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# Development of a charcoal rot rating index for multilocation trials of sorghum

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ABSTRACT

Comparing the performance of sorghum genotypes for charcoal rot resistance in a multilocation trial becomes difficult due to non-uniform disease reactions over locations obtained by applying mean number of nodes cross (MNC) scale. This study analyzed the relationship between disease incidence and severity and developed a disease rating index for use in the multilocation trial. The incidence-severity relationship for the disease was studied based on multilocation and multiyear data sets obtained from the all India coordinated research programme on sorghum. The incidence, severity and relationship between them varied depending on the crop growing environments (year, locations) suggesting that it would be inappropriate to consider incidence in place of severity and *vice versa* for the measurement of the disease. The reasons for the inconsistent I-S relationship were attributed to the environmental and pathogenic variations across the locations and years. Five charcoal rot rating indices (CRI 1 to CRI 5) were developed combining incidence and severity in different proportions to average out these effects. Suitability of the indices for comparing the performance of sorghum genotypes in the multilocation trials was tested using genotype + genotype-environment (GGE) biplot analysis. CRI 2 that combined incidence and severity in the 40:60 proportions was found to be the most stable index in terms of performance across the locations. CRI 2 rated the charcoal rot reactions of the sorghum genotypes with greater accuracy and reliability ($R^2 = 0.341$, $p = 0.001$) compared to the existing MNC scale ($R^2 = 0.001$, $p = 0.965$) in replicated field trials. The index (CRI 2) will help identify disease reactions among sorghum genotypes with greater consistency in multilocation trials.

## 1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important crops in the semi-arid tropics cultivated on an area of approximately 42.3 million ha. India has the largest acreage of sorghum (6.2 million ha) in Asia (Das and Padmaja, 2016). Charcoal rot (CR) caused by *Macrophomina phaseolina* (Tassi) Goid. is a disease of sorghum of worldwide importance (ICRISAT, 1984; Das and Padmaja, 2016). The grain yield losses due to CR vary from 23 to 64% under conditions favorable for the disease (Mughogho and Pande, 1984). The infection of sorghum roots by the CR pathogen is favored by high soil moisture stress and high temperature. The disease is commonly observed when the crop is subjected to post-flowering moisture stress, which often occurs during the cultivation of post-rainy sorghum in India. The largest area under post-rainy sorghum in India is in the states of Maharashtra and Karnataka with a smaller area in Telangana.

Multilocation trials are part of the all India coordinated research programme on sorghum (AICRP-S). In this programme many improved genotypes are evaluated every year in multiple locations for agronomic traits as well as pest and disease resistance before their release for cultivation. The test locations of such trial represent climatic and geographical diversity. The major post-rainy test locations in India include Solapur and Parbhani in Maharashtra and Dharwad and Bijapur in Karnataka. Recently Rakshit et al. (2012b) described four mega-environments among post-rainy testing locations in India. Comparison of data from multilocation trials for different traits is important for release

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of a variety for cultivation in different geographic regions. For the CR resistance trait the genotypes are tested at the above four locations.

Performance of genotypes for CR resistance in multiple locations is compared based on data from multilocation trials. The mean number of nodes crossed (MNC) by the CR lesion is recorded on a 1–5 scale (1 = first internode invaded, but rot does not extend to the second internode, 2 = second internode invaded, 3 = third internode invaded, 4 = fourth internode invaded and 5 = more than four internodes invaded, with shredding of the stalk and death of the plant) (Rosenow, 1984). CR reaction is determined as highly resistant (HR) (MNC ≤ 1), resistant (R) (MNC = 1.1–2.0), moderately resistant (MR) (MNC = 2.1–3.0), susceptible (S) (MNC = 3.1–4.0) and highly susceptible (HS) (MNC > 4.0). However, inconsistent CR reaction of a test genotype across location is quite a common observation (AICSIP, 2010). This makes it questionable to compare the performance of sorghum genotypes for CR resistance among locations. Such variations may occur due to difference in environmental factors or pathogenic status (Das et al., 2008a) among the locations. The environmental factors like the soil moisture and the temperature play crucial role in CR development. The scale for determining CR reaction of a genotype also plays an important role. The MNC scale, which is solely based on disease severity, is reliable for comparing CR reactions of genotypes in a single environment. For comparing CR reactions of genotypes across environments an index combining incidence and severity may be more reliable. Groth et al. (1999) while working on wheat scab observed that the disease index measure, which was the product of incidence and severity, was more repeatable than either of the components and suggested that it was due to averaging effects of the environment in the product. An index generally gives greater repeatability over locations.

Before combining incidence and severity for developing a CR rating index it is essential to study the interrelationship between these measurements. The incidence-severity (I-S) relationship for soil-borne diseases was explained as early as 1934 by Godfrey, who calculated the correlation for the percentage of plants infested with nematodes and the number of root knot galls per plant. There have been many studies of the I-S relationship mostly for polycyclic diseases including rust (Eversmeyer et al., 1973), gummosis (Cardoso et al., 2004) and for some monocyclic diseases including root knot nematodes (Godfrey, 1934) wilt (Harris, and Yang, 1996; Xiao and Subbarao, 1998) and charcoal rot (Taliei et al., 2012). For soil borne disease like CR, incidence is important as the pathogen tend to accumulate in the soil. There is no study that has critically analyzed the relationship among measurements of CR based on data sets. Such study will help to understand whether CR incidence, which is easy to measure, can be used in place of CR severity. AICRP-S has long-term data sets on CR available at the ICAR-Indian Institute of Millets Research (ICAR-IIMR) Hyderabad, which can be accessed and analyzed for I-S relationship studies. This study was undertaken to analyze the relationship between CR incidence and severity using long-term multilocation trial data from AICRP-S, and to develop a suitable rating index for assessment of CR resistance of sorghum genotypes in the multilocation trial.

## 2. Materials and methods

### 2.1. Sources of multilocation data

Location-wise genotypic means for three measurements of CR *viz.*, CR percentage or incidence (CRP), mean length of spread of lesion (MLS) and MNC from three multilocation trials at four locations (Bijapur, Dharwad, Parbhani and Solapur) in India (Table 1) were obtained for the period 2006 to 2015 from the annual data books of AICRP-S (Table 2). The trials were the advanced varietal and hybrid trial-I (AVHT-I), the advanced varietal and hybrid trial-II (AVHT-II), and the initial varietal and hybrid trial (IVHT). In any particular year all the trials were simultaneously conducted at all the locations with the same set of genotype (number and name). However, the number of genotype varied in different years. Occasionally data were not available due to the trial not being sown at a particular location and year, or non-reporting of data from the location. In the field trials each genotype was grown in a plot of 2 rows of 4 m length with 45 cm between rows and 12 cm between plants, and replicated thrice in a randomized block design. Same experimental plots were used in these locations year after year for the multilocation CR trials. CR infected sorghum stalks were chopped, spread over and buried into the soil each year. This practice helped in maintaining soil-borne inoculums of CR in the experimental plots.

**Table 1**
Information on the location of charcoal rot evaluation.

| Location | Latitude and Longitude | Annual rainfall (mm) | Altitude (m, above sea level) | Depth of soil in the experimental plots |
|---|---|---|---|---|
| Bijapur | 16° 49′ N; 75° 42′ E | 594 | 611 | Shallow (≤45 cm) |
| Dharwad | 15° 27′ N; 75° 00′ E | 776 | 730 | Medium (46–75 cm) |
| Parbhani | 19° 15′ N; 76° 46′ E | 957 | 421 | Medium (46–75 cm) |
| Solapur | 17° 39′ N; 75° 54′ E | 695 | 474 | Shallow (≤45 cm) |

**Table 2**
Data collection scheme for studies on the incidence-severity relationships and disease rating index for charcoal rot of sorghum.

| Year | Trial name | Number of genotypes tested[a] | Locations |
|---|---|---|---|
| 2006 | AVHT-I | 16 | BIJ, DHR, PAR |
| | AVHT-II | 18 | BIJ, DHR |
| | IVHT | 23 | BIJ, DHR, PAR |
| 2007 | AVHT-I | 20 | BIJ, DHR |
| | AVHT-II | 13 | BIJ, DHR |
| | IVHT | 23 | BIJ, DHR |
| 2008 | AVHT-I | 20 | BIJ, DHR, SOL |
| | AVHT-II | 18 | BIJ, DHR, SOL |
| | IVHT | 29 | BIJ, DHR, SOL |
| 2009 | AVHT-I | 30 | DHR, SOL |
| | AVHT-II | 18 | DHR, SOL |
| | IVHT | 35 | DHR, SOL |
| 2010 | AVHT-I | 24 | BIJ, DHR, PAR, SOL |
| | AVHT-II | 28 | BIJ, DHR, PAR, SOL |
| | IVHT | 16 | BIJ, DHR, PAR, SOL |
| 2011 | AVHT-I | 24 | BIJ, DHR, PAR, SOL |
| | AVHT-II | 26 | BIJ, DHR, PAR, SOL |
| | IVHT | 16 | BIJ, DHR, PAR, SOL |
| 2012 | AVHT-I | 23 | DHR, PAR, SOL |
| | AVHT-II | 12 | DHR, PAR, SOL |
| | IVHT | 17 | DHR, PAR, SOL |
| 2013 | AVHT-I | 21 | BIJ, DHR, PAR |
| | AVHT-II | 19 | BIJ, DHR, PAR |
| | IVHT | 13 | BIJ, DHR, PAR |
| 2014 | AVHT-I | 27 | BIJ, DHR, PAR |
| | AVHT-II | 16 | BIJ, PAR |
| | IVHT | 18 | BIJ, PAR |
| 2015 | AVHT-I | 18 | BIJ, DHR, PAR, SOL |
| | AVHT-II | 27 | BIJ, PAR, SOL |
| | IVHT | 9 | BIJ, DHR, PAR |

[a] Indicate number of entries simultaneously tested for each trial at each locations with 3 replications (plot size: 2 rows of 4 m length with 60 cm row to row and 10–12 cm plant to plant spacing). AVHT-I and II = Advanced Varietal and Hybrid Trial-I and II; IVHT = Initial Varietal and Hybrid Trial; Locations: BIJ = Bijapur, DHR = Dharwad, PAR = Parbhani, SOL = Solapur.

### 2.2. The I-S relationship

Linear correlation coefficients between CRP and MNC and between CRP and MLS were calculated for each trial (total three trials per location) in each location (total four locations per trial) and year (total 10