Assessment of Grain Yield Losses Caused by Rice Blast Disease in Major Rice Growing Areas in Tanzania

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Abstract: ***Pyricularia oryzae Cavara, [(synonym P. grisea Sacc (teleomorph: Magnaporthe grisea (Hebert) Barr)] causal agent of rice blast disease, is a major problem facing rice growers worldwide. In Tanzania, rice blast is considered as the most serious disease, resulting in severe yield losses especially, when susceptible rice varieties are grown. In order to assess yield losses caused by P. oryzae, studies were conducted in the screen-house using ten rice varieties viz; Jaribu 220, Supa, Kalamata, Shingo ya Mwali, Mwarabu, Mbawambili, Kihogo, IR 64, TXD 306 and TXD 85. Results showed that rice blast disease affected rice plants at all stages of growth and resulted in reduction in number of tillers per plant, grain weight, number of seeds per panicle and grain yield. Most of the rice varieties were susceptible to P. oryzae at seedling, early tillering and heading stages (reproductive stages). During the early growth stages symptoms were mainly found on leaves. Leaf blast disease severity reached maximum at tillering stage, then the disease symptoms disappeared gradually. Leaf blast development progressed significantly differently (P<0.05) between rice varieties. The varieties Mwarabu and Jaribu 220 were the most susceptible at 45 and 55 days after inoculation (DAI). The area under disease progress curve (AUDPC) increased with leaf age. The relationship between rice blast disease severity and grain yield loss indicated that each increase in the disease severity resulted in a simultaneous reduction in grain yield. Both leaf and panicle rice blast disease severities were positive and highly significantly correlated with grain yield losses (r = 0.96, P < 0.001 and r = 0.91, P < 0.001, respectively). The number of tillers and seeds per panicle were negatively correlated with disease severity and grain yield weight (r = -0.912 and -0.958 respectively). The varieties Jaribu 220, Mbawambili, Kalamata and Supa were susceptible to blast disease. Tiller loss/hill and seed loss/panicle due to rice blast disease ranged from 20 to 78.19 % and 7.97 to 64.48 %, respectively, and grain yield losses of between 11.9 to 37.8 % per hectare were recorded for such rice varieties.***

Keywords: AUDPC, *Pyricularia oryzae*, rice blast disease, yield losses

1. Introduction

Rice blast disease is one of the most devastating diseases that can cause high grain yield losses in farmers' fields [1], [21], [26]. It is a fungal disease caused by *Pyricularia oryzae* which belongs to the class Ascomyceta and the genus *Magnaporthe* [11]. The asexual state is called *Magnaporthe oryzae* [8], [31], [11]. The disease occurs worldwide where rice is grown, but its occurrence and severity vary yearly, based on location and environmental conditions [10]. The disease infects all parts of the rice plant except roots, but leaves and panicles are the most seriously affected parts [34]. Leaf blast lesions reduce the net photosynthetic rate of individual leaves [22]. Neck blast is considered the most destructive phase of the disease and can occur without being preceded by severe leaf blast [47]. The necrotic lesions on mature rice plants particularly in the panicle can cause major yield losses [11]. Several studies have reported that leaf, panicle and neck blast disease incidences caused similar yield losses. In Japan the yield losses of 20 to 100 % were reported by [20] and [34]. In Brazil, yield losses as high as 100 % [36] have been reported in upland rice varieties. In India, losses of 5 – 10 %, were recorded [32], while 8 % yield losses in Korea and 14 % losses in China and 50 to 85 % in the Philippines have been reported [42]. Previous work [13] reported grain yield losses of 38.21 to 64.57 % due to neck blast in Vietnam on susceptible rice varieties..

About 5-70 % grain yield losses were reported in Kashmir depending upon the stage of the crop infected and severity of the disease [3]. Inoculation reduced grain yield from 22 to 26 % in Italy [22]. Grain yield losses of 25.21 to 45.52 % were recorded in Rajasthan [25]. In Iran, low yield losses of 0.99 - 1.22 % have been reported [27]. Other studies in Iran reported yield reduction of 10-20 % in susceptible rice varieties, but in severe cases the yield loss caused by rice blast may reach up to 80 % [33]. Panicle blast disease severity affects grain filling [5]. Infected panicles caused 20 to 100 % yield losses in Japan [34] and 100 % in Brazil [37]. Yield losses due to blast disease have a direct impact on the welfare of farm households as well as on the national economy.

The symptoms of rice blast disease on leaves, nodes and panicles may vary according to the environmental conditions, the age of the plant and the level of resistance of the host genotypes [9]. Climatic conditions affect greatly the disease establishment, development and severity, resulting in large genotype-by-environment interactions. The yield variability among both different rice varieties and rice growing areas, explain the effects of climate and crop management on rice yields. However, yield constraints are related to disease incidence and severity in relation to crop management and environmental conditions [28]. Earlier studies [27] demonstrated that rice blast disease incidence and severity during the reproductive stage (75 days after seeding) was most closely related to yield losses with an infected area of 1 % corresponding to 3 % yield loss. However, these studies reported also that most of the resistant rice varieties were severely diseased, although the level of disease was lower than that of susceptible varieties [4]. In Tanzania, information on rice grain yield losses in relation to rice blast disease level is limited. Therefore, the objective of this study was to investigate the effect of rice blast disease on grain yield in major rice growing areas of Tanzania.

2. Materials and Methods

Ten rice varieties preferred by farmers in Tanzania (Kalamata, Mbawambili, Supa, TXD 306, TXD 85, Kihogo, Mwarabu, IR64, Shingo ya Mwali and Jaribu 220) were evaluated to determine the effect of rice blast disease on yield losses. The experiment was conducted in the screen-house at the Chinese Agricultural Technology Demonstration Centre in Dakawa, Mvomero district, Morogoro region. The seeds of each variety were sown in one square meter plot (experimental unit) at a spacing of 20 cm x 20 cm arranged in a completely randomized design, with three replications. Each replication consisted of a plot with five rows and each plot contained 25 seeds of each variety. The plots were flooded with water and such conditions were maintained until the grains reached physiological maturity. The non-inoculated plots were sprayed with Tricyclazole fungicide to prevent occurrence of rice blast disease.

2.1 Inoculum Preparation and Inoculation

Pyricularia oryzae was cultured in Petri dishes on oatmeal agar, incubated at 25 ± 1 °C to induce sporulation [40]. After sporulation, spore suspension at a concentration of about 10^4 spores/ml was prepared in sterilized distilled water with 0.1 % Tween 20 to increase spore dispersion [37]. The conidial concentration of 2 x 10^5 spores/ml was prepared [29]. Spore counts were done using a haemocytometer. When the plants reached the 4-5 leaf stage (21 days after seeding), they were inoculated with *P. oryzae* following the procedures described in literature [46]. Inoculation was done in the evening using a low-pressure spray bottle on each individual rice plant. All agronomic practices including fertilizer (UREA 120 kgN/ha) were applied as recommended.

2.2 Disease Assessment

Rice blast disease evaluation was conducted throughout the growing season, starting with observation of the first disease symptoms after inoculation. Observation of blast disease symptoms was done at 14 days after inoculation based on blast disease assessment given by the standard evaluation system [17], using a 0 to 9 scale where; 0 = no lesions; 1 = small, brown, specks of pinhead size; 3 = small, roundish to slightly elongated, necrotic, gray spots about 1-2 mm in diameter; 5 = typical blast lesions infecting < 10 % of the leaf area; 7 = typical blast lesions infecting 26-50 % of the leaf area; 9 = typical blast lesions infecting >51 % leaf area and many dead leaves.

Rice blast disease severity was then calculated using the following formula [14]:

$$\text{Disease severity} = \frac{\sum n \times v \times 100\%}{N \times V} \qquad (1)$$

where, n = number of leaves infected by blast, v = value score of each category attack, N = number of leaves observed and V = value of the highest score.

Rice blast disease development on plants was observed six times at 15, 25, 35, 45, 55, and 65 days after inoculation (DAI). Diseased leaf area was calculated by multiplying the length and width of lesion.

The area under disease progress curve (AUDPC) was calculated from single ratings as described in literature [43], [33] and [26] with modification as follows;

$$\text{AUDPC} = \sum [(0.5)(Y_{i+1} + Yi)(T_{i+1} + Ti)] \qquad (2)$$

Where, Y = disease severity at time i and T = time (days) of the assessment.

The percentages of panicle blast disease severity (PBS) were obtained by rating individual panicles using the formula described by [18] and [33] with modifications as shown below;

$$\text{PBS} = (A/B) \times 100 \qquad (3)$$

Where, A = the number of infected panicles, and B = the number of panicles observed for each variety per plot. Based on both the leaf and panicle severities, rice varieties were classified as resistant (R) with 0-15 %; moderately resistant (MR) with 15.1-30 %; moderately susceptible (MS) with 30.1-50 %; or susceptible (S) with 50.1-100 % disease severities [38].

At physiological maturity, three middle rows of each plot were harvested and kept separately. The panicles of each variety were threshed manually and grain weight was recorded. Rice grain yield was determined at 13 % grain moisture content [27]. Percent grain yield losses caused by rice blast disease for each variety were also determined using the formula described by [27].

$$\text{Yield loss} = \frac{\text{Yield of non-inoculated} - \text{Yield of inoculated}}{\text{Yield of non-inoculated}} \times 100 \qquad (4)$$

Weather data for the months of March to July 2013 were collected from the Meteorological station at Dakawa and from Tanzania Meteorological Agency websites. Before analysis data were transformed using arcsine transformation formula [27] as shown:

$$Y = \text{Arcsin}\sqrt{p} \qquad (5)$$

Where, Y is transformed data, p is the observed proportion

2.3 Data Analysis

Data were analysed using GENSTAT computer statistical package for ANOVA to determine significant differences between ten rice varieties. Comparison between means was done using Duncan's Multiple Range Test (DMRT). A regression analysis was done to find out the correlation between the disease levels and percent loss in yield. Charts/graphs were drawn using the Microsoft Excel program [4].

3. Results and Discussion

Rice blast disease symptoms on leaves, neck and panicles are shown in Figure 1. Depending upon the genetic makeup, each of ten rice varieties reacted differently to rice blast disease. Rice blast disease symptoms were observed on leaves of all rice varieties between 14 and 20 days after inoculation. The symptoms began on the lower leaves 15 days after inoculation and progressed to the upper leaves. After heading, *P. oryzae* infected the panicles. Panicle blast caused direct yield losses, since filling of the grain on infected panicles was poor (Table 1). Leaf lesions began as small whitish, grayish spots and enlarged progressively. The shape, colour and size of the leaf lesions varied with plant age.

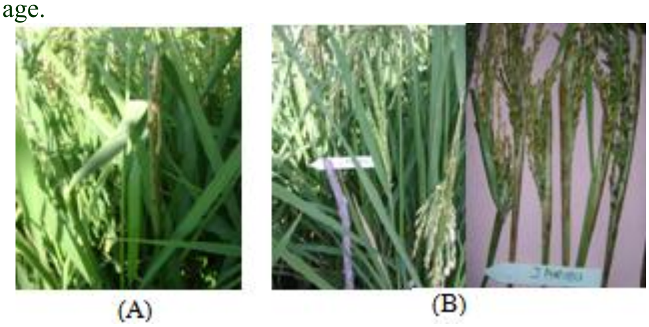

Figure 1: Rice blast disease symptoms on leaves (A) and panicles (B) (photos: C. J. Chuwa, Dakawa, Morogoro)

Generally, most of the rice varieties tested were susceptible to *P. oryzae* in the seedling, early tillering and heading stages of the crop. It was noted that, the symptoms of rice blast disease on leaves were observed in the early growth stages of the rice crop. This is because rice plants are more susceptible to blast disease at young than at mature stages of development [2]. The trend of rice blast disease development revealed that when the plants were at maximum tillering, the disease symptoms on the leaves tended to disappear gradually. Such a situation had been reported to be attributed to adult plant resistance [2].

4.1 Leaf blast disease progress in rice varieties grown at Dakawa, Morogoro

Leaf blast disease progress curves for ten rice varieties under screen-house conditions are shown in Figure 2. Leaf blast disease development progressed differently on different rice varieties. However for all varieties, the disease started at a low severity level, gradually increasing in severity over time.

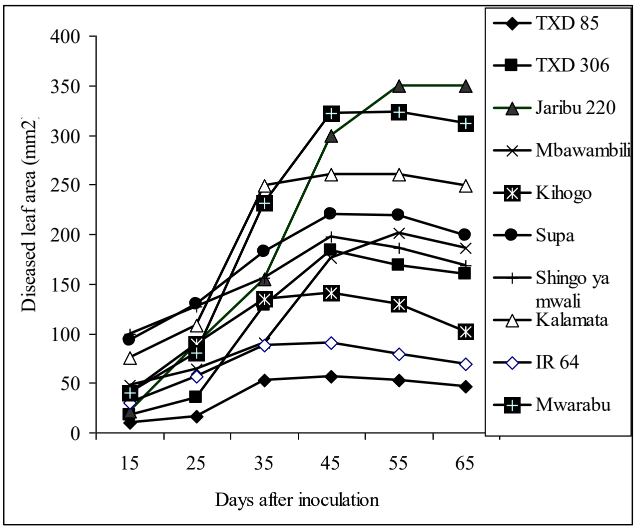

Figure 2: Leaf blast disease progress curves for ten rice varieties grown by farmers in Tanzania.

The lowest and the highest diseased leaf area could have been caused by genetic diversity of the varieties, age of the plant and weather conditions. This means that high relative humidity, rainfall but moderate temperatures, were associated with high rice blast disease severities for Jaribu 220 and Mwarabu (Table 2). Similar results regarding the influence epidemiological factors on rice blast development have been reported [6], [30]. Average rainfall of 42.4 mm has been noted to influence the development of rice blast disease severity on both leaves and panicles (Table 2). Such findings have also been reported by other workers [22], [42].

The results revealed that as the rice plants approached maturity, they gained resistance to rice blast disease [30]. These findings are also supported by the other previous studies [4] on the assessment of blast disease and yield losses in susceptible and partially resistant rice cultivars in two irrigated lowland environments. The results indicated that rice blast disease progressed and reached maximum at 45 and 55 DAI and then gradually declined. This decline in disease was attributed to adult disease resistance, leaf senescence and formation of new leaves. In quantitative resistance, where differences in the level of resistance are usually less distinct, measuring disease progress is important for understanding plant–pathogen interaction [45].

4.2 Effect of rice blast disease on grain formation

The area under disease progress curve (AUDPC) in screen-house conditions was significantly ($P \leq 0.05$) different between the ten rice varieties tested (Table 1). The highest AUDPC values were obtained from Jaribu 220 (889.0) followed by Mwarabu (652.5), Kalamata (590.2) and Shingo ya mwali (564.4). On the other hand, the lowest AUDPC values were recorded from TXD 85 (184.5) and IR 64 (179.1) followed by TXD 306 (276.1), Kihogo (391.1) and Mbawambili (456.6). However, TXD85 and IR64 had similar trends of rice blast disease progress (Table 1). Early occurrence of rice blast disease at young stage of rice plant growth has been reported to cause high damage on the leaves and finally disturb all physiological processes in the plant [16], [27]. The level of rice blast disease severity increased with age of rice plants during the season. The highest AUDPC values on Jaribu 220, Mwarabu, and Kalamata rice varieties showed that these varieties have high levels of susceptibility to leaf blast (Table 3). The lowest AUDPC values on TXD 85 and IR 64 showed that these varieties had high significant levels of resistance to rice blast disease (Table 3). Similar results have been reported by other workers [41], [33]. Therefore, rice varieties TXD 85 and IR 64 can be used as donor parents for breeding moderate resistant rice varieties to blast disease in Tanzania. The AUDPC is considered as the best parameter to declare a variety resistant or susceptible [24]. It provides more precise and practical classification of resistant and susceptible varieties than that based on the percentage disease score of each variety [19], [23].

Table 1: The percentage of unfilled grains on different rice varieties inoculated by rice blast disease in the screen-house at Dakawa, Morogoro, Tanzania

Variety	AUDPC	Unfilled grains Inoculated (%)	Unfilled grains Non-inoculated (%)
1. Mbawambili	456.60abc	52.67bc	8.67a
2. TXD 306	276.10ab	14.00a	6.33a
3. Kihogo	391.10abc	25.67ab	13.33a
4. TXD 85	184.50a	19.67a	8.67a
5. Jaribu220	889.00d	74.33c	10.00a
6. Supa	496.70bc	26.33ab	12.33a
7. Kalamata	590.20c	41.00ab	12.67a
8. Shingo ya mwali	564.40c	12.33a	12.00a
9. IR 64	179.10a	18.67a	8.00a
10. Mwarabu	652.50cd	13.00a	5.67a
CV %	**32.4**	**56.5**	**51.0**

Means in the same column followed by the same letter are not significantly different by Duncan's Multiple Range Test at P < 0.05. CV% = Percent of coefficient of variation.

The percentages of unfilled rice grains significantly differed (P≤ 0.05) between varieties (Table 1). Inoculated plants had higher percentages of unfilled grains than non-inoculated plants. The average of unfilled rice grains on Jaribu 220 was significantly higher (74.33 %), followed by Mbawambili (52.67 %). The lowest percentages of unfilled rice grains were on TXD 306 (14 %), TXD 85 (19.67 %), Shingo ya Mwali (12.33 %), IR 64 (18.67 %) and Mwarabu (13 %), followed by Kihogo (25.67 %), Supa (26.33 %) and Kalamata (41 %) rice varieties. Results revealed that the highest AUDPC corresponded with high percentage of unfilled grain. Similar findings were reported earlier [7], [33].

4.3 Regression and correlations between leaf and panicle blast parameters and grain yield losses in rice

In Figure 3, the coefficient of determination (R^2) for both leaf and panicle blast disease were highly significant (R^2 = 0.930, P < 0.001 and R^2 = 0.837, P < 0.001, respectively). These results indicate that 93 % of grain yield losses per ha was due to leaf blast disease severity and 83.7 % of grain yield losses was caused by panicle severity. The significance of the linear regression implies that some portion of the variability (93 % and 83.7 %) in grain yield losses were indeed explained by the linear function of leaf and panicle rice blast disease severities, respectively.

However, both leaf and panicle blast disease severities were highly significantly correlated with grain yield losses (r = 0.963, P < 0.001 and r = 0.915, P < 0.001, respectively) in inoculated rice varieties (Figure 3).

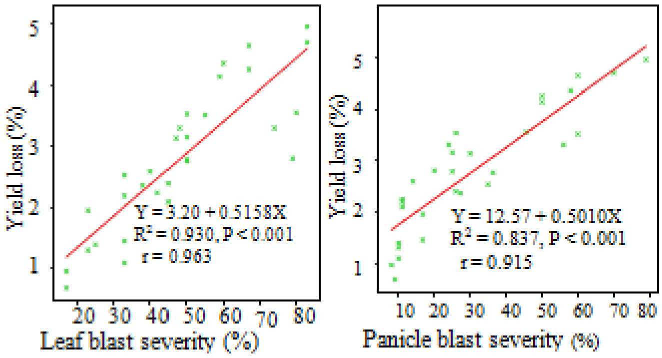

Figure 3: Relationship between a) leaf blast disease severity and grain yield loss, and b) panicle blast disease severity and grain yield loss in selected rice varieties grown in Tanzania, and 2 years experimentation (n = 30).

These results indicate that leaf and panicle blast disease severities were directly related to grain yield losses. The findings that an increase in leaf or panicle blast disease severity corresponded to an increase in grain yield losses have also been reported [44].

Based on linear regression equations related to leaf (Y = 3.20 + 0.5158X) and panicle (Y = 12.57 + 0.5010X) blast disease severities, it can be estimated that each unit increase of leaf blast severity corresponded to an increased grain yield loss of 0.5158 % per ha (Figure 4). The corresponding reduction in grain yield for each unit increase of panicle blast was 0.501 % yield loss. These models show that differences in yield losses between rice varieties were due to both leaf and panicle blast disease development. The regression model obtained can be used to estimate rice grain yield losses due to blast disease. These findings are in agreement with the previous findings [4], [27] that the regression model with high coefficient of determination is useful for forecasting yield losses.

In this study, weather factors including temperature, rainfall and relative humidity (RH) have played an important role on the development of rice blast disease severity. The different levels of rice blast disease severity on rice varieties were most likely due to the corresponding differences in the weather parameters recorded during the growing period and genetic diversity of the varieties studied. The average minimum (18. 9 °C) and maximum (30 °C), temperature and RH of 74.1 % (Table 2) were important epidemiological factors to rice blast disease development.

However, the high severity level of rice blast disease was due to the environmental conditions being favourable for the development of *Pyricularia oryzae*. Similar findings have been reported by [42] when they were studying the effect of epidemiological factors on the incidence of paddy blast (*Pyricularia oryzae*) disease in Pakistan. It is well known that the environmental conditions, especially moderate temperatures (25 – 30 °C) and high relative humidity, are important factors inducing and facilitating sporulation and growth of *P. oryzae* [5], [8], [22], [3]. The presence of high rice blast disease severity on leaves and panicles affected the rate of photosynthesis in the rice plants resulting into reduced grain filling and high percentages of unfilled grains [22]. Similar results have also been reported by [11] when working with inhibitory activity of *Chaetomium globosum* Kunze extract against Philippine strains of *Pyricularia oryzae*

Table 2: Monthly temperatures, precipitation and relative humidity at Dakawa, Morogoro region, Tanzania from March to July 2013, when the current experiment was conducted

Month	Temperature			Rainfall	Relative humidity
	Min	Max	Mean	(mm)	(%)
March	22.0	32.1	27.1	95.4	79.6
April	21.3	30.1	25.7	96.0	82.5
May	19.5	29.6	24.6	19.3	78.0
June	16.1	29.1	22.6	0.1	66.5
July	15.4	29.3	22.4	1.3	64.0
Average	**18.9**	**30.0**	**24.5**	**42.4**	**74.1**

Source: Meteorological Department, Mvomero district, Morogoro region and http://www.weatheronline.co.uk/weather/maps/city?lang=en&plz=&plzn=_&wmo=63866&cont=afri&r=0&level=162&region=0009&land=tz&mod=tab&art=pre&noregion=1&fmm=3&fyy=2013&lmm=7&lyy=2013.

4.4 Effect of Rice Blast Disease on Tillering, Seeds and Grain Yield

The results in Table 3 indicate that, rice blast disease had a substantial impact on reduction of the number of tillers per hill, seeds per panicle and grain yield. There was significant reduction (P<0.05) of the number of tillers, panicle number and grain yield between rice varieties used. The tillers per hill between inoculated and non-inoculated rice plants were highly significantly different (*t*-value = 3.55, P < 0.001) except on TXD 85 and IR 64 varieties (Table 4).

However, the number of tillers/hill was not significantly different (P < 0.05) between the varieties Shingo ya Mwali, Kihogo, Kalamata, Jaribu 220, Mbawambili, Supa and IR 64 for inoculated plots. The highest tillers per hill were recorded on TXD 306 and TXD 85 varieties in diseased (inoculated) plants, while in healthy (non-inoculated) plants, TXD 306, followed by Supa, Jaribu 220 and Mbawambili were recorded with the highest number of tillers per hill (Table 4). This study revealed that rice blast disease reduces number of tillers from 20 - 78.19 %. This range is significant to justify high reduction in grain yield per plant. The highest percentage of tiller loss was recorded on Jaribu 220, followed by Mbawambili, Supa and Kalamata.

The number of seeds per panicle between inoculated and non-inoculated plants were highly significantly different (*t*-value = 6.50, P<0.001) (Table 4) except on Shingo ya Mwali, TXD 85, Mwarabu and IR 64 varieties. The highest number of seeds per panicle was recorded on TXD 306 in both inoculated and non-inoculated plants, followed by TXD 85, Kihogo and Shingo ya Mwali, varieties. The lowest seeds per panicle were recorded on Jaribu 220 (109.7) on inoculated plants followed by Kalamata (137.7), Mbawambili (143.3), Mwarabu (189.7), Supa (162.7) and IR64 (158.3). Rice blast disease caused seed loss/panicle ranging from 7.97 to 64.48 %. These results corresponded to high grain yield losses (Table 4). The rice grain yields between inoculated and non-inoculated plants were highly significantly different at *t*-value 8.04 and *P* < 0.05 on Mbawambili, Jaribu 220 and Kalamata varieties (Table 4). The highest grain yield was recorded on TXD 306 (10283 kg/ha and 11067 kg/ha for inoculated and non-inoculated plants, respectively) while the lowest grain yield was recorded on IR 64 in both inoculated and non-inoculated plants, followed by Jaribu 220 and Mbawambili.

Percentage rice grain yield losses due to rice blast disease were significantly different (P < 0.05) between the ten rice varieties (Table 4). Yield losses from Shingo ya Mwali, Kihogo, TXD 85, Supa, TXD 306, Mwarabu and IR 64 varieties did not differ significantly at the 5 % level. Yield losses from variety Jaribu 220 differed significantly from Kihogo, Mwarabu, TXD 85, Supa, TXD 306 and IR 64 at the 5 % level (Table 4). However, the highest percentage of yield losses was recorded on Jaribu 220 (37.8 %) followed by Mbawambili (31.0 %) and Kalamata (29.6 %) and the lowest yield losses were recorded on TXD 306 (11.9 %) IR64 (16.0 %), and Kihogo (15.5 %) followed by TXD 85 (17.0 %).

These results indicate that yield losses due to rice blast disease caused by *P. oryzae* ranged between 11.9 and 37.8 %. Similar yield losses have been reported in Egypt [12], Iran [27], and Korea [4], [44]. Early occurrence of rice blast disease at young stages of rice plant growth can cause considerable leaf and panicle damage and reduce tillering ability. Reduced tillering may result in a simultaneous reduction in grain yield.

Table 3: The reaction of various rice varieties to blast disease caused by Pyricularia oryzae

Leaf blast			Panicle blast		
Varieties	Severity (%)	Host behavior	Varieties	Incidence (%)	Host behavior
Nil	0-15	Resistant	Nil	0-15	Resistant
TXD 306 and TXD 85	15.1–30	Moderately resistant	TXD 306, TXD 85, IR 64 and Mwarabu	15.1– 30	Moderately resistant
Kihogo, Mbawambili, IR 64 and Shingo ya Mwali	30.1–50	Moderately susceptible	Kihogo, Supa and Shingo ya Mwali	30.1– 50	Moderately susceptible
Jaribu 220, Supa, Mwarabu and Kalamata	50.1–100	Susceptible	Mbawambili, Jaribu 220 and Kalamata	50.1– 100	Susceptible

Table 4: The number of tillers/hill, seeds/panicle, grain yield and yield loss from rice blast on varieties preferred by farmers at Dakawa, Morogoro

Varieties	Tillers/hill Inoculated	Tillers/hill Non-inoculated	Tiller loss/hill (%)	Seeds/panicle Inoculated	Seeds/panicle Non-inoculated	Seed loss/panicle (%)	Grain Yield (Kg/ha) Inoculated	Grain Yield (Kg/ha) Non-inoculated	Yield loss (%)
1. Shingo ya mwali	4.667a	10.00b	53.33	203.7bc	244.7cd	16.76	8267bc	10037cd	17.7ab
2. Kihogo	5.667a	10.67b	46.86	214.3bc	296.7de	27.77	9633cd	11427de	15.5a
3. Kalamata	5.000a	18.00cd	72.22	137.7ab	330.0e	58.27	7800b	11100cde	29.6bcd
4. TXD 85	13.000c	15.00cd	13.33	215.3bc	294.7cde	26.94	7567b	9133bc	17.0ab
5. Mbawambili	6.333a	27.33de	76.84	143.3ab	288cde	50.24	6167a	9033bc	31.0cd
6. JARIBU 220	5.667a	26.00de	78.19	109.7a	308.3de	64.48	6130a	10027cd	37.8d
7. Mwarabu	10.000b	18.33cd	45.45	189.7abc	263cd	27.87	7867b	9247bc	13.0a
8. Supa	7.333ab	29.00de	74.72	162.7ab	235.7c	30.97	8550bc	11033cd	22.3abc
9. TXD306	14.667c	36.67e	59.99	253.3c	352.3f	28.10	10283d	11067de	11.9a
10. IR 64	8.000ab	10.00b	20.00	158.3ab	172.0a	07.97	5967a	7097ab	16.0a
Mean	**8.033**	**19.033**		**176.6**	**278.54**		**7823**	**9980**	**21.4**
CV %	**21.9**	**19.5**		**23.4**	**11.2**		**10.9**	**10.4**	**35.1**

Means in the same column followed by the same letter are not significantly different by Duncan's Multiple Range Test at $P < 0.05$.
CV % = Percent of coefficient of variation.

The number of tillers and seeds per panicle were negatively correlated with grain yield losses (r = -0.857 and -0.958, respectively) at 5 % (Figure 4). These results revealed a direct relationship between number of tillers and seeds per panicle with grain yield. Similar coefficients of correlations (r) have been reported [44] in the study of damage analysis of rice panicle blast on disease occurrence time and severity. It was noted that at tillering stage, rice seedlings were more susceptible to blast disease than mature plants [47] and the number of tillers and seeds were reduced substantially [22]. Whereas, late rice blast infection of plants at tillering stage had only small effect on both tillers and grain seed reduction [44].

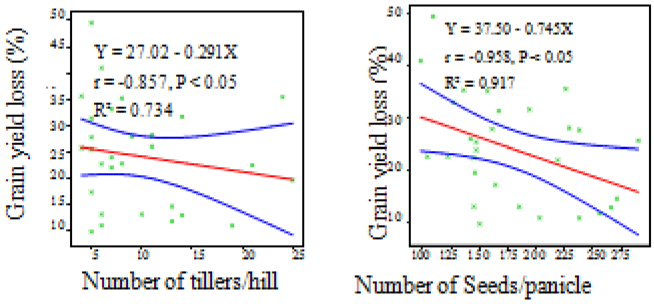

Figure 4: Regression and correlation coefficient between a) number of tillers/hill and grain yield loss b) seeds/panicle and grain yield loss on selected rice varieties grown at Dakawa in Tanzania.

The regression equations of number of tillers and seeds/panicle with grain yield losses ($Y = 27.02 - 0.291X$, $R^2 = 0.734$ and $Y = 37.50 - 0.745X$, $R^2 = 0.917$, respectively) were the most appropriate models for predicting yield losses due to rice blast disease (Figure 4). High coefficients of determination have been reported in the analysis showing the percentage of yield losses due to the effect of rice blast disease on tillers and seeds [27].

4. Conclusion

Results of the current study revealed that rice blast disease significantly reduced tillering ability and grain yield. Yield reduction was influenced by varieties grown. Both the number of tillers and seeds per panicle were reduced by blast disease, contributing to the differences in grain yield recorded between rice varieties. Losses in grain yield due to panicle and leaf rice blast disease ranged from 11.9 % to 37.8 %. Tillers loss/hill and seeds loss/panicle due to rice blast disease ranged from 20 to 78.19 % and 7.97 to 64.48 %, respectively, and grain yield weight ranged from 7,776.4 kg/ha to 10,046.1 kg/ha and was influenced by both leaf and panicle rice blast disease. These results demonstrate that IR 64, TXD 85, TXD 306 and Kihogo were promising rice varieties resistant to rice blast disease, while Jaribu 220, Kalamata and Mbawambili varieties were susceptible to rice blast. Management measures to reduce the impact of rice blast on yield are thus, needed. Such management measures should include breeding for rice blast disease resistance.

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