.4 (5.0)	2.4 (7.7)	60	103	TC
21	IE 2911	1.5	1.1	1.3	1.1	1.0	1.1	1.2 (6.2)	0.2 (0.7)	0.6 (3.2)	83	129	TC
22	IE 2957	1.5	2.0	1.7	2.0	1.0	1.5	1.7 (7.3)	0.9 (4.0)	1.2 (5.5)	70	91	TC

23	IE 3045	1.5	2.0	1.7	1.8	1.6	1.7	7.1 (15.3)	7.5 (15.6)	7.3 (15.5)	62	114	LO
24	IE 3077	1.2	2.0	1.5	1.3	1.2	1.2	5.1 (13)	5.3 (13.2)	5.2 (13.1)	62	104.2	TC
25	IE 3104	1.5	2.0	1.7	3.7	4.8	4.3	47.2 (42.5)	44.6 (40.6)	46.3 (42.3)	55	86	I
26	IE 3317	1.5	1.1	1.3	1.6	1.3	1.4	3.6 (11)	1.4 (5.0)	2.4 (8.6)	76	110	TC
27	IE 3391	1.5	1.6	1.5	1.2	1.0	1.1	2.6 (9.3)	0.4 (2.6)	1.5 (5.8)	79	122	TC
28	IE 3392	1.2	2.0	1.5	1.8	1.0	1.4	3.6 (11)	1.4 (5.0)	2.4 (8.6)	66	95	TC
29	IE 3470	1.5	1.6	1.5	1.4	1.3	1.3	6.1 (14.2)	6.0 (13.9)	6.0 (14)	62	109	TC
30	IE 3475	1.2	2.4	1.7	1.6	1.4	1.5	3.6 (11)	5.1 (12.6)	4.3 (11.6)	74	101	I
31	IE 3614	1.5	2.0	1.7	1.4	1.0	1.2	3.6 (11)	0.2 (0.7)	1.8 (5.6)	75	123	TC
32	IE 3721	1.2	2.0	1.5	1.9	1.0	1.5	0.2 (0.7)	0.9 (4.0)	0.5 (2.1)	83	134	TC
33	IE 3945	1.2	2.0	1.5	1.8	1.0	1.4	1.7 (7.3)	2.1 (8.4)	1.8 (7.7)	79	123.2	TC
34	IE 3952	1.5	1.6	1.5	1.6	1.2	1.4	0.2 (0.7)	0.9 (4.0)	0.5 (2.1)	79	77	TC
35	IE 3973	1.5	1.6	1.5	2.0	1.3	1.6	2.2 (8.5)	1.2 (4.5)	1.6 (6.3)	76	85	TC
36	IE 4028	1.2	1.6	1.3	1.4	1.1	1.3	4.6 (12.4)	3.8 (11.2)	4.2 (11.7)	74	130	TC
37	IE 4057	1.5	2.4	1.9	1.2	1.1	1.1	1.2 (4.6)	1.4 (6.7)	1.2 (5.5)	70	105	TC
38	IE 4073	1.7	1.6	1.7	1.1	1.0	1.1	0.4 (1.4)	0.2 (0.7)	0.3 (0.8)	79	96	TC
39	IE 4121	1.2	1.6	1.3	1.7	1.5	1.6	7.1 (15.2)	5.5 (13.5)	6.3 (14.3)	62	114	TC
40	IE 4329	1.5	1.6	1.5	1.1	1.1	1.1	2.6 (9.3)	0.7 (3.4)	1.6 (6.2)	74	114	TC
41	IE 4491	1.7	1.6	1.7	2.0	1.4	1.7	10.0 (18.3)	6.3 (14.2)	8.1 (16.3)	62	125	TC
42	IE 4497	1.2	1.6	1.3	1.8	1.4	1.6	5.6 (13.3)	5.8 (13.7)	5.7 (13.5)	70	110	TC
43	IE 4545	1.2	1.1	1.1	1.9	1.3	1.6	11.0 (19)	7.7 (15.9)	9.4 (17.5)	74	110	TC
44	IE 4565	1.7	2.0	1.9	1.3	1.0	1.2	4.6 (12.4)	0.7 (3.4)	2.6 (7.7)	73	125	TC
45	IE 4570	1.2	1.1	1.1	1.2	1.2	1.2	2.2 (8.2)	2.1 (6.1)	2.1 (7.0)	62	118	TC
46	IE 4622	2.3	1.6	2.1	1.3	1.3	1.3	3.1 (10.1)	1.6 (5.4)	2.3 (7.6)	75	102	I
47	IE 4646	1.5	1.1	1.3	1.7	1.2	1.4	4.1 (11.6)	5.1 (12.8)	4.5 (12.2)	79	93	TC
48	IE 4671	2.0	1.1	1.7	2.3	1.2	1.7	12.9 (20.8)	3.6 (10.8)	8.3 (15.8)	67	95	TC
49	IE 4709	1.9	1.9	2.2	1.3	1.6	1.4	0.4 (1.4)	0.3 (1.1)	0.2 (0.8)	45	85	LO

50	IE 4734	1.5	1.6	1.5	4.7	4.6	4.8	47.2 (42.5)	47.0 (42)	47.5 (43)	51	98	I
51	IE 4757	1.5	2.0	1.7	3.1	3.2	3.2	19.8 (25.8)	12.6 (20.4)	16.3 (23.3)	62	110.2	TC
52	IE 4795	1.7	1.6	1.7	2.1	1.1	1.6	10.0 (17.9)	8.0 (16.1)	9.0 (17.1)	73	105.2	TC
53	IE 4797	1.5	6.0	3.5	2.8	1.8	2.3	30.5 (32.9)	21.4 (26.9)	26.2 (30.3)	74	90	TC
54	IE 4816	*	1.6	1.5	*	1.0	1.2	*	2.1 (8.3)	3.1 (8.0)	85	90	LO
55	IE 5066	1.5	1.6	1.5	1.4	1.1	1.2	4.1 (11.7)	1.2 (4.5)	2.6 (8.0)	62	107	TC
56	IE 5091	1.2	2.0	1.5	1.9	1.4	1.7	9.0 (17.2)	2.9 (8.7)	5.9 (12.9)	62	110.2	TC
57	IE 5106	1.2	1.6	1.3	2.1	1.1	1.6	5.1 (11.8)	1.2 (4.5)	3.1 (8)	70	105	TC
58	IE 5201	1.5	2.0	1.7	1.7	1.0	1.4	1.7 (5.5)	7.7 (15.9)	4.7 (10.7)	80	109.8	LO
59	IE 5306	1.5	1.1	1.3	1.7	1.5	1.6	3.6 (11)	2.6 (9.2)	3.1(10)	75	110	TC
60	IE 5367	1.5	2.0	1.7	2.8	1.2	2.0	20.3 (26.3)	10.2 (18.3)	15.3 (22.5)	74	115	TC
61	IE 5537	1.5	2.0	1.7	1.6	1.6	1.6	6.6 (14.7)	8.2 (16.4)	7.4 (15.6)	60	105	TC
62	IE 5817	1.5	1.6	1.5	2.5	1.8	2.2	11.9 (19.9)	9.7 (17.8)	10.8 (19)	67	100	I
63	IE 5870	1.5	3.8	2.5	3.7	3.3	3.5	31.5 (33.5)	28.0 (31.1)	30.0 (32.8)	55	100	I
64	IE 6059	1.5	3.3	2.3	2.3	2.1	2.2	11.9 (19.9)	11.6 (19.5)	11.8 (19.9)	62	130	TC
65	IE 6082	1.5	6.0	3.5	4.7	4.8	4.9	58.9 (49.1)	42.2 (39.2)	51.0 (44.9)	62	105	I
66	IE 6154	1.5	1.6	1.5	1.4	1.5	1.5	4.1 (11.6)	8.0 (14.1)	6.0 (12.9)	77	95.4	TC
67	IE 6165	1.2	1.1	1.1	1.4	1.4	1.4	4.1 (11.6)	5.3 (13.1)	4.7 (12.4)	79	90	I
68	IE 6221	1.2	1.6	1.3	1.6	1.3	1.5	4.6 (11.6)	4.1 (11.6)	4.3 (11.8)	74	100	I
69	IE 6240	1.2	2.0	1.5	1.3	1.2	1.3	2.6 (9.3)	3.6 (10.8)	3.1 (10)	71	115.2	TC
70	IE 6294	1.7	1.6	1.7	1.7	1.2	1.4	5.1 (12.8)	2.6 (9.2)	3.8 (10.9)	74	110	TC
71	IE 6326	1.2	1.1	1.1	1.6	1.2	1.4	5.6 (13.3)	0.2 (0.7)	2.8 (6.8)	75	95	TC
72	IE 6337	1.7	1.6	1.7	1.7	1.0	1.4	1.2 (4.6)	0.2 (0.7)	0.6 (2.4)	70	92	TC
73	IE 6350	1.7	1.6	1.7	1.4	1.0	1.2	4.6 (12.4)	1.2 (4.5)	2.8 (8.3)	79	95	TC
74	IE 6421	1.2	2.0	1.5	2.0	1.1	1.5	9.5 (17.8)	4.6 (12.2)	7.0 (15)	70	110	TC
75	IE 6473	1.2	2.0	1.5	1.1	1.0	1.1	1.7 (7.3)	0.7 (3.4)	1.1 (5.2)	76	123	TC
76	IE 6514	1.5	2.0	1.7	1.8	1.0	1.4	11.0 (19.1)	4.6 (12.2)	7.8 (15.7)	76	115	TC

77	IE 6537	1.3	2.0	1.6	1.8	1.0	1.4	0.4 (1.4)	0.2 (0.7)	0.3 (0.8)	78	95	TC
78	IE 7018	1.7	2.0	1.9	1.8	1.0	1.4	6.6 (14.8)	0.2 (0.7)	3.3 (7.6)	70	121	TC
79	IE 7079	1.7	2.0	1.9	1.4	1.2	1.3	5.6 (13.6)	3.1 (9.5)	4.3 (11.5)	62	115	TC
80	IE 7320	1.2	1.6	1.3	1.2	1.1	1.1	4.1 (11.6)	3.1 (9.5)	3.6 (10.5)	62	128.2	TC
81	VR 708 C	4.5	7.0	5.8	4.7	4.4	4.6	50.1 (44.1)	53.6 (45.6)	52.4 (45.7)	55	90	TC
82	PR 202 C	1.7	2.0	1.9	1.7	1.3	1.5	8.5 (16.8)	5.5 (13.5)	7.0 (15.2)	62	110	TC
83	RAU 8 C	1.2	2.0	1.5	1.9	2.2	2.0	8.5 (8.5)	10.7 (18.7)	9.6 (17.9)	62	95	TC
84	VL 149 C	1.2	4.7	2.8	4.5	4.2	4.4	42.3 (39.7)	38.5 (37.2)	40.7 (39.1)	60	87.2	TC
Mean		1.5	2.0	1.74	2.0	1.6	1.75	9.3	7.42	8.29	70.2	105.8	-
SE (m)±		0.25	0.4	0.28	0.29	0.3	0.23	2.77	2.22	2.15	1.49	0.20	-
LSD ($P < 0.05$)[f]		0.7	1.1	0.8	0.8	0.7	0.7	7.7	6.2	6.0	0.6	4.15	-

*****Data not available; C = Check, Values in parentheses are angular transformed values

[a] Mean of two replications, 10 plants/replication at 40 DAS for leaf blast and at physiological maturity for neck and finger blast

[b] Leaf blast severity on 1–9 scale where 1= no infection and 9= >75% leaf area covered with lesions

[c] Neck blast severity on 1–5 scale where 1= no infection and 5= >6 cm lesions on the neck region

[d] Finger blast severity (%) across all panicles/all tillers in a row

[e] Days = days to flowering; Height = Plant height; Spike type: TC = Top curved, I = Incurved, LO = Long open; [f] Trial least significant difference.

Table 4.24. Blast disease reaction of finger millet mini-core collection under field condition during 2009 & 2010 rainy seasons at ICRISAT, Patancheru based on pooled data in Table 4.22

Accession No	Origin	Race	Sub-race	Leaf blast[a]	Neck blast[b]	Finger blast[c]
IE 501	India	*Vulgaris*	*Stellata*	HR	HS	HS
IE 518	India	*Vulgaris*	*Incurvata*	R	MR	MR
IE 1055	Unknown	*Vulgaris*	*Digitata*	HR	R	R
IE 2034	India	*Vulgaris*	*Incurvata*	HR	R	R
IE 2042	India	*Vulgaris*	*Incurvata*	HR	R	R
IE 2217	India	*Vulgaris*	*Stellata*	HR	R	R
IE 2296	India	*Vulgaris*	*Digitata*	HR	R	R
IE 2312	India	*Elongata*	*Sparsa*	HR	R	R
IE 2430	Kenya	*Vulgaris*	*Digitata*	HR	R	R
IE 2437	Kenya	*Plana*	*Confundere*	HR	MR	R
IE 2457	Kenya	*Compacta*	*	HR	R	R
IE 2572	Kenya	*Plana*	*Grandiglum a*	R	HR	R
IE 2589	USA	*Plana*	*Seriata*	HR	R	R
IE 2606	Malawi	*Vulgaris*	*Incurvata*	HR	R	R
IE 2619	Malawi	*Vulgaris*	*Incurvata*	HR	R	R
IE 2710	Malawi	*Plana*	*Confundere*	HR	R	R
IE 2790	Malawi	*Elongata*	*Laxa*	HR	R	R
IE 2821	Nepal	*Compacta*	*	HR	R	R
IE 2871	Zambia	*Compacta*	*	HR	R	HR
IE 2872	Zambia	*Vulgaris*	*Digitata*	HR	R	R
IE 2911	Zambia	*Vulgaris*	*Incurvata*	HR	R	HR
IE 2957	Germany	*Vulgaris*	*Liliacea*	HR	R	R
IE 3045	India	*Vulgaris*	*Liliacea*	HR	R	R
IE 3077	India	*Vulgaris*	*Incurvata*	HR	R	R
IE 3104	India	*Vulgaris*	*Incurvata*	HR	HS	HS
IE 3317	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 3391	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 3392	Zimbabwe	*Compacta*	*	HR	R	R
IE 3470	India	*Vulgaris*	*Stellata*	HR	R	R

IE 3475	India	*Vulgaris*	*Incurvata*	HR	R	R
IE 3614	Unknown	*Plana*	*Confundere*	HR	R	R
IE 3721	Uganda	*Compacta*	*	HR	R	HR
IE 3945	Uganda	*Plana*	*Confundere*	HR	R	R
IE 3952	Uganda	*Plana*	*Confundere*	HR	R	HR
IE 3973	Uganda	*Vulgaris*	*Stellata*	HR	R	R
IE 4028	Uganda	*Vulgaris*	*Incurvata*	HR	R	R
IE 4057	Uganda	*Plana*	*Seriata*	HR	R	R
IE 4073	Uganda	*Elongata*	*Reclusa*	HR	R	HR
IE 4121	Uganda	*Plana*	*Confundere*	HR	R	R
IE 4329	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	R
IE 4491	Zimbabwe	*Elongata*	*Reclusa*	HR	R	R
IE 4497	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 4545	Zimbabwe	*Compacta*	*	HR	R	R
IE 4565	Zimbabwe	*Elongata*	*Reclusa*	HR	R	R
IE 4570	Zimbabwe	*Plana*	*Confundere*	HR	R	R
IE 4622	Zimbabwe	*Compacta*	*	R	R	R
IE 4646	Zimbabwe	*Plana*	*Grandiglum a*	HR	R	R
IE 4671	India	*Vulgaris*	*Digitata*	HR	R	R
IE 4709	Burundi	*Africana*	*	R	R	HR
IE 4734	India	*Vulgaris*	*Digitata*	HR	HS	HS
IE 4757	India	*Vulgaris*	*Stellata*	HR	S	MR
IE 4795	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 4797	Maldives	*Vulgaris*	*Liliacea*	MR	MR	S
IE 4816	India	*Elongata*	*Reclusa*	HR	R	R
IE 5066	Senegal	*Vulgaris*	*Incurvata*	HR	R	R
IE 5091	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 5106	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	R
IE 5201	India	*Vulgaris*	*Digitata*	HR	R	R
IE 5306	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 5367	Kenya	*Vulgaris*	*Liliacea*	HR	R	MR
IE 5537	Nepal	*Vulgaris*	*Stellata*	HR	R	R

IE 5817	Nepal	*Vulgaris*	*Incurvata*	HR	MR	R
IE 5870	Nepal	*Vulgaris*	*Digitata*	R	S	S
IE 6059	Nepal	*Vulgaris*	*Digitata*	R	MR	MR
IE 6082	Nepal	*Plana*	*Confundere*	MR	HS	HS
IE 6154	Nepal	*Vulgaris*	*Incurvata*	HR	R	R
IE 6165	Nepal	*Vulgaris*	*Incurvata*	HR	R	R
IE 6221	Nepal	*Vulgaris*	*Stellata*	HR	R	R
IE 6240	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	R
IE 6294	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	R
IE 6326	Zimbabwe	*Vulgaris*	*Digitata*	HR	R	R
IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	HR
IE 6350	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	R
IE 6421	Uganda	*Vulgaris*	*Digitata*	HR	R	R
IE 6473	Uganda	*Plana*	*Confundere*	HR	R	R
IE 6514	Zimbabwe	*Vulgaris*	*Incurvata*	HR	R	R
IE 6537	Nigeria	*Vulgaris*	*Incurvata*	HR	R	HR
IE 7018	Kenya	*Vulgaris*	*Incurvata*	HR	R	R
IE 7079	Kenya	*Vulgaris*	*Liliacea*	HR	R	R
IE 7320	Kenya	*Vulgaris*	*Digitata*	HR	R	R
VR 708 - SC	India	*	*	R	HS	HS
PR 202 - RC	India	*Vulgaris*	*Incurvata*	HR	R	R
RAU 8 - RC	India	*Vulgaris*	*Incurvata*	HR	R	R
VL 149 - SC	India	*Compacta*	*	R	HS	HS

* Information not available; SC: Susceptible check; RC: Resistant check
HR: Highly Resistant; R: Resistant; MR: Moderately Resistant; S: Susceptible; HS: Highly Susceptible

[a] Leaf blast reaction based on leaf blast severity (1–9 scale): 1.0: HR; 2.0-3.0:R; 3.1-5.0:MR; 5.0-7.0:S; 7.1-9.0: HS

[b] Neck blast reaction based on severity (1–5 scale): 0-1.0:HR; 1.1-2.0: R; 2.1-3.0: MR; 3.1-4.0: S; 4.1-5.0:HS

[c] Finger blast reaction based on severity (%): 0-1.0: HR; 2.0-10: R; 11-20: MR; 21-30: S; >30: HS

Table 4.25. Origin of finger millet mini-core collection and their reaction to blast disease under field and greenhouse conditions during the rainy season 2009 and 2010 rainy seasons at ICRISAT, Patancheru

Country of origin	No. of accessions	Leaf blast severity (1–9 scale)				Neck blast (1-5 scale) under field[a]		Finger blast (%) under field[a]	
		Field [a]		Greenhouse[b]					
		Range	No.	Range	No.	Range	No.	Range	No.
Burundi	1	2.2	1	1.15	1	1.4	1	0.2	1
Kenya	8	1.3-2.9	8	1.1-4.45	5	1.0-2.4	7	1.2-15.3	7
Malawi	4	1.3-1.7	4	1.6-3.4	3	1.1-1.5	4	1.4-4.4	4
Nigeria	1	1.6	1	3.45	0	1.4	1	0.3	1
Senegal	1	1.5	1	1.6	1	1.2	1	2.6	1
Uganda	10	1.3-1.9	10	1.0-3.15	9	1.0-1.6	10	0-7.0	10
Zambia	3	1.3-1.5	3	1-1.05	3	1.1-1.3	3	0.6-2.4	3
Zimbabwe	21	1.1-2.1	21	1.3-3.3	16	1.1-1.7	21	0.6-9.4	21
India	17	1.1-2.8	17	1.4-3.9	9	1.2-4.8	12	3.1-55	12
Maldives	1	3.5	0	3.5	0	2.3	0	26.2	0
Nepal	9	1.0-3.5	8	1-5.1	6	1.1-4.9	5	2.8-51.	6
U.S.A	1	1.5	1	2	1	1.2	1	2.2	1
Germany	1	1.7	1	1.6	1	1.5	1	1.2	1
Unknown	2	1.5-1.7	2	2.05-2.1	2	1.2-1.7	2	1.8-4.9	2
Total	80	-	78		58	-	69	-	70

[a] Based on the mean of 2 years of screening in field conditions with two replication; No. = Number of resistant accessions across 2 years

[b] Based on mean of two replication in greenhouse evaluation using Patancheru isolate (FMP1); No.= Number of resistant accessions

Table 4.26. Evaluation of mini-core collection of finger millet for leaf blast resistance using Patancheru isolate (FMP1) under greenhouse conditions

Entry No.	Genotype	Origin	Race	Subrace	Leaf Blast (1 – 9 Scale)[a]	Reaction
1	IE 501	India	*Vulgaris*	*Stellata*	3.15	MR
2	IE 518	India	*Vulgaris*	*Incurvata*	3.6	MR
3	IE 1055	Unknown	*Vulgaris*	*Digitata*	2.05	R
4	IE 2034	India	*Vulgaris*	*Incurvata*	4.05	MR
5	IE 2042	India	*Vulgaris*	*Incurvata*	3.45	MR
6	IE 2217	India	*Vulgaris*	*Stellata*	2.75	R
7	IE 2296	India	*Vulgaris*	*Digitata*	2.9	R
8	IE 2312	India	*Elongata*	*Sparsa*	3.85	MR
9	IE 2430	Kenya	*Vulgaris*	*Digitata*	3.15	MR
10	IE 2437	Kenya	*Plana*	*Confundere*	2.05	R
11	IE 2457	Kenya	*Compacta*	*	1.1	HR
12	IE 2572	Kenya	*Plana*	*Grandiglum a*	2.0	R
13	IE 2589	USA	*Plana*	*Seriata*	1.95	HR
14	IE 2606	Malawi	*Vulgaris*	*Incurvata*	3.85	MR
15	IE 2619	Malawi	*Vulgaris*	*Incurvata*	2.7	R
16	IE 2710	Malawi	*Plana*	*Confundere*	1.6	HR
17	IE 2790	Malawi	*Elongata*	*Laxa*	2.0	R
18	IE 2821	Nepal	*Compacta*	*	2.1	R
19	IE 2871	Zambia	*Compacta*	*	1.05	HR
20	IE 2872	Zambia	*Vulgaris*	*Digitata*	1.0	HR
21	IE 2911	Zambia	*Vulgaris*	*Incurvata*	1.0	HR
22	IE 2957	Germany	*Vulgaris*	*Liliacea*	1.85	HR
23	IE 3045	India	*Vulgaris*	*Liliacea*	2.1	R
24	IE 3077	India	*Vulgaris*	*Incurvata*	3.2	MR
25	IE 3104	India	*Vulgaris*	*Incurvata*	2.25	R
26	IE 3317	Zimbabwe	*Vulgaris*	*Digitata*	2.55	R
27	IE 3391	Zimbabwe	*Vulgaris*	*Digitata*	3.15	MR
28	IE 3392	Zimbabwe	*Compacta*	*	2.0	R
29	IE 3470	India	*Vulgaris*	*Stellata*	3.7	MR
30	IE 3475	India	*Vulgaris*	*Incurvata*	4.65	MR
31	IE 3614	Unknown	*Plana*	*Confundere*	2.1	R
32	IE 3721	Uganda	*Compacta*	*	2.2	R
33	IE 3945	Uganda	*Plana*	*Confundere*	2.0	R
34	IE 3952	Uganda	*Plana*	*Confundere*	1.1	HR
35	IE 3973	Uganda	*Vulgaris*	*Stellata*	1.65	HR
36	IE 4028	Uganda	*Vulgaris*	*Incurvata*	2.9	R
37	IE 4057	Uganda	*Plana*	*Seriata*	3.15	MR
38	IE 4073	Uganda	*Elongata*	*Reclusa*	1.45	HR
39	IE 4121	Uganda	*Plana*	*Confundere*	1.85	HR
40	IE 4329	Zimbabwe	*Vulgaris*	*Incurvata*	3.2	MR
41	IE 4491	Zimbabwe	*Elongata*	*Reclusa*	2.25	R
42	IE 4497	Zimbabwe	*Vulgaris*	*Digitata*	2.5	R

43	IE 4545	Zimbabwe	*Compacta*	*	3.15	MR
44	IE 4565	Zimbabwe	*Elongata*	*Reclusa*	2.2	R
45	IE 4570	Zimbabwe	*Plana*	*Confundere*	1.5	HR
46	IE 4622	Zimbabwe	*Compacta*	*	2.25	R
47	IE 4646	Zimbabwe	*Plana*	*Grandiglum a*	3.6	MR
48	IE 4671	India	*Vulgaris*	*Digitata*	1.4	HR
49	IE 4709	Burundi	*Africana*	*	1.15	HR
50	IE 4734	India	*Vulgaris*	*Digitata*	2.5	R
51	IE 4757	India	*Vulgaris*	*Stellata*	2.3	R
52	IE 4795	Zimbabwe	*Vulgaris*	*Digitata*	2.2	R
53	IE 4797	Maldives	*Vulgaris*	*Liliacea*	6.55	MR
54	IE 4816	India	*Elongata*	*Reclusa*	1.5	HR
55	IE 5066	Senegal	*Vulgaris*	*Incurvata*	1.6	HR
56	IE 5091	Zimbabwe	*Vulgaris*	*Digitata*	2.0	R
57	IE 5106	Zimbabwe	*Vulgaris*	*Incurvata*	1.85	HR
58	IE 5201	India	*Vulgaris*	*Digitata*	1.4	HR
59	IE 5306	Zimbabwe	*Vulgaris*	*Digitata*	2.5	R
60	IE 5367	Kenya	*Vulgaris*	*Liliacea*	2.0	R
61	IE 5537	Nepal	*Vulgaris*	*Stellata*	1.55	HR
62	IE 5817	Nepal	*Vulgaris*	*Incurvata*	1.35	HR
63	IE 5870	Nepal	*Vulgaris*	*Digitata*	3.1	MR
64	IE 6059	Nepal	*Vulgaris*	*Digitata*	1.15	HR
65	IE 6082	Nepal	*Plana*	*Confundere*	5.2	S
66	IE 6154	Nepal	*Vulgaris*	*Incurvata*	1.0	HR
67	IE 6165	Nepal	*Vulgaris*	*Incurvata*	1.55	HR
68	IE 6221	Nepal	*Vulgaris*	*Stellata*	1.0	HR
69	IE 6240	Zimbabwe	*Vulgaris*	*Incurvata*	1.3	HR
70	IE 6294	Zimbabwe	*Vulgaris*	*Incurvata*	3.2	MR
71	IE 6326	Zimbabwe	*Vulgaris*	*Digitata*	3.0	R
72	IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*	1.65	HR
73	IE 6350	Zimbabwe	*Vulgaris*	*Incurvata*	1.85	HR
74	IE 6421	Uganda	*Vulgaris*	*Digitata*	1.0	HR
75	IE 6473	Uganda	*Plana*	*Confundere*	2.0	R
76	IE 6514	Zimbabwe	*Vulgaris*	*Incurvata*	2.1	R
77	IE 6537	Nigeria	*Vulgaris*	*Incurvata*	3.45	MR
78	IE 7018	Kenya	*Vulgaris*	*Incurvata*	1.4	HR
79	IE 7079	Kenya	*Vulgaris*	*Liliacea*	3.5	MR
80	IE 7320	Kenya	*Vulgaris*	*Digitata*	4.45	MR
81	VR 708 -SC	India	-	-	8.0	HS
82	PR 202 -RC	India	*Vulgaris*	*Incurvata*	3.0	R
83	RAU 8 -RC	India	*Vulgaris*	*Incurvata*	2.4	S
84	VL 149 -SC	India	*Compacta*	*	5.1	S
				Mean	2.5	
				SE (m) ±	0.23	
				LSD (P<0.01)	0.86	

*Information not available; [a]Mean of 2 replications.

RC: Resistant check; SC: Susceptible check

Table 4.28. Variance due to genotype (g), environment (e), and g × e interaction for leaf, neck and finger blast severity among 80 finger millet mini-core accessions at five locations, 2009 rainy season, India

Trait	Patancheru σ^2g	Vizianagaram σ^2g	Nandyal σ^2g	Mandya σ^2g	Naganahalli σ^2g	Pooled analysis σ^2g	Environment		
							$\sigma^2g \times e$	Wald statistics	*P*
Leaf blast	0.21**	0.18**	0.02	0.06*	0.18**	0.09**	0.02*	26.44	<0.001
Neck blast	0.73**	1.30**	1.63**	1.97**	1.40**	0.50**	0.93**	105.51	<0.001
Finger blast	174.11**	167.11**	253.65**	229.64**	95.15**	74.23**	111.85**	293.65	<0.001

** indicates significant at $P = 0.01$; * indicates significant at $P = 0.05$.

Table 4.29. Evaluation of finger millet mini-core collection for blast resistance - leaf blast (LB), neck blast (NB) and finger blast (FB) under field conditions at five locations, 2009 rainy season, India

Accession No.	Patancheru			Vizianagaram			Nandyal			Mandya			Naganahalli			Mean		
	LB[1] (1-9)	NB[2] (1-5)	FB[3] (%)	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB
IE 501	1.5	4.8	64 (53.1)[@]	1.5	4.9	57 (49)	1.5	4.6	61.5 (51.6)	1.5	5.0	64 (53.1)	2.0	4.8	45 (42.1)	1.6	4.8	58.3 (49.8)
IE 518	2.0	2.8	18.5 (26)	2.0	3.1	33.5 (35.4)	2.0	3.0	54.0 (47.3)	1.0	4.3	58 (49.6)	1.5	3.2	29.5 (33)	1.7	3.3	38.7 (38.5)
IE 1055	1.5	2.1	6.5 (14.8)	1.0	1.2	0	2.0	2.5	33.5 (35.4)	1.5	1.1	2.0 (8.1)	1.5	1.0	0	1.5	1.6	8.4 (16.8)
IE 2034	1.5	1.5	7.5 (15.9)	1.0	1.0	0	1.5	2.7	31.5 (34.1)	1.0	1.1	12.5 (20.7)	1.0	1.0	6.5 (14.8)	1.2	1.5	11.6 (19.9)
IE 2042	2.0	2.1	9 (17.4)	1.0	1.0	0	1.5	1.4	26.0 (30.7)	1.5	4.6	36.0 (36.9)	1.5	2.2	23.5 (29)	1.5	2.3	18.9 (27.8)
IE 2217	1.5	2.1	4 (11.5)	1.5	2.2	11.5 (19.8)	1.5	2.8	38.0 (38.1)	1.5	3.7	43.0 (41)	1.0	3.2	27 (31.3)	1.4	2.8	24.7 (29.8)
IE 2296	1.5	1.9	1.5 (7.0)	1.0	1.0	0	1.5	2.4	33.0 (35.1)	1.5	1.1	16.0 (23.6)	1.5	1.0	2 (8.1)	1.4	1.5	10.5 (18.9)
IE 2312	1.5	1.9	5 (12.9)	1.0	1.0	0	1.0	2.8	36.5 (37.2)	2.0	1.2	46.0 (42.7)	1.0	1.0	15 (22.8)	1.3	1.6	20.5 (26.9)
IE 2430	1.0	1.6	2 (8.1)	1.5	1.8	4.5 (12.2)	1.5	1.2	22.0 (28)	2.0	1.1	11.0 (19.4)	1.5	1.0	1 (5.7)	1.5	1.3	8.1 (16.5)
IE 2437	1.0	2.6	7 (15.3)	1.5	1.0	0	1.5	4.4	51.0 (45.6)	1.5	1.0	2.0 (8.1)	1.0	1.0	0	1.3	2.0	12 (20.2)
IE 2457	1.5	2.0	2.5 (9.1)	*	*	*	1.0	1.0	12.0 (20.3)	1.0	2.0	18.5 (25.5)	1.5	1.6	9 (17.5)	1.25	1.7	10.5 (18.9)
IE 2572	*	*	*	*	*	*	1.0	2.5	16.0 (23.6)	*	*	*	1.0	1.0	3 (10)	1.0	1.8	9.5 (17.9)
IE 2589	1.0	1.4	4 (11.5)	1.5	1.1	0	1.5	1.8	6.0 (14.2)	1.5	1.0	5.5 (13.6)	1.5	1.0	4.5 (12.2)	1.4	1.3	4 (11.5)
IE 2606	1.5	1.6	3.5 (10.8)	1.0	1.0	0	1.0	2.0	25.0 (30)	2.0	3.9	23.0 (28.7)	1.0	1.4	9 (17.5)	1.3	2.0	12.1 (20.4)
IE 2619	1.0	1.7	2 (8.1)	1.0	1.0	0	1.0	1.0	7.0 (15.3)	2.0	1.5	20.0 (26.6)	2.0	1.2	9.5 (18)	1.4	1.3	7.7 (16.1)
IE 2710	1.0	1.2	2.5 (9.1)	1.0	1.0	0	2.0	1.5	21.0 (27.3)	2.0	1.0	6.5 (14.8)	1.5	1.0	2.5 (9.1)	1.5	1.1	6.5 (14.8)
IE 2790	1.0	1.8	5 (12.9)	1.0	1.0	0	1.5	1.8	29.0 (32.6)	2.0	1.0	18.5 (25.5)	1.5	1.0	4 (11.5)	1.4	1.3	11.3 (19.6)
IE 2821	1.0	1.1	2 (8.1)	*	*	*	1.0	1.1	21.5 (27.6)	1.5	1.9	21.0 (27.3)	1.0	1.0	3.5 (10.8)	1.1	1.3	12 (20.3)
IE 2871	1.5	1.4	0.5 (4.0)	*	*	*	1.5	1.0	4.5 (12.2)	2.0	1.0	6.5 (14.8)	1.5	1.0	0	1.7	1.1	2.9 (9.8)
IE 2872	1.0	1.5	3.5 (10.8)	1.0	1.0	0	1.5	1.5	15.5 (23.2)	1.5	3.3	36.0 (36.9)	1.0	1.0	8 (16.4)	1.2	1.7	12.6 (20.8)
IE 2911	1.5	1.1	1 (5.7)	1.5	1.0	0	1.5	1.1	9.0 (17.5)	1.5	1.0	1.0 (5.7)	1.5	1.0	1.5 (7)	1.5	1.0	2.5 (9.1)
IE 2957	1.5	2.0	1.5 (7.0)	1.0	1.0	0	1.0	1.7	9.5 (18)	1.5	1.0	4.5 (12.2)	1.0	1.0	4 (11.5)	1.2	1.3	3.9 (11.4)
IE 3045	1.5	1.8	7 (15.3)	1.0	1.8	0	2.0	1.3	22 (28)	1.5	1.5	31 (33.8)	1.5	1.3	13.5 (21.6)	1.5	1.5	14.7 (22.5)
IE 3077	1.0	1.3	5 (12.9)	1.0	2.0	22 (28)	1.0	1.2	26.5 (31)	2.0	1.2	16.0 (23.6)	1.0	1.0	1.5 (7)	1.2	1.3	14.2 (22.1)
IE 3104	1.5	3.8	48 (43.8)	1.5	4.2	57 (49)	1.5	3.4	72.0 (58.1)	1.5	3.5	34.0 (35.7.)	1.5	1.1	4.5 (12.2)	1.5	3.2	43.1 (41)
IE 3317	1.5	1.6	3.5 (10.8)	1.0	2.1	19.5 (26.2)	1.5	2.9	34.0 (35.7)	1.0	4.1	40.0 (39.2)	1.0	1.3	11 (19.4)	1.2	2.4	21.6 (27.7)
IE 3391	1.5	1.2	2.5 (14.2)	1.0	1.0	0	1.5	1.5	34.0 (35.7)	1.0	2.0	32.0 (34.4)	1.5	1.0	2.5 (9.1)	1.3	1.3	14.2 (22.1)
IE 3392	1.0	1.8	3.5 (10.8)	1.0	1.0	0	1.0	1.7	24.0 (29.3)	2.0	1.2	16.0 (23.6)	1.0	1.0	4 (11.5)	1.2	1.3	9.5 (18)
IE 3470	1.5	1.4	6 (14.2)	1.0	2.2	12.5 (20.7)	1.5	2.4	29.0 (32.6)	1.0	1.7	16.5 (24)	1.5	2.1	17 (24.4)	1.3	2.0	16.2 (23.7)
IE 3475	1.0	1.6	3.5 (10.8)	1.0	1.2	0	1.5	1.6	32.0 (34.4)	1.5	1.7	19.0 (25.8)	1.0	1.1	11.5 (20)	1.2	1.4	13.2 (21.3)
IE 3614	1.5	1.4	3.5 (10.8)	1.0	1.3	0	1.5	1.7	22.0 (28)	1.5	1.7	15.0 (22.8)	1.5	1.0	1 (5.7)	1.4	1.4	8.3 (16.7)
IE 3721	1.0	1.9	0	*	*	*	1.5	3.3	33.0 (35.1)	1.0	1.9	18.0 (25.1)	1.0	1.0	2 (8.1)	1.1	2.0	13.3 (21.4)

IE 3945	1.0	1.8	1.5 (7)	1.0	1.0	0	1.5	2.8	24.0 (29.3)	1.0	2.7	24.0 (29.3)	1.5	1.0	1 (5.7)	1.2	1.9	10.1 (18.5)
IE 3952	1.5	1.6	0	*	*	*	1.0	1.0	23.5 (29)	1.5	1.2	16.5 (24)	1.0	1.0	3 (10)	1.25	1.2	10.8 (19.2)
IE 3973	1.5	2.0	2 (8.1)	1.0	2.4	11 (19.4)	1.5	1.1	15.5 (23.2)	2.0	2.5	20.5 (26.9)	1.5	1.7	10.5 (19)	1.5	1.9	11.9 (20.2)
IE 4028	1.0	1.4	4.5 (12.2)	1.0	1.0	0	1.0	3.6	37.0 (37.5)	2.0	1.4	30.0 (33.2)	1.0	1.0	4.2 (11.8)	1.2	1.7	15.1 (22.9)
IE 4057	1.5	1.2	1 (5.7)	1.0	1.5	0	2.0	4.8	72.0 (58.1)	2.0	1.0	15.5 (23.2)	1.5	1.0	1.5 (7)	1.6	1.9	18 (25.1)
IE 4073	2.0	1.0	0	2.0	1.8	0	1.0	3.5	39.0 (38.6)	1.5	1.1	14.5 (22.4)	1.0	1.2	7 (15.3)	1.5	1.7	12.1 (20.4)
IE 4121	1.0	1.7	7 (15.3)	1.0	1.0	0	1.5	1.2	18.0 (25.1)	1.5	2.6	24.0 (29.3)	1.5	1.1	8 (16.4)	1.3	1.5	11.4 (19.7)
IE 4329	1.5	1.1	2.5 (9.0)	1.0	1.8	1.5 (7)	1.5	1.4	21.0 (27.3)	1.5	1.2	13.5 (21.6)	1.0	1.1	10 (18.4)	1.3	1.3	9.7 (18.1)
IE 4491	2.0	2.0	10 (18.4)	1.0	1.0	0	1.5	2.4	33.0 (35.1)	1.0	3.5	35.0 (36.3)	1.5	1.0	7.5 (15.9)	1.4	2.0	17.1 (24.4)
IE 4497	1.0	1.8	5.5 (13.6)	1.5	1.3	1 (5.7)	1.0	1.8	9.0 (17.5)	1.0	1.0	6.0 (14.2)	1.0	1.0	7 (15.3)	1.1	1.4	5.7 (13.8)
IE 4545	1.0	1.9	11 (19.4)	1.0	1.0	0	1.5	1.5	18.0 (25.1)	1.5	3.0	26.5 (31)	1.0	1.0	6 (14.2)	1.2	1.7	12.3 (20.5)
IE 4565	2.0	1.3	4.5 (12.2)	2.5	2.4	16.5 (24)	1.5	1.0	19.0 (25.8)	2.0	3.1	28.0 (31.9)	1.5	1.7	6 (14.2)	1.9	1.9	14.8 (22.6)
IE 4570	1.0	1.2	2 (8.1)	1.5	2.1	1 (5.7)	2.0	1.7	26.0 (30.7)	2.0	3.6	35.0 (36.3)	1.0	1.0	1.5 (7)	1.5	1.9	13.1 (21.2)
IE 4622	3.0	1.3	3 (10)	1.0	1.6	0	1.0	1.5	24.5 (29.7)	1.5	3.3	38.0 (38.1)	2.0	1.1	6 (14.2)	1.7	1.8	14.3 (22.2)
IE 4646	1.5	1.7	4 (11.5)	1.0	1.4	0	1.0	1.8	31.5 (34.1)	1.0	1.7	23.5 (29)	1.0	1.3	13 (21.1)	1.1	1.6	14.7 (22.5)
IE 4671	2.5	2.3	13 (21.1)	1.0	1.8	6.5 (14.8)	1.5	3.1	23.5 (29)	1.5	1.5	17.0 (24.4)	1.5	1.0	1.5 (7)	1.6	1.9	12.3 (20.5)
IE 4709	3.0	1.2	0	1.0	1.0	0	2.0	4.1	32.0 (34.4)	1.0	3.1	52.0 (46.1)	1.0	1.2	15.5 (23)	1.6	2.1	19.9 (26.5)
IE 4734	1.5	4.9	48 (43.9)	1.0	1.7	12 (20.3)	1.0	3.8	32.5 (34.8)	1.0	4.1	53.0 (46.7)	1.5	3.9	37 (37.5)	1.2	3.7	36.8 (37.3)
IE 4757	1.5	3.2	20 (26.6)	1.0	3.3	35.2 (36.4)	2.0	1.2	22.5 (28.3)	1.0	2.1	23.0 (28.7)	1.0	4.0	46 (42.7)	1.3	2.8	29.3 (32.8)
IE 4795	2.0	2.1	10 (18.4)	1.0	1.7	0	1.0	3.7	49.0 (44.4)	1.5	2.9	27.0 (31.3)	1.5	2.6	25 (30)	1.4	2.6	22.2 (28.1)
IE 4797	1.5	2.8	31 (33.8)	1.0	1.0	0	1.5	1.8	22.0 (28)	1.5	4.0	54.0 (47.3)	1.0	2.5	25 (30)	1.3	2.4	26.4 (30.9)
IE 4816	*	*	*	*	*	*	1.0	1.1	6.0 (14.2)	1.5	4.6	49.0 (44.4)	1.5	2.3	16 (23.6)	1.3	2.7	23.7 (29.1)
IE 5066	1.5	1.4	4 (11.5)	1.5	1.0	0	1.5	1.1	12.5 (20.7)	1.0	5.0	61.0 (51.4)	1.0	3.8	24.5 (30)	1.3	2.5	20.4 (26.9)
IE 5091	1.0	1.9	9(17.4)	1.0	1.0	0	1.5	4.1	32.5 (34.8)	2.0	4.4	35.0 (36.3)	2.0	1.5	6 (14.2)	1.5	2.6	16.5 (24)
IE 5106	1.0	2.1	5 (12.9)	1.0	1.0	0	1.5	1.2	18.0 (25.1)	2.0	2.3	17.0 (24.4)	1.5	1.1	2.5 (9.1)	1.4	1.5	8.5 (17)
IE 5201	1.5	1.7	1.5 (7)	*	*	*	1.5	1.1	22.0 (28)	1.5	1.0	18.0 (25.1)	1.5	1.0	3 (10)	1.5	1.2	11.1 (19.5)
IE 5306	1.5	1.7	3.5 (10.8)	1.0	3.2	25 (30)	1.5	2.1	34.53 (36)	1.5	1.5	23.5 (28)	1.5	1.0	1.5 (7)	1.5	1.9	17.6 (24.8)
IE 5367	1.5	2.9	20.5 (27)	1.0	1.0	0	1.0	2.5	58.0 (49.6)	2.0	2.4	35.0 (36.3)	3.0	2.6	16 (23.6)	1.7	2.3	25.9 (30.6)
IE 5537	1.5	1.6	6.5 (14.8)	1.0	1.1	4.5 (12.2)	1.5	4.4	75.0 (60)	1.0	1.8	22.0 (28)	1.0	1.0	13 (21)	1.2	2.0	24.2 (29.5)
IE 5817	1.5	2.5	12 (20.3)	1.0	1.2	0	1.0	1.3	5.5 (13.6)	1.0	4.9	61.0 (51.4)	2.0	3.6	20 (26.6)	1.3	2.7	19.7 (26.3)
IE 5870	1.5	3.8	32 (34.4)	1.5	1.0	0	2.0	3.9	28.5 (32.3)	1.5	4.6	55.0 (47.9)	3.0	4.0	43 (41)	1.9	3.5	31.7 (34.3)
IE 6059	1.5	2.3	12 (20.3)	1.5	1.0	0	1.0	2.4	32.0 (34.4)	1.0	1.8	27.0 (31.3)	1.5	1.2	11.5 (20)	1.3	1.7	16.5 (24)
IE 6082	1.5	4.9	60 (50.8)	1.0	1.0	0	2.0	3.6	27.0 (31.3)	1.5	2.0	24.0 (29.3)	1.5	1.7	11 (19.4)	1.3	2.6	24.4 (29.6)
IE 6154	1.5	1.4	4 (11.5)	2.0	1.0	0	1.5	2.7	38.0 (38.1)	2.5	1.0	14.0 (22)	2.0	1.2	10.5 (19)	1.9	1.5	13.3 (21.4)
IE 6165	1.0	1.4	4 (11.5)	1.5	1.0	0	2.0	2.2	22.0 (28)	1.0	2.2	29.0 (32.6)	1.0	1.6	4.5 (12.2)	1.3	1.7	11.9 (20.2)
IE 6221	1.0	1.6	4.5 (12.2)	1.5	1.4	0	1.5	1.0	14.5 (22.4)	1.5	1.9	35.0 (36.3)	2.0	1.0	8 (16.4)	1.5	1.4	12.4 (20.6)
IE 6240	1.0	1.3	2.5 (9.1)	2.0	1.0	0	1.5	1.2	14.0 (22)	1.5	1.4	19.0 (25.8)	1.0	1.1	4 (11.5)	1.4	1.2	7.9 (16.3)
IE 6294	2.0	1.7	5 (12.9)	1.5	2.8	22 (28)	1.0	5.0	86.0 (68)	1.5	3.9	30.0 (33.2)	1.5	1.0	0	1.5	2.9	28.6 (32.3)
IE 6326	1.0	1.6	5.5 (12.9)	2.0	1.0	0	1.5	1.2	16.0 (23.6)	1.5	2.8	30.0 (33.2)	1.0	1.0	8.5 (17)	1.4	1.5	12 (20.3)
IE 6337	2.0	1.7	1 (5.7)	1.5	1.0	0	1.0	1.8	10.5 (18.9)	2.0	1.6	8.5 (17)	2.0	1.0	3 (10)	1.7	1.4	4.6 (12.4)

IE 6350	2.0	1.4	4.5 (12.2)	2.0	1.0	0	1.5	2.4	29.0 (32.6)	1.5	3.8	42.0 (40.4)	1.0	1.1	4 (11.5)	1.5	1.9	15.9 (23.5)
IE 6421	1.0	2.0	9.5 (18)	1.0	1.0	0	1.5	4.9	32.0 (34.4)	1.5	1.2	14.0 (22)	1.5	1.0	2 (8.1)	1.3	2.0	11.5 (19.8)
IE 6473	1.0	1.1	1.5 (7)	1.0	1.0	0	1.5	2.4	43.0 (41)	1.5	1.7	17.0 (24.4)	1.5	1.0	4 (11.5)	1.3	1.4	13.1 (21.2)
IE 6514	1.5	1.8	11 (19.4)	1.0	2.0	8 (16.4)	1.0	1.0	6.0 (14.1)	1.5	3.8	51.0 (45.6)	1.5	1.4	11.5 (20)	1.3	2.0	17.5 (24.7)
IE 6537	1.0	1.8	0	*	*	*	1.5	1.5	18.5 (25.5)	*	*	*	1.5	1.0	0	1.3	1.4	6.2 (14.4)
IE 7018	2.0	1.8	6.5 (14.8)	1.0	1.0	0	1.5	1.0	10.0 (18.4)	2.0	1.1	5.5 (13.6)	2.0	1.0	2.5 (9.1)	1.7	1.2	4.9 (12.8)
IE 7079	2.0	1.4	5.5 (13.6)	1.0	1.0	0	1.5	1.0	19.5 (26.2)	2.0	2.7	38.0 (38.1)	1.5	1.1	4.5 (12.2)	1.6	1.4	13.5 (21.6)
IE 7320	1.0	1.2	4 (11.5)	2.0	1.0	0	1.0	1.0	13.5 (21.6)	1.5	2.0	30.5 (33.5)	2.0	1.0	3 (10)	1.4	1.2	10.2 (18.6)
VR 708 - SC	4.5	4.9	51 (45.6)	4.5	4.2	51 (45.6)	3.5	4.1	47.0 (43.3)	3.5	4.0	43.5 (41.3)	4.5	4.5	34 (35.7)	4.1	4.3	45.3 (42.3)
Mean	1.5	1.9	8.9 (17.4)	1.3	1.5	5.7 (13.8)	1.4	2.2	27.9 (31.7)	1.5	2.3	26.6 (31.2)	1.4	1.5	9.8 (18.2)	1.43	1.9	15.5 (23.1)
SE (m)±[4]	0.30	0.29	2.80	0.30	0.32	2.3	0.14	0.47	5.93	0.20	0.33	2.9	0.25	0.41	2.7	0.18	0.3	3.2
LSD (*P*<0.05)[5]	0.85	0.82	7.80	0.84	0.97	6.5	0.40	1.31	16.57	0.56	0.92	8.12	0.71	1.1	6.8	0.51	0.8	8.9

*****Data not available. [@]Values in parentheses are angular transformed values

[1] Leaf blast severity on a 1 – 9 scale where 1= no infection and 9= >75% leaf area covered with lesions.

[2] Neck blast severity on a 1 – 5 scale where 1= no infection/pinhead size lesions and 5= >6 cm lesions on the neck region

[3] Finger blast severity (%) across all panicles/all tillers in a row

[4] Standard error mean; [5]Trial least significant difference.

Table 4.31. Blast disease reaction of finger millet mini-core collection under field condition at five locations during 2009 rainy season based on data in Table 4.29

Accession No.	Patancheru			Vizianagaram			Nandyal			Mandya			Naganahalli		
	LB[a]	NB[b]	FB[c]	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB
IE 501	HR	HS	HS	R	HS	HS	HR	HS	HS	HR	HS	HS	R	HS	HS
IE 518	R	MR	MR	R	S	HS	R	MR	HS	HR	HS	HS	HR	S	S
IE 1055	HR	MR	R	HR	R	HR	R	MR	HS	HR	R	R	HR	HR	HR
IE 2034	HR	R	R	HR	HR	HR	HR	MR	HS	HR	R	R	HR	HR	R
IE 2042	R	MR	R	HR	HR	HR	HR	R	S	HR	HS	HS	HR	MR	S
IE 2217	HR	MR	R	HR	MR	MR	HR	MR	HS	HR	S	S	HR	S	S
IE 2296	HR	R	HR	HR	HR	HR	HR	MR	HS	HR	R	R	HR	HR	R
IE 2312	HR	R	R	HR	HR	HR	HR	MR	HS	MR	R	R	HR	HR	MR
IE 2430	HR	R	R	HR	R	R	HR	R	S	R	R	R	HR	HR	HR
IE 2437	HR	MR	R	HR	HR	HR	HR	HS	HS	HR	HR	HR	HR	HR	HR
IE 2457	HR	R	R	*	*	*	HR	HR	MR	HR	R	R	HR	R	R
IE 2572	*	*	*	*	*	*	HR	MR	MR	*	*	*	HR	HR	R
IE 2589	HR	R	R	HR	R	HR	HR	R	R	HR	HR	HR	HR	HR	R
IE 2606	HR	R	R	HR	HR	HR	HR	R	S	R	S	S	HR	R	R
IE 2619	HR	R	R	HR	HR	HR	HR	HR	R	R	R	R	R	R	R
IE 2710	HR	R	R	HR	HR	HR	R	R	S	R	HR	HR	HR	HR	R
IE 2790	HR	R	R	HR	HR	HR	HR	R	S	R	HR	HR	HR	HR	R
IE 2821	HR	R	R	*	*	*	HR	R	S	HR	R	R	HR	HR	R
IE 2871	HR	R	HR	*	*	*	HR	HR	R	R	HR	HR	HR	HR	HR
IE 2872	HR	R	R	HR	HR	HR	HR	R	MR	HR	S	S	HR	HR	R
IE 2911	HR	R	HR	HR	HR	HR	HR	R	R	HR	HR	HR	HR	HR	HR
IE 2957	HR	R	HR	HR	HR	HR	HR	R	R	HR	HR	HR	HR	HR	R
IE 3045	HR	R	R	HR	R	HR	R	R	S	HR	R	R	HR	R	MR
IE 3077	HR	R	R	HR	R	S	HR	R	S	R	R	R	HR	HR	HR
IE 3104	HR	S	HS	HR	HS	HS	HR	S	HS	HR	S	S	HR	R	R
IE 3317	HR	R	R	HR	MR	MR	HR	MR	HS	HR	HS	HS	HR	R	MR
IE 3391	HR	R	R	HR	HR	HR	HR	R	HS	HR	R	R	HR	HR	R
IE 3392	HR	R	R	HR	HR	HR	HR	R	S	R	R	R	HR	HR	R

IE 3470	HR	R	R	HR	MR	MR	HR	MR	S	HR	R	R	HR	MR	MR
IE 3475	HR	R	R	HR	R	HR	HR	R	HS	HR	R	R	HR	R	MR
IE 3614	HR	R	R	HR	R	HR	HR	R	S	HR	R	R	HR	HR	HR
IE 3721	HR	R	HR	HR	*	*	HR	S	HS	HR	R	R	HR	HR	R
IE 3945	HR	R	HR	HR	HR	HR	HR	MR	S	HR	MR	MR	HR	HR	HR
IE 3952	HR	R	HR	*	*	*	HR	HR	S	HR	R	R	HR	HR	R
IE 3973	HR	R	R	HR	MR	MR	HR	R	MR	R	MR	MR	HR	R	R
IE 4028	HR	R	R	HR	HR	HR	HR	S	HS	R	R	R	HR	HR	R
IE 4057	HR	R	HR	HR	R	HR	R	HS	HS	R	HR	HR	HR	HR	HR
IE 4073	R	HR	HR	R	R	HR	HR	S	HS	HR	R	R	HR	R	R
IE 4121	HR	R	R	HR	HR	HR	HR	R	MR	HR	MR	MR	HR	R	R
IE 4329	HR	R	R	HR	R	HR	HR	R	S	HR	R	R	HR	R	R
IE 4491	R	R	R	HR	HR	HR	HR	MR	HS	HR	S	S	HR	HR	R
IE 4497	HR	R	R	HR	R	HR	HR	R	R	HR	HR	HR	HR	HR	R
IE 4545	HR	R	MR	HR	HR	HR	HR	R	MR	HR	MR	MR	HR	HR	R
IE 4565	R	R	R	R	MR	MR	HR	HR	MR	R	S	S	HR	R	R
IE 4570	HR	R	R	HR	MR	HR	R	R	S	R	S	S	HR	HR	HR
IE 4622	R	R	R	HR	R	HR	HR	R	S	HR	S	S	R	R	R
IE 4646	HR	R	R	HR	R	HR	HR	R	HS	HR	R	R	HR	R	MR
IE 4671	R	MR	MR	HR	R	R	HR	S	S	HR	R	R	HR	HR	HR
IE 4709	R	R	HR	HR	HR	HR	R	HS	HS	HR	S	S	HR	R	MR
IE 4734	HR	HS	HS	HR	R	MR	HR	S	HS	HR	HS	HS	HR	S	HS
IE 4757	HR	S	MR	HR	S	HS	R	R	S	HR	MR	MR	HR	S	HS
IE 4795	R	MR	R	HR	R	HR	HR	S	HS	HR	MR	MR	HR	MR	S
IE 4797	HR	MR	HS	HR	HR	HR	HR	R	S	HR	S	S	HR	MR	S
IE 4816	*	*	*	*	*	*	HR	R	R	HR	HS	HS	HR	MR	MR
IE 5066	HR	R	R	HR	HR	HR	HR	R	MR	HR	HS	HS	HR	S	S
IE 5091	HR	R	R	HR	HR	HR	HR	HS	HS	R	HS	HS	R	R	R
IE 5106	HR	MR	R	HR	HR	HR	HR	R	MR	R	MR	MR	HR	R	R
IE 5201	HR	R	HR	*	*	*	HR	R	S	HR	HR	HR	HR	HR	R
IE 5306	HR	R	R	*	S	S	HR	MR	HS	HR	R	R	HR	HR	HR
IE 5367	HR	MR	MR	HR	HR	HR	HR	MR	HS	R	MR	MR	R	MR	MR

IE 5537	HR	R	R	HR	R	R	HR	HS	HS	HR	R	R	HR	HR	MR
IE 5817	HR	MR	MR	HR	R	HR	HR	R	R	HR	HS	HS	R	S	MR
IE 5870	HR	S	HS	HR	HR	HR	R	S	S	HR	HS	HS	R	S	HS
IE 6059	HR	MR	MR	HR	HR	HR	HR	MR	HS	HR	R	R	HR	R	MR
IE 6082	HR	HS	HS	HR	HR	HR	R	S	S	HR	R	R	HR	R	MR
IE 6154	HR	R	R	R	HR	HR	HR	MR	HS	R	HR	HR	R	R	R
IE 6165	HR	R	R	HR	HR	HR	R	MR	S	HR	MR	MR	HR	R	R
IE 6221	HR	R	R	HR	R	HR	HR	HR	MR	HR	R	R	R	HR	R
IE 6240	HR	R	R	R	HR	HR	HR	R	MR	HR	R	R	HR	R	R
IE 6294	R	R	R	HR	MR	S	HR	HS	HS	HR	S	S	HR	HR	HR
IE 6326	HR	R	R	R	HR	HR	HR	R	MR	HR	MR	MR	HR	HR	R
IE 6337	R	R	HR	HR	HR	HR	HR	R	R	R	R	R	R	HR	R
IE 6350	R	R	R	HR	HR	HR	HR	MR	S	HR	S	S	HR	R	R
IE 6421	HR	R	R	HR	HR	HR	HR	HS	HS	HR	R	R	HR	HR	R
IE 6473	HR	R	HR	HR	HR	HR	HR	MR	HS	HR	R	R	HR	HR	R
IE 6514	HR	R	MR	HR	R	R	HR	HR	R	HR	S	S	HR	R	MR
IE 6537	HR	R	HR	*	*	*	HR	R	MR	*	*	*	HR	HR	HR
IE 7018	R	R	R	HR	HR	HR	HR	HR	R	R	R	R	R	HR	R
IE 7079	R	R	R	HR	HR	HR	HR	HR	MR	R	MR	MR	HR	R	R
IE 7320	HR	R	R	HR	HR	HR	HR	HR	MR	HR	R	R	R	HR	R
VR 708	MR	HS	HS	MR	HS	HS	MR	HS	HS	MR	S	S	MR	HS	HS

* Data not available

HR: Highly Resistant; R: Resistant; MR: Moderately Resistant; S: Susceptible; HS: Highly Susceptible

[a] Leaf blast (LB) reaction based on leaf blast severity (1–9 scale): 1.0: HR; 2.0-3.0:R; 3.1-5.0:MR; 5.-7.0:S; 7.1-9.0: HS; [b] Neck Blast reaction based on severity (1 – 5 scale): 0-1.0: HR; 1.1-2.0: R; 2.1-3.0; MR; 3.1-4.0: S; 4.1-5.0: HS; [c] Finger blast reaction based on severity (%): 0-1.0: HR; 2.0-10: R; 11-20: MR; 21-30: S; >30: HS

Table 4.32. Agronomic traits and mean blast severity of seven resistant mini-core accessions across five locations during 2009 rainy season, India

IE No.	Origin	Race	Sub-race	Agronomic traits[a]			Neck blast severity (1–5 scale)[b]						Finger blast severity (%)[c]					
				DF	Plant height (cm)	Spike type	Pat[d]	Viz	Nan	M an	Nag	Mean	Pat	Viz	Nan	Man	Nag	Mean
IE 2589	USA	*Plana*	*Seriata*	71	137	TC	1.4	1.1	1.8	1.0	1.0	1.3	4.0	0	6.0	5.5	4.5	4.0
IE 2619	Malawi	*Vulgaris*	*Incurvata*	82	105	TC	1.7	1.0	1.0	1.5	1.2	1.3	2.0	0	7.0	20	9.5	7.7
IE 2911	Zambia	*Vulgaris*	*Incurvata*	82	105	TC	1.1	1.0	1.1	1.0	1.0	1.0	1.0	0	9.0	1.0	1.5	2.5
IE 2957	Germany	*Vulgaris*	*Liliacea*	70	91	TC	2.0	1.0	1.7	1.0	1.0	1.3	1.5	0	9.5	4.5	4.0	3.9
IE 4497	Zimbabwe	*Vulgaris*	*Digitata*	70	110	TC	1.8	1.3	1.8	1.0	1.0	1.0	5.5	1.0	9.0	6.0	7.0	5.7
IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*	70	92	TC	1.7	1.0	1.8	1.6	1.0	1.4	1.0	0	10.5	8.5	3.0	4.6
IE 7018	Kenya	*Vulgaris*	*Incurvata*	70	121	TC	1.8	1.0	1.0	1.1	1.0	1.2	6.5	0	10.0	5.5	2.5	4.9
VR 708	India	-	-	55	90	TC	4.9	4.5	3.5	3.5	4.5	4.3	51	51	47	43.5	34	45.3
Mean	-	-	-	71.3	106.4	-	2.1	1.5	1.7	1.5	1.5	1.6	9.1	6.5	13.5	11.8	8.3	9.8

[a] Recorded only at Patancheru; DF = Days to 50% flowering; TC = Top curved

[b] Mean neck blast severity based on 1-5 scale where 1= no infection/pinhead size lesions; 2 = 0.1–2.0 cm of lesions on the neck region; 3 = 2.1–4.0 cm; 4 = 4.1–6.0 cm and 5= >6 cm lesions on the neck region

[c] Mean finger blast severity across all tillers in a row; [d] Pat = Patancheru, Viz = Vizianagaram, Nan= Nandyal; Man = Mandya and Nag = Naganahalli.

Table 4.33. Evaluation of Finger Millet Blast Resistance Stability Nursery (FMBRSN) – 2010 at five locations: disease scores for leaf blast (LB), neck blast (NB) and finger blast (FB)

Genotype	Patancheru			Vizianagaram			Nandyal			Mandya			Naganahalli			Mean		
	LB[1]	NB[2]	FB[3]	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB
IE 2589	3.0	1.0	2.0 (8.1)	2.3	1.0	0.5 (4.1)	2.0	1.3	4.5 (12.2)	2.0	1.0	3 (9.9)	2.0	1.3	4.8 (12.6)	2.3	1.1	3 (9.9)
IE 2619	2.0	1.2	4.0 (11.5)	2.1	1.2	4.5 (12.2)	1.8	1.2	8.3 (16.7)	1.8	1.2	11.3 (19.6)	1.8	1.4	5.3 (13.2)	1.9	1.2	6.7 (14.9)
IE 2710	2.0	1.0	0	2.3	1.8	6.8 (15.1)	2.0	1.1	11.3 (19.6)	2.0	1.7	9 (17.5)	2.0	1.3	3.5 (10.8)	2.1	1.4	6.1 (14.3)
IE 2872	2.0	1.0	0	1.9	2.9	24 (29.3)	1.7	1.0	15.8 (23.4)	1.7	1.1	2.8 (9.5)	1.7	1.1	1 (5.7)	1.8	1.4	8.7 (17.2)
IE 2911	2.0	1.0	0.5 (4.1)	1.7	1.0	4.8 (12.6)	1.5	1.1	9 (17.5)	1.5	1.0	1.8 (7.6)	1.5	1.1	1.5 (7.0)	1.6	1.0	3.5 (10.8)
IE 2957	2.0	1.0	1.0 (5.7)	1.4	1.0	0.5 (4.1)	1.6	1.0	9 (17.5)	1.6	4.4	46.5 (43)	1.6	3.2	21.5 (27.6)	1.6	2.1	15.7 (23.3)
IE 3077	1.5	1.5	10 (18.4)	5.0	2.0	25.5 (30.3)	5.0	2.8	27.3 (31.5)	5.0	3.9	21.8 (27.8)	5.0	3.9	32.3 (34.6)	4.3	2.8	23.4 (28.9)
IE 3392	2.0	1.0	0	3.9	1.5	6.8 (15.1)	2.0	5.0	50 (45)	2.0	1.1	11.5 (19.8)	2.0	1.4	5 (12.9)	2.4	2.0	14.7 (22.5)
IE 3543	2.0	2.2	17.8 (24.9)	5.4	4.7	44 (41.6)	6.7	5.0	44.5 (41.8)	6.7	4.8	42 (40.4)	6.7	4.4	38.5 (38.4)	5.5	4.2	37.4 (37.7)
IE 4057	2.5	1.0	3.5 (10.8)	4.8	1.5	6.5 (14.8)	3.3	4.8	49.5 (44.7)	3.4	2.0	11 (19.4)	3.3	1.1	3 (10)	3.4	2.1	14.7 (22.5)
IE 4497	2.0	1.2	3.3 (10.4)	1.3	1.0	0.8 (5)	1.4	1.1	10 (18.9)	1.4	1.1	7.8 (16.2)	1.4	1.5	5 (12.9)	1.5	1.2	5.5 (13.5)
IE 4755	2.5	2.6	18.5 (25.5)	7.8	3.8	50.5 (45.3)	6.2	4.2	41 (39.8)	6.2	4.5	49 (44.4)	6.2	4.9	48.5 (44.1)	5.8	4.0	41.5 (40.1)
IE 4759	2.0	2.5	20 (26.6)	8.4	4.9	50 (45)	3.6	4.4	39 (38.6)	3.6	4.8	47.5 (43.6)	3.6	5.0	50 (45)	4.2	4.3	41.3 (40)
IE 4797	5.5	2.6	20.3 (26.7)	3.7	2.2	12.5 (20.7)	3.4	1.9	14 (22)	3.4	4.0	35 (36.3)	3.4	2.0	16 (23.6)	3.9	2.5	19.6 (26.2)
IE 5066	1.5	1.0	0	2.5	2.3	22.5	1.9	1.4	23.5	1.9	3.2	14.3	1.9	3.1	25.5	1.9	2.2	17.2

						(28.3)			(29)			(22.2)			(30.3)			(24.5)
IE 5091	2.0	1.6	8.8 (17.2)	1.9	2.5	21.3 (27.5)	3.0	4.6	47 (43.3)	3.3	5.0	50 (45)	3.0	2.2	17.8 (24.9)	2.6	3.2	29 (32.6)
IE 5106	2.0	1.2	2.3 (8.6)	1.3	1.4	6.8 (15.1)	3.0	2.9	28 (31.9)	3.0	1.2	6.8 (15.1)	3.0	1.3	6.8 (15.1)	2.4	1.6	10.1 (28.5)
IE 5817	2.0	2.9	26 (30.7)	2.6	3.2	31 (33.8)	4.6	4.7	46 (42.7)	4.6	4.3	46.5 (43)	4.6	4.6	36.5 (37.2)	3.7	3.9	37.2 (37.6)
IE 5870	5.5	3.8	35 (36.3)	3.9	3.6	38.5 (38.4)	6.8	4.7	46.5 (43)	6.8	5.0	50 (45)	6.8	5.0	50 (45)	6.0	4.4	44 (41.6)
IE 6082	7.0	5.0	52 (46.1)	2.1	5.0	52 (46.1)	6.8	4.6	39.5 (38.9)	7.3	5.0	50 (45)	6.8	5.0	52 (46.1)	6.0	4.9	49.1 (44.5)
IE 6221	3.0	2.8	24.8 (29.8)	4.3	2.5	20.5 (26.9)	5.3	1.9	22 (28)	5.5	4.9	47.5 (43.6)	5.3	2.3	20.5 (26.9)	4.7	2.9	27.1 (31.3)
IE 6240	3.0	1.9	15.8 (21.8)	4.4	1.3	12 (20.3)	4.7	4.9	51.5 (45.9)	4.7	4.9	37.5 (43.6)	4.7	2.9	18 (25.1)	4.3	3.2	27 (31.3)
IE 6337	2.0	1.0	3.5 (10.8)	2.4	1.5	5 (12.9)	1.6	1.0	7.5 (15.9)	1.6	1.2	6 (14.2)	1.6	1.5	7.8 (16.2)	1.8	1.2	6 (14.1)
IE 6421	2.0	1.0	0.3 (2.9)	2.4	2.5	24 (29.3)	3.1	1.4	28.5 (32.3)	3.1	2.6	18.5 (25.5)	3.1	1.3	5.5 (13.6)	2.7	1.8	15.4 (23.1)
IE 7018	2.0	1.0	1.5 (7.0)	2.0	1.0	4 (11.5)	1.7	1.0	9.5 (18)	1.7	1.6	6.8 (15.1)	1.7	1.1	1 (5.7)	1.8	1.1	4.6 (12.3)
IE 7079	2.0	1.1	1.5 (7.0)	2.1	1.0	10.5 (18.9)	2.5	1.0	13 (21.1)	2.5	3.1	19 (25.8)	2.5	1.3	8 (16.4)	2.3	1.5	10.4 (18.8)
GPU 28 R Check	1.0	1.0	0.5 (4.1)	1.0	1.5	7.5 (15.9)	1.4	5.0	50 (45)	1.4	1.0	1.8 (7.6)	1.4	1.0	6 (14.2)	1.2	1.9	13.2 (21.3)
VR 708 S Check	5.3	3.9	35.5 (36.6)	8.0	4.4	59.5 (50.5)	5.5	4.7	37.5 (37.8)	5.5	5.0	47.5 (43.6)	5.5	5.0	50 (45)	6.0	4.6	46 (42.7)
Mean	2.6	1.8	11 (19.4)	3.3	2.3	19.7 (26.4)	3.3	2.8	28 (31.9)	3.4	3.0	25.1 (30)	3.3	2.5	19.3 (26.1)	3.2	2.5	20.6 (27)
LSD *(P*<0.05)[4]	0.9	0.77	9.2	0.8	0.9	8.2	1.0	0.4	6.4	0.8	0.7	5.8	1.0	0.8	13.8	-	-	-

[1] Leaf blast severity on a 1–9 scale where 1= no infection and 9= >75% leaf area covered with lesions.

[2] Neck blast severity on a 1 – 5 scale where 1= no infection/pinhead size lesions and 5= >6 cm lesions on the neck region.

[3] Finger blast severity (%) across all panicles/all tillers in a row. [4] Trial least significant difference.

	Leaf blast		Neck blast		Finger Blast	
Factors	**SE(m)±**	**LSD *(P*<0.05)**	**SE(m)±**	**LSD *(P*<0.05)**	**SE(m)±**	**LSD *(P*<0.05)**
Location (L)	0.05	0.16	0.04	0.13	0.60	1.6
Accessions (A)	0.14	0.39	0.11	0.32	1.4	4.0
L × A	0.31	0.88	0.25	0.72	3.2	8.9

Table 4.36. Blast disease reaction of Finger Millet Blast Resistance Stability Nursery (FMBRSN) accessions under field conditions at five locations during 2010 rainy season based on data in table 4.33.

Genotype	Origin	Race	Sub-race	Patancheru			Vizianagaram			Nandyal			Mandya			Naganahalli			Mean reaction		
				LB[1]	NB[2]	FB[3]	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB
IE 2589	USA	*Plana*	*Seriata*	R	R	R	R	HR	HR	R	R	R	R	HR	R	R	R	R	R	R	R
IE 2619	Malawi	*Vulgaris*	*Incurvata*	R	R	R	R	R	R	HR	R	R	HR	R	MR	HR	R	R	HR	R	R
IE 2710	Malawi	*Plana*	*Confundere*	R	HR	HR	R	R	R	R	R	MR	R	R	R	R	R	R	R	R	R
IE 2872	Zambia	*Vulgaris*	*Digitata*	R	HR	HR	HR	MR	S	HR	HR	MR	HR	R	R	HR	R	HR	HR	R	R
IE 2911	Zambia	*Vulgaris*	*Incurvata*	R	HR	HR	HR	HR	R	HR	R	R	HR	HR	HR	HR	R	HR	HR	HR	R
IE 2957	Germany	*Vulgaris*	*Liliacea*	R	HR	HR	HR	HR	HR	HR	HR	R	HR	HS	HS	HR	S	S	HR	MR	MR
IE 3077	India	*Vulgaris*	*Incurvata*	HR	R	R	MR	R	S	MR	MR	S	MR	S	S	MR	S	HS	MR	MR	S
IE 3392	Zimbabwe	*Vulgaris*	*Liliacea*	R	HR	HR	MR	R	R	R	HS	HS	R	R	MR	R	R	R	R	R	MR
IE 3543	India	*Spontanea*	*	R	MR	MR	MR	HS	R	HS	HS	HS	S	HS	HS	S	HS	HS	S	HS	HS
IE 4057	Uganda	*Plana*	*Seriata*	R	HR	R	MR	R	R	MR	HS	HS	MR	R	MR	MR	R	R	MR	MR	MR
IE 4497	Zimbabwe	*Vulgaris*	*Digitata*	R	R	R	HR	HR	HR	HR	R	R	HR	R	R	HR	R	R	HR	R	R
IE 4755	India	*Vulgaris*	*Stellata*	R	MR	MR	HS	S	HS	HS	HS	HS	S	HS	HS	S	HS	HS	S	S	HS
IE 4759	India	*Vulgaris*	*Stellata*	R	MR	MR	HS	HS	HS	MR	HS	HS	MR	HS	HS	MR	HS	HS	MR	HS	HS
IE 4797	Maldives	*Vulgaris*	*Liliacea*	S	MR	MR	MR	MR	MR	MR	R	MR	MR	S	HS	MR	R	MR	MR	MR	MR
IE 5066	Senegal	*Vulgaris*	*Incurvata*	HR	HR	HR	R	MR	S	HR	R	S	HR	S	MR	HR	S	S	HR	MR	MR
IE 5091	Zimbabwe	*Vulgaris*	*Digitata*	R	R	R	HR	MR	S	R	HS	HS	MR	HS	HS	R	MR	MR	R	S	S
IE 5106	Zimbabwe	*Vulgaris*	*Incurvata*	R	R	R	HR	R	R	R	MR	S	R	R	R	R	R	R	R	R	R
IE 5817	Nepal	*Vulgaris*	*Incurvata*	R	MR	S	R	S	HS	MR	HS	HS	MR	HS	HS	MR	HS	HS	MR	S	HS
IE 5870	Nepal	*Vulgaris*	*Digitata*	S	S	HS	MR	S	HS	HS	HS	HS	S	HS	HS	S	HS	HS	S	HS	HS
IE 6082	Nepal	*Plana*	*Confundere*	S	S	HS	R	HS	HS	HS	HS	HS	HS	HS	HS	S	HS	HS	S	HS	HS
IE 6221	Nepal	*Vulgaris*	*Stellata*	R	MR	S	MR	MR	MR	HS	R	S	S	HS	HS	S	MR	MR	MR	MR	S
IE 6240	Zimbabwe	*Vulgaris*	*Incurvata*	R	R	MR	MR	R	MR	MR	HS	HS	MR	HS	HS	MR	MR	MR	MR	S	S
IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*	R	HR	R	R	R	R	HR	HR	R	HR	R	R	HR	R	R	HR	R	R
IE 6421	Uganda	*Vulgaris*	*Digitata*	R	HR	HR	R	MR	S	MR	R	S	MR	MR	MR	MR	R	R	R	R	MR
IE 7018	Kenya	*Vulgaris*	*Incurvata*	R	HR	HR	R	HR	R	HR	HR	R	HR	R	R	HR	R	HR	HR	R	R
IE 7079	Kenya	*Vulgaris*	*Liliacea*	R	R	HR	R	HR	R	R	HR	MR	R	S	MR	R	R	R	R	R	R

GPU 28 (RC)	India	-	-	HR	HR	HR	HR	R	R	HR	HS	HS	HR	HR	HR	HR	HR	R	HR	R	MR
VR 708 (SC)	India	-	-	S	S	HS	HS	HS	HS	HS	HS	HS	S	HS	HS	S	HS	HS	S	HS	HS
Mean reaction				R	R	MR	MR	MR	MR	MR	MR	S	MR	MR	S	MR	MR	MR	MR	MR	MR

* Data not available; RC = Resistant check; SC = Susceptible check

HR: Highly Resistant; R: Resistant; MR: Moderately Resistant; S: Susceptible; HS: Highly Susceptible; [1] Leaf blast (LB) reaction based on severity on a 1 – 9 scale: 1.0: HR; 2.0–3.0:R; 3.1–5.0:MR; 5.–7.0:S; 7.1–9.0: HS; [2] Neck blast (NB) reaction based on severity on a 1 – 5 scale: 0–1.0: HR; 1.1–2.0: R; 2.1–3.0; MR; 3.1–4.0: S; 4.1–5.0: HS; [3] Finger blast (FB) reaction based on severity (%): 0–1.0: HR; 2.0–10: R; 11–20: MR; 21–30: S; >30: HS

Table 4.38. Mean blast severity on 24 tested finger millet mini-core accessions at five locations during the 2009 and 2010 rainy seasons

Accession No.	Leaf blast severity (1-9 scale)						Neck blast severity (1-5 scale)						Finger blast severity (%)					
	Pat[1]	Viz	Nan	Man	Nag	Mean	Pat	Viz	Nan	Man	Nag	Mean	Pat	Viz	Nan	Man	Nag	Mean
IE 2589	2.0	1.9	1.8	1.8	1.8	1.8	1.2	1.1	1.5	1.0	1.2	1.2	3.0 (10)	0.3 (1.4)	5.3 (13.2)	4.3 (11.7)	4.6 (12.2)	3.5 (9.4)
IE 2619	1.5	1.6	1.4	1.9	1.9	1.6	1.4	1.1	1.1	1.4	1.3	1.3	3.0 (10)	2.3 (6.1)	7.6 (15.9)	15.6 (22.9)	7.4 (15.6)	7.2 (14.1)
IE 2710	1.5	1.6	2.0	2.0	1.8	1.8	1.1	1.4	1.3	1.6	1.1	1.3	1.3 (6.4)	3.4 (7.5)	16.2 (23.3)	7.8 (16)	3.0 (10)	6.3 (12)
IE 2872	1.5	1.4	1.6	1.6	1.4	1.5	1.3	2.0	1.3	2.2	1.1	1.1	1.8 (7.6)	12.0 (14.7)	15.6 (23.2)	19.4 (21.4)	4.5 (12.1)	10.6 (15)
IE 2911	1.8	1.6	1.5	1.5	1.5	1.6	1.1	1.0	1.1	1.0	1.0	1.0	0.8 (5)	2.4 (6.3)	9.0 (17.4)	1.4 (4.7)	1.5 (5.8)	3 (7.7)
IE 2957	1.8	1.2	1.3	1.5	1.3	1.4	1.5	1.0	1.4	2.7	2.1	1.7	1.3 (6.4)	0.3 (1.4)	9.3 (17.4)	25.5 (27.5)	12.8 (19.4)	9.8 (14.4)
IE 3077	1.3	3.0	3.0	3.5	3.0	2.7	1.4	2.0	2.0	2.6	2.5	2.1	7.5 (15.9)	23.8 (29.2)	26.9 (31.2)	18.9 (25.7)	16.9 (20.6)	18.8 (24.4)
IE 3392	1.5	2.4	1.5	2.0	1.5	1.8	1.4	1.3	3.4	1.2	1.2	1.67	1.8 (7.6)	3.4 (7.3)	37.0 (37.2)	13.8 (21.3)	4.5 (12.1)	12.1 (16.7)
IE 4057	2.0	2.9	2.6	2.7	2.4	2.5	1.1	1.5	4.8	1.5	1.1	2.0	2.3 (8.6)	3.3 (7.3)	60.8 (51.4)	13.3 (21.1)	2.3 (6.0)	16.4 (18.6)
IE 4497	1.5	1.4	1.2	1.2	1.2	1.3	1.5	1.2	1.5	1.0	1.2	1.37	4.4 (12)	0.9 (3.8)	9.8 (18.2)	6.9 (14.7)	6.0 (14)	5.6 (12.2)
IE 4797	3.5	2.3	2.5	2.2	2.2	2.6	2.7	1.6	1.8	4.0	2.3	2.5	25.6 (30.4)	6.3 (10.6)	18.0 (24.9)	44.5 (41.8)	20.5 (26.7)	23 (26)
IE 5066	1.5	2.0	1.7	1.5	1.5	1.6	1.2	1.6	1.2	4.1	3.5	2.3	2.0 (8.1)	11.3 (14.1)	18.0 (24.9)	37.6 (36.8)	25.0 (30)	18.8 (22.3)
IE 5091	1.5	1.4	2.3	2.7	2.5	2.1	1.8	1.7	4.4	4.7	1.9	2.87	8.9 (17.3)	10.6 (13.7)	39.8 (39)	42.5 (40.6)	11.9 (19.4)	22.7 (26)
IE 5106	1.5	1.1	2.2	2.5	2.2	1.9	1.6	1.2	2.1	1.7	1.2	1.6	3.6 (11)	3.4 (7.4)	23.0 (28.2)	11.9 (19.7)	4.6 (9.9)	9.3 (15.1)

IE 5817	1.8	1.8	2.8	2.8	3.3	2.5	2.7	2.2	3.0	4.6	4.1	3.3	19.0 (25.9)	15.5 (16.9)	25.8 (28.1)	53.8 (47.2)	28.3 (31.9)	28.9 (29.9)
IE 5870	3.5	2.7	4.4	4.2	4.9	3.9	3.8	2.3	4.3	4.8	4.5	3.9	33.5 (35.4)	19.3 (19.2)	37.5 (37.6)	52.5 (46.4)	46.5 (42.9)	38 (36.3)
IE 6082	4.3	1.1	4.4	4.4	4.1	3.9	5.0	3.0	4.1	3.5	3.4	3.9	56.0 (48.5)	26.0 (23.3)	33.3 (35.1)	37.0 (37.2)	31.5 (32.8)	37 (35.4)
IE 6221	2.0	2.9	3.4	3.5	3.6	3.1	2.2	2.0	1.5	3.4	1.7	2.1	14.6 (22.5)	10.3 (13.5)	18.3 (25.2)	41.3 (39.9)	14.3 (21)	19.7 (24.1)
IE 6240	2.0	3.2	3.1	3.1	2.9	2.9	1.6	1.2	3.0	3.1	2.0	2.2	9.1 (17.6)	6.0 (10)	32.8 (33.9)	28.3 (31.8)	11.0 (18.3)	17.4 (21.9)
IE 6337	2.0	2.0	1.3	1.8	1.8	1.8	1.4	1.3	1.4	1.4	1.2	1.3	2.3 (8.6)	2.5 (4.6)	9.0 (17.4)	7.3 (15.5)	5.4 (13)	5.3 (11.6)
IE 6421	1.5	1.7	2.3	2.3	2.3	1.8	1.5	1.8	3.2	1.9	1.1	1.9	4.9 (12.8)	12.0 (14.4)	30.3 (33.3)	16.3 (23.7)	3.8 (10.7)	13.5 (18.4)
IE 7018	2.0	1.5	1.6	1.9	1.9	1.8	1.4	1.0	1.0	1.4	1.0	1.2	4.0 (11.5)	2.0 (6.0)	9.8 (17.9)	6.1 (14.3)	1.8 (6.6)	4.8 (10.9)
IE 7079	2.0	1.5	2.0	2.2	2.0	1.9	1.2	1.0	1.0	2.9	1.2	1.5	3.5 (10.8)	5.3 (9.5)	16.3 (23.7)	28.5 (31.9)	6.3 (13.8)	12 (17.8)
VR 708 (SC)[2]	5.2	6.3	4.5	4.5	5.1	5.1	4.4	4.3	4.4	4.5	4.7	4.5	39.3 (38.8)	55.3 (48)	42.3 (40.5)	45.5 (42.4)	42.0 (40.3)	44.9 (42.0)
Mean	2.1	2.2	2.3	2.5	2.4	2.27	1.9	1.7	2.3	2.6	2.0	2.1	10.6	1.3	23	24.2	13.1	16.34
SE (m)±	0.2	0.2	0.26	0.2	0.24	-	0.2	0.2	0.2	0.2	0.2	-	1.8	1.2	1.9	1.6	2.5	-
LSD (P<0.05)[3]	0.6	0.6	0.7	0.62	0.7	-	0.5	0.5	0.54	0.57	0.57	-	5.2	3.5	5.4	4.7	7.4	-

[1] Pat = Patancheru; Viz = Vizianagaram; Nan = Nandyal; Man = Mandya; Nag = Naganahalli;
[2] SC = Susceptible check; [3] Trial least significant difference (LSD)

	Leaf blast		**Neck blast**		**Finger Blast**	
Factors	**SE(m)±**	**LSD (P<0.05)**	**SE(m)±**	**LSD (P<0.05)**	**SE(m)±**	**LSD (P<0.05)**
Year (Y)	0.02	0.08	0.03	0.06	0.25	0.68
Location (L)	0.04	0.13	0.02	0.10	0.39	1.08
Accession (A)	0.10	0.28	0.08	0.23	0.85	2.4
Y × A	0.14	0.4	0.18	0.33	1.21	3.4
Y × L	0.06	0.18	0.05	0.15	0.55	1.54

L × A	0.23	0.64	0.11	0.52	1.91	5.3
Y × L × A	0.32	0.91	0.26	0.74	2.7	7.5

Table 4.40. Leaf, neck and finger blast severity of 24 finger millet mini-core accessions tested for blast resistance at five locations during the 2009 and 2010 rainy seasons

Accession No.	Average severity[1]			Relative variation2		
	Leaf blast (1-9 scale)	Neck blast (1-5 scale)	Finger blast (%)	Leaf blast[3]	Neck blast	Finger blast
VR 708	5.1 a	4.45 a	44.9 a	0.28 ef	0.13 g	0.14 c
IE 5870	3.92 b	3.94 b	37.0 b	0.71 abc	0.32 cdefg	0.40 bc
IE 6082	3.87 b	3.92 b	37.0 b	0.78 ab	0.44 abcdefg	0.48 abc
IE 6221	3.08 c	2.13 fg	19.7 e	0.76 abc	0.59 abcd	0.65 abc
IE 6240	2.85 dc	2.17 fg	17.4 ef	0.80 ab	0.78 a	0.92 abc
IE 3077	2.73 de	2.07 fg	18.8 ef	0.86 a	0.61 abcd	0.43 abc
IE 4797	2.61 de	2.54 e	23 d	0.78 ab	0.25 defg	0.42 abc
IE 4057	2.52 e	1.99 g	16.4 fg	0.60 abcd	0.47 abcdefg	1.06 abc
IE 5817	2.51 e	3.29 c	28.9 c	0.71 abc	0.40 bcdefg	0.66 abc
IE 5091	2.06 f	2.87 d	22.7 d	0.55 bcde	0.38 bcdefg	0.52 abc
IE 7079	1.94 gf	1.46 ijk	12.0 hi	0.38 edf	0.19 fg	0.71 abc
IE 5106	1.91 fgh	1.56 ij	9.3 jk	0.54 bcde	0.61 abcd	1.02 abc
IE 2589	1.83 fghi	1.18 lm	3.5 m	0.53 bcdef	0.44 abcdefd	0.64 abc
IE 7018	1.8 fghi	1.16 lm	5.0 lm	0.26 f	0.32 cdefg	0.78 abc
IE 6421	1.8 f	1.93 gh	13.5 gh	0.62 abcd	0.70 ab	0.64 abc
IE 3392	1.78 fghi	1.67 i	12.1 hi	0.58 abcd	0.58 abcde	0.95 abc
IE 2710	1.77 fghi	1.3 ijk	6.3 l	0.37 edf	0.54 abcdef	1.45 a
IE 6337	1.75 fghi	1.32 ijk	5.3 lm	0.35 edf	0.77 a	0.94 abc
IE 2619	1.63 ghij	1.25 klm	7.2 kl	0.48 cdef	0.54 abcdef	0.68 abc
IE 5066	1.62 ghijk	2.32 ef	18.8 ef	0.60 abcd	0.44 abcdefg	0.81 abc
IE 2911	1.57 hijk	1.03 m	3.0 m	0.59 abcd	0.22 efg	1.38 ab
IE 2872	1.49 ijk	1.54 ij	10.6 ij	0.60 abcd	0.71 ab	1.11 abc
IE 2957	1.4 jk	1.72 hi	9.8 ij	0.54 bcde	0.65 abc	0.86 abc
IE 4497	1.3 k	1.37 klm	5.6 lm	0.53 bcdef	0.63 abc	1.03 abc

[1] Average severity on the tested accessions across different locations and over years.

[2] Relative variation was calculated by dividing standard deviation across locations and over years with the square root of [mean severity × (1 – mean severity)]

[3] Figures followed by same letters are not significantly different according to least significant difference test ($P > 0.05$)

Table 4.42. Leaf (LB), neck (NB) and finger blast (FB) severity* of selected finger millet accessions against five isolates of *M. grisea* under greenhouse conditions

Accession No.	FMP1[1]			FMV25[2]			FMNd31[3]			FMM39[4]			FMNg54[5]			Mean		
	LB	**NB**	**FB**	**LB**	**NB**	**FB**	**LB**	**NB**	**FB**	**LB**	**NB**	**FB**	**LB**	**NB**	**FB**	**LB**	**NB**	**FB**
IE 2911	1.2	1.3	0 (0)[#]	3.5	1.0	0 (0)	2.2	1.0	0 (0)	2.5	1.0	0 (0)	4.5	1.0	0 (0)	2.8	1.1	0 (0)[#]
IE 2957	1.5	1.0	0 (0)	2.9	2.7	12.3 (20)	1.9	1.0	4.38 (12)	2.5	1.0	0 (0)	3.4	1.0	6.0 (14)	2.5	1.3	4.54 (9.3)
IE 4497	2.5	4.4	36.8 (37)	5.5	5.0	37.9 (38)	2.7	1.0	0.21 (1.5)	3.5	1.0	0 (0)	5.2	1.0	0 (0)	3.9	2.5	15 (15)
IE 6337	1.7	4.9	80 (63.4)	4.8	5.0	64.6 (54)	5.5	5.0	62 (52.2)	2.2	4.8	25.4 (30)	3.5	4.8	77.5(62)	3.5	4.9	61.9 (52)
IE 7018	1.4	3.1	16.2 (23)	2.9	4.1	20.7 (27)	3.8	5.0	52.1 (46.2)	6.3	1.0	0 (0)	4.2	1.1	0 (0)	3.7	2.9	17.8 (19)
GPU 28	3.3	1.0	0 (0)	2.3	1.5	4.7 (12)	2.9	4.3	24.2 (29.4)	1.1	1.0	0 (0)	2.5	1.0	0 (0)	2.4	1.8	5.67 (8.2)
VR 708	4.9	5.0	78.3 (63)	6.7	5.0	71.2 (58)	7.0	5.0	82.1 (65)	5.2	4.9	65 (54)	5.2	4.9	100 (90)	5.8	4.9	79.3 (66)
Mean	2.3	3.0	30.2 (27)	4.1	3.5	30.1 (30)	3.7	3.7	32.1 (29.5)	3.3	3.3	12.9 (12)	4.1	3.2	26.2 (24)	3.5	2.8	26.3 (24)
LSD (*P*<0.01)	0.9	1.4	22.3	0.8	0.88	12.38	0.9	0.5	13.8	0.8	0.2	2.67	1.1	0.30	4.6	-	-	-

* Mean of three replications; [#]Values in parentheses are angular transformed values

LB: Leaf blast (1 – 9 scale) NB: Neck blast (1–5 scale); FB: Finger blast severity (%) across all tillers in each replication

[1] **FMP1:** Finger millet isolate from Patancheru and isolate no.1; [2] **FMV25:** Finger millet blast isolate from Vizianagaram and isolate no.25; [3] **FMNd31:** Finger millet blast isolate from Nandyal and isolate no. 31; [4] **FMM39:** Finger millet blast isolate from Mandya and isolate no. 39; [5] **FMNg 54:** Finger millet blast isolate from Naganahalli and isolate no. 54.

Factors	Leaf blast		Neck blast		Finger Blast	
	SE (m)±	**LSD (*P*<0.01)**	**SE (m)±**	**LSD (*P*<0.01)**	**SE (m)±**	**LSD (*P*<0.01)**
Isolate (I)	0.07	0.28	0.066	0.250	1.15	4.34
Accession (A)	0.09	0.33	0.07	0.296	1.37	5.13
I × A	0.20	0.75	0.176	0.662	3.06	11.84

Table 4.43. Leaf (LB), neck (NB) and finger blast (FB) reaction of selected finger millet accessions against five isolates of *M. grisea* under greenhouse conditions

Genotype	Leaf, neck and finger blast reaction using different isolates																	
	FMP1[1]			FMV25[2]			FMNd31[3]			FMM39[4]			FMNg54[5]			Mean		
	LB[#]	NB[*]	FB[&]	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB	LB	NB	FB
IE 2911	HR	HR	HR	MR	HR	HR	R	HR	HR	R	HR	HR	MR	HR	HR	R	HR	HR
IE 2957	HR	HR	HR	R	MR	MR	HR	HR	R	R	HR	HR	MR	HR	R	R	HR	R
IE 4497	R	HS	HS	S	HS	HS	R	HR	HR	MR	HR	HR	S	HR	HR	MR	MR	MR
IE 6337	HR	HS	HS	MR	HS	HS	S	HS	HS	R	HS	S	MR	HS	HS	MR	HS	HS
IE 7018	HR	MR	MR	R	HS	MR	MR	HS	HS	S	HR	HR	MR	HR	HR	MR	MR	MR
GPU 28 (RC)[5]	MR	HR	HR	R	R	R	R	HS	S	HR	HR	HR	R	HR	HR	R	R	R
VR 708 (SC)[6]	MR	HS	HS	S	HS	HS	S	HS	HS	S	HS	HS	S	HS	HS	S	HS	HS

HR: Highly Resistant; R: Resistant; MR: Moderately Resistant; S: Susceptible; HS: Highly Susceptible

[1] **FMP1:** Finger millet blast isolate from Patancheru and isolate no. 1; [2]**FMV25:** Isolate from Vizianagaram and no. 25; [3]**FMNd31:** Isolate from Nandyal and no. 31;
[4] **FMM39: I**solate from Mandya and no. 39; [5]**FMNg 54:** Isolate from Naganahalli and no. 54;
[5] RC: Resistant check;
[6] SC: Susceptible check

Table 4.44. Weather data and neck (NB) and finger blast (FB) severity in four susceptible finger millet accessions at five locations in India during 2009-2010.

Location	Relative humidity (%)[1]				Mean temperature (°C)				Rainfall (mm)	No. of rainy days	NB (1-5 scale)[2]		FB (%)	
	Minimum		Maximum		Minimum		Maximum							
	Mean	Range	Mean	Range	Mean	Range	Mean	Range			Mean	Range	Mean	Range
Patancheru	57.6±1.8	44.8-64	92±2.5	87.3-95.6	19.9±1.0	13.2-23.1	29.6±0.9	27.3-31	132.6	39.5	3.4±0.6	2.2-4.9	26.8±3.8	18-51
Vizianagaram	65.3±2.3	47.5-79.7	86±0.8	79.4-90.3	25.1±1.1	19.2-28.2	30.4±0.6	27.6-32	194.8	35	3.9±0.5	2-4.7	40.6±11	24-64
Nandyal	65.6±4.0	54.4-73.5	79.4±3	71.5-83.8	23±1.0	18.5-25.6	32.2±1.0	29.7-33.4	39.8	30	3.3±0.8	2-4.95	34±11	20-54
Mandya	50.1±0.5	46.7-52.3	91±0	90.8-91	19.8±0	18.8-20.6	30.6±0	30-31	83.2	34.5	3.6±0.8	2.2-5	32.6±5	20-47.5
Naganahalli	62.7±2.9	51.5-73.4	90.9±1.6	86.9-95.7	18.1±0.4	14.8-19.4	29.2±0.3	27.9-30	94.4	38	3.9±1.0	2.1-5	35.5±11	16-50

[1] Data are means of two years and 2 replications.

[2] Data for four accessions: IE 3077, IE 4755, IE 4759 and VR 708

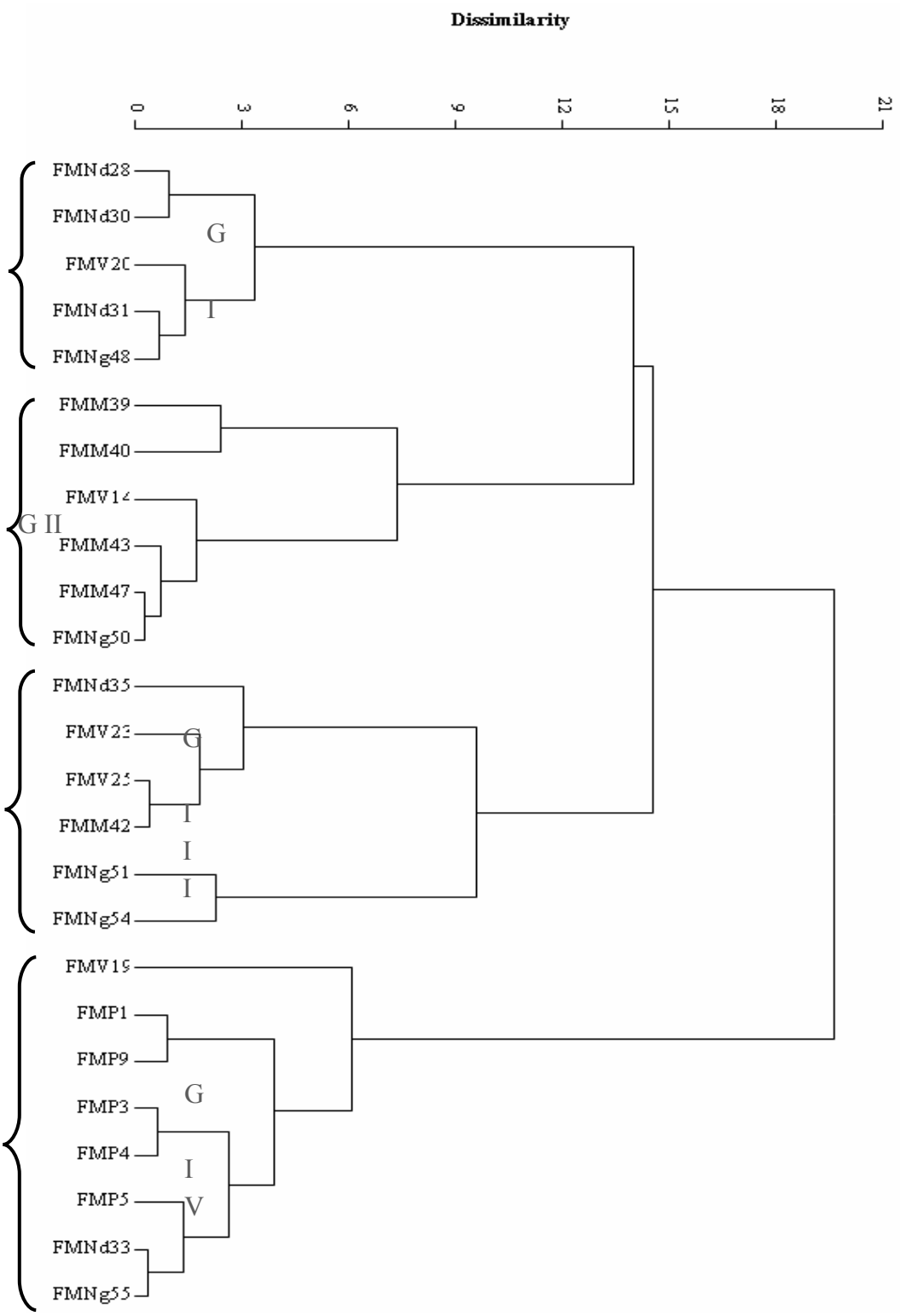

Figure 4.2. Dendrogram of 25 isolates of *M. grisea*, based on principal components analysis (79.1% variation captured) of leaf blast severity recorded on 12 differential hosts.

Leaf Blast

Neck blast

Neck and Finger blast

Figure 4.1. Finger millet blast symptoms on various plant parts.

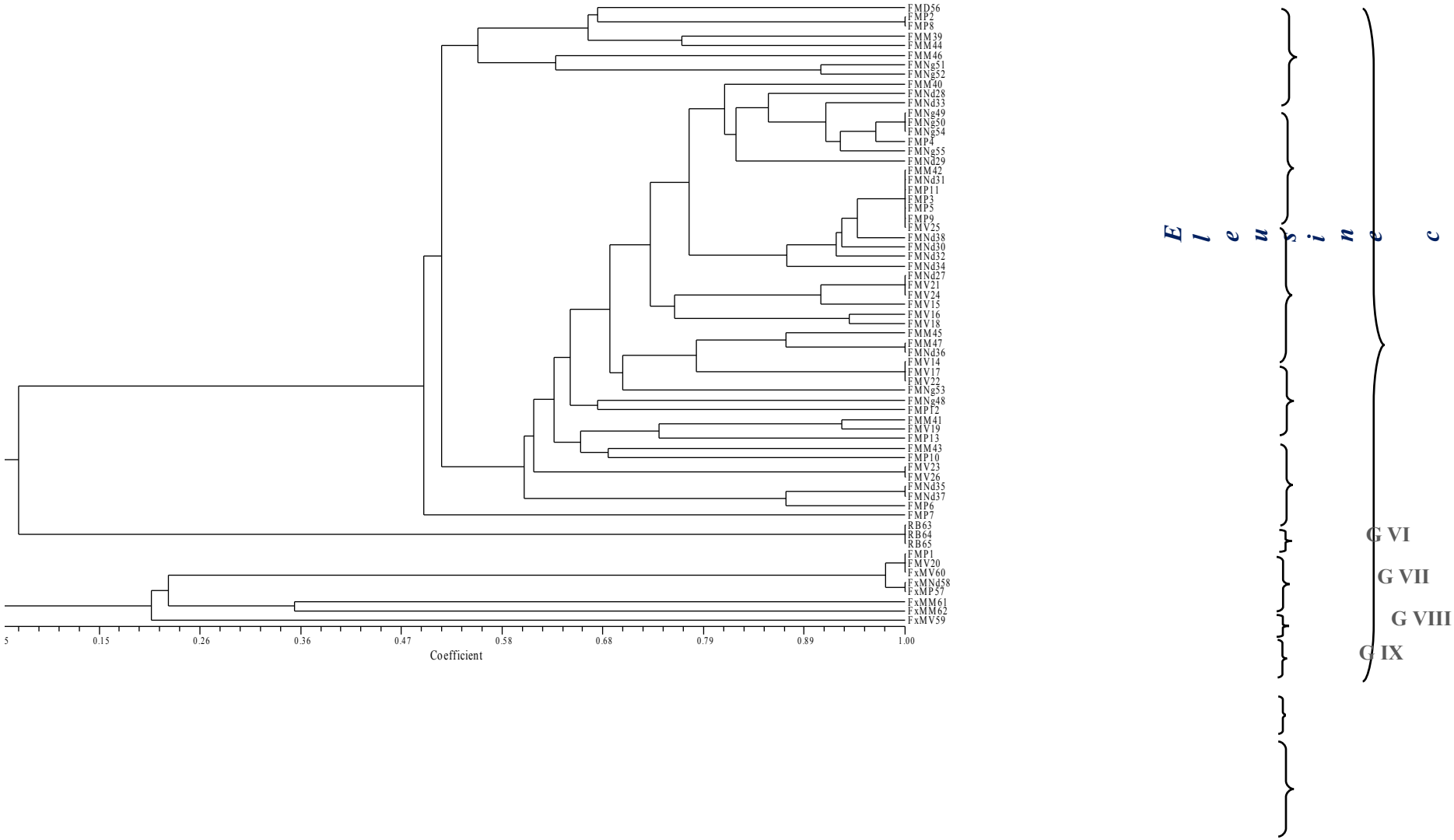

Figure 4.3. Dendrogram depiciting the genetic relationship among the 65 isolates of *M. grisea* from different host based on similarity coefficients calculated from SSR data.

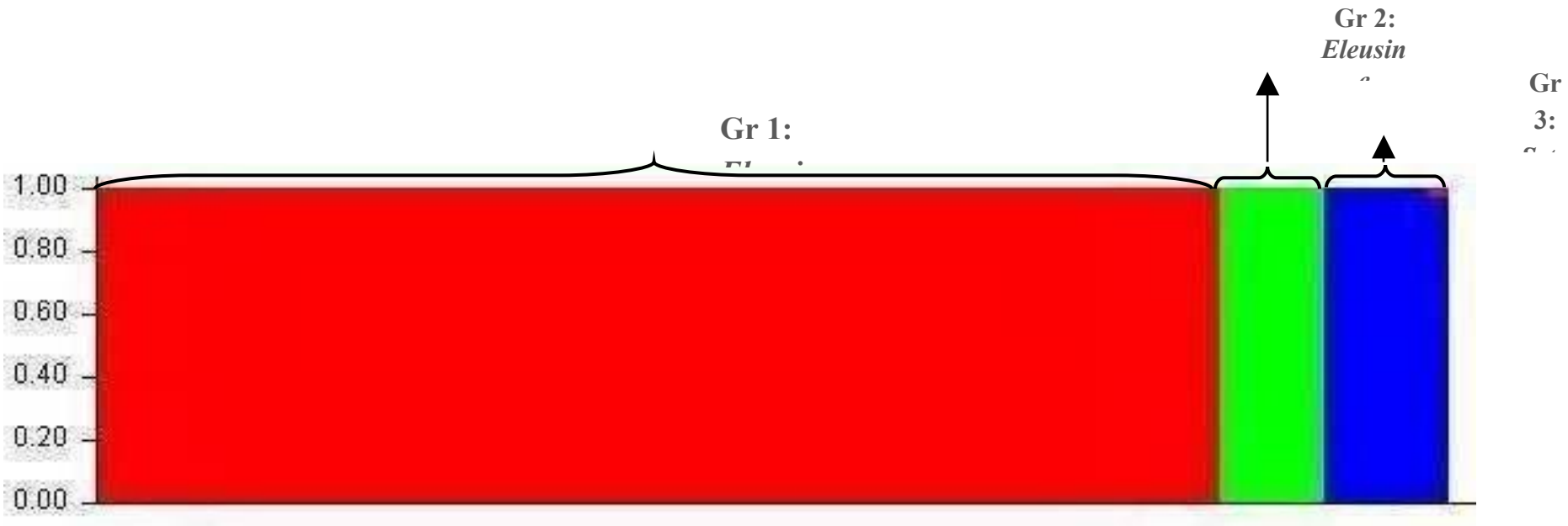

Figure 4.4. Population structure of 65 *M. grisea* isolates based on 17 SSR loci (*K* = 3) using STRUCTURE (Pritchard *et al*., 2000). Three different colors [Group 1 (Red): *Eleusine coracana,* Group 2 (Green): *Setaria italica* + *Eleusine coracana,* and Group 3 (Blue): *Setaria italica* + *Oryza sativa*) represent three subpopulations (or groups) in *M. grisea* based on estimated membership probabilities (*Q*) and then all the isolates were sorted by *Q*.

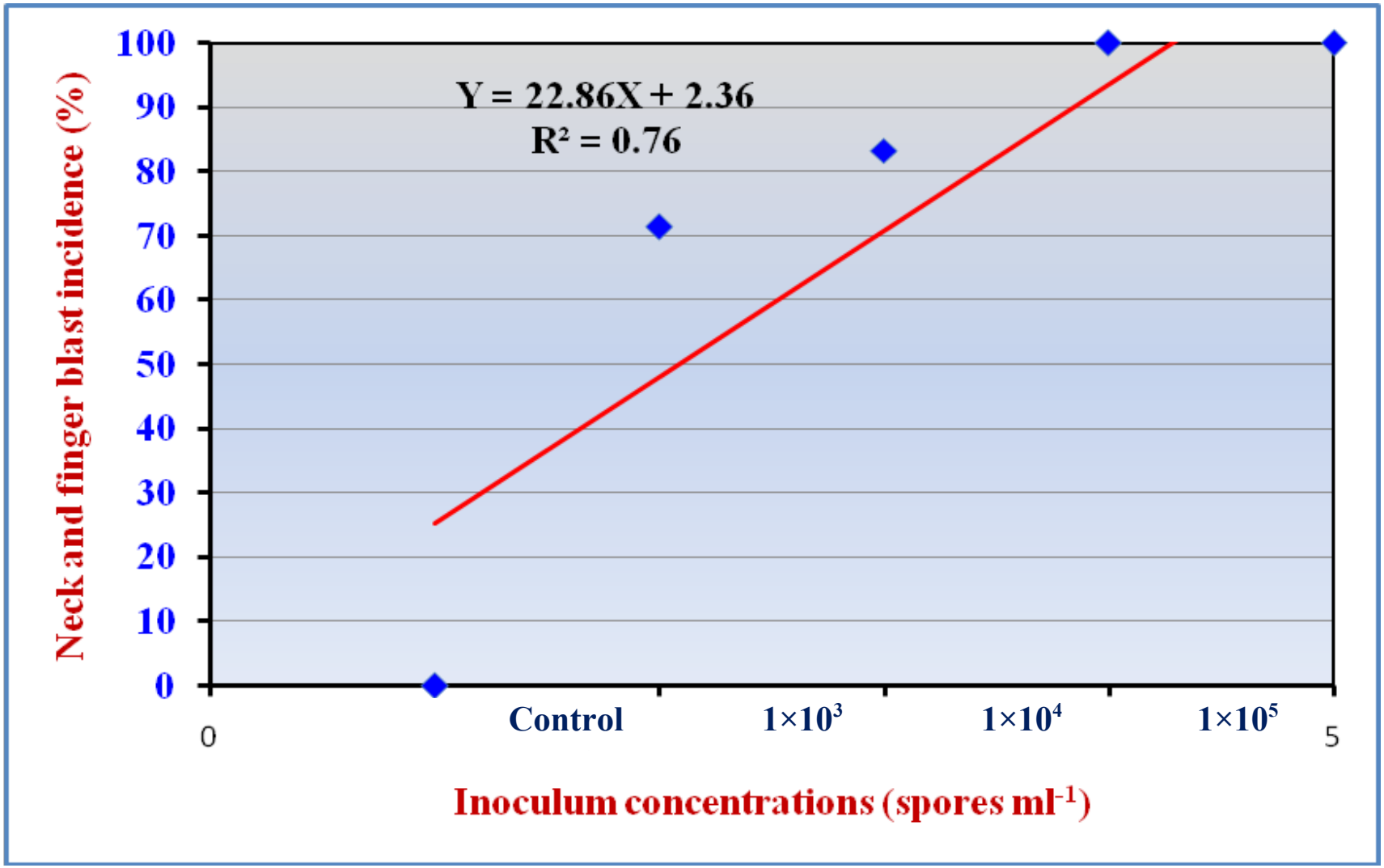

Figure 4.5. Effect of inoculum concentrations on neck and finger blast incidence in finger millet plants inoculated with fm stain of Patancheru isolate (FMP1).

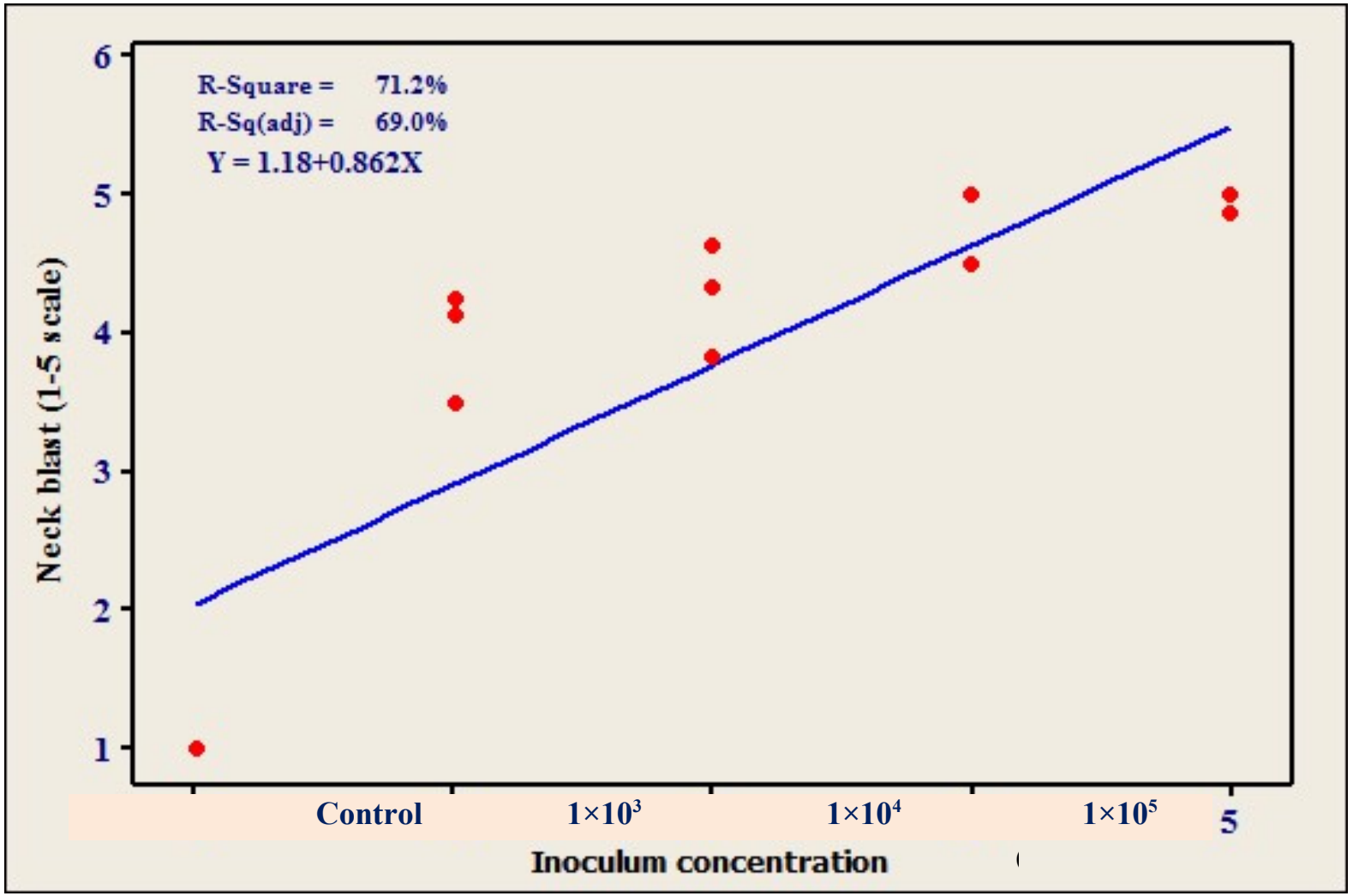

Figure 4.6. Effect of inoculum concentrations on neck blast severity (1–5 scale) in finger millet inoculated with fm stain of Patancheru isolate (FMP1) by inject inoculation method. Disease severity rating based on a 1 – 5 scale, where 1 = no lesions/pinhead size lesions and 5 = >6 cm lesions on the neck region.

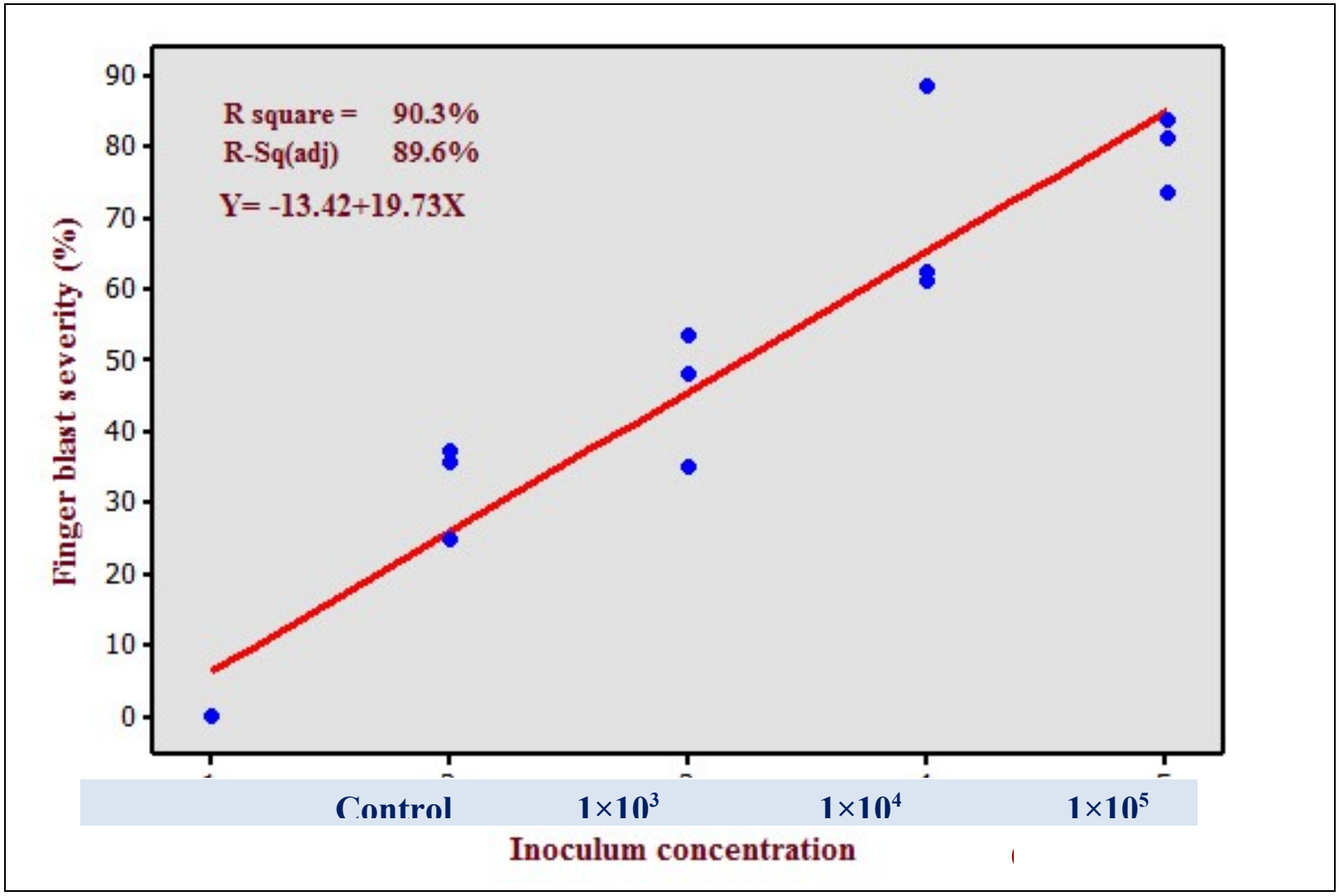

Figure 4.7. Effect of inoculum concentrations on finger blast severity (%) in finger millet inoculated with fm stain of Patancheru isolate (FMP1) by inject inoculation method.

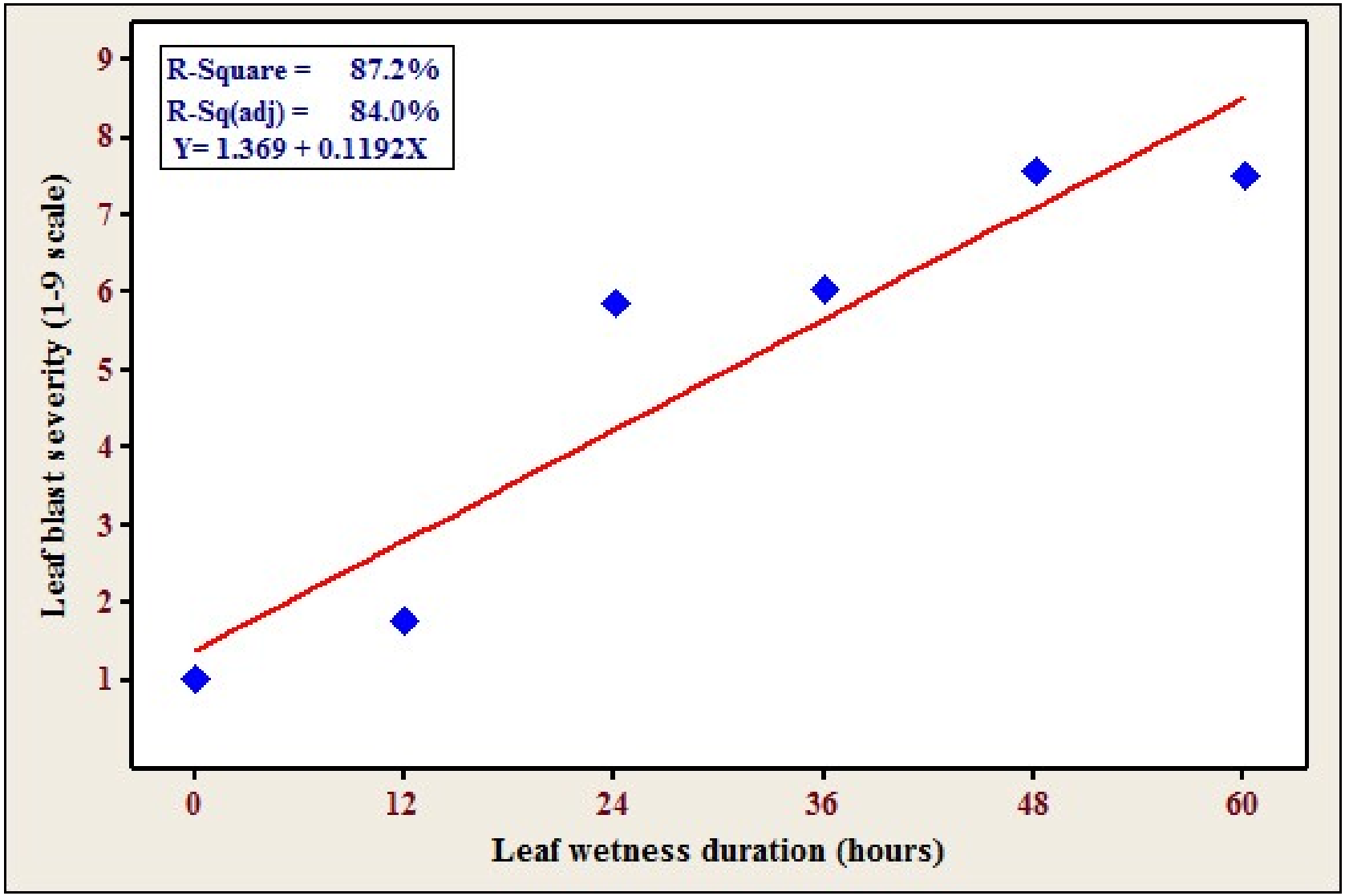

Figure 4.8. Effect of leaf wetness duration on leaf blast severity caused by *M. grisea* on finger millet.

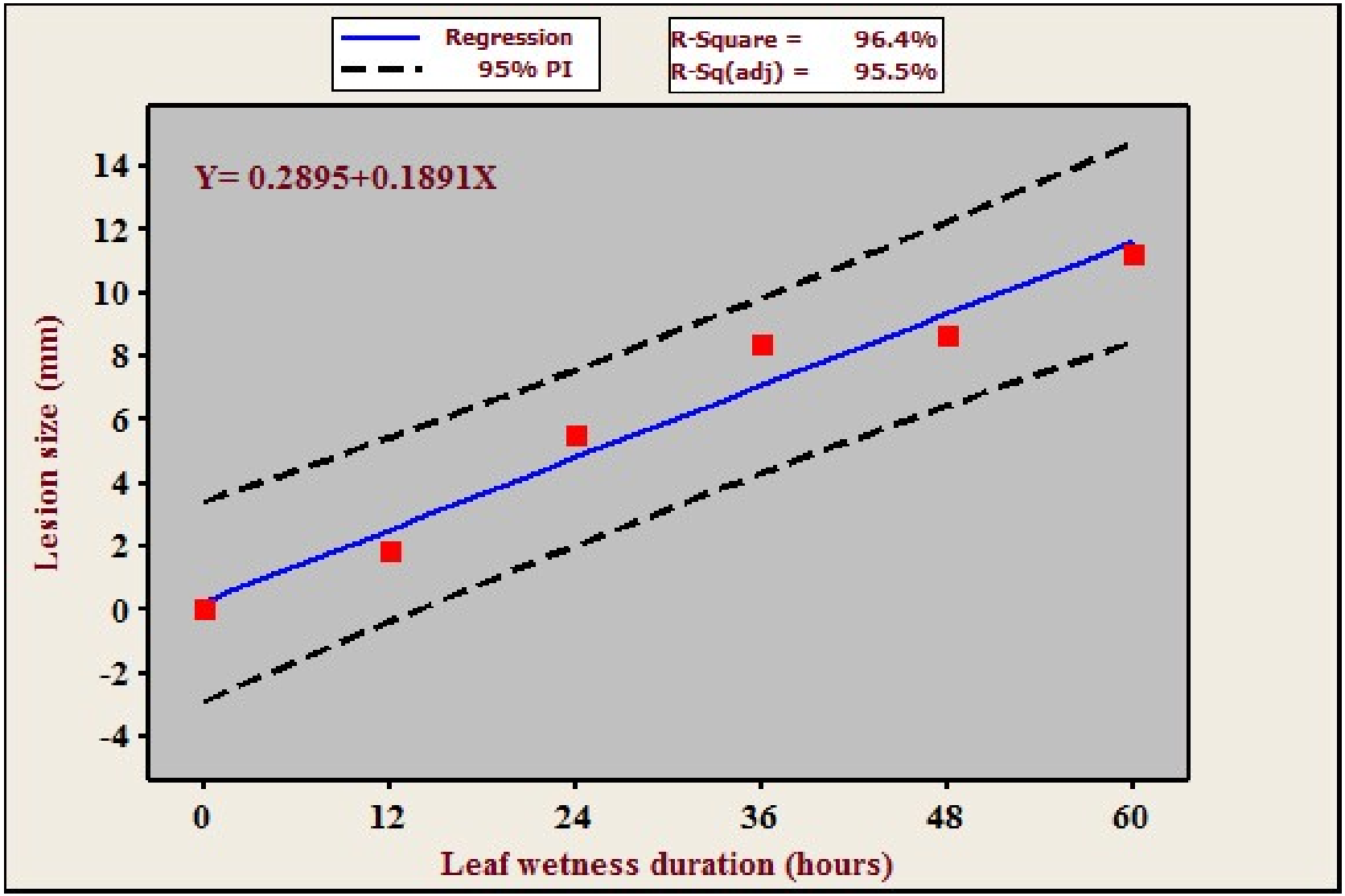

Figure 4.9. Observed and predicted values of mean blast lesion size (mm) plotted against various leaf wetness durations.

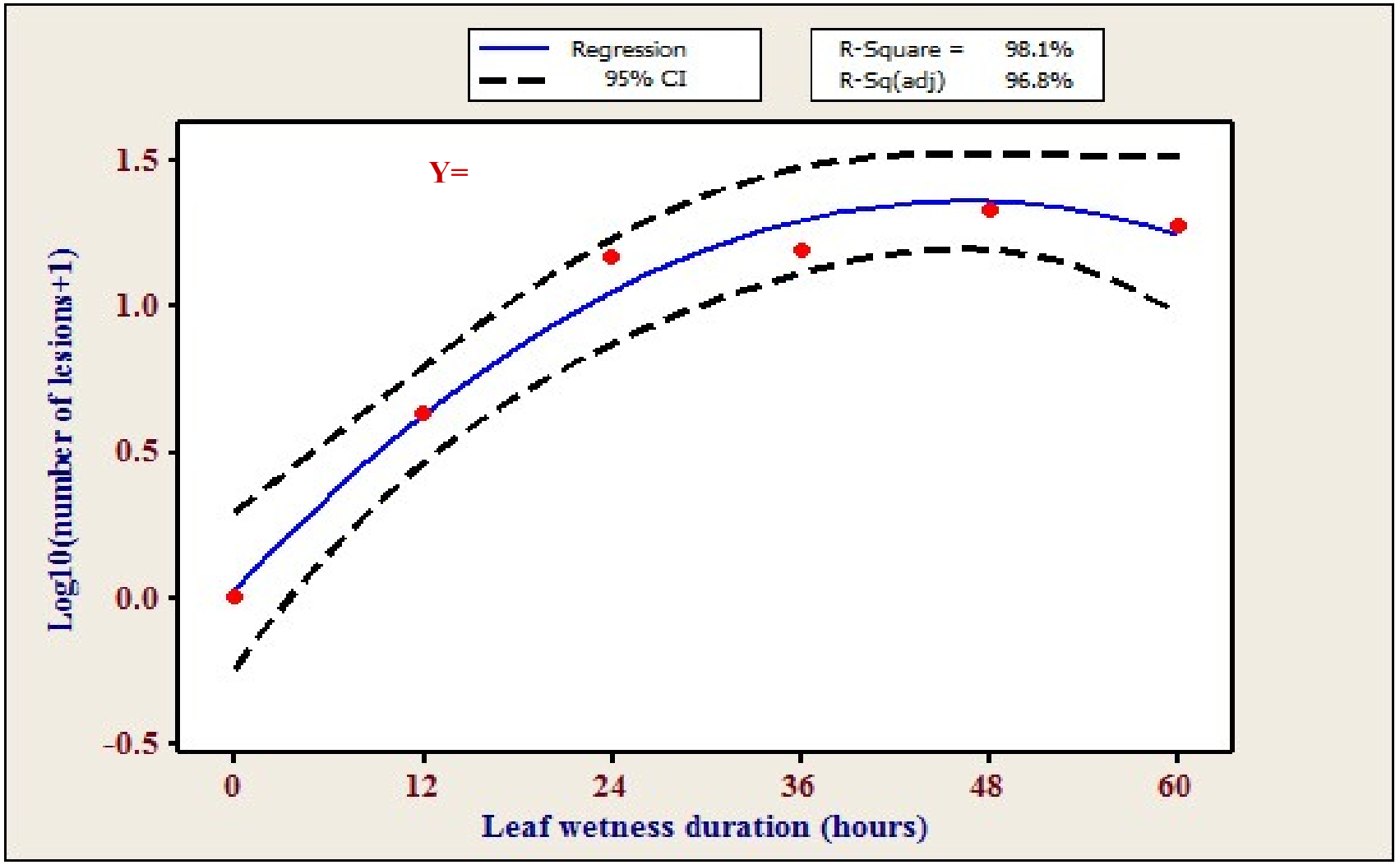

Figure 4.10. Observed and predicted mean disease severity [Log_{10}(number of lesions/plant+1)] at various leaf wetness durations. The solid lines in graph was genereated by polynomial model and the data points represent the mean log_{10}(number of lesions/plant +1).

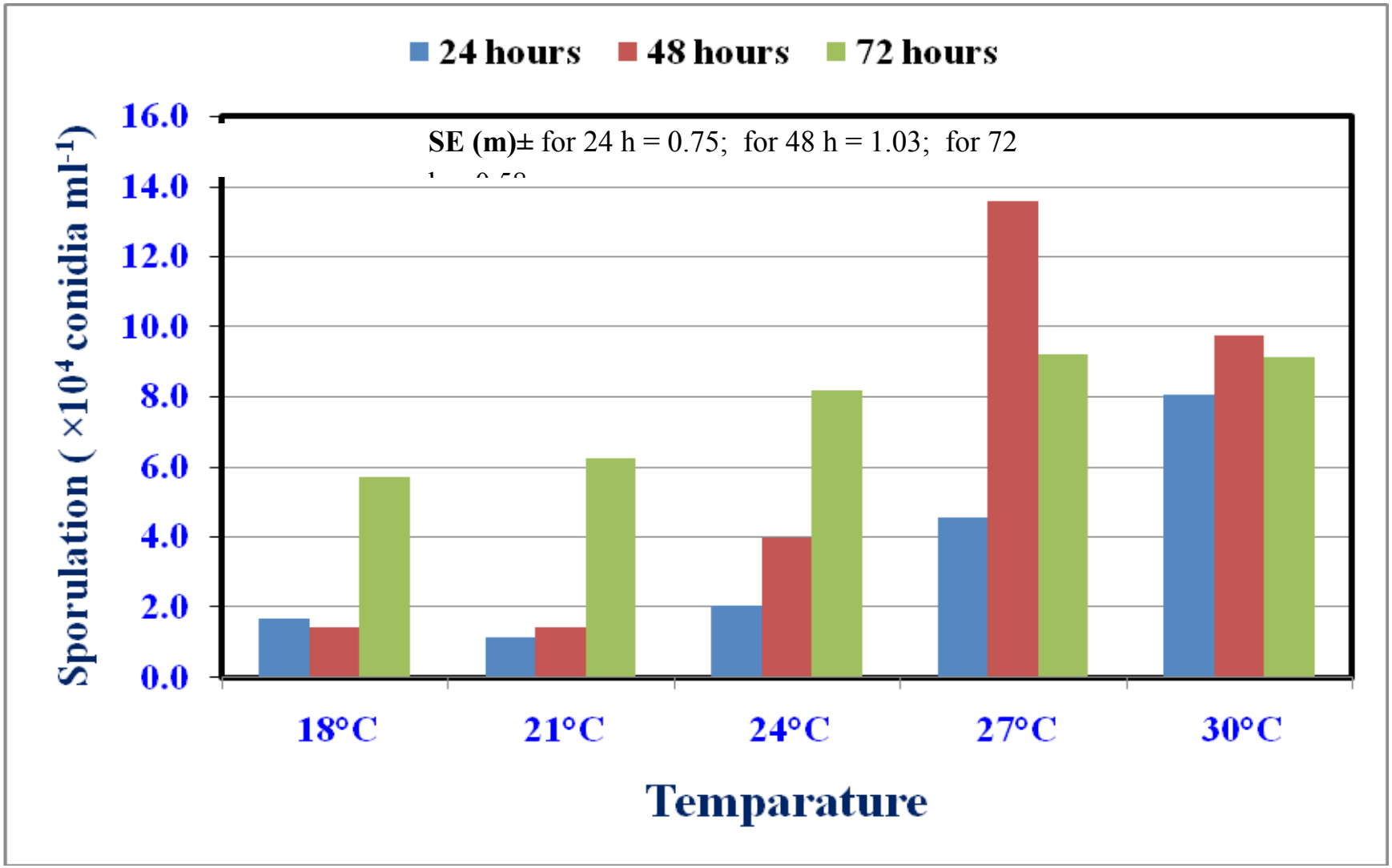

Figure 4.11. Sporulation of *M. grisea* on foliage at different temperatures.

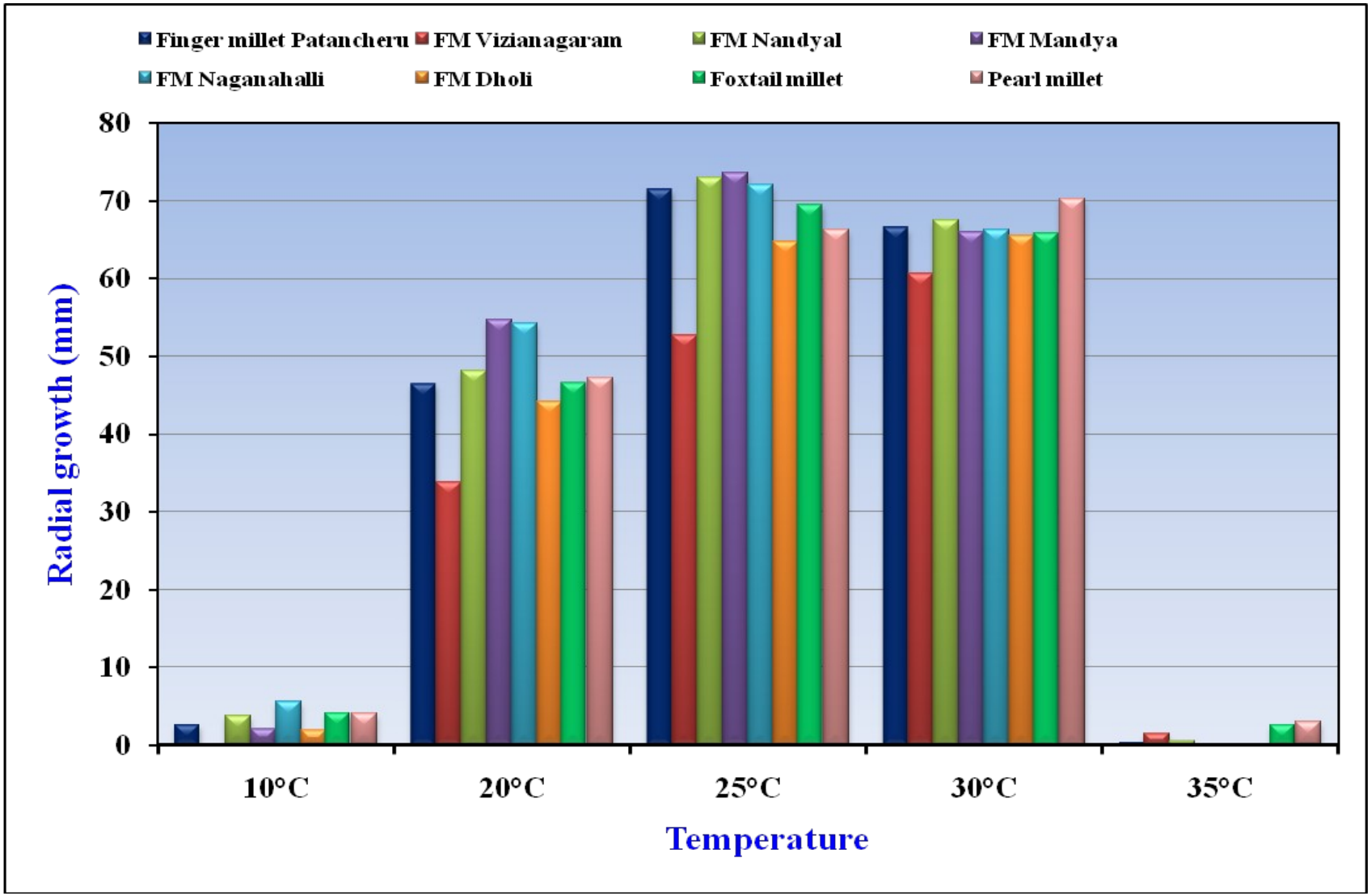

Figure 4.12. Radial growth of *M. grisea* isolates at different temperatures.

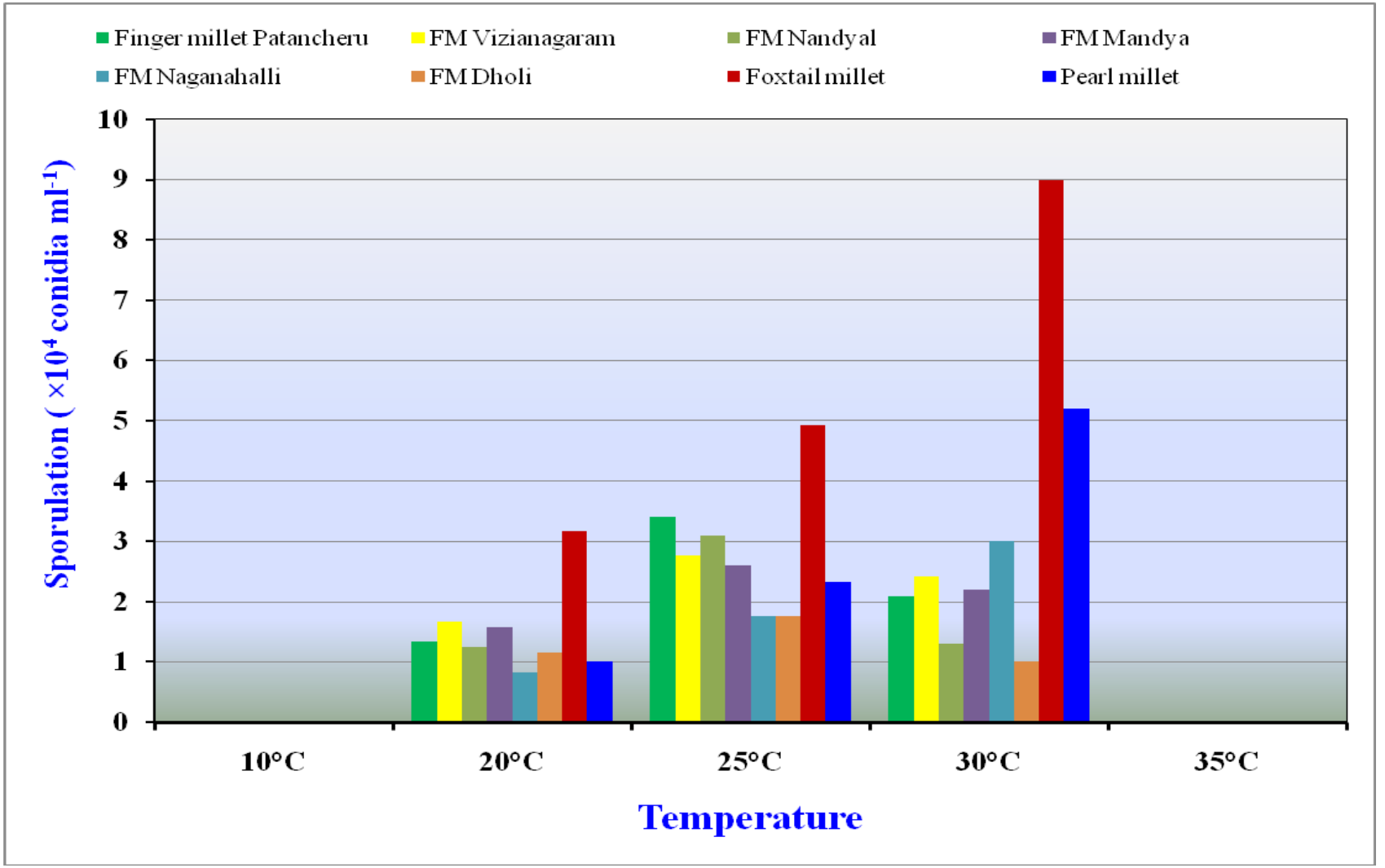

Figure 4.13. Sporulation of *M. grisea* isolates at different temperatures.

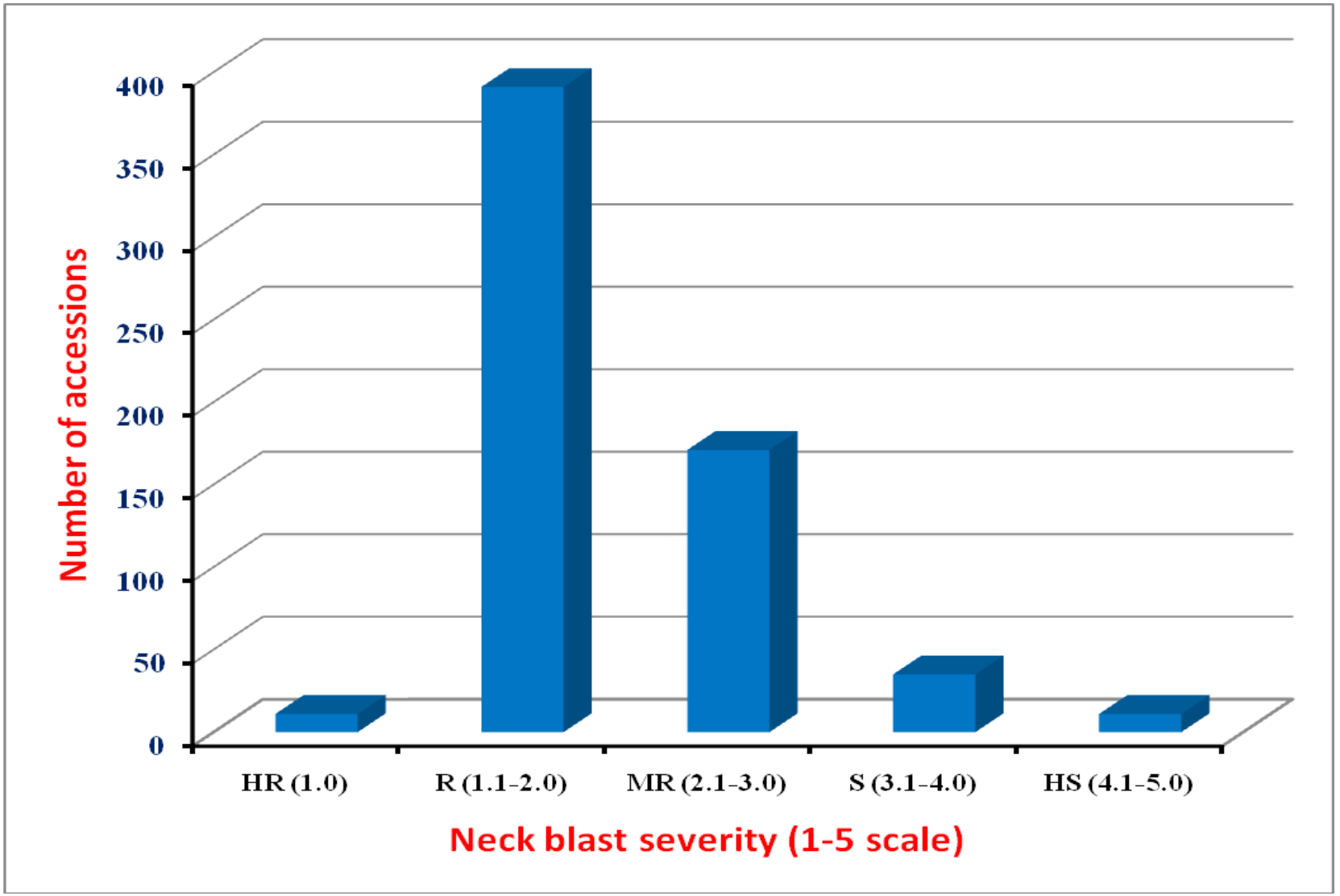

Figure 4.14. Classification of finger millet core collection into different reaction types based on neck blast severity (1–5 scale).

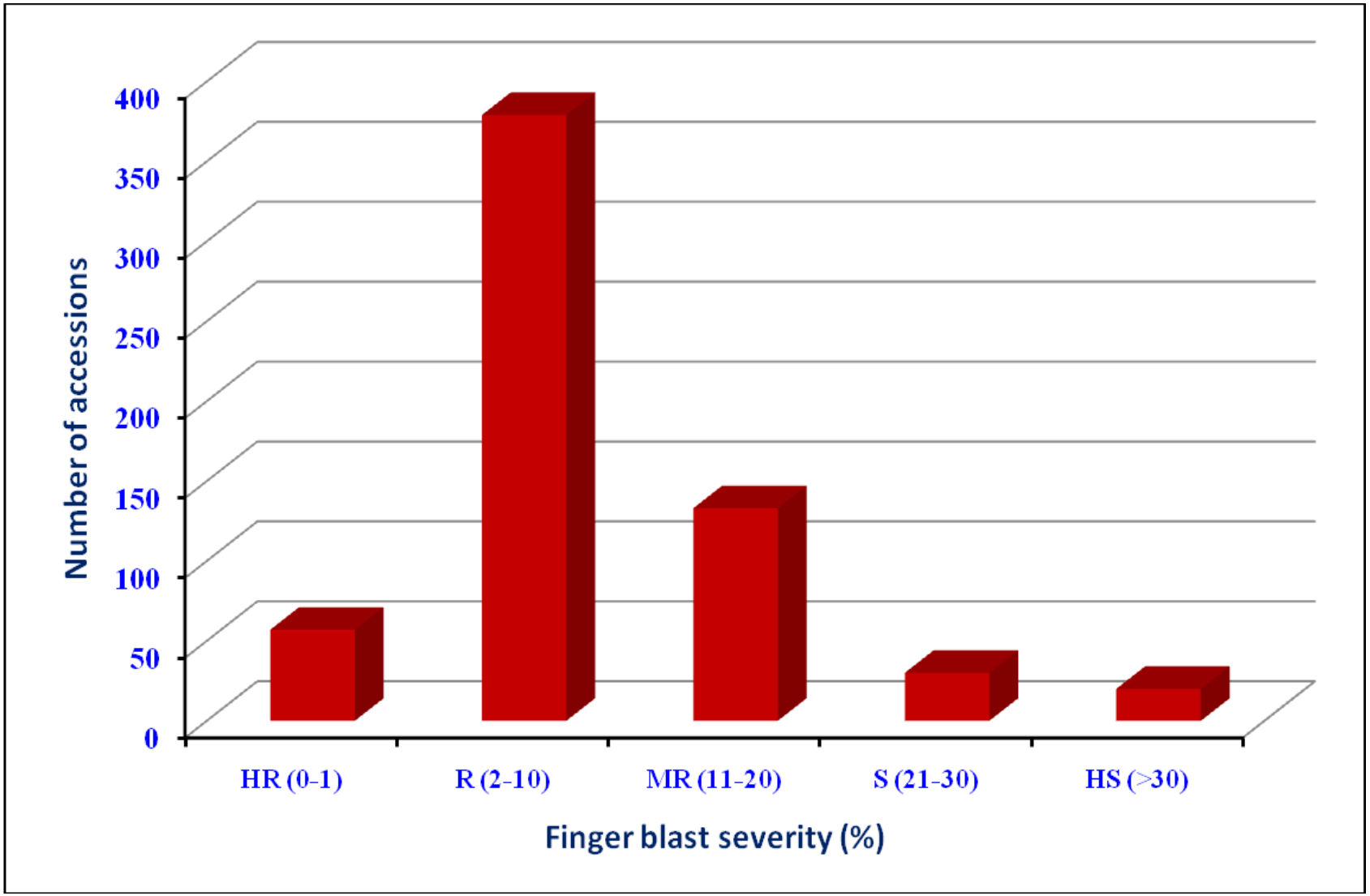

Figure 4.15. Classification of finger millet core collection into different reaction types based on finger blast severity (%).

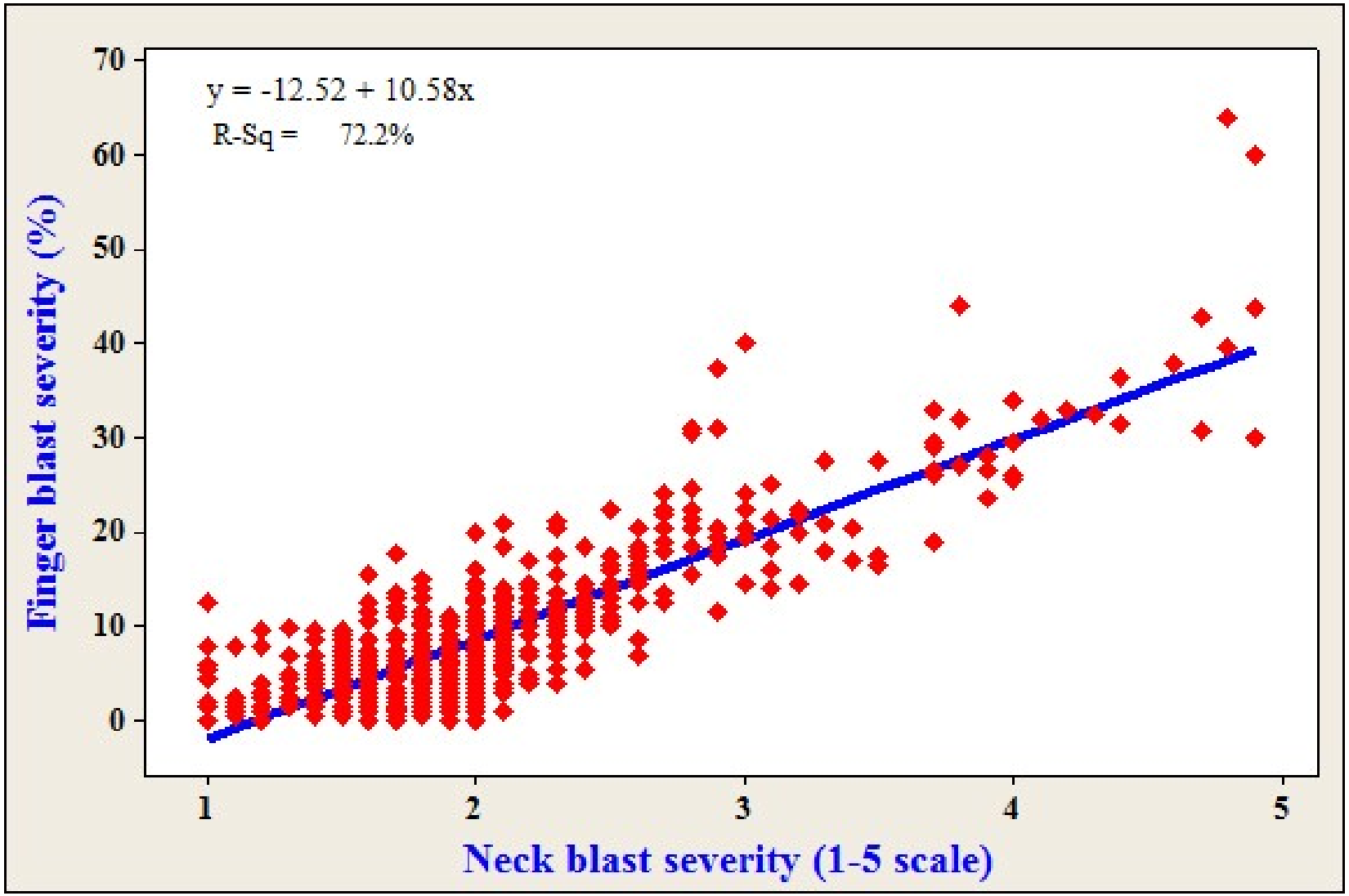

Figure 4.16. Relationship of neck and finger blast severity of finger millet core collection under field conditions during the 2009 rainy season at ICRISAT, Patancheru, India.

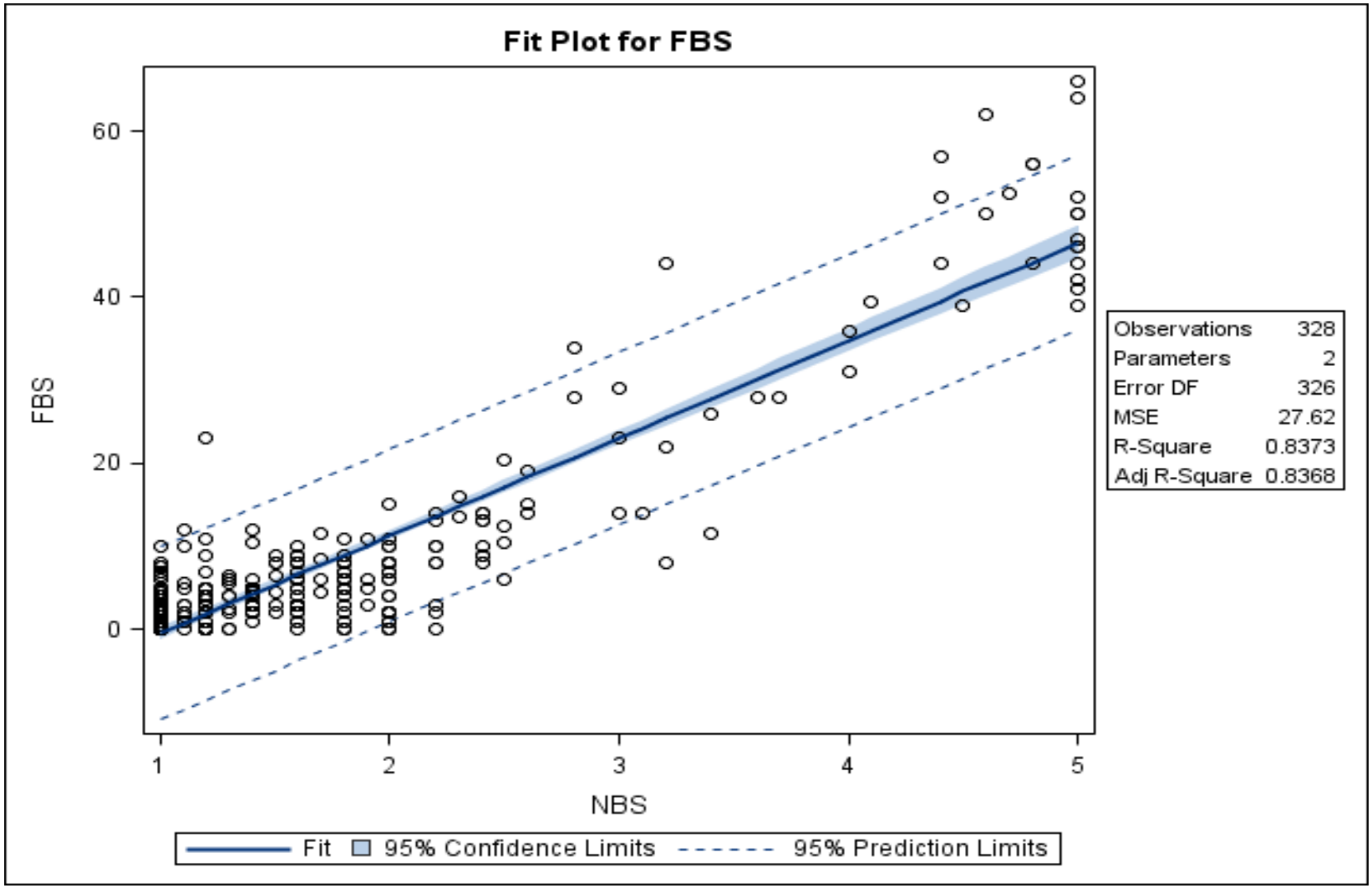

Figure 4.17. Relationship between neck (NBS on 1-5 scale) and finger blast severity (%-FBS) of finger millet mini-core evaluated for blast resistance in field conditions during the 2009 and 2010 rainy seasons at ICRISAT, Patancheru, India

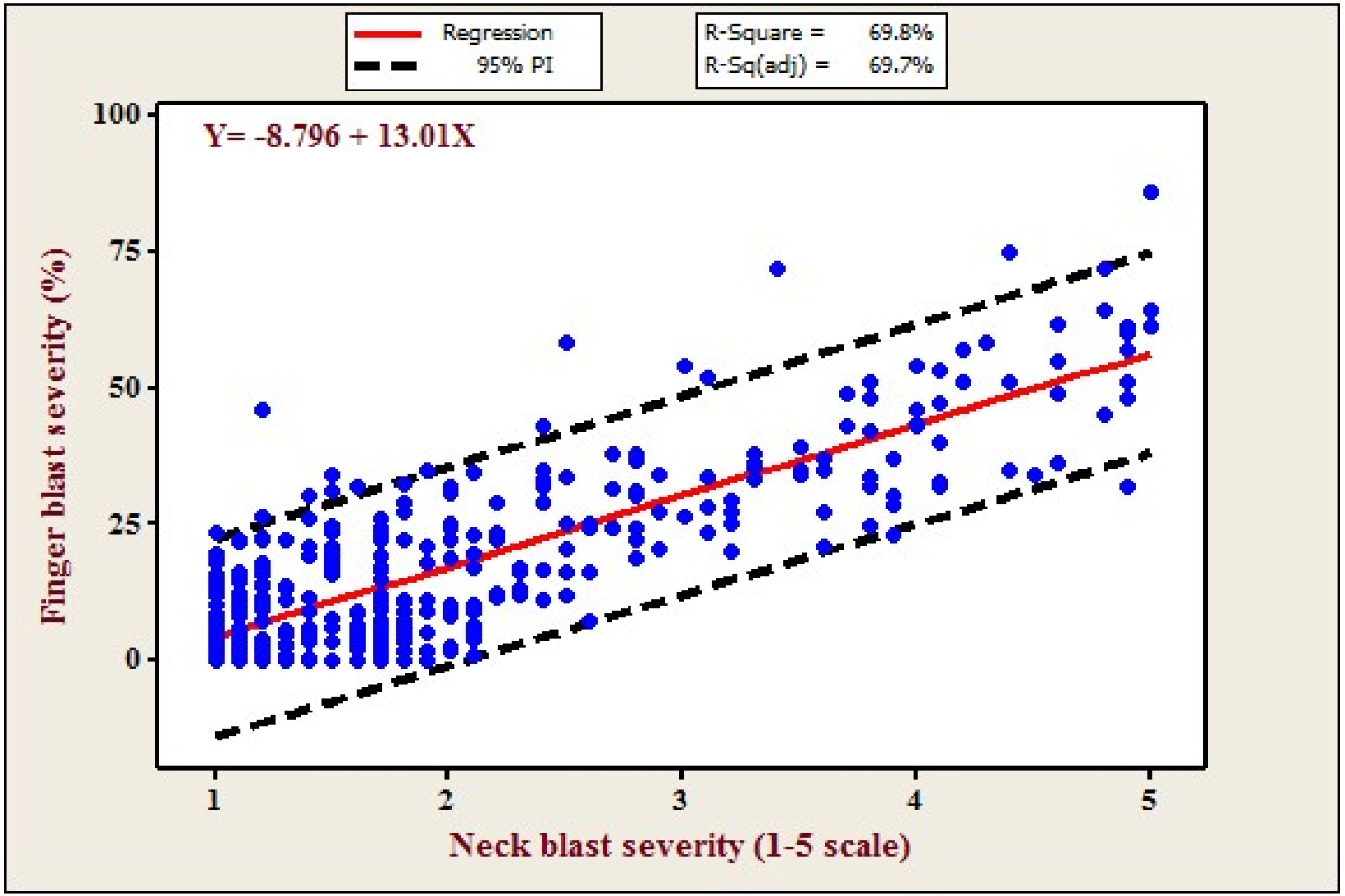

Figure 4.18. Relationship between neck and finger blast severity of finger millet mini-core evaluated for blast resistance under field conditions during the 2009 rainy season at five locations in India.

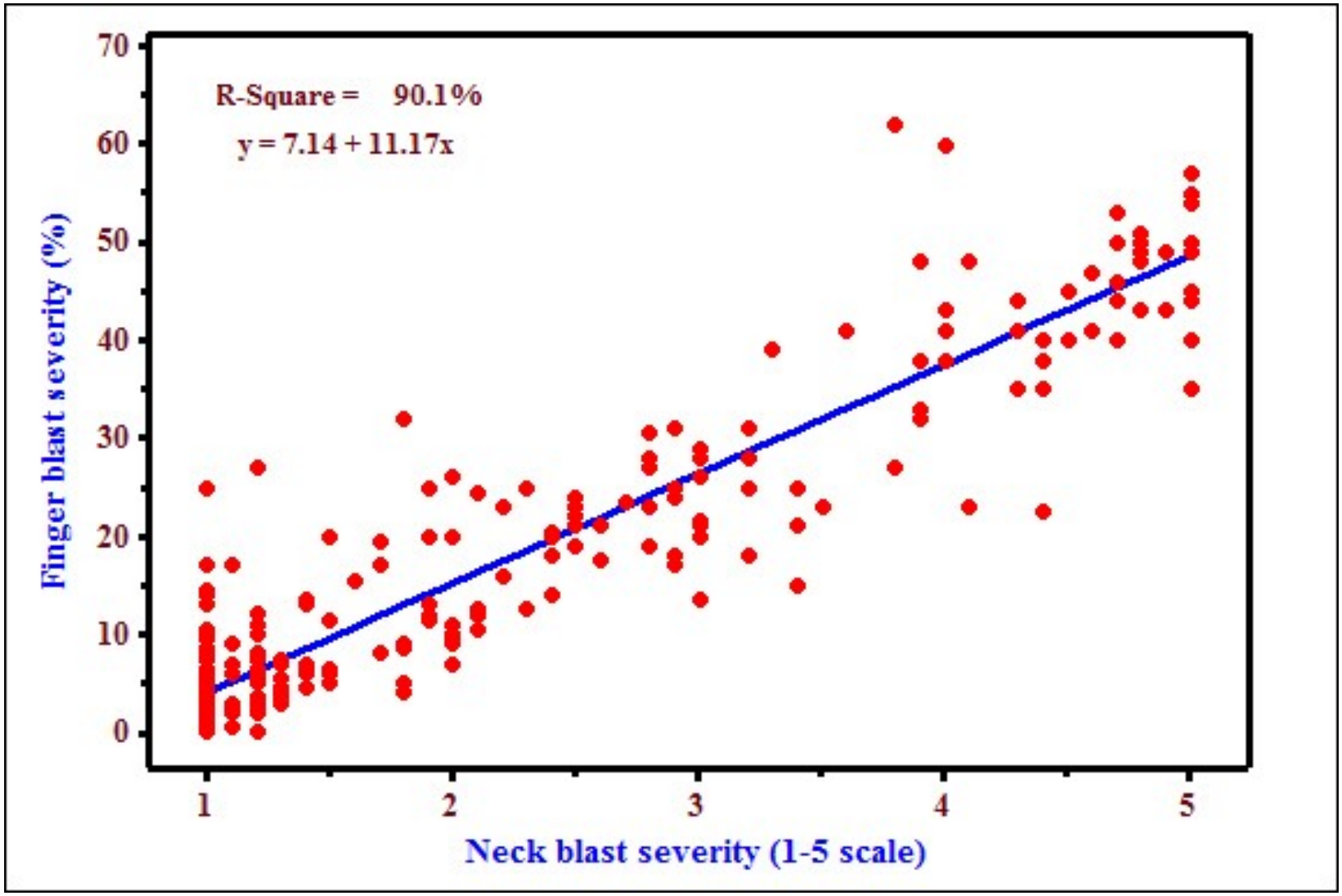

Figure 4.19. Relationship between neck and finger blast severity of Finger Millet Blast Resistance Stability Nursery - 2010 evaluated for blast resistance under field conditions during the 2010 rainy season at five locations in India.

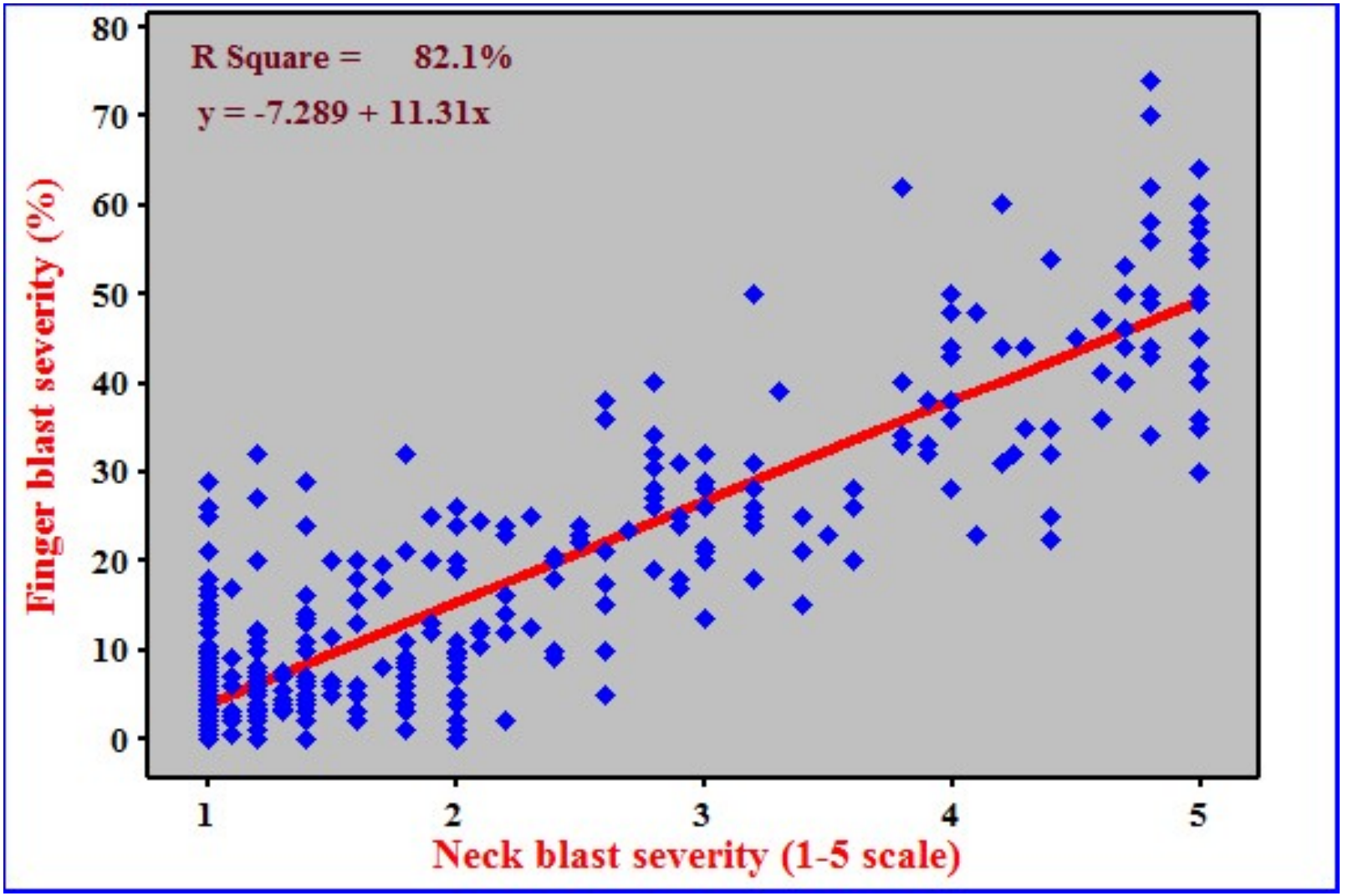

Figure 4.20. Relationship between neck and finger blast severity of 24 finger millet accessions evaluated for blast resistance under field conditions during 2009 and 2010 rainy seasons at five locations in India.

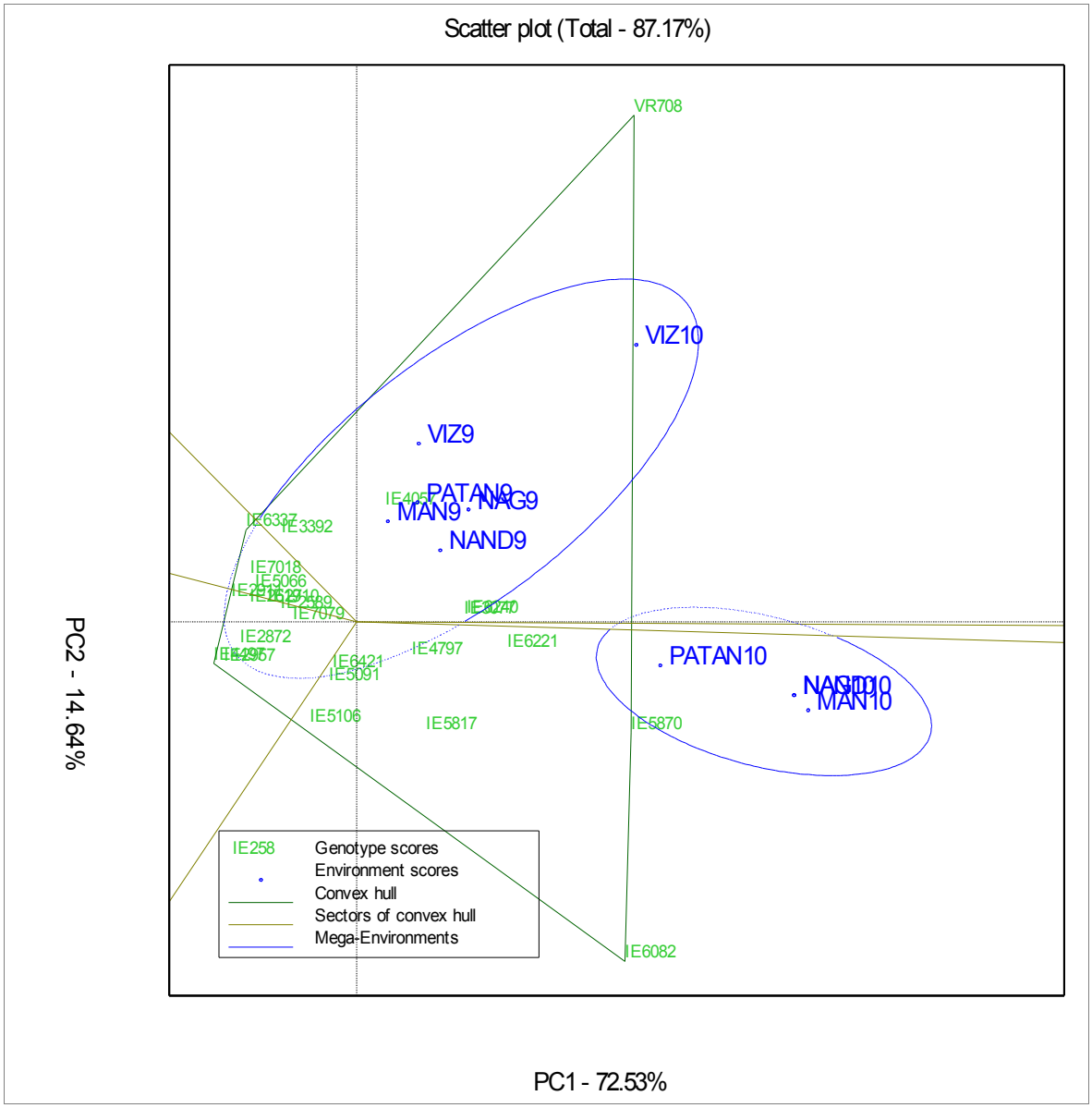

Figure 4.21. Polygon view of GGE biplot of 23 finger millet mini-core accessions and susceptible check (VR 708) evaluated for leaf blast resistance at five locations during 2009 and 2010 rainy seasons. Environments are denoted as Patancheru 2009 (PATAN9) and 2010 (PATAN10), Vizianagaram (VIZ9 and VIZ10), Nandyal (NAND9 and NAND10), Mandya (MAN9 and MAN10) and Naganahalli (NAG9 and NAG10); Accessions at the vertices of the polygon represent entries furthest from the biplot origin.

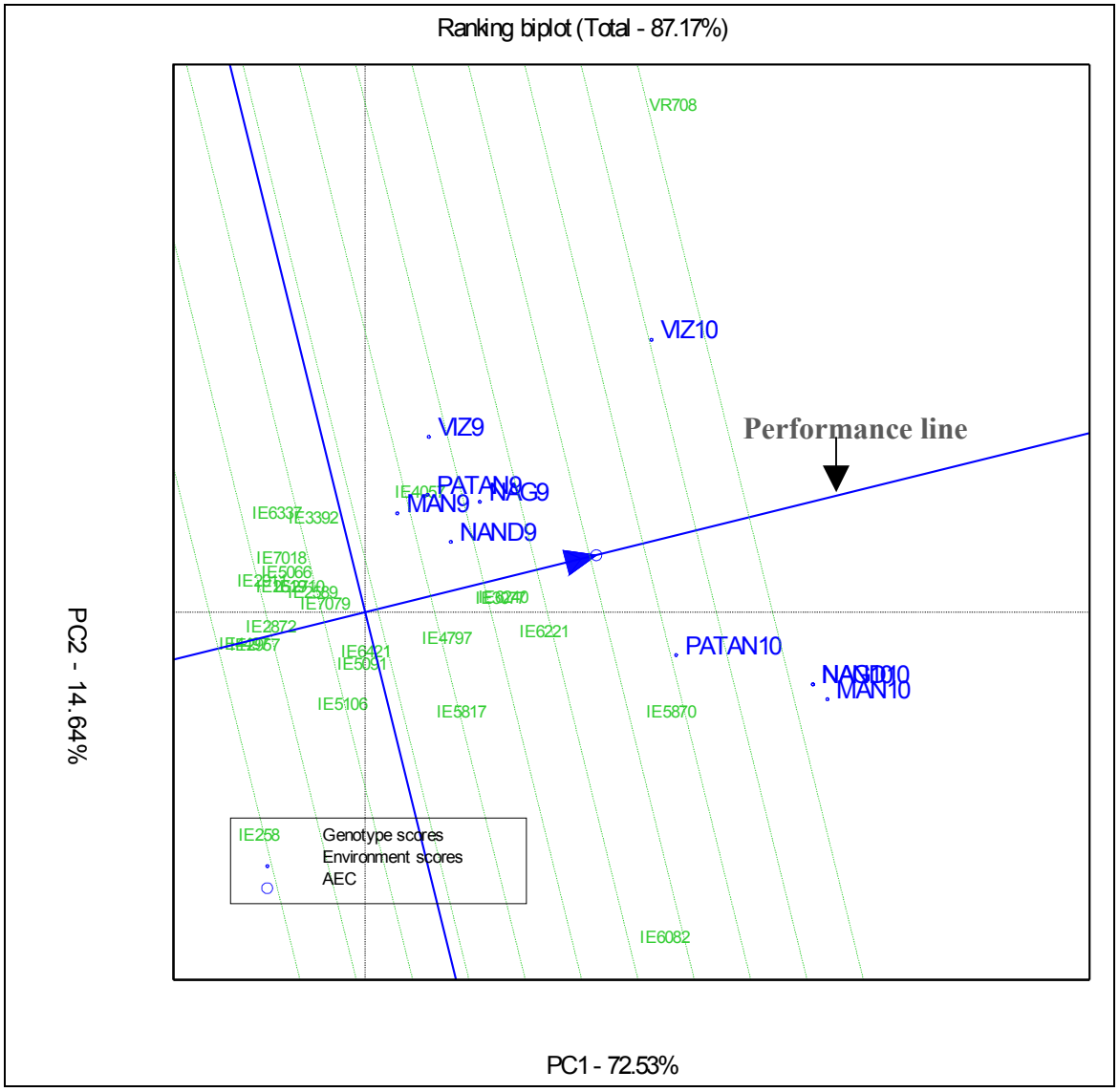

Figure 4.22. GGE biplot showing a comparison of 23 finger millet mini-core collection and susceptible check (VR 708) for leaf blast severity across five environments during 2009 and 2010 rainy seasons. Environments are denoted as Patancheru 2009 (PATAN9) and 2010 (PATAN10), Vizianagaram (VIZ9 and VIZ10), Nandyal (NAND9 and NAND10), Mandya (MAN9 and MAN10) and Naganahalli (NAG9 and NAG10).

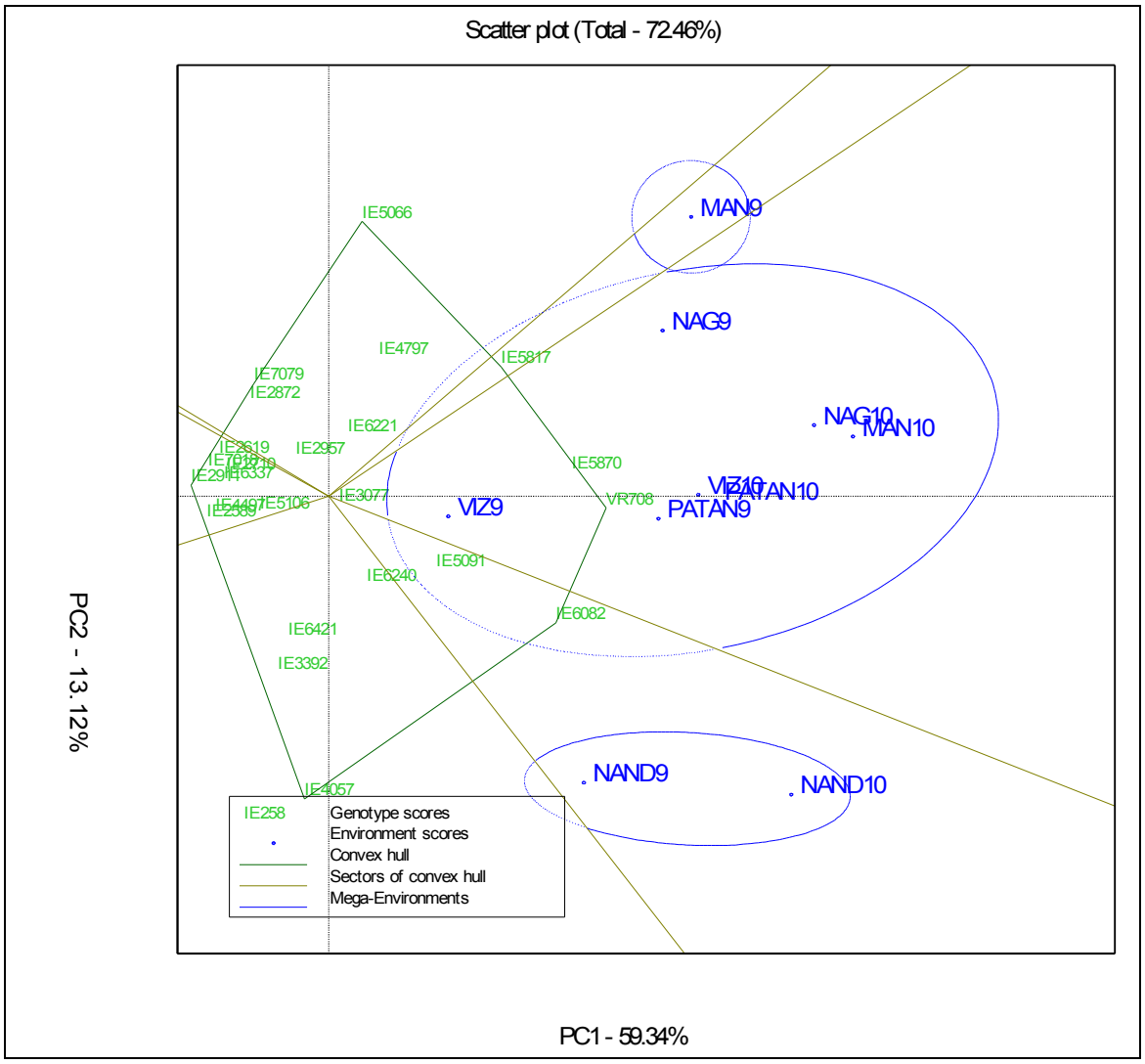

Figure 4.23. Polygon view of GGE biplot of 23 finger millet mini-core accessions and susceptible check (VR 708) evaluated for neck blast resistance at five locations during 2009 and 2010 rainy seasons. Environments are denoted as Patancheru 2009 (PATAN9) and 2010 (PATAN10), Vizianagaram (VIZ9 and VIZ10), Nandyal (NAND9 and NAND10), Mandya (MAN9 and MAN10) and Naganahalli (NAG9 and NAG10); Accessions at the vertices of the polygon represent entries furthest from the biplot origin.

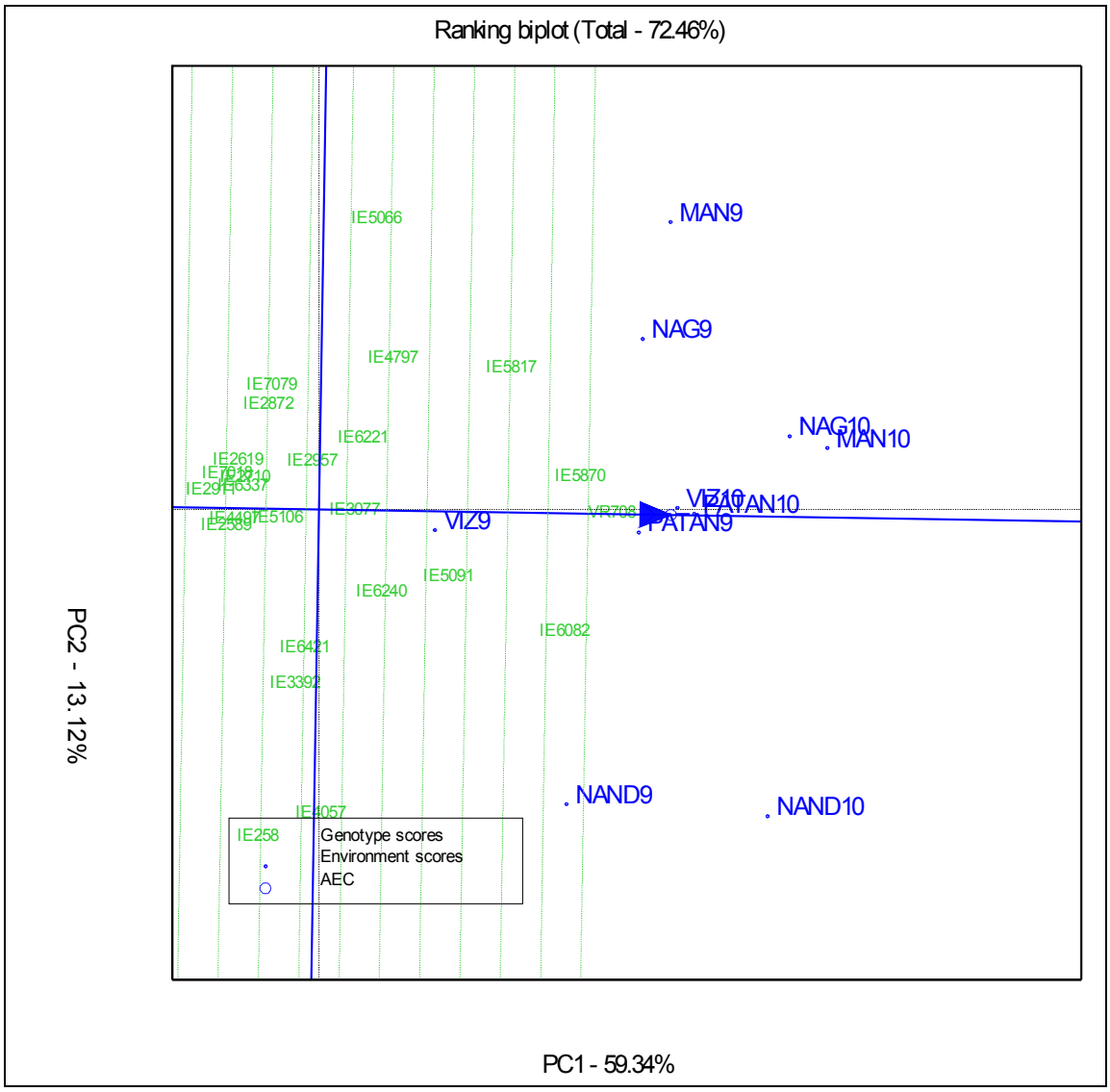

Figure 4.24. GGE biplot showing a comparison of 23 finger millet mini-core collection and susceptible check (VR 708) for neck blast severity across five environments during 2009 and 2010 rainy seasons. Environments are denoted as Patancheru 2009 (PATAN9) and 2010 (PATAN10), Vizianagaram (VIZ9 and VIZ10), Nandyal (NAND9 and NAND10), Mandya (MAN9 and MAN10) and Naganahalli (NAG9 and NAG10).

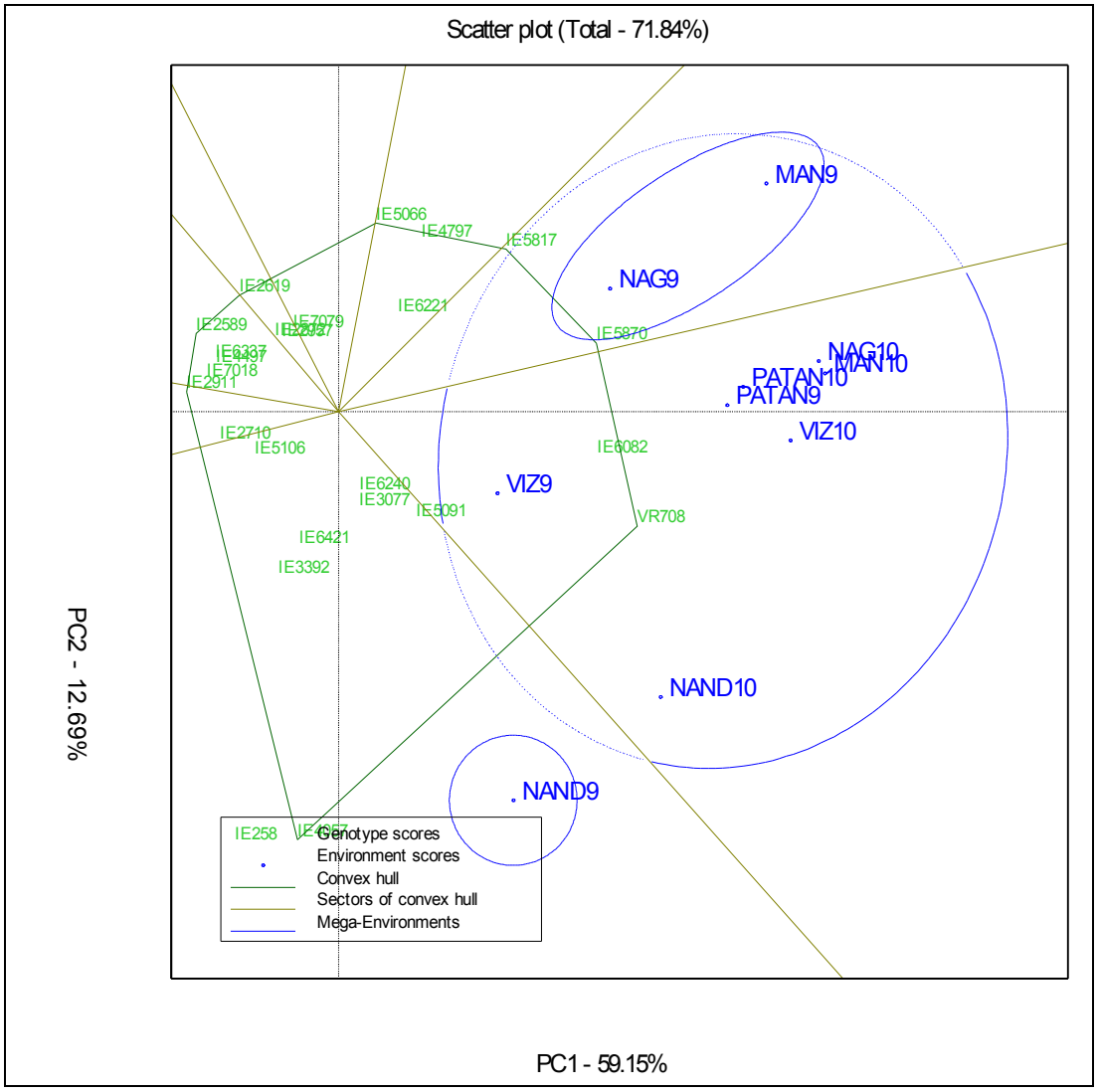

Figure 4.25. Polygon view of GGE biplot of 23 finger millet mini-core accessions and susceptible check (VR 708) evaluated for finger blast resistance at five locations during 2009 and 2010 rainy seasons. Environments are denoted as Patancheru 2009 (PATAN9) and 2010 (PATAN10), Vizianagaram (VIZ9 and VIZ10), Nandyal (NAND9 and NAND10), Mandya (MAN9 and MAN10) and Naganahalli (NAG9 and NAG10); Accessions at the vertices of the polygon represent entries furthest from the biplot origin.

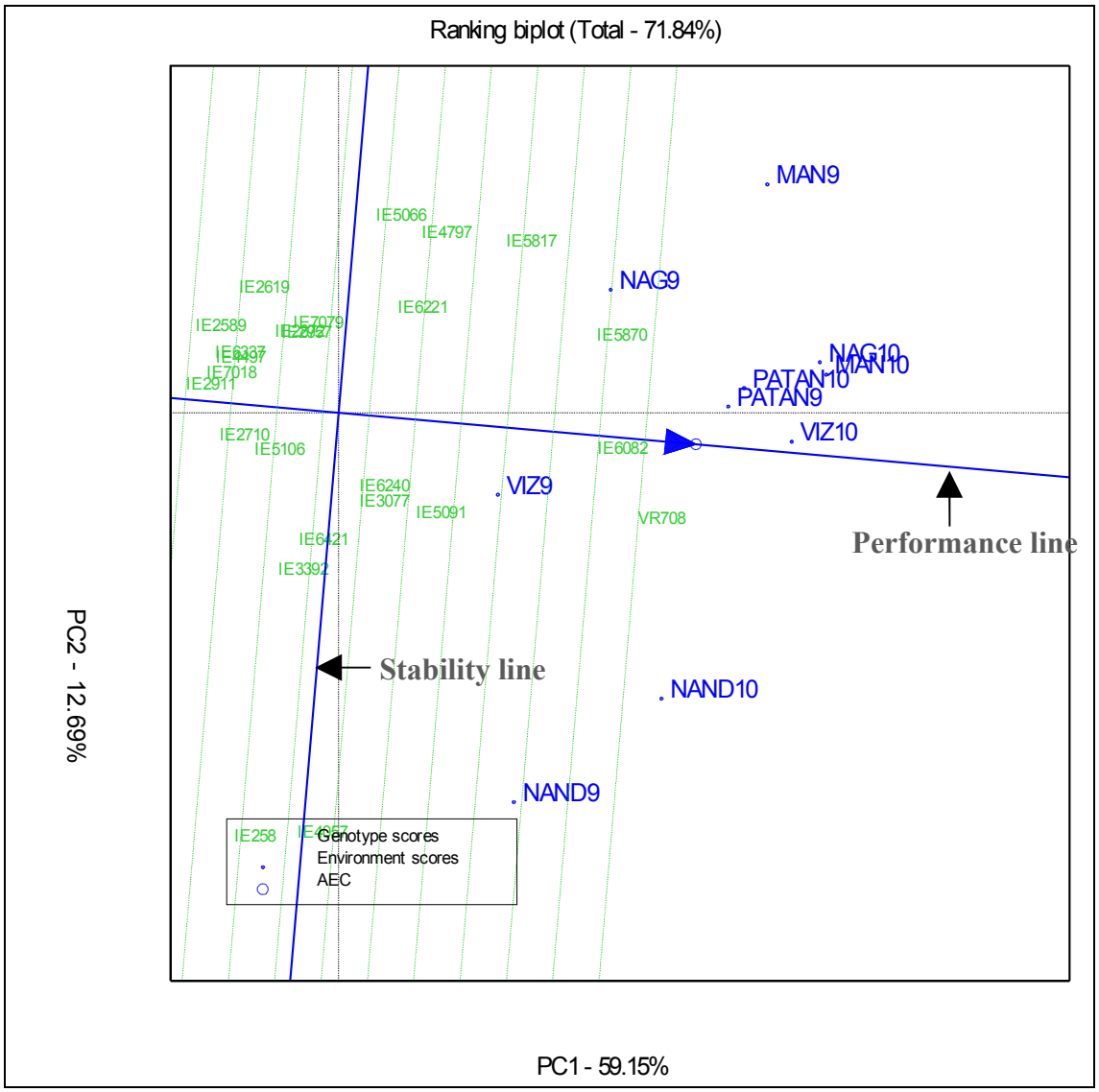

Figure 4.26. GGE biplot showing a comparison of 23 finger millet mini-core collection and susceptible check (VR 708) for finger blast severity across five environments during 2009 and 2010 rainy seasons. Environments are denoted as Patancheru 2009 (PATAN9) and 2010 (PATAN10), Vizianagaram (VIZ9 and VIZ10), Nandyal (NAND9 and NAND10), Mandya (MAN9 and MAN10) and Naganahalli (NAG9 and NAG10).

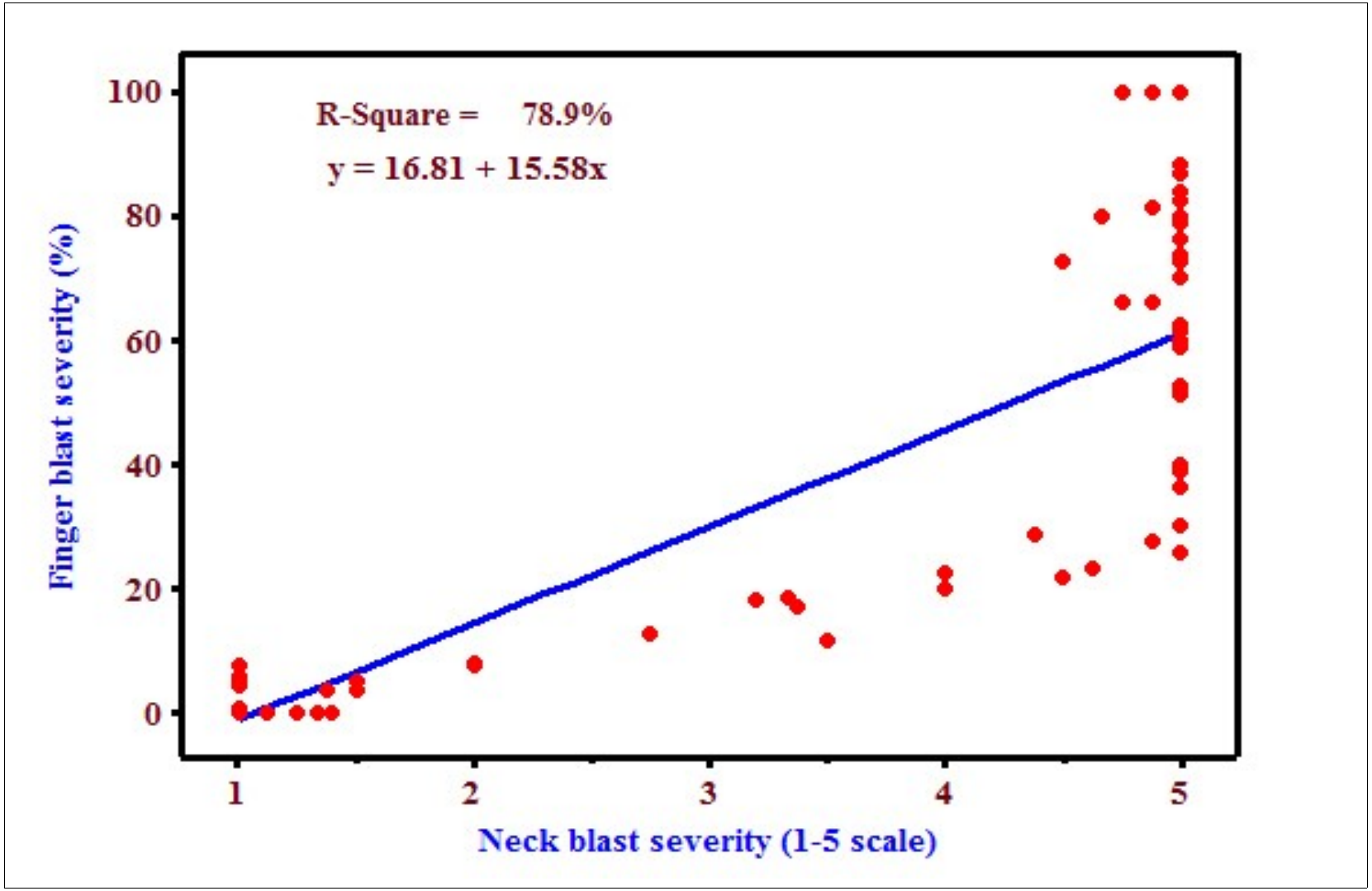

Figure 4.27. Relationship between neck and finger blast severity of selected finger millet mini-core accessions evaluated for stability of blast resistance under greenhosue conditions using the isolates from five locations.

CHAPTER V

SUMMARY AND CONLUSIONS

In the present investigation, studies pertaining to cultural, morphological, pathogenic and genetic diversity in the pathogen, epidemiology and identification of host plant resistance to the disease using mini-core collection were carried out at ICRISAT, Patancheru, Andhra Pradesh, India. The field experiments were conducted at ICRISAT research farm, Patancheru, ARS, Vizianagaram and RARS, Nandyal of Andhra Pradesh and ZARS, Mandya, OFRS, Naganahalli of Karnataka. The results obtained in these investigations are summarized below.

A total of 125 blast disease samples from finger millet, 6 from foxtail millet, 3 from rice and 5 from pearl millet were collected from major finger millet growing areas of India during the rainy season 2009 and 2010. A total of 70 monoconidial isolates of *Magnaporthe grisea*, 56 from finger millet, 6 from foxtail millet, 3 from rice and 5 from pearl millet were obtained from the samples collected from different locations. Of the total isolates, 15 each were from Patancheru and Vizianagaram, 13 from Nandyal, 14 from Mandya, 8 from Naganahalli and one each from Dholi, Aurangabad, Hissar, Jaipur and Solan. A total of 43 isolates of *M. grisea* were from Andhra Pradesh, 22 from Karnataka and each one each from Bihar, Maharashtra, Haryana, Himachal Pradesh and Rajasthan. The purified single spore cultures were maintained on OMA medium and preserved on filter paper discs stored at 4°C. Subsequently, detached leaf blast lesions of each isolate collected from pathogenicity studies were air-dried and stored in plastic zippy bags at 4°C for further use.

During the pathogenicity studies, considerable variation was found among the isolates from finger millet for leaf blast severity however, no significant differences were observed among the isolates from foxtail and pearl millet. Of the 56 isolates from finger millet, the isolate FMNd33 recorded the highest disease severity (score 8.7 on a 1–9 scale) while the isolate FMM44 recorded the lowest disease severity (3.05). Pathogenicity tests revealed the differences in aggressiveness indicating quantitative polygenic resistance to blast in finger millet. *M. grisea* isolates from different crops showed a continuous array of symptoms from very minute brown specks to large elliptical lesions following inoculation of pot-grown seedlings in the greenhouse. The lesion morphology and size varied from crop to crop. In general, very long and narrow blast lesions were observed on finger millet compared to foxtail millet and pearl millet. Cross-inoculation tests showed that *M. grisea* isolates from finger millet failed to infect foxtail millet and pearl millet, and *vice versa*.

Diversity in cultural characters such as colony colour, texture and growth pattern were noticed among the isolates, but no clear-cut groupings were observed between isolates from different hosts. It was observed that isolates that were grayish green and sector forming produced more spores than others. The isolates with cottony and submerged growth were poor spore producer with some exceptions. Among the isolates from different hosts, maximum sporulation was observed in foxtail millet isolates followed by rice, pearl millet and finger millet.

Variations in morphological characters such as colony growth, size of the conidia and sporulation was observed. Maximum radial growth was recorded in finger millet isolates and minimum was in pearl millet isolates. Colony diameter ranged from 49–84 mm in finger millet isolates, 61–77 mm in foxtail millet, 59–63.5 mm in rice and 49–54.5 mm in pearl millet isolates. Conidial measurements did not reveal any specific pattern for isolates from the four crops. However, the conidial size ranged from 15.2–24×4.2–8 µm in rice, 12–36.7 × 6–11.1 µm in pearl millet, 10–35 × 5–12 µm in foxtail millet and 10.2–30.5 × 2–10 µm in finger millet. Variations in sporulation capacity were noticed within the isolates from the same location and between the isolates from finger millet and rice.

Five selected representative isolates (one isolate/location) were evaluated for pathogenicity (leaf blast) on Finger Millet Blast Resistance Stability Nursery consisting of 28 accessions. Isolates varied greatly for virulence, disease severity and disease reaction. Among the five isolates, FMNg55 was highly virulent as it induced susceptible reaction on 27 of the 28 accessions and the isolate FMP1 was weakly virulent with only 10 accessions were showing susceptible reaction. Of the five isolates, the highest mean leaf blast severity across the accessions was recorded with the isolate FMM42 (5.2) and the lowest with FMP1 (2.8). Among the 28 accessions, 21 accessions showed clear differential reactions while the remaining were susceptible to all the isolates. None of the accessions showed resistance to all the five isolates.

Sixteen accessions of the FMBRSN developed varying reaction types for leaf, neck and finger infection over 2 years of evaluation at the five locations. A set of 10 putative host differentials were selected based on FMBRSN field evaluation over 2 years at five locations and greenhouse evaluation for leaf blast.

Twenty isolates (4 isolates/location) were evaluated for pathogenicity on a set of 12 host differentials (IE 2619, IE 2911, IE 2957, IE 3392, IE 4057, IE 4497, IE 5097, IE 6240, IE 6337, IE 7079, GPU 28 and VR 708) to detect variability within the isolates of *M. grisea* from same location (intra-population) and between the locations (inter-populations). The isolates

varied significantly for virulence, disease severity and disease reaction types. Isolates FMP5, FMV23, FMNg54 and FMNg55 were highly virulent infecting 11 of the 12 accessions and the isolate, FMV14 was the least virulent and could infect only two accessions. Isolate FMV23 recorded the highest mean disease severity (6.5) across the host genotypes, while FMP1 recorded the lowest disease severity (2.6). All the isolates were highly aggressive on the susceptible genotype VR 708 and least aggressive on GPU 28, while low to moderate aggressiveness was observed for all the isolates on the remaining 10 host differential accessions and also highly variable within and across the isolate-genotype combinations. A dendrogram generated by the principal component analysis of leaf blast severity clustered the 25 isolates into four pathotype groups. Location-specific grouping of all the five isolates from Patancheru, 3 of the 5 isolates from Nandyal and 4 of the 5 isolates from Mandya was observed within three distinct groups.

Genetic diversity of *M. grisea* isolates from different hosts using 24 SSR markers showed a high degree of polymorphism at DNA level and cluster analysis of SSR data grouped the isolates on the basis of their origin from different hosts with few exceptions. Two isolates from finger millet and one isolate from foxtail millet were grouped together indicated the some gene flow between host-limited forms of *M. grisea*. Based on similarity coefficient, the isolates from finger millet were clustered into nine groups. The isolates from different plant parts (leaf and neck) were randomly distributed among the overall population in the dendrogram. In contrast, the isolates from neck and finger samples from the same genotype and location were clustered in one group at 90% similarity matrix. The classification of isolates based on SSR analysis did not show any lineage with the geographical distribution of the isolates. No correlation was observed between pathogenicity data and SSR data of 25 *M. grisea* isolates. The SSR analysis showed more diversity than virulence analysis. Model based population structure analysis revealed three distinct populations based on their host origin with varying levels of ancestral admixtures among the 65 *M. grisea* isolates from different hosts.

Disease severity increased with increasing inoculum concentrations and higher concentrations produced severe infection. Spore concentrations of 1×10^5 and 1×10^6 conidia ml^{-1} after 7 days of inoculation caused similar levels of leaf blast infection and thus an inoculation concentration of 1×10^5 conidia ml^{-1} was used for the remaining experiments. Significant differences were observed between 1×10^6 and 1×10^4 conidia ml^{-1} for neck blast severity, and between two higher (1×10^5 and 1×10^6 conidia ml^{-1}) and two lower concentrations (1×10^3 and 1×10^4 conidia ml^{-1}) for finger blast severity. The two higher concentrations produced the same

high levels of neck and finger blast severity compared to other concentrations therefore, 1×10^6 conidia ml^{-1} was used for the remaining experiments. For finger millet blast, this is the first report on effect inoculum concentrations on incidence and severity of neck and finger blast by inject inoculation method – an effective inoculation technique.

Leaf blast severity, lesion size and number of lesions increased with leaf wetness duration and a linear relationship was found between wetness duration and disease severity. The leaf wetness duration of 48 and 60 h produced significantly higher disease severity than these of 12 and 24 h. A severe outbreak of this disease seems to require 48 h of leaf wetness duration and, although a low level of disease appeared in 24 h wetness duration as well.

Influence of temperature on sporulation showed that 27°C was optimum for sporulation of *M. grisea* lesions in finger millet. All the isolates from different hosts exhibited maximum growth and sporulation at 25°C and 30°C on Oat-meal agar medium although for finger millet isolates it occurred at 25°C and for pearl millet isolates at 30°C. The maximum growth of foxtail millet blast isolate was recorded at 25°C and sporulation (9×10^4 conidia ml^{-1}) at 30°C. This study showed that the intra- and inter-host isolates of the fungus showed differential response in the preference of temperatures and finger millet and foxtail millet isolates are more close than the pearl millet isolate.

Finger millet core collection consisting of 622 accessions was evaluated for blast resistance in field by artificial inoculation with the blast pathogen at appropriate stage of the crop during the rainy season 2009 at ICRISAT, Patancheru. A total of 402 accessions were found neck blast resistant, 436 finger blast resistant and 372 had combined resistance to both the diseases. Blast resistant accessions in the core collection originated from 19 countries indicating the wide geographical diversity among resistant accessions. Most of the accessions from Asian origin were susceptible to neck and finger blast while those from African origin were resistant. A significant strong positive correlation was found between neck blast and finger blast ratings in host-plant resistance experiments.

Field and greenhouse screening techniques were developed for leaf, neck and finger blast screening. These methods involved artificial inoculation of plants at appropriate stages and favourable conditions (temperature and relative humidity) were provided for disease development. We also developed a more precise 1–5 rating scale for neck blast and estimation of finger blast severity (%) based on severity under field conditions to categorize accessions into highly resistant, resistant, moderately resistant, susceptible and highly susceptible.

A finger millet mini-core collection comprised of 80 germplasm accessions developed from a core collection was evaluated to identify sources of blast resistance in field by artificial inoculation over two years (2009 & 2010) at Patancheru. Sixty-eight accessions were found to have combined resistance to leaf, neck and finger blast in both the experiments. These resistant accessions belong to five basic races of finger millet that originated from 13 countries and exhibited considerable diversity for agronomic traits. A significant weak to moderate correlations were found between leaf blast with neck (r = 0.25, $P \leq 0.001$) and finger blast (r = 0.30, $P \leq 0.001$). Leaf, neck or finger blast severity was negatively correlated with plant height (r = –0.21, –0.26 and –0.27) and DF (r = –0.19, –0.55 and –0.57) whereas it was weakly positively correlated with spike type (r = 0.17, 0.06 and 0.07). Of the 68 resistant accessions, nine (IE 1055, -2821, -2872, -4121, -4491, -4570, -5066, -5091, and -5537) had desirable agronomic traits, such as early flowering (<65 days to flowering), medium plant height (105–125 cm), semi-compact to compact inflorescence. Mini-core collection, further evaluated under greenhouse condition to confirm their leaf blast resistance, showed 58 accessions to be resistant to leaf blast with significant, and moderate to low level of correlation (r = 0.44, $P<0.0001$) between greenhouse and field screenings for leaf blast.

Mini-core was tested for blast resistance at five locations (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli) during the rainy season 2009. Leaf, neck and finger blast severity across the five locations indicated highly significant effects of ($P<0.0001$) of location, accession and interactions of accession with location ($P<0.05$). Most of the accessions in the mini-core had leaf blast severity score <2.0 on a 1–9 scale. Of the 80 accessions, 60 were resistant to neck blast at Patancheru, 59 at Vizianagaram, 45 at Nandyal, 44 at Mandya and 66 at Naganahalli whereas, 64 were resistant to finger blast at Patancheru, 58 at Vizianagaram, 11 at Nandyal, 10 at Mandya and 56 at Naganahalli. However, the largest number accessions (58 accessions) were resistant to both neck (score ≤3.0 on 1–5 scale) and finger blast (≤10%) at Patancheru followed by 57 at Vizianagaram, 56 at Naganahalli, and the lowest number of accessions (10 accessions) at Mandya followed by 11 at Nandyal. Of the 80 mini-core accessions, 21 showed high neck blast resistance (score ≤3.0 on 1–5 scale) whereas 7 were resistant to finger blast across the 5 environments. Seven (IE 2589, -2619, -2911, -2957, -4497, -6337 and -7018) of the 80 mini-core accessions showed high blast resistance across 5 environments with a mean of 1.0 to 1.4 score on 1–5 scale for neck blast and 2.5 to 7.7% for finger blast severity. Differential reactions across the locations was evident in 60 accessions that were categorized into seven groups.

The FMBRSN–2010 evaluated at five locations during the rainy season (*kharif)* 2010, its analysis of variance exhibited significant effects of location (L), accession (A) and interaction between L × A for leaf, neck and finger blast severity. Two accessions (IE 4755 and IE 4759) showed susceptible reaction during the rainy season 2009 and in FMBRSN–2010 confirming the relationship between early maturity and blast susceptibility. Significant and positive correlations were found between leaf blast at seedling stage with neck (r = 0.70; P<0.0001) and finger blast (r = 0.70; P<0.0001) across the locations. Largest number of accessions (17 out of 26) were resistant to all three types of blast at Patancheru; 11 at Naganahalli; 10 at Vizianagaram; 8 at Mandya and 7 at Nandyal. Of the 7 stable resistant accessions during 2009, two (IE 2619 and IE 2957) were found susceptible to neck and finger blast in FMBRSN-2010. Of the 28 FMBRSN accessions, 21 showed differential reactions to leaf, neck and finger blast, 5 stable resistant across locations and the remaining two checks were resistant and susceptible.

Analysis of variance for blast severity across the five locations over two years indicated highly significant (P<0.0001) effects of genotypes/accession (A), location (L), Year (Y), and interactions of A × L and A × Y, except for Y × L for leaf blast. Analysis of resistance stability using relative variation and GGE biplot method showed that, five accessions (IE 2589, -2911, -4497, -6337 and -7018) were most resistant to leaf, neck and finger blast across the five locations over two years. Several other accessions (IE 2619, -2710, -2872, -2957 and -5106) that were stable at specific locations could be utilized in resistance breeding at those locations. The variations in disease severity on tested accessions at Naganahalli were higher for leaf blast, Mandya and Nandyal for neck and finger blast whereas, variations were low at Vizianagaram and Patancheru for all the three phases of blast.

Analysis of weather data from five location over two years and neck, and finger blast severity on four highly susceptible accessions did not show any significant association between blast severity and weather variables (temperature and relative humidity) however, positive association was observed with amount and frequency of rainfall.

To confirm stability of resistance, five accessions were further evaluated under greenhouse conditions using the isolates from geographically diverse locations (Patancheru, Vizianagaram, Nandyal, Mandya and Naganahalli). The largest proportion of variability for all the three phases of blast severity was accounted by accession, followed by accession × isolate interaction and isolate. Of the five accessions, IE 2911 was found resistant to all three types/phases of blast (leaf, neck and finger) against five isolates and IE 2957 was resistant with

exceptions. The accessions IE 4497 and IE 6337 were considered as differential host based on neck and finger blast reaction. A significant and moderate positive correlations were found between leaf blast with neck (r = 0.36; P<0.0001) and finger blast (r = 0.37; P<0.0001), whereas, significant positive correlation was found between neck and finger blast severity (r = 0.90; P<0.0001).

CONCLUSIONS AND FUTURE STRETEGIES

Distinctive patterns of pathogenicity and genetic diversity observed in the present investigation emphasizes the variability in *M. grisea* population in India. A well-planned strategy to monitor virulence changes in the pathogen population and resistance breakdown in host cultivars, and identification and incorporation of novel resistance genes will help in reducing the chances of epidemics and losses from blast in finger millet.

Ten accessions identified in the present study could serve as differential hosts for the finger millet blast system. More work should be done by screening the identified host differentials in the present study against representative isolates from India or elsewhere.

Cluster analysis of the SSR data permitted the grouping of isolates on the basis of their hosts, however two isolates from finger millet and one from foxtail millet were grouped together indicating some genetic drift between the two populations. A combination of molecular and pathological assays is required to trace out the role of host-pathogen interaction. Further, isolates from weed-hosts should be collected from the same locations for the studying the possible gene flow between the isolates from different hosts.

Maximum disease occurred after 48 h of leaf wetness and 1×10^5 and 1×10^6 conidia ml^{-1} inoculum concentrations. Optimum temperature for maximum sporulation of blast lesions was at 27°C whereas, maximum growth and sporulation of *M. grisea* isolates from different hosts on Oat-meal agar medium at 25°C and 30°C. Future research on epidemiology should focus on interaction between wetness and temperature to enable development of risk assessment models and study the effect of relative humidity levels on disease development. For wider application of weather data-based disease forecasting, it would be necessary to obtain the data both from the meteorological observatory and microclimate conditions in the field, and determine correlations of these with the disease severity data.

Effective greenhouse and field screening techniques have been developed and the rating systems have been further refined for accurate assessment of disease severity. These would

tremendously help in evaluating germplasm and breeding lines for resistance and enhancing effectiveness of resistance breeding.

A significant weak to moderate correlations were found between leaf blast with neck and finger blast in the present investigation emphasizes the further histological and physiological studies on finger millet plants at different stages of disease development are needed to elucidate the nature of adult-plant resistance to leaf, neck and finger blast.

The accession, IE 2911 was found resistant to all three phases of blast (leaf, neck and finger) in field across the locations and over two years and also in greenhouse screening. For a successful plant breeding program in the country, the breeding material should undergo thorough screening using all available potential pathotypes of *M. grisea*. To identify such pathotypes at right time, in a right way, it is essential to develop a series of good near-isogenic lines containing different resistance genes which seems to be a prerequisite for identification of new virulences in *M. grisea* populations. DNA markers should be developed to identify different pathotypes/races of the pathogen.

Further studies should be conducted on mating type behavior involving larger number of isolates sampled from geographically diverse areas and genetically diverse host cultivars to understand the changes on the mating type behavior of the pathogen.

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Appendix – A

Table 4.19. Evaluation of finger millet core collection (622 + 4 checks) for blast resistance under field conditions during 2009 rainy season at ICRISAT, Patancheru

Ent. No.	Accession No.	Origin	Race	Subrace	NB	Reaction	FB	Reaction
1	IE 0006	India	*Vulgaris*	*Digitata*	3.7	**S**	26.5 (26.8)	**S**
2	IE 0009	India	*Vulgaris*	*Incurvata*	2.3	**MR**	9.0 (9.01)	**R**
3	IE 0061	India	*Elongata*	*Reclusa*	2.5	**MR**	10.0 (10.02)	**R**
4	IE 0196	India	*Vulgaris*	*Stellata*	4.3	**HS**	32.5 (33.1)	**HS**
5	IE 0224	India	*Vulgaris*	*Stellata*	2.4	**MR**	11.0 (11.02)	**MR**
6	IE 0501	India	*Vulgaris*	*Stellata*	4.8	**HS**	64.0 (69.45)	**HS**
7	IE 0510	India	*Vulgaris*	*Incurvata*	2.7	**MR**	18.0 (18.1)	**MR**
8	IE 0518	India	*Vulgaris*	*Incurvata*	2.8	**MR**	18.5 (18.6)	**MR**
9	IE 0546	India	*Vulgaris*	*Liliacea*	3.9	**S**	26.5 (26)	**S**
10	IE 0563	India	*Vulgaris*	*Stellata*	4.1	**HS**	32.0 (32.57)	**HS**
11	IE 0588	India	*Vulgaris*	*Incurvata*	3	**MR**	20.5 (20.65)	**MR**
12	IE 0593	India	*Vulgaris*	*Stellata*	1.6	**R**	10.5 (10.52)	**R**
13	IE 0595	India	*Vulgaris*	*Liliacea*	3.7	**S**	19.0 (19.63)	**MR**
14	IE 0615	India	*Vulgaris*	*Incurvata*	2.8	**MR**	20.5 (6.50)	**MR**
15	IE 0633	India	*Vulgaris*	*Incurvata*	2.9	**MR**	19.5 (4.50)	**MR**
16	IE 0667	India	*Vulgaris*	*Incurvata*	2	**R**	6.5 (15.56)	**R**
17	IE 0678	India	*Vulgaris*	*Incurvata*	1.9	**R**	4.5 (20.65)	**R**
18	IE 0680	India	*Vulgaris*	*Incurvata*	2.6	**MR**	15.5 (15.56)	**MR**
19	IE 0712	India	*Vulgaris*	*Incurvata*	3	**MR**	20.5 (20.65)	**MR**
20	IE 0808	India	*Vulgaris*	*Incurvata*	2.6	**MR**	16.0 (16.07)	**MR**
21	IE 0817	India	*Vulgaris*	*Liliacea*	3.7	**S**	26.0 (26.30)	**S**
22	IE 0821	India	*Vulgaris*	*Digitata*	3.2	**S**	22.5 (22.69)	**S**
23	IE 0848	India	*Vulgaris*	*Digitata*	3.1	**S**	16.0 (16.07)	**S**
24	IE 0872	Mexico	*Vulgaris*	*Digitata*	1.3	**R**	3.5 (3.50)	**R**
25	IE 0886	Pakistan	*Vulgaris*	*Incurvata*	2.5	**MR**	11.0 (11.02)	**MR**
26	IE 0895	Uganda	*Compacta*	*NA*	1.7	**R**	3.5 (3.50)	**R**
27	IE 0930	Uganda	*Vulgaris*	*Incurvata*	2.6	**MR**	8.5 (8.51)	**R**
28	IE 0942	India	*Vulgaris*	*Liliacea*	3.5	**S**	16.5 (16.58)	**MR**
29	IE 0954	India	*Vulgaris*	*Incurvata*	2.8	**MR**	15.5 (15.56)	**MR**
30	IE 0991	Unknown	*Plana*	*Confundere*	2.2	**MR**	10.0 (10.02)	**R**
31	IE 1010	Unknown	*Compacta*	*NA*	1.7	**R**	3.5 (3.50)	**R**
32	IE 1023	Unknown	*Compacta*	*NA*	2.3	**MR**	5.5 (5.50)	**R**
33	IE 1026	Unknown	*Compacta*	*NA*	2	**R**	3.5 (3.50)	**R**
34	IE 1055	Unknown	*Vulgaris*	*Digitata*	2.1	**MR**	10.0 (10.02)	**R**
35	IE 2006	India	*Vulgaris*	*Digitata*	1.2	**HR**	8.0 (8.01)	**R**
36	IE 2008	India	*Vulgaris*	*Incurvata*	2.6	**MR**	12.5 (12.53)	**MR**
37	IE 2014	India	*Vulgaris*	*Digitata*	2.4	**MR**	11.5 (11.53)	**MR**
38	IE 2030	India	*Vulgaris*	*Incurvata*	2	**R**	4.5 (4.50)	**R**
39	IE 2034	India	*Vulgaris*	*Incurvata*	1.5	**R**	7.5 (7.51)	**R**
40	IE 2039	India	*Vulgaris*	*Incurvata*	2.4	**MR**	5.5 (5.50)	**R**
41	IE 2042	India	*Vulgaris*	*Incurvata*	2.1	**MR**	9.0 (9.01)	**R**
42	IE 2047	India	*Vulgaris*	*Digitata*	1.2	**R**	1.5 (1.50)	**HR**
43	IE 2062	India	*Vulgaris*	*Incurvata*	1.9	**R**	4.5 (4.50)	**R**
44	IE 2064	India	*Vulgaris*	*Incurvata*	2.2	**MR**	9.0 (9.01)	**R**
45	IE 2065	India	*Vulgaris*	*Incurvata*	1.6	**HR**	4.5 (4.50)	**R**

46	IE 2088	India	*Vulgaris*	*Digitata*	1.9	**R**	6.5 (6.50)	**R**
47	IE 2091	India	*Vulgaris*	*Digitata*	3.2	**S**	22.0 (22.18)	**MR**
48	IE 2093	India	*Vulgaris*	*Incurvata*	4.4	**HS**	31.5 (32.05)	**HS**
49	IE 2106	India	*Elongata*	*Reclusa*	2.9	**MR**	37.5 (38.44)	**HS**
50	IE 2108	India	*Elongata*	*Reclusa*	2.9	**MR**	31.0 (31.52)	**HS**
51	IE 2116	India	*Vulgaris*	*Incurvata*	2.7	**MR**	12.5 (12.53)	**MR**
52	IE 2118	India	*Elongata*	*Reclusa*	3.7	**S**	33.0 (33.63)	**HS**
53	IE 2131	India	*Vulgaris*	*Incurvata*	2.6	**MR**	15.0 (15.06)	**MR**
54	IE 2139	India	*Vulgaris*	*Incurvata*	3.1	**S**	21.5 (21.67)	**S**
55	IE 2146	India	*Vulgaris*	*Digitata*	2.7	**MR**	24.0 (24.24)	**S**
56	IE 2150	India	*Vulgaris*	*Incurvata*	4.2	**HS**	33.0 (33.63)	**HS**
57	IE 2169	India	*Vulgaris*	*Digitata*	3.1	**S**	18.5 (18.61)	**MR**
58	IE 2180	India	*Vulgaris*	*Digitata*	3.7	**S**	29.0 (29.42)	**S**
59	IE 2183	India	*Vulgaris*	*Digitata*	4	**S**	29.5 (29.95)	**S**
60	IE 2187	India	*Vulgaris*	*Incurvata*	3.7	**S**	29.5 (29.95)	**S**
61	IE 2212	India	*Vulgaris*	*Digitata*	2.5	**MR**	22.5 (22.69)	**S**
62	IE 2217	India	*Vulgaris*	*Incurvata*	2.1	**MR**	4.0 (4.00)	**R**
63	IE 2223	India	*Elongata*	*Reclusa*	2.1	**MR**	21.0 (21.16)	**S**
64	IE 2235	India	*Vulgaris*	*Incurvata*	2.3	**MR**	4.0 (4.00)	**R**
65	IE 2238	India	*Vulgaris*	*Incurvata*	4	**S**	25.5 (25.78)	**S**
66	IE 2264	India	*Vulgaris*	*Incurvata*	1.6	**R**	4.5 (4.50)	**R**
67	IE 2288	India	*Vulgaris*	*Incurvata*	2.3	**MR**	11.0 (11.02)	**MR**
68	IE 2293	India	*Vulgaris*	*Stellata*	4.8	**HS**	39.5 (40.61)	**HS**
69	IE 2296	India	*Vulgaris*	*Digitata*	1.9	**R**	1.5 (1.50)	**HR**
70	IE 2299	India	*Vulgaris*	*Digitata*	2.4	**MR**	12.5 (12.53)	**MR**
71	IE 2312	India	*Elongata*	*Sparsa*	1.9	**R**	5.0 (5.00)	**R**
72	IE 2322	India	*Vulgaris*	*Stellata*	4	**S**	34.0 (34.69)	**HS**
73	IE 2323	India	*Vulgaris*	*Stellata*	4.4	**HS**	36.5 (37.36)	**HS**
74	IE 2341	Kenya	*Plana*	*Confundere*	1.7	**R**	5.0 (5.00)	**R**
75	IE 2350	Kenya	*Plana*	*Confundere*	1.8	**R**	4.0 (4.00)	**R**
76	IE 2354	Kenya	*Compacta*	*NA*	2	**R**	2.0 (2.00)	**R**
77	IE 2355	Kenya	*Compacta*	*NA*	1.5	**R**	5.5 (5.50)	**R**
78	IE 2358	Kenya	*Plana*	*Confundere*	2	**R**	8.0 (8.01)	**R**
79	IE 2363	Kenya	*Plana*	*Confundere*	1.4	**R**	1.5 (1.50)	**HR**
80	IE 2379	Kenya	*Plana*	*Confundere*	2.1	**MR**	9.0 (9.01)	**R**
81	IE 2384	Kenya	*Plana*	*Confundere*	1.7	**R**	5.0 (5.00)	**R**
82	IE 2386	Kenya	*Plana*	*Confundere*	2	**R**	6.5 (6.50)	**R**
83	IE 2393	Kenya	*Compacta*	*NA*	2.1	**MR**	5.5 (5.50)	**R**
84	IE 2399	Kenya	*Compacta*	*NA*	1.5	**R**	8.5 (8.51)	**R**
85	IE 2402	Kenya	*Plana*	*Confundere*	2.1	**MR**	7.0 (7.01)	**R**
86	IE 2416	Kenya	*Compacta*	*NA*	1.6	**R**	4.5 (4.50)	**R**
87	IE 2425	Kenya	*Plana*	*Confundere*	1.5	**R**	6.0 (6.00)	**R**
88	IE 2430	Kenya	*Plana*	*Confundere*	1.6	**R**	2.0 (2.00)	**R**
89	IE 2437	Kenya	*Plana*	*Confundere*	2.6	**MR**	7.0 (7.01)	**R**
90	IE 2440	Kenya	*Compacta*	*NA*	1.7	**R**	1.2 (1.20)	**HR**
91	IE 2452	Kenya	*Compacta*	*NA*	2	**R**	2.0 (2.00)	**R**
92	IE 2457	Kenya	*Compacta*	*NA*	2	**R**	2.5 (2.50)	**R**
93	IE 2476	Kenya	*Compacta*	*NA*	2.2	**MR**	7.5 (7.51)	**R**
94	IE 2486	Kenya	*Plana*	*Confundere*	2.3	**MR**	4.0 (4.00)	**R**
95	IE 2487	Kenya	*Compacta*	*NA*	1.9	**R**	1.5 (1.50)	**HR**
96	IE 2500	Kenya	*Compacta*	*NA*	2.3	**MR**	8.0 (8.01)	**R**

97	IE 2502	Kenya	*Plana*	*Confundere*	2.1	**MR**	5.5 (5.50)	**R**
98	IE 2503	Kenya	*Compacta*	*NA*	2	**R**	3.0 (3.00)	**R**
99	IE 2523	Kenya	*Compacta*	*NA*	1.2	**R**	0.0 (0.00)	**HR**
100	IE 2535	Kenya	*Plana*	*Confundere*	2.2	**MR**	4.0 (4.00)	**R**
101	IE 2551	Kenya	*Vulgaris*	*Incurvata*	1.2	**R**	0.0 (0.00)	**HR**
102	IE 2564	Kenya	*Compacta*	*NA*	1.9	**R**	5.5 (5.50)	**R**
103	IE 2568	Kenya	*Compacta*	*NA*	1	**HR**	2.0 (2.00)	**R**
104	IE 2572	Kenya	*Plana*	*Grandigluma*		*	*	*
105	IE 2573	Kenya	*Plana*	*Grandigluma*	1.7	**R**	0.5 (0.50)	**HR**
106	IE 2574	Kenya	*Plana*	*Confundere*	1.7	**R**	4.5 (4.50)	**R**
107	IE 2581	Italy	*Plana*	*Confundere*	1.5	**R**	1.5 (1.50)	**HR**
108	IE 2586	Italy	*Plana*	*Confundere*	1.9	**R**	7.5 (7.51)	**R**
109	IE 2587	Italy	*Compacta*	*NA*	1.9	**R**	1.0 (1.00)	**HR**
110	IE 2589	USA	*Plana*	*Seriata*	1.4	**R**	4.0 (4.00)	**R**
111	IE 2590	USA	*Compacta*	*NA*	2	**R**	4.0 (4.00)	**R**
112	IE 2591	USA	*Plana*	*Confundere*	2.2	**MR**	11.0 (11.02)	**MR**
113	IE 2593	USA	*Plana*	*Confundere*	1.8	**R**	4.5 (4.50)	**R**
114	IE 2606	Malawi	*Vulgaris*	*Incurvata*	1.6	**R**	3.5 (3.50)	**R**
115	IE 2608	Malawi	*Elongata*	*Reclusa*	1.6	**R**	8.5 (8.51)	**R**
116	IE 2619	Malawi	*Vulgaris*	*Incurvata*	1.7	**R**	2.0 (2.00)	**R**
117	IE 2622	Malawi	*Vulgaris*	*Incurvata*	2.2	**MR**	11.5 (11.53)	**MR**
118	IE 2633	Malawi	*Vulgaris*	*Incurvata*	1.5	**R**	3.0 (3.00)	**R**
119	IE 2644	Malawi	*Plana*	*Grandigluma*	2.1	**MR**	10.5 (10.52)	**R**
120	IE 2645	Malawi	*Elongata*	*Laxa*	1	**HR**	4.5 (4.50)	**R**
121	IE 2652	Malawi	*Plana*	*Confundere*	1.2	**HR**	2.5 (2.50)	**R**
122	IE 2653	Malawi	*Plana*	*Confundere*	1.6	**R**	12.5 (12.53)	**MR**
123	IE 2674	Malawi	*Plana*	*Confundere*	1.5	**HR**	2.5 (2.50)	**R**
124	IE 2689	Malawi	*Plana*	*Confundere*	1	**HR**	6.0 (6.00)	**R**
125	IE 2704	Malawi	*Vulgaris*	*Digitata*	1	**HR**	8.0 (8.01)	**R**
126	IE 2710	Malawi	*Plana*	*Confundere*	1.2	**R**	2.5 (2.50)	**R**
127	IE 2713	Malawi	*Elongata*	*Reclusa*	1	**HR**	6.0 (6.00)	**R**
128	IE 2732	Malawi	*Compacta*	*NA*	1.1	**HR**	8.0 (8.01)	**R**
129	IE 2760	Malawi	*Plana*	*Confundere*	1.2	**HR**	9.5 (9.51)	**R**
130	IE 2780	Malawi	*Elongata*	*Reclusa*	1.8	**R**	11.5 (11.53)	**MR**
131	IE 2790	Malawi	*Elongata*	*Laxa*	1.8	**MR**	10.4 (10.42)	**R**
132	IE 2794	Malawi	*Spontanea*	*NA*	2.5	**MR**	10.0 (10.02)	**R**
133	IE 2799	Ethiopia	*Elongata*	*Reclusa*	1	**HR**	1.5 (1.50)	**HR**
134	IE 2818	Nepal	*Elongata*	*Sparsa*	2	**R**	20.0 (20.14)	**MR**
135	IE 2820	Nepal	*Vulgaris*	*Incurvata*	3.3	**S**	21.0 (21.16)	**S**
136	IE 2821	Nepal	*Vulgaris*	*Incurvata*	1.1	**HR**	2.0 (2.00)	**R**
137	IE 2825	Tanzania	*Vulgaris*	*Digitata*	1.3	**R**	7.0 (7.01)	**R**
138	IE 2838	India	*Vulgaris*	*Stellata*	2.4	**MR**	9.5 (9.51)	**R**
139	IE 2850	India	*Vulgaris*	*Incurvata*	2.3	**MR**	11.5 (11.53)	**MR**
140	IE 2857	Zambia	*Vulgaris*	*Incurvata*	2.1	**MR**	14.0 (14.05)	**MR**
141	IE 2861	Zambia	*Vulgaris*	*Incurvata*	1.5	**R**	4.5 (4.50)	**R**
142	IE 2868	Zambia	*Vulgaris*	*Incurvata*	1.4	**R**	2.5 (2.50)	**R**
143	IE 2869	Zambia	*Plana*	*Confundere*	1.6	**R**	2.5 (2.50)	**R**
144	IE 2871	Zambia	*Vulgaris*	*Incurvata*	1.4	**R**	0.5 (0.50)	**HR**
145	IE 2872	Zambia	*Vulgaris*	*Digitata*	1.5	**R**	9.0 (9.01)	**R**
146	IE 2884	Zambia	*Vulgaris*	*Incurvata*	1.8	**R**	0.5 (0.50)	**HR**
147	IE 2890	Zambia	*Vulgaris*	*Incurvata*	1.8	**R**	1.0 (1.00)	**HR**

148	IE 2896	Zambia	*Compacta*	*NA*	1.2	**HR**	0.0 (0.00)	**HR**
149	IE 2909	Zambia	*Plana*	*Confundere*	1.5	**R**	3.0 (3.00)	**R**
150	IE 2911	Zambia	*Compacta*	*NA*	1.1	**HR**	1.0 (1.00)	**HR**
151	IE 2921	Malawi	*Spontanea*	*NA*	2.1	**MR**	8.0 (8.01)	**R**
152	IE 2938	Malawi	*Plana*	*Confundere*	1.2	**HR**	9.5 (9.51)	**R**
153	IE 2939	Malawi	*Plana*	*Confundere*	1.1	**HR**	0.5 (0.50)	**HR**
154	IE 2945	Malawi	*Vulgaris*	*Digitata*	1	**HR**	12.5 (12.53)	**MR**
155	IE 2957	Germany	*Vulgaris*	*Liliacea*	2	**R**	1.5 (1.50)	**HR**
156	IE 2971	Sri Lanka	*Vulgaris*	*Incurvata*	2.1	**MR**	10.5 (10.52)	**R**
157	IE 2983	Sri Lanka	*Compacta*	*NA*	1.5	**R**	3.2 (3.20)	**R**
158	IE 2996	India	*Compacta*	*NA*	2.6	**MR**	18.0 (18.10)	**MR**
159	IE 2999	India	*Vulgaris*	*Incurvata*	2.5	**MR**	14.0 (14.05)	**MR**
160	IE 3000	India	*Vulgaris*	*Incurvata*	2.3	**MR**	12.5 (12.53)	**MR**
161	IE 3015	India	*Plana*	*Confundere*	1.2	**HR**	8.0 (8.01)	**R**
162	IE 3025	Ethiopia	*Elongata*	*Reclusa*		*	*	*
163	IE 3028	India	*Vulgaris*	*Incurvata*	2.5	**MR**	16.0 (16.07)	**MR**
164	IE 3038	India	*Elongata*	*Laxa*	2.9	**MR**	17.5 (17.59)	**MR**
165	IE 3045	India	*Vulgaris*	*Incurvata*	1.8	**R**	7.0 (7.01)	**R**
166	IE 3046	India	*Vulgaris*	*Stellata*	1.6	**R**	15.5 (15.56)	**MR**
167	IE 3062	India	*Elongata*	*Laxa*	1.5	**R**	8.0 (8.01)	**R**
168	IE 3066	India	*Spontanea*	*NA*	2.2	**MR**	13.0 (13.04)	**MR**
169	IE 3070	India	*Spontanea*	*NA*	3.1	**S**	14.0 (14.05)	**MR**
170	IE 3073	India	*Elongata*	*Laxa*	1.8	**R**	8.0 (8.01)	**R**
171	IE 3075	India	*Elongata*	*Laxa*	2	**R**	11.5 (11.53)	**MR**
172	IE 3077	India	*Vulgaris*	*Liliacea*	1.3	**R**	5.0 (5.00)	**R**
173	IE 3094	India	*Vulgaris*	*Liliacea*	2.4	**MR**	14.5 (14.55)	**MR**
174	IE 3096	India	*Vulgaris*	*Liliacea*	2.3	**MR**	12.5 (12.53)	**MR**
175	IE 3101	India	*Spontanea*	*NA*	2.8	**MR**	18.5 (18.61)	**MR**
176	IE 3104	India	*Vulgaris*	*Liliacea*	3.8	**S**	44.0 (45.56)	**HS**
177	IE 3106	India	*Vulgaris*	*Liliacea*	3	**MR**	20.5 (20.65)	**MR**
178	IE 3111	India	*Vulgaris*	*Liliacea*	2.7	**MR**	22.5 (22.69)	**S**
179	IE 3114	India	*Elongata*	*Laxa*	2	**R**	8.0 (8.01)	**R**
180	IE 3120	India	*Vulgaris*	*Liliacea*	2.8	**MR**	24.5 (24.75)	**S**
181	IE 3124	India	*Vulgaris*	*Liliacea*	2.5	**MR**	13.0 (13.04)	**MR**
182	IE 3127	India	*Elongata*	*Laxa*	1.5	**R**	6.5 (6.50)	**R**
183	IE 3134	India	*Vulgaris*	*Incurvata*	1.3	**R**	7.0 (7.01)	**R**
184	IE 3135	India	*Elongata*	*Laxa*	1.8	**R**	6.5 (6.50)	**R**
185	IE 3165	Zambia	*Elongata*	*Laxa*	2	**R**	6.5 (6.50)	**R**
186	IE 3169	Zambia	*Vulgaris*	*Digitata*	1.9	**R**	6.5 (6.50)	**R**
187	IE 3174	Zambia	*Vulgaris*	*Digitata*	1.8	**R**	6.5 (6.50)	**R**
188	IE 3175	Zambia	*Vulgaris*	*Liliacea*	1.2	**R**	4.0 (4.00)	**R**
189	IE 3196	Tanzania	*Plana*	*Seriata*	1.2	**R**	3.0 (3.00)	**R**
190	IE 3225	Mozambique	*Vulgaris*	*Incurvata*	1.7	**R**	7.0 (7.01)	**R**
191	IE 3238	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	8.0 (8.01)	**R**
192	IE 3248	Zimbabwe	*Vulgaris*	*Digitata*	1.3	**R**	5.0 (5.00)	**R**
193	IE 3254	Zimbabwe	*Vulgaris*	*Digitata*	2	**R**	13.0 (13.04)	**MR**
194	IE 3257	Zimbabwe	*Vulgaris*	*Liliacea*	1.9	**R**	5.0 (5.00)	**R**
195	IE 3270	Zimbabwe	*Elongata*	*Laxa*	2	**R**	4.0 (4.00)	**R**
196	IE 3278	Zimbabwe	*Vulgaris*	*Digitata*	1.3	**R**	2.0 (2.00)	**R**
197	IE 3280	Zimbabwe	*Vulgaris*	*Incurvata*	1.5	**R**	4.5 (4.50)	**R**
198	IE 3287	Zimbabwe	*Elongata*	*Laxa*	1.8	**R**	4.5 (4.50)	**R**

199	IE 3291	Zimbabwe	*Vulgaris*	*Digitata*	2.1	**MR**	6.5 (6.50)	**R**
200	IE 3313	Zimbabwe	*Spontanea*	*NA*	2	**R**	4.0 (4.00)	**R**
201	IE 3317	Zimbabwe	*Vulgaris*	*Digitata*	1.6	**R**	3.5 (3.50)	**R**
202	IE 3329	Zimbabwe	*Vulgaris*	*Digitata*	2.1	**MR**	6.0 (6.00)	**R**
203	IE 3330	Zimbabwe	*Elongata*	*Laxa*	2	**R**	7.0 (7.01)	**R**
204	IE 3334	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	4.0 (4.00)	**R**
205	IE 3363	Zimbabwe	*Vulgaris*	*Digitata*	2	**R**	6.0 (6.00)	**R**
206	IE 3391	Zimbabwe	*Vulgaris*	*Digitata*	1.2	**R**	2.5 (2.50)	**R**
207	IE 3392	Zimbabwe	*Vulgaris*	*Liliacea*	1.8	**MR**	6.0 (6.00)	**R**
208	IE 3412	Zimbabwe	*Vulgaris*	*Digitata*	2.2	**MR**	12.5 (12.53)	**MR**
209	IE 3413	Zimbabwe	*Vulgaris*	*Digitata*	1.9	**R**	6.5 (6.50)	**R**
210	IE 3431	Zimbabwe	*Vulgaris*	*Digitata*	1.6	**R**	5.0 (5.00)	**R**
211	IE 3443	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	3.5 (3.50)	**R**
212	IE 3446	Zimbabwe	*Vulgaris*	*Digitata*	1.2	**R**	1.0 (1.00)	**HR**
213	IE 3449	U.K.	*Vulgaris*	*Liliacea*	1.8	**R**	4.5 (4.50)	**R**
214	IE 3450	U.K.	*Spontanea*	*NA*	2.2	**MR**	11.0 (11.02)	**MR**
215	IE 3455	U.K.	*Vulgaris*	*Digitata*	1.8	**R**	7.0 (7.01)	**R**
216	IE 3470	India	*Spontanea*	*NA*	1.4	**R**	6.0 (6.00)	**R**
217	IE 3475	India	*Spontanea*	*NA*	1.6	**R**	3.5 (3.50)	**R**
218	IE 3477	Kenya	*Vulgaris*	*Liliacea*	1.9	**R**	4.0 (4.00)	**R**
219	IE 3478	Kenya	*Vulgaris*	*Digitata*	1.9	**R**	6.1 (6.10)	**R**
220	IE 3489	Kenya	*Vulgaris*	*Incurvata*	1.7	**R**	5.5 (5.50)	**R**
221	IE 3492	Kenya	*Vulgaris*	*Digitata*	2	**R**	5.5 (5.50)	**R**
222	IE 3502	Kenya	*Vulgaris*	*Digitata*	1.9	**R**	5.0 (5.00)	**R**
223	IE 3510	Kenya	*Vulgaris*	*Digitata*	1.6	**R**	5.5 (5.50)	**R**
224	IE 3515	Kenya	*Vulgaris*	*Digitata*	2	**R**	3.5 (3.50)	**R**
225	IE 3531	Kenya	*Vulgaris*	*Digitata*	2	**R**	4.0 (4.00)	**R**
226	IE 3533	Kenya	*Vulgaris*	*Digitata*	2.1	**MR**	4.0 (4.00)	**R**
227	IE 3543	India	*Spontanea*	*NA*	3.2	**S**	22.0 (22.18)	**S**
228	IE 3547	India	*Spontanea*	*NA*	2.4	**MR**	14.0 (14.05)	**MR**
229	IE 3559	India	*Spontanea*	*NA*	2.3	**MR**	10.5 (10.52)	**R**
230	IE 3566	India	*Elongata*	*Laxa*	2.6	**MR**	14.5 (14.55)	**MR**
231	IE 3575	India	*Vulgaris*	*Stellata*	2.2	**MR**	11.0 (11.02)	**MR**
232	IE 3581	India	*Vulgaris*	*Stellata*	2.9	**MR**	17.5 (17.59)	**MR**
233	IE 3604	India	*Vulgaris*	*Incurvata*	2.3	**MR**	12.0 (12.03)	**MR**
234	IE 3612	Unknown	*Vulgaris*	*Incurvata*	2.1	**MR**	7.0 (7.01)	**R**
235	IE 3614	Unknown	*Plana*	*Confundere*	1.4	**R**	3.5 (3.50)	**R**
236	IE 3654	Uganda	*Vulgaris*	*Incurvata*	2.1	**MR**	7.5 (7.51)	**R**
237	IE 3657	Uganda	*Vulgaris*	*Incurvata*	1.4	**R**	9.5 (9.51)	**R**
238	IE 3663	Uganda	*Compacta*	*NA*	1.7	**R**	4.7 (4.70)	**R**
239	IE 3693	Uganda	*Plana*	*Confundere*	1.8	**R**	3.0 (3.00)	**R**
240	IE 3694	Uganda	*Vulgaris*	*Incurvata*	1.4	**R**	0.5 (0.50)	**HR**
241	IE 3697	Uganda	*Vulgaris*	*Incurvata*	1.7	**R**	3.0 (3.00)	**R**
242	IE 3704	Uganda	*Vulgaris*	*Digitata*	1.9	**R**	2.5 (2.50)	**R**
243	IE 3705	Uganda	*Vulgaris*	*Incurvata*	1.7	**R**	1.0 (1.00)	**HR**
244	IE 3721	Uganda	*Vulgaris*	*Incurvata*	1.9	**R**	0.0 (0.00)	**HR**
245	IE 3723	Uganda	*Plana*	*Confundere*	1.8	**R**	2.5 (2.50)	**R**
246	IE 3738	Uganda	*Vulgaris*	*Incurvata*	1.8	**R**	14.0 (14.05)	**MR**
247	IE 3753	Uganda	*Vulgaris*	*Incurvata*	1.7	**R**	3.5 (3.50)	**R**
248	IE 3758	Uganda	*Compacta*	*NA*	1.7	**R**	5.0 (5.00)	**R**
249	IE 3769	Uganda	*Compacta*	*NA*	2	**R**	5.0 (5.00)	**R**

250	IE 3779	Uganda	*Vulgaris*	*Stellata*	1.7	**R**	5.5 (5.50)	**R**
251	IE 3780	Uganda	*Elongata*	*Reclusa*	1.8	**R**	2.0 (2.00)	**R**
252	IE 3803	Uganda	*Compacta*	*NA*	2.3	**MR**	12.5 (12.53)	**MR**
253	IE 3808	Uganda	*Vulgaris*	*Stellata*	1.5	**R**	0.5 (0.50)	**HR**
254	IE 3817	Uganda	*Vulgaris*	*Stellata*	1.5	**R**	2.5 (2.50)	**R**
255	IE 3821	Uganda	*Compacta*	*NA*	1.7	**R**	3.0 (3.00)	**R**
256	IE 3826	Uganda	*Vulgaris*	*Stellata*	1.4	**R**	4.0 (4.00)	**R**
257	IE 3827	Uganda	*Vulgaris*	*Incurvata*	1.9	**R**	4.5 (4.50)	**R**
258	IE 3901	Uganda	*Vulgaris*	*Incurvata*	1.9	**R**	1.5 (1.50)	**HR**
259	IE 3910	Uganda	*Vulgaris*	*Incurvata*	1.9	**R**	2.5 (2.50)	**R**
260	IE 3935	Uganda	*Vulgaris*	*Stellata*	1.9	**R**	6.0 (6.00)	**R**
261	IE 3945	Uganda	*Plana*	*Confundere*	1.8	**R**	1.5 (1.50)	**HR**
262	IE 3947	Uganda	*Plana*	*Confundere*	1.5	**R**	4.0 (4.00)	**R**
263	IE 3952	Uganda	*Plana*	*Confundere*	1.6	**R**	0.0 (0.00)	**HR**
264	IE 3973	Uganda	*Compacta*	*NA*	2	**R**	2.0 (2.00)	**R**
265	IE 3987	Uganda	*Vulgaris*	*Incurvata*	1.8	**R**	5.0 (5.00)	**R**
266	IE 4028	Uganda	*Vulgaris*	*Incurvata*	1.4	**R**	4.5 (4.50)	**R**
267	IE 4036	Uganda	*Vulgaris*	*Digitata*	2	**R**	7.5 (7.51)	**R**
268	IE 4047	Uganda	*Vulgaris*	*Digitata*	1.6	**R**	4.5 (4.50)	**R**
269	IE 4057	Uganda	*Plana*	*Seriata*	1.2	**HR**	1.0 (1.00)	**HR**
270	IE 4070	Uganda	*Vulgaris*	*Incurvata*	2	**R**	2.0 (2.00)	**R**
271	IE 4073	Uganda	*Elongata*	*Reclusa*	1.0	**R**	0 (0)	**HR**
272	IE 4097	Uganda	*Compacta*	*NA*	1.9	**R**	7.0 (7.01)	**R**
273	IE 4107	Uganda	*Vulgaris*	*Incurvata*	1.4	**R**	2.0 (2.00)	**R**
274	IE 4110	Uganda	*Plana*	*Confundere*	3	**MR**	19.5 (19.63)	**MR**
275	IE 4115	Uganda	*Vulgaris*	*Incurvata*	2	**R**	6.5 (6.50)	**R**
276	IE 4116	Uganda	*Plana*	*Confundere*	1.8	**R**	1.0 (1.00)	**HR**
277	IE 4118	Uganda	*Plana*	*Confundere*	1.9	**R**	7.0 (7.01)	**R**
278	IE 4121	Uganda	*Plana*	*Confundere*	1.7	**R**	13.0 (13.04)	**MR**
279	IE 4122	Uganda	*Vulgaris*	*Incurvata*	1.7	**R**	4.5 (4.50)	**R**
280	IE 4134	Uganda	*Vulgaris*	*Stellata*	2.1	**MR**	8.5 (8.51)	**R**
281	IE 4147	Uganda	*Vulgaris*	*Incurvata*	1.9	**R**	8.0 (8.01)	**R**
282	IE 4152	Uganda	*Vulgaris*	*Incurvata*	1.7	**R**	1.0 (1.00)	**HR**
283	IE 4163	Uganda	*Elongata*	*Reclusa*	1.7	**R**	2.0 (2.00)	**R**
284	IE 4165	Uganda	*Plana*	*Confundere*	1.5	**R**	0.5 (.50)	**HR**
285	IE 4181	Uganda	*Compacta*	*NA*	1.7	**R**	2.5 (2.50)	**R**
286	IE 4192	Uganda	*Vulgaris*	*Digitata*	1.7	**R**	7.5 (7.51)	**R**
287	IE 4218	Burundi	*Vulgaris*	*Incurvata*	2	**R**	11.0 (11.02)	**MR**
288	IE 4220	Zimbabwe	*Vulgaris*	*Incurvata*	1.7	**R**	3.0 (3.00)	**R**
289	IE 4229	Zimbabwe	*Vulgaris*	*Incurvata*	1.7	**R**	0.0 (0.00)	**HR**
290	IE 4245	Zimbabwe	*Vulgaris*	*Incurvata*	2	**R**	4.5 (4.50)	**R**
291	IE 4257	Zimbabwe	*Vulgaris*	*Digitata*	1.5	**R**	4.0 (4.00)	**R**
292	IE 4274	Zimbabwe	*Vulgaris*	*Incurvata*	1.8	**R**	9.0 (9.01)	**R**
293	IE 4287	Zimbabwe	*Compacta*	*NA*	1.7	**R**	6.5 (6.50)	**R**
294	IE 4295	Zimbabwe	*Plana*	*Confundere*	2	**R**	4.0 (4.00)	**R**
295	IE 4296	Zimbabwe	*Vulgaris*	*Digitata*	2.1	**MR**	12.0 (12.03)	**MR**
296	IE 4310	Zimbabwe	*Vulgaris*	*Digitata*	1.9	**R**	4.5 (4.50)	**R**
297	IE 4312	Zimbabwe	*Compacta*	*NA*	2	**R**	3.5 (3.50)	**R**
298	IE 4329	Zimbabwe	*Vulgaris*	*Incurvata*	1.1	**R**	2.5 (2.50)	**R**
299	IE 4339	Zimbabwe	*Plana*	*Confundere*	1.7	**R**	3.0 (3.00)	**R**
300	IE 4340	Zimbabwe	*Compacta*	*NA*	2.1	**MR**	18.5 (18.61)	**MR**

301	IE 4347	Zimbabwe	*Plana*	*Confundere*	1.8	**R**	5.5 (5.50)	**R**
302	IE 4350	Zimbabwe	*Vulgaris*	*Digitata*	2.1	**MR**	7.0 (7.01)	**R**
303	IE 4383	Zimbabwe	*Compacta*	*NA*	1.8	**R**	7.5 (7.50)	**R**
304	IE 4386	Zimbabwe	*Compacta*	*NA*	1.8	**R**	3.5 (3.50)	**R**
305	IE 4401	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	5.5 (5.50)	**R**
306	IE 4403	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	2.5 (2.50)	**R**
307	IE 4414	India	*Vulgaris*	*Digitata*	2.5	**MR**	10.5 (10.52)	**R**
308	IE 4425	India	*Vulgaris*	*Incurvata*	2.6	**MR**	20.5 (20.65)	**MR**
309	IE 4443	Cameroon	*Spontanea*	*NA*	3	**MR**	40.0 (41.15)	**HS**
310	IE 4476	Zimbabwe	*Spontanea*	*NA*	2	**R**	4.5 (4.50)	**R**
311	IE 4483	Zimbabwe	*Vulgaris*	*Incurvata*	1.7	**R**	3.5 (3.50)	**R**
312	IE 4491	Zimbabwe	*Elongata*	*Reclusa*	2	**R**	10.0 (10.02)	**R**
313	IE 4497	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	5.5 (5.50)	**R**
314	IE 4519	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	5.0 (5.00)	**R**
315	IE 4525	Zimbabwe	*Vulgaris*	*Digitata*	1.4	**R**	2.5 (2.50)	**R**
316	IE 4529	Zimbabwe	*Vulgaris*	*Digitata*	2.3	**MR**	11.0 (11.02)	**MR**
317	IE 4545	Zimbabwe	*Compacta*	*NA*	1.9	**R**	11.0 (11.02)	**MR**
318	IE 4554	Zimbabwe	*Vulgaris*	*Digitata*	2	**R**	7.5 (7.51)	**R**
319	IE 4563	Zimbabwe	*Vulgaris*	*Incurvata*	2	**R**	3.5 (3.50)	**R**
320	IE 4565	Zimbabwe	*Elongata*	*Reclusa*	1.3	**R**	4.5 (4.50)	**R**
321	IE 4570	Zimbabwe	*Compacta*	*NA*	1.2	**R**	7.9 (7.87)	**R**
322	IE 4584	Zimbabwe	*Vulgaris*	*Digitata*	2.1	**MR**	13.2 (13.24)	**MR**
323	IE 4585	Zimbabwe	*Vulgaris*	*Digitata*	1.7	**R**	13.6 (13.59)	**MR**
324	IE 4622	Zimbabwe	*Compacta*	*NA*	1.3	**R**	9.8 (9.85)	**R**
325	IE 4646	Zimbabwe	*Plana*	*Grandigluma*	1.7	**R**	11.5 (11.48)	**MR**
326	IE 4647	Zimbabwe	*Vulgaris*	*Incurvata*	2	**R**	14.1 (14.18)	**MR**
327	IE 4658	India	*Vulgaris*	*Liliacea*	1.7	**R**	17.7 (17.75)	**MR**
328	IE 4671	India	*Vulgaris*	*Digitata*	2.3	**MR**	21.1 (21.29)	**S**
329	IE 4677	India	*Vulgaris*	*Digitata*	2.1	**MR**	12.9 (12.96)	**MR**
330	IE 4688	India	*Vulgaris*	*Digitata*	2	**R**	12.8 (12.83)	**MR**
331	IE 4708	Burundi	*Spontanea*	*NA*	4.7	**HS**	42.7 (44.12)	**HS**
332	IE 4709	Burundi	*Africana*	*NA*	1.2	**R**	1.1 (1.11)	**HR**
333	IE 4734	India	*Compacta*	*NA*	4.9	**HS**	43.9 (45.39)	**HS**
334	IE 4755	India	*Vulgaris*	*Stellata*	3.7	**S**	26.0 (26.30)	**S**
335	IE 4757	India	*Compacta*	*NA*	3.2	**S**	20.0 (20.14)	**MR**
336	IE 4759	India	*Vulgaris*	*Stellata*	3.9	**S**	28.0 (28.38)	**S**
337	IE 4789	Zimbabwe	*Vulgaris*	*Digitata*	2.4	**MR**	18.5 (18.61)	**MR**
338	IE 4795	Zimbabwe	*Compacta*	*NA*	2.1	**MR**	10.0 (10.02)	**R**
339	IE 4797	Maldives	*Vulgaris*	*Liliacea*	2.8	**MR**	31.0 (31.52)	**HS**
340	IE 4801	India	*Compacta*	*NA*	2.7	**MR**	13.5 (13.54)	**MR**
341	IE 4816	India	*Plana*	*Confundere*		*	*	*
342	IE 4817	India	*Vulgaris*	*Stellata*	3	**MR**	14.5 (14.55)	**MR**
343	IE 4826	India	*Vulgaris*	*Digitata*	2.4	**MR**	14.0 (14.05)	**MR**
344	IE 4842	India	*Compacta*	*NA*	1.7	**R**	11.0 (11.02)	**MR**
345	IE 4866	India	*Plana*	*Confundere*	1.3	**R**	1.5 (1.50)	**HR**
346	IE 4887	India	*Vulgaris*	*Incurvata*	2.5	**MR**	14.0 (14.05)	**MR**
347	IE 4905	Uganda	*Plana*	*Seriata*	1.4	**R**	0.5 (0.50)	**HR**
348	IE 4909	Uganda	*Plana*	*Confundere*	2.1	**MR**	5.5 (5.50)	**R**
349	IE 4911	Uganda	*Plana*	*Confundere*	1.7	**R**	1.5 (1.50)	**HR**
350	IE 4916	Uganda	*Compacta*	*NA*	1.6	**R**	2.0 (2.00)	**R**
351	IE 4963	Uganda	*Vulgaris*	*Incurvata*	1.6	**R**	3.0 (3.00)	**R**

352	IE 4972	Uganda	*Plana*	*Confundere*	1.7	**R**	3.0 (3.00)	**R**
353	IE 4984	Uganda	*Compacta*	*NA*	2.1	**MR**	7.0 (7.01)	**R**
354	IE 4997	Uganda	*Plana*	*Confundere*	2.1	**MR**	3.5 (3.50)	**R**
355	IE 4998	Uganda	*Compacta*	*NA*	1.9	**R**	4.0 (4.00)	**R**
356	IE 5030	Zimbabwe	*Vulgaris*	*Incurvata*	1.9	**R**	1.5 (1.50)	**HR**
357	IE 5065	Malawi	*Vulgaris*	*Incurvata*	1.6	**R**	1.5 (1.50)	**HR**
358	IE 5066	Senegal	*Vulgaris*	*Incurvata*	1.4	**R**	4.0 (4.00)	**R**
359	IE 5090	Zimbabwe	*Vulgaris*	*Incurvata*	1.8	**R**	4.5 (4.50)	**R**
360	IE 5091	Zimbabwe	*Elongata*	*Reclusa*	1.9	**R**	9.0 (9.01)	**R**
361	IE 5105	Zimbabwe	*Plana*	*Confundere*	2	**R**	3.0 (3.00)	**R**
362	IE 5106	Zimbabwe	*Vulgaris*	*Incurvata*	2.1	**MR**	5.0 (5.00)	**R**
363	IE 5107	Zimbabwe	*Elongata*	*Reclusa*	2.1	**MR**	6.5 (6.50)	**R**
364	IE 5112	India	*Compacta*	*NA*	2.1	**MR**	13.0 (13.04)	**MR**
365	IE 5120	India	*Vulgaris*	*Incurvata*	1.5	**R**	2.5 (2.50)	**R**
366	IE 5123	India	*Elongata*	*Reclusa*	2	**R**	4.9 (4.90)	**R**
367	IE 5124	India	*Vulgaris*	*Incurvata*	2.1	**MR**	3.0 (3.00)	**R**
368	IE 5129	India	*Plana*	*Confundere*	1.8	**R**	0.5 (0.50)	**HR**
369	IE 5142	India	*Vulgaris*	*Incurvata*	2	**R**	4.5 (4.50)	**R**
370	IE 5145	India	*Vulgaris*	*Liliacea*	2.9	**MR**	17.5 (17.59)	**MR**
371	IE 5149	India	*Vulgaris*	*Incurvata*	1.9	**R**	6.5 (6.50)	**R**
372	IE 5156	India	*Vulgaris*	*Stellata*	1.8	**R**	4.5 (4.50)	**R**
373	IE 5165	India	*Plana*	*Confundere*	1.8	**R**	2.0 (2.00)	**R**
374	IE 5173	India	*Vulgaris*	*Stellata*	2	**R**	5.0 (5.00)	**R**
375	IE 5177	India	*Vulgaris*	*Incurvata*	2.1	**MR**	5.5 (5.50)	**R**
376	IE 5179	India	*Vulgaris*	*Stellata*	1.5	**R**	7.0 (7.01)	**R**
377	IE 5182	India	*Plana*	*Seriata*	2.5	**MR**	17.5 (17.59)	**MR**
378	IE 5186	India	*Plana*	*Confundere*	2.3	**MR**	10.0 (10.02)	**R**
379	IE 5193	India	*Vulgaris*	*Incurvata*	2.2	**MR**	14.5 (14.55)	**MR**
380	IE 5201	India	*Vulgaris*	*Liliacea*	1.7	**R**	1.5 (1.50)	**HR**
381	IE 5208	India	*Compacta*	*NA*	1.7	**R**	3.0 (3.00)	**R**
382	IE 5229	India	*Vulgaris*	*Stellata*	2.6	**MR**	15.5 (15.56)	**MR**
383	IE 5231	India	*Vulgaris*	*Incurvata*	2.1	**MR**	13.0 (13.04)	**MR**
384	IE 5239	India	*Vulgaris*	*Digitata*	1.9	**R**	1.0 (1.00)	**HR**
385	IE 5245	India	*Vulgaris*	*Incurvata*	1.8	**R**	4.0 (4.00)	**R**
386	IE 5260	India	*Vulgaris*	*Stellata*	1.4	**R**	7.0 (7.01)	**R**
387	IE 5295	Zimbabwe	*Vulgaris*	*Incurvata*	1.6	**R**	6.5 (6.50)	**R**
388	IE 5306	Zimbabwe	*Vulgaris*	*Digitata*	1.7	**R**	3.5 (3.50)	**R**
389	IE 5314	Zambia	*Plana*	*Seriata*	1.6	**R**	6.0 (6.00)	**R**
390	IE 5315	Zambia	*Plana*	*Seriata*	1.8	**R**	7.4 (7.41)	**R**
391	IE 5317	Zambia	*Plana*	*Confundere*	2	**R**	0.0 (0.00)	**HR**
392	IE 5320	India	*Compacta*	*NA*	2.3	**MR**	12.5 (12.53)	**MR**
393	IE 5321	India	*Vulgaris*	*Liliacea*	2	**R**	6.0 (6.00)	**R**
394	IE 5331	India	*Vulgaris*	*Stellata*	1.7	**R**	1.5 (1.50)	**HR**
395	IE 5343	Kenya	*Plana*	*Seriata*	1.7	**R**	3.5 (3.50)	**R**
396	IE 5349	Kenya	*Vulgaris*	*Stellata*	2.2	**MR**	5.0 (5.00)	**R**
397	IE 5359	Kenya	*Vulgaris*	*Incurvata*	2.4	**MR**	10.0 (10.02)	**R**
398	IE 5364	Kenya	*Vulgaris*	*Stellata*	2	**R**	5.5 (5.50)	**R**
399	IE 5367	Kenya	*Vulgaris*	*Digitata*	2.9	**MR**	20.5 (20.65)	**MR**
400	IE 5383	Kenya	*Vulgaris*	*Incurvata*	1.4	**R**	2.0 (2.00)	**R**
401	IE 5388	Kenya	*Vulgaris*	*Stellata*	2.6	**MR**	16.5 (16.58)	**MR**
402	IE 5390	Kenya	*Vulgaris*	*Stellata*	2.9	**MR**	18.5 (18.61)	**MR**

403	IE 5407	Kenya	*Vulgaris*	*Stellata*	1.8	**R**	9.0 (9.01)	**R**
404	IE 5419	Kenya	*Vulgaris*	*Stellata*	2	**R**	2.0 (2.00)	**R**
405	IE 5421	Kenya	*Vulgaris*	*Stellata*	2.1	**MR**	4.0 (4.00)	**R**
406	IE 5435	Kenya	*Vulgaris*	*Liliacea*	1.4	**R**	4.0 (4.00)	**R**
407	IE 5457	Kenya	*Vulgaris*	*Incurvata*	1.8	**R**	2.0 (2.00)	**R**
408	IE 5475	India	*Vulgaris*	*Digitata*	1.9	**R**	6.0 (6.00)	**R**
409	IE 5480	India	*Vulgaris*	*Incurvata*	1.4	**R**	4.0 (4.00)	**R**
410	IE 5485	India	*Vulgaris*	*Stellata*	1.9	**R**	9.0 (9.01)	**R**
411	IE 5491	Unknown	*Vulgaris*	*Incurvata*	1.7	**R**	6.0 (6.00)	**R**
412	IE 5495	Unknown	*Plana*	*Confundere*	1.6	**R**	1.0 (1.00)	**HR**
413	IE 5502	Nepal	*Vulgaris*	*Incurvata*	1.8	**R**	5.5 (5.50)	**R**
414	IE 5517	Nepal	*Vulgaris*	*Digitata*	1.6	**R**	6.0 (6.00)	**R**
415	IE 5519	Nepal	*Elongata*	*Reclusa*	2.4	**MR**	9.5 (9.51)	**R**
416	IE 5525	Nepal	*Elongata*	*Sparsa*	2	**R**	16.0 (16.07)	**MR**
417	IE 5537	Nepal	*Vulgaris*	*Stellata*	1.6	**R**	6.5 (6.50)	**R**
418	IE 5542	Nepal	*Vulgaris*	*Stellata*	2.7	**MR**	19.0 (19.12)	**MR**
419	IE 5563	Nepal	*Vulgaris*	*Liliacea*	2	**R**	7.5 (7.51)	**R**
420	IE 5578	Nepal	*Vulgaris*	*Incurvata*	1.8	**R**	10.0 (10.02)	**R**
421	IE 5584	Nepal	*Vulgaris*	*Stellata*	2	**R**	14.5 (14.55)	**MR**
422	IE 5591	Nepal	*Vulgaris*	*Stellata*	2	**R**	6.5 (6.50)	**R**
423	IE 5620	Nepal	*Vulgaris*	*Liliacea*	3.1	**S**	25.0 (25.27)	**S**
424	IE 5635	Nepal	*Vulgaris*	*Digitata*	2.8	**MR**	22.5 (22.69)	**S**
425	IE 5647	Nepal	*Vulgaris*	*Incurvata*	1.8	**R**	8.5 (8.51)	**R**
426	IE 5653	Nepal	*Elongata*	*Sparsa*	2.7	**MR**	20.5 (20.65)	**MR**
427	IE 5672	Nepal	*Vulgaris*	*Liliacea*	2.4	**MR**	18.5 (18.61)	**MR**
428	IE 5689	Nepal	*Vulgaris*	*Incurvata*	1.7	**R**	6.5 (6.50)	**R**
429	IE 5711	Nepal	*Vulgaris*	*Stellata*	1.5	**R**	3.5 (3.50)	**R**
430	IE 5733	Nepal	*Vulgaris*	*Digitata*	2.1	**MR**	11.0 (11.02)	**MR**
431	IE 5736	Nepal	*Vulgaris*	*Stellata*	4.6	**HS**	38.0 (38.98)	**HS**
432	IE 5748	Nepal	*Elongata*	*Sparsa*	2.3	**MR**	13.5 (13.54)	**MR**
433	IE 5782	Nepal	*Compacta*	*NA*	3.2	**S**	14.5 (14.55)	**MR**
434	IE 5788	Nepal	*Elongata*	*Reclusa*	3	**MR**	24.0 (24.24)	**S**
435	IE 5791	Nepal	*Vulgaris*	*Stellata*	2.8	**MR**	30.5 (30.99)	**HS**
436	IE 5794	Nepal	*Vulgaris*	*Digitata*	3.5	**S**	27.5 (27.86)	**S**
437	IE 5806	Nepal	*Vulgaris*	*Incurvata*	2.7	**MR**	22.0 (22.18)	**S**
438	IE 5812	Nepal	*Vulgaris*	*Incurvata*	2.5	**MR**	14.5 (14.55)	**MR**
439	IE 5813	Nepal	*Vulgaris*	*Liliacea*	1.6	**R**	11.5 (11.53)	**MR**
440	IE 5817	Nepal	*Vulgaris*	*Incurvata*	2.5	**MR**	12.0 (12.03)	**MR**
441	IE 5831	Nepal	*Vulgaris*	*Liliacea*	2.1	**MR**	9.5 (9.51)	**R**
442	IE 5845	Nepal	*Vulgaris*	*Incurvata*	2.3	**MR**	13.5 (13.54)	**MR**
443	IE 5870	Nepal	*Vulgaris*	*Digitata*	3.8	**S**	32.0 (32.57)	**HS**
444	IE 5873	Nepal	*Elongata*	*Sparsa*	1.9	**R**	8.0 (8.04)	**R**
445	IE 5896	Nepal	*Elongata*	*Sparsa*	1.8	**R**	4.0 (4.00)	**R**
446	IE 5945	Nepal	*Vulgaris*	*Stellata*	1.5	**R**	9.5 (9.51)	**R**
447	IE 5956	Nepal	*Vulgaris*	*Incurvata*	2.1	**MR**	5.7 (5.70)	**R**
448	IE 5960	Nepal	*Vulgaris*	*Stellata*	4	**S**	26.0 (26.30)	**S**
449	IE 5961	Nepal	*Vulgaris*	*Digitata*	2	**R**	9.5 (9.51)	**R**
450	IE 5968	Nepal	*Vulgaris*	*Stellata*	2.9	**MR**	11.5 (11.53)	**MR**
451	IE 5992	Nepal	*Vulgaris*	*Stellata*	1.8	**R**	8.5 (8.51)	**R**
452	IE 5999	Nepal	*Plana*	*Seriata*	3.3	**S**	18.0 (18.10)	**MR**
453	IE 6012	Nepal	*Vulgaris*	*Stellata*	1.8	**R**	7.5 (7.51)	**R**

454	IE 6013	Nepal	*Vulgaris*	*Liliacea*	3.9	**S**	23.5 (23.72)	**S**
455	IE 6020	Nepal	*Vulgaris*	*Stellata*	1.9	**R**	8.5 (8.51)	**R**
456	IE 6025	Nepal	*Elongata*	*Sparsa*	2.2	**MR**	14.0 (14.05)	**MR**
457	IE 6029	Nepal	*Vulgaris*	*Stellata*	1.7	**R**	5.0 (5.00)	**R**
458	IE 6033	Nepal	*Vulgaris*	*Incurvata*	2	**R**	5.0 (5.00)	**R**
459	IE 6055	Nepal	*Vulgaris*	*Incurvata*	2.3	**MR**	12.5 (12.53)	**MR**
460	IE 6059	Nepal	*Vulgaris*	*Digitata*	2.3	**MR**	12.0 (12.03)	MR
461	IE 6072	Nepal	*Vulgaris*	*Stellata*	3.5	**S**	17.5 (17.59)	**MR**
462	IE 6074	Nepal	*Vulgaris*	*Digitata*	2.3	**MR**	15.5 (15.56)	**MR**
463	IE 6082	Nepal	*Plana*	*Seriata*	4.9	**HS**	60.0 (64.35)	**HS**
464	IE 6088	Nepal	*Elongata*	*Sparsa*	2	**R**	16.0 (16.07)	**MR**
465	IE 6112	Nepal	*Plana*	*Seriata*	2.5	**MR**	16.5 (16.58)	**MR**
466	IE 6117	Nepal	*Vulgaris*	*Stellata*	1.4	**R**	3.5 (3.50)	**R**
467	IE 6122	Nepal	*Vulgaris*	*Incurvata*	1.9	**R**	4.0 (4.00)	**R**
468	IE 6127	Nepal	*Vulgaris*	*Incurvata*	2.8	**MR**	21.5 (21.67)	**MR**
469	IE 6154	Nepal	*Plana*	*Seriata*	1.4	**R**	4.0 (4.00)	**R**
470	IE 6165	Nepal	*Vulgaris*	*Incurvata*	1.4	**R**	4.0 (4.00)	**R**
471	IE 6167	Nepal	*Vulgaris*	*Stellata*	3.4	**S**	17.0 (17.08)	**MR**
472	IE 6175	Nepal	*Elongata*	*Sparsa*	3.3	**S**	27.5 (27.86)	**S**
473	IE 6221	Nepal	*Vulgaris*	*Stellata*	1.6	**R**	4.5 (4.50)	**R**
474	IE 6227	Nepal	*Vulgaris*	*Digitata*	1.7	**R**	2.5 (2.50)	**R**
475	IE 6229	Nepal	*Vulgaris*	*Incurvata*	2.1	**MR**	4.0 (4.00)	**R**
476	IE 6239	Zimbabwe	*Plana*	*Seriata*	1.6	**R**	7.0 (7.01)	**R**
477	IE 6240	Zimbabwe	*Vulgaris*	*Incurvata*	1.3	**R**	2.5 (2.50)	**R**
478	IE 6241	Zimbabwe	*Elongata*	*Sparsa*	2	**R**	12.5 (12.53)	**MR**
479	IE 6252	Zimbabwe	*Vulgaris*	*Incurvata*	2.4	**MR**	13.0 (13.04)	**MR**
480	IE 6255	Zimbabwe	*Vulgaris*	*Stellata*	2.3	**MR**	12.0 (12.03)	**MR**
481	IE 6280	Zimbabwe	*Vulgaris*	*Incurvata*	2	**R**	13.0 (13.04)	**MR**
482	IE 6294	Zimbabwe	*Vulgaris*	*Incurvata*	1.7	**R**	5.0 (5.00)	**R**
483	IE 6300	Zimbabwe	*Vulgaris*	*Digitata*	1.9	**R**	6.0 (6.00)	**R**
484	IE 6313	Zimbabwe	*Vulgaris*	*Incurvata*	1.9	**R**	10.5 (10.52)	**R**
485	IE 6321	Zimbabwe	*Elongata*	*Reclusa*	1.8	**R**	8.0 (8.01)	**R**
486	IE 6326	Zimbabwe	*Plana*	*Seriata*	1.6	**R**	5.5 (5.50)	**R**
487	IE 6332	Zimbabwe	*Vulgaris*	*Stellata*	1.9	**R**	4.5 (4.50)	**R**
488	IE 6337	Zimbabwe	*Vulgaris*	*Incurvata*	1.7	**R**	1.0 (1.00)	**HR**
489	IE 6350	Zimbabwe	*Vulgaris*	*Liliacea*	1.4	**R**	8.5 (8.51)	**R**
490	IE 6358	Zimbabwe	*Plana*	*Grandigluma*	2	**R**	5.5 (5.50)	**R**
491	IE 6362	Zimbabwe	*Plana*	*Confundere*	2	**R**	10.0 (10.02)	**R**
492	IE 6387	Zimbabwe	*Vulgaris*	*Incurvata*	1.9	**R**	2.0 (2.00)	**R**
493	IE 6396	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	9.0 (9.01)	**R**
494	IE 6417	Uganda	*Compacta*	*NA*	1.9	**R**	5.0 (5.00)	**R**
495	IE 6421	Uganda	*Vulgaris*	*Digitata*	2	**R**	9.5 (9.51)	**R**
496	IE 6440	Uganda	*Vulgaris*	*Incurvata*	2.3	**MR**	12.0 (12.03)	**MR**
497	IE 6443	Uganda	*Plana*	*Confundere*	2.3	**MR**	10.5 (10.52)	**R**
498	IE 6447	Uganda	*Vulgaris*	*Digitata*	1.9	**R**	10.5 (10.52)	**R**
499	IE 6472	Uganda	*Vulgaris*	*Incurvata*	1.9	**R**	7.0 (7.01)	**R**
500	IE 6473	Uganda	*Plana*	*Confundere*	1.1	**R**	1.5 (1.50)	**HR**
501	IE 6495	Uganda	*Vulgaris*	*Incurvata*	2.4	**MR**	12.0 (12.03)	**MR**
502	IE 6514	Zimbabwe	*Vulgaris*	*Incurvata*	1.8	**R**	11.0 (11.02)	**MR**
503	IE 6528	Zimbabwe	*Compacta*	*NA*	1.7	**R**	9.0 (9.01)	**R**
504	IE 6533	Nigeria	*Elongata*	*Sparsa*	1.7	**R**	12.0 (12.03)	**MR**

505	IE 6537	Nigeria	*Vulgaris*	*Incurvata*	1.8	**R**	0 (0)	**HR**
506	IE 6541	Nigeria	*Vulgaris*	*Incurvata*	1	**HR**	1.5 (1.50)	**HR**
507	IE 6546	Nigeria	*Elongata*	*Laxa*	1	**HR**	0.0 (0.00)	**HR**
508	IE 6549	Nigeria	*Vulgaris*	*Incurvata*	1	**HR**	5.5 (5.50)	**R**
509	IE 6555	Uganda	*Compacta*	*NA*	1.9	**R**	3.5 (3.50)	**R**
510	IE 6557	Uganda	*Compacta*	*NA*	2	**R**	7.0 (7.01)	**R**
511	IE 6567	Uganda	*Plana*	*Confundere*	1.8	**R**	5.5 (5.50)	**R**
512	IE 6575	Uganda	*Compacta*	*NA*	1.7	**R**	0.5 (0.50)	**HR**
513	IE 6576	Uganda	*Compacta*	*NA*	2	**R**	3.5 (3.50)	**R**
514	IE 6591	Uganda	*Vulgaris*	*Digitata*	1.5	**R**	8.0 (8.01)	**R**
515	IE 6592	Uganda	*Compacta*	*NA*	1.9	**R**	1.5 (1.50)	**HR**
516	IE 6599	Uganda	*Vulgaris*	*Incurvata*	2	**R**	10.5 (10.52)	**R**
517	IE 6611	Uganda	*Vulgaris*	*Incurvata*	2.4	**MR**	10.5 (10.52)	**R**
518	IE 6613	Uganda	*Vulgaris*	*Digitata*	2	**R**	1.0 (1.00)	**R**
519	IE 6635	Zimbabwe	*Vulgaris*	*Incurvata*	2.1	**MR**	11.5 (11.53)	**MR**
520	IE 6636	Zimbabwe	*Vulgaris*	*Incurvata*	1.7	**R**	6.5 (6.50)	**R**
521	IE 6638	Zimbabwe	*Plana*	*Confundere*	1.8	**R**	5.0 (5.00)	**R**
522	IE 6645	Zimbabwe	*Vulgaris*	*Stellata*	2.6	**MR**	17.5 (17.59)	**MR**
523	IE 6652	Zimbabwe	*Compacta*	*NA*	2.2	**MR**	4.5 (4.50)	**R**
524	IE 6655	Zimbabwe	*Plana*	*Confundere*	2	**R**	2.0 (2.00)	**R**
525	IE 6660	Zimbabwe	*Vulgaris*	*Digitata*	2	**R**	6.0 (6.00)	**R**
526	IE 6667	Zimbabwe	*Vulgaris*	*Digitata*	1.7	**R**	1.5 (1.50)	**HR**
527	IE 6679	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	6.5 (6.50)	**R**
528	IE 6692	Malawi	*Compacta*	*NA*	2	**R**	9.5 (9.51)	**R**
529	IE 6699	Tanzania	*Plana*	*Confundere*	2	**R**	12.5 (12.53)	**MR**
530	IE 6705	Zaire	*Plana*	*Confundere*	2	**R**	4.5 (4.50)	**R**
531	IE 6708	India	*Vulgaris*	*Stellata*	3.8	**S**	27.0 (27.34)	**S**
532	IE 6715	South Africa	*Elongata*	*Laxa*	2.4	**MR**	18.5 (18.61)	**MR**
533	IE 6726	Uganda	*Vulgaris*	*Digitata*	2.1	**MR**	1.0 (1.00)	**HR**
534	IE 6729	India	*Vulgaris*	*Digitata*	1.7	**R**	2.5 (2.50)	**R**
535	IE 6766	Unknown	*Vulgaris*	*Digitata*	1.6	**R**	6.0 (6.00)	**R**
536	IE 6786	Unknown	*Vulgaris*	*Digitata*	2.1	**MR**	5.0 (5.00)	**R**
537	IE 6788	Unknown	*Vulgaris*	*Digitata*	2	**R**	2.0 (2.00)	**R**
538	IE 6792	Zimbabwe	*Vulgaris*	*Incurvata*	2	**R**	8.5 (8.51)	**R**
539	IE 6793	Zimbabwe	*Vulgaris*	*Incurvata*	2.2	**MR**	7.0 (7.01)	**R**
540	IE 6796	Zimbabwe	*Vulgaris*	*Stellata*	2.1	**MR**	9.0 (9.01)	**R**
541	IE 6806	Zimbabwe	*Vulgaris*	*Incurvata*	2.1	**MR**	5.0 (5.00)	**R**
542	IE 6814	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	7.5 (7.51)	**R**
543	IE 6835	Zimbabwe	*Vulgaris*	*Digitata*	1.8	**R**	7.5 (7.51)	**R**
544	IE 6836	Zimbabwe	*Plana*	*Confundere*	1.9	**R**	7.0 (7.01)	**R**
545	IE 6846	Zimbabwe	*Vulgaris*	*Incurvata*	1.4	**R**	5.0 (5.00)	**R**
546	IE 6852	Zimbabwe	*Vulgaris*	*Incurvata*	1.8	**R**	5.0 (5.00)	**R**
547	IE 6855	Zimbabwe	*Vulgaris*	*Incurvata*	2	**R**	5.0 (5.00)	**R**
548	IE 6859	Zimbabwe	*Vulgaris*	*Digitata*	1.9	**R**	5.0 (5.00)	**R**
549	IE 6877	Zimbabwe	*Compacta*	*NA*	1.8	**R**	10.0 (10.02)	**R**
550	IE 6880	Zimbabwe	*Compacta*	*NA*	1.8	**R**	5.0 (5.00)	**R**
551	IE 6890	Zimbabwe	*Vulgaris*	*Incurvata*	1.6	**R**	7.5 (7.51)	**R**
552	IE 6917	Zimbabwe	*Vulgaris*	*Incurvata*	1.6	**R**	4.5 (4.50)	**R**
553	IE 6922	Zambia	*Vulgaris*	*Incurvata*	2.6	**MR**	18.5 (18.61)	**MR**
554	IE 6923	Zambia	*Compacta*	*NA*	2.3	**MR**	7.0 (7.01)	**R**
555	IE 6928	Unknown	*Plana*	*Confundere*	1.6	**R**	3.5 (3.50)	**R**

556	IE 6937	Unknown	*Vulgaris*	*Incurvata*	1.8	**R**	13.0 (13.04)	**MR**
557	IE 6941	Unknown	*Vulgaris*	*Digitata*	1.5	**R**	4.5 (4.50)	**R**
558	IE 6952	Zambia	*Compacta*	*NA*	2.1	**MR**	7.0 (7.01)	**R**
559	IE 6957	Unknown	*Compacta*	*NA*	1.3	**R**	2.5 (2.50)	**R**
560	IE 6964	Unknown	*Vulgaris*	*Incurvata*	1.4	**R**	7.0 (7.01)	**R**
561	IE 6974	Kenya	*Vulgaris*	*Digitata*	2	**R**	7.0 (7.01)	**R**
562	IE 6993	Kenya	*Plana*	*Confundere*	1.9	**R**	8.5 (8.51)	**R**
563	IE 6996	Kenya	*Vulgaris*	*Incurvata*	2.4	**MR**	7.5 (7.51)	**R**
564	IE 7018	Kenya	*Compacta*	*NA*	1.8	**R**	6.5 (6.50)	**R**
565	IE 7039	Kenya	*Plana*	*Confundere*	1.9	**R**	10.0 (10.02)	**R**
566	IE 7040	Kenya	*Vulgaris*	*Liliacea*	2.1	**MR**	11.0 (11.02)	**MR**
567	IE 7072	Kenya	*Plana*	*Confundere*	1.8	**R**	3.0 (3.00)	**R**
568	IE 7079	Kenya	*Vulgaris*	*Liliacea*	1.4	**R**	5.5 (5.50)	**R**
569	IE 7081	Kenya	*Vulgaris*	*Incurvata*	2.3	**MR**	20.5 (20.65)	**MR**
570	IE 7092	Kenya	*Plana*	*Confundere*	1.7	**R**	4.5 (4.50)	**R**
571	IE 7120	Kenya	*Vulgaris*	*Digitata*	1.5	**R**	4.5 (4.50)	**R**
572	IE 7123	Unknown	*Plana*	*Confundere*	1.9	**R**	3.0 (3.00)	**R**
573	IE 7126	Unknown	*Compacta*	*NA*	1.5	**R**	5.0 (5.00)	**R**
574	IE 7128	Unknown	*Compacta*	*NA*	1.3	**R**	2.5 (2.50)	**R**
575	IE 7139	Kenya	*Vulgaris*	*Liliacea*	1.7	**R**	3.0 (3.00)	**R**
576	IE 7157	Kenya	*Plana*	*Confundere*	1.9	**R**	2.5 (2.50)	**R**
577	IE 7163	Kenya	*Vulgaris*	*Digitata*	3.4	**S**	20.5 (20.65)	**MR**
578	IE 7179	Kenya	*Plana*	*Confundere*	1.5	**R**	1.0 (1.00)	**HR**
579	IE 7189	Kenya	*Plana*	*Seriata*	1.5	**R**	7.0 (7.01)	**R**
580	IE 7190	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	9.0 (9.01)	**R**
581	IE 7199	Kenya	*Vulgaris*	*Digitata*	1.5	**R**	8.0 (8.01)	**R**
582	IE 7217	Kenya	*Vulgaris*	*Digitata*	2	**R**	5.0 (5.00)	**R**
583	IE 7223	Kenya	*Plana*	*Seriata*	1.9	**R**	6.5 (6.50)	**R**
584	IE 7240	Kenya	*Vulgaris*	*Digitata*	2.6	**MR**	17.5 (17.59)	**MR**
585	IE 7244	Kenya	*Vulgaris*	*Digitata*	1.5	**R**	4.5 (4.50)	**R**
586	IE 7249	Kenya	*Plana*	*Confundere*	1.8	**R**	4.2 (4.20)	**R**
587	IE 7254	Kenya	*Compacta*	*NA*	1.9	**R**	5.0 (5.00)	**R**
588	IE 7258	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	3.5 (3.50)	**R**
589	IE 7270	Kenya	*Plana*	*Confundere*	1.6	**R**	2.5 (2.50)	**R**
590	IE 7271	Kenya	*Plana*	*Confundere*	2	**R**	5.0 (5.00)	**R**
591	IE 7272	Kenya	*Vulgaris*	*Digitata*	1.7	**R**	6.5 (6.50)	**R**
592	IE 7273	Kenya	*Plana*	*Confundere*	2.2	**MR**	17.0 (17.08)	**MR**
593	IE 7280	Kenya	*Vulgaris*	*Incurvata*	2.5	**MR**	14.5 (14.55)	**MR**
594	IE 7293	Kenya	*Compacta*	*NA*	1.6	**R**	0.0 (0.00)	**HR**
595	IE 7304	Kenya	*Vulgaris*	*Digitata*	1.9	**R**	3.0 (3.00)	**R**
596	IE 7320	Kenya	*Vulgaris*	*Digitata*	1.2	**R**	4.0 (4.00)	**R**
597	IE 7321	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	4.5 (4.50)	**R**
598	IE 7338	Kenya	*Plana*	*Confundere*	1.8	**R**	1.0 (1.00)	**HR**
599	IE 7346	Kenya	*Vulgaris*	*Digitata*	2	**R**	13.0 (13.04)	**MR**
600	IE 7366	Kenya	*Compacta*	*NA*	2.4	**MR**	11.0 (11.02)	**MR**
601	IE 7374	Kenya	*Plana*	*Confundere*	2.3	**MR**	17.5 (17.59)	**MR**
602	IE 7380	Kenya	*Vulgaris*	*Digitata*	1.7	**R**	3.5 (3.50)	**R**
603	IE 7386	Kenya	*Plana*	*Confundere*	2	**R**	7.0 (7.01)	**R**
604	IE 7390	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	5.0 (5.00)	**R**
605	IE 7404	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	6.0 (6.00)	**R**
606	IE 7407	Kenya	*Vulgaris*	*Incurvata*	2.1	**MR**	8.0 (8.01)	**R**

607	IE 7425	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	5.5 (5.50)	**R**
608	IE 7435	Kenya	*Vulgaris*	*Stellata*	1.9	**R**	3.5 (3.50)	**R**
609	IE 7463	Kenya	*Vulgaris*	*Incurvata*	1.9	**R**	5.5 (5.50)	**R**
610	IE 7470	Kenya	*Vulgaris*	*Digitata*	1.8	**R**	5.0 (5.00)	**R**
611	IE 7482	Kenya	*Vulgaris*	*Incurvata*	1.3	**R**	1.5 (1.50)	**HR**
612	IE 7488	Kenya	*Compacta*	*NA*	2.3	**MR**	9.5 (9.51)	**R**
613	IE 7500	Kenya	*Vulgaris*	*Digitata*	2.2	**MR**	5.0 (5.00)	**R**
614	IE 7504	Kenya	*Vulgaris*	*Digitata*	1.6	**R**	5.5 (5.50)	**R**
615	IE 7505	Kenya	*Vulgaris*	*Incurvata*	1.8	**R**	2.0 (2.00)	**R**
616	IE 7508	Ethiopia	*Vulgaris*	*Incurvata*	3	**S**	22.5 (22.69)	**S**
617	IE 7537	Nepal	*Vulgaris*	*Incurvata*	1.3	**R**	5.0 (5.00)	**R**
618	IE 7539	Unknown	*Elongata*	*Sparsa*	1.8	**R**	11.0 (11.02)	**MR**
619	IE 7549	Nepal	*Vulgaris*	*Stellata*	1.8	**R**	15.0 (15.06)	**MR**
620	IE 7556	Nepal	*Vulgaris*	*Digitata*	1.6	**R**	4.5 (4.50)	**R**
621	IE 7558	Unknown	*Vulgaris*	*Incurvata*	1.5	**R**	8.5 (8.51)	**R**
622	IE 7561	Nepal	*Vulgaris*	*Incurvata*	1.6	**R**	4.0 (4.00)	**R**
623	PR 202 Check	India	-	-	1.7	**R**	8.5 (8.51)	**R**
624	RAU 8 Check	India	-	-	1.9	**R**	10.5 (10.52)	**R**
625	VL 149 Check	India	-	-	4.7	**HS**	30.7 (31.15)	**HS**
626	VR 708 Check	India	-	-	4.9	**HS**	30.1 (31)	**HS**
				Mean	2.04	-	9.03	-
				SE (m) ±	0.31	-	4.18	-
				LSD (P<0.05)	0.88	-	11.63	-

*Data not available;

[1]Neck blast severity on a 1 – 5 scale where 1= no infection and 5= >6 cm lesions on the neck region.

[2]Finger blast severity (%) across all panicles/all tillers in a row.

HR: Highly Resistant; R: Resistant; MR: Moderately Resistant; S: Susceptible; HS: Highly Susceptible

Neck Blast reaction based on severity (1 –5 scale): 0-1.0: HR; 1.1-2.0: R; 2.1-3.0; MR; 3.1-4.0: S; 4.1-5.0: HS;

Finger blast reaction based on severity (%): 0-1.0: HR; 2.0-10: R; 11-20: MR; 21-30: S; >30: HS