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# Characterizing agronomic response of rice genotypes to bacterial leaf streak disease in Uganda

**Kanaabi Michael\*[1,2]., Tusiime, Geoffrey[1]., Tukamuhabwa, Phinehas[1]., Zziwa, Simon[1,2]
JL Andaku [1], Lamo, Jimmy[2]**

[1]*Department of Agricultural Production, School of Agricultural Sciences, Makerere University, Kampala, Uganda*

[2]*Cereals Research and Development Program, National Crops Resources Research Institute, Kampala, Uganda*

**Abstract**

Bacterial leaf streak disease (*Xanthomonas Oryzae* pv. *Oryzicola*) is a devastating disease of rice that is endemic to Asia and parts of the West African coast. In 2014, researchers in Uganda confirmed the occurrence of bacterial leaf streak disease (BLS) in the country. Having been only recently confirmed in the country, the agronomic response of rice genotypes to the disease has not been studied and therefore the extent of damage to rice due to bacterial leaf streak disease (BLS) has not yet been estimated. A study was conducted with the objective of characterizing the agronomic response of rice genotypes with varying levels of reaction to BLS. Spray inoculation was done 30 days after planting and data collected on BLS incidence and severity starting 15 days after inoculation, then every 10 days for the next 40 days. Data were also collected on yield and yield components at maturity. A strong positive correlation (r=0.99) was found to exist between BLS AUDPC and loss in 1000 grain weight. Regression of AUDPC against yield loss was found to be highly significant (P=0.002), with a high coefficient of determination ($R^2$-0.98). The study revealed that BLS caused yield losses of 0.8-19.2% and losses in panicle fertility of 2.1-13.6%.

\* **Corresponding Author:** Kanaabi, Michael ✉ kanaabimichael@gmail.com

## Introduction

The occurrence of bacterial leaf streak disease in Uganda was confirmed recently (Afolabi *et al.,* 2014), although symptoms had been seen years earlier. According to Nino-Liu *et al.,* (2006), the disease is endemic to Asia and parts of the West African coast where it first was reported in Nigeria in the early 1980s (Nino-Liu *et al.,* 2006), then in Burkina Faso (Wonni *et al.,* 2011), Madagascar (Poulin *et al.,* 2014), Mali (Wonni *et al.,* 2014) and Burundi (Afolabi *et al.,* 2014a). The pathogen is seed born so it can be rapidly distributed to new areas through infected seed. Its dispersal is also aided by irrigation water and insects in addition to transimission through direct plant – plant contact. The pathogen gains entry into the leaf epidermis via the stomata although injury due to mechanical damage may also aid its entry. In Asia and the USA, BLS is of quarantine importance (Nino-Liu *et al.,* 2006). Chen *et al.,* (2007) reported that in Asia, BLS causes yield losses of up to 60% on susceptible rice varieties.

Typically, successful infection of a plant host by a pathogen is a result of the interaction of a virulent pathogen with a susceptible host under favorable environmental conditions (John and Fielding, 2014). Diseases constrain rice production by causing losses in both the quality and quantity of harvested produce due to their negative impact on the plant's physiological processes (Muller *et al.,* 2010). Measuring or predicting the effect of a disease is vital in making disease management decisions. Much as the eventual effect is loss in yield, the agronomic components that bring about this need elucidation. This information is important for resistance breeding. It has long been established that resistance breeding is the most feasible approach to manage grain diseases. A field experiment was therefore set up to study the effect of BLS on grain yield and yield attributes of rice using rice genotypes with varying levels of susceptibility to BLS disease.

## Materials and methods

Three highly susceptible rice genotypes; Du 363, Agoro and Jaribu; one moderately susceptible; Namche 2 and one resistant genotype; Nerica 1 (Kanaabi *et al.,* 2016) were selected and used for this study. The experiment was laid out in the field at the National Crops Resources research Institute in Namulonge in a randomized complete block design arranged as a split plot with inoculum as the main plot factor and rice genotypes as the sub plot factors with four replicates. The inoculum consisted of the virulent BLS isolate collected from Namulonge and sterile distilled water. The plots were 1.8m x 1.4m in size. The rice was transplanted at a spacing of 20cm between the rows and 20 cm between plants (IRRI, 2013) and 2 seedlings per hill. Seedlings were transplanted 15 days after sowing. The seedlings were thinned to one plant per hill upon establishment to give a population of 80 plants per plot. Rice genotypes were separated by a 60cm unplanted alley while the main plots were separated by a four meter unplanted alley. Normal agronomic practices including weeding and fertilizer application were followed to provide optimum growth conditions. The experiment was repeated once.

### Inoculum preparation and inoculation

Inoculum was prepared following the procedure described by Vera Cruz *et al.,* (2012. Bacterial cultures were grown for 72 hours on modified Wakimoto medium consisting of pepton 5g/l, bactor agar 17g/l, sucrose 20g/l, calcium nitrate 0.5g/l and sodium phosphate 0.82 g/l. The cells were re-suspended in sterile distilled water at an optical density of 0.35 and a wave length of 600 nm using a spectrophotometer to give an estimated concentration of $1 \times 10^8$ CFU/ml (Guo *et al.,* 2012; Wonni *et al.,* 2015). Plants were spray inoculated (Vera Cruz *et al.,* 2012) at 35 days after planting using the Namulonge BLS isolate. For the control, plants were spray inoculated with sterile distilled water (SDW).

### Data collection and analysis

Data were collected on the disease incidence and severity 15 days after inoculation and every 10 days after that for the next 40 days. Data on disease incidence were collected by counting the number of plants showing typical BLS symptoms per plot and expressing this as a percentage of all the plants in a plot. Disease severity was evaluated based on the

intensity of BLS symptoms on infected plants. Scores of these symptoms ranging from 0 to 9 were made in accordance to guidelines from the international rice research institute (IRRI) where; 0 - No lesions, 1- sporadically few lesions, 3 - few lesions per plant but all over the field, 5 - plenty of lesions per plant all over the field, 7- leaf tips yellow, 9 - leaves drying (IRRI, 1968). Percentages disease severity was estimated following IRRI's standard evaluation system for rice as shown in Fig. 4 (IRRI, 2013).

At maturity, 10 stools were randomly selected from the middle rows of each plot and data were collected on; plant height by measuring the distance from ground level to the top of the last panicle at the tip of the plant , number of productive tillers, number of panicles, panicle length, flag leaf length and flag leaf width. At harvest, 10 panicles were randomly selected from the middle rows of each plot and harvested separately. These were sundried to 14% moisture content, weighed and hand threshed to separate the straw from the grain. The number of filled and empty grains per panicle per genotype were recorded and their averages used to compute the loss in spikelet fertility using by the formula; Loss in spikelet fertility (%) = [(Average number of empty grains on panicle)/ Average total number of grains on panicle]* 100. Loss in spikelet fertility due to BLS was then computed as the difference in fertility loss between BLS inoculated plots sterile distilled water inoculated plots.

The filled grains from the ten panicles harvested from each plot were then combined into one composite sample from which three samples each of 1000 grains were randomly drawn and their weight taken using an analytical balance to give the mean 1000 grain weight at 14% moisture content (IBPGR and IRRI, 1980). The difference in 1000 grain weight between the BLS inoculated and water inoculated plots was computed as the loss in yield due to BLS.

[Loss in spikelet fertility (%)

$= \left(\dfrac{\text{Av. no. of empty grains on panicle}}{\text{Av. total no. of grains on a panicle}}\right) * 100$ ]

Loss in spikelet fertility due to BLS was then computed as the difference in fertility loss between BLS inoculated plots and sterile distilled water inoculated plots.

The filled grains from the ten panicles harvested from each plot were then combined into one composite sample from which three sub - samples each having 1000 grains were randomly drawn and their weight taken using an analytical balance to give the mean 1000 grain weight at 14% moisture content (IBPGR and IRRI, 1980). The difference in 1000 grain weight between the BLS inoculated and water inoculated plots was computed as the loss in yield due to BLS. Analysis of variance (ANOVA) was done using Genstat statistical software to test for the significance of observed differences in the measured parameters between the BLS and water inoculated plots. Graphs were generated using Microsoft excel soft ware. Error bars on the graphs were generated from the standard error of the mean.The data on disease severity were subjected to Area Under the Disease Progress Curve (AUDPC) according to Shaner and Finney (1977) as:

$$\text{AUDPC} = \sum_{i=1}^{n} \left[\frac{Yi + 1 + Yi}{2}\right] [(Xi + 1 - Xi)]$$

Where: Yi – disease severity at the $i^{th}$ observation, Xi – time (Days after inoculation) at the $i^{th}$ observation, n – total number of observations. Regression analysis was performed using Microsoft Excel 2013 software to explain the linear relationship between BLS AUDPC and loss in yield due to BLS, using the model: Y = α + βx + ε. Where; Y is loss in grain yield due to BLS, α is the expected loss in grain yield if BLS AUDPC were zero, χ is the BLS AUDPC, $^{β}$ is the amount by which loss in grain yield would be expected to increase if BLS AUDPC increased by one unit and ε is the random (unexplained) variation.

## Results

*Reaction of rice genotypes to BLS upon inoculation under field conditions at NaCRRI*

Symptoms of BLS were observed on all the five genotypes upon inoculation. The first symptoms presented seven days after inoculation as small water soaked streaks on all the genotypes. By the tenth day, the streaks had began expanding vertically along the

leaf veins forming conspicuous translucent intervennial water soaked streaks on the leaf lamina on the susceptible genotypes Du 363, Agoro, Jaribu and on the moderately susceptible Namche 2 (Fig. 1a). By the fifteenth day, yellow droplets of bacterial ooze could be observed along the streaks on these four genotypes. The streaks turned yellow to golden in color (Fig. 1b). Twenty days after inoculation, the streaks had turned brown and had began coalescing (Fig. 1c). Infected leaves had turned brown and completely died 33 days after inoculation in Agoro, Jaribu and Du 363 (Fig. 1d). Secondary infections

were observed to occur starting 21 days after inoculation on the genotypes Du 363, Agoro Jaribu and Namche 2. This infection cycle was also observed for the resistant Nerica 1. However for Nerica 1, in as much as symptoms expressed at the same time as the other genotypes, these progressed very slowly. No bacterial ooze was observed on infected leaves as symptoms were restricted to small, short, translucent water soaked streaks. Secondary infections were observed 25 days after inoculation but leaf death due to BLS was not observed to occur in Namche 2 and Nerica 1.



**Fig. 1.** Stages of development of BLS on field inoculated rice plants; 3a- interveinal water soaked streaks with bacterial ooze, 3b-yellowing or goldening of streaks, 3c- coalescing of streaks, 3d - Leaf browning and death.

*Incidence of BLS on field inoculated rice genotypes*
The incidence of BLS is presented in Fig. 2. At 15 DAI, BLS was present in all the inoculated plots. Initially, Nerica 1 had the lowest BLS incidence at 28% followed by Agoro and Namche 2 at 44.4% and 47.5% respectively. Jaribu had the highest BLS incidence at 66.3% followed by DU 363 at 59.7%. For Agoro, Jaribu and Du 363, the disease incidence increased steadily in the plots and peaked at 45 DAI when all plants in the inoculated plots exhibited BLS symptoms. BLS incidence remained steady at 100% for the three genotypes even at 55 DAI. Du 363 registered the most rapid increase in BLS incidence over time. For Namche 2, the incidence peaked at 97.5%, 45 DAI and then slightly declined to 90.3% at 55 DAI. For Nerica 1 however, the disease peaked twice in the inoculated plots.

The first and highest peak was at 64.3%, 25 DAI. The incidence decreased to up to 39.1%, 45 DAI before peaking again at 53.9%, 55 DAI.
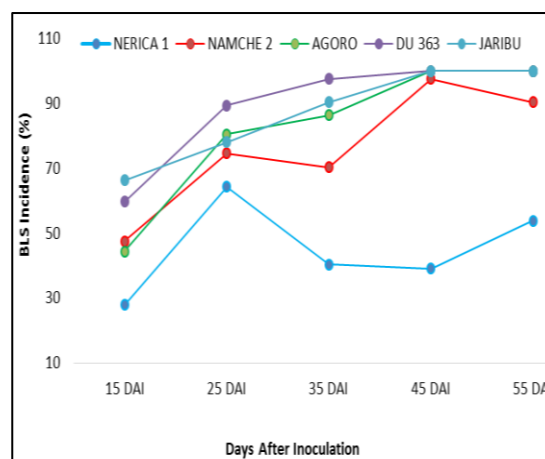


**Fig. 2.** Incidence of BLS on field inoculated rice genotypes 15 to 55 days after inoculation.

*Severity of BLS on field inoculated rice genotypes*

The severity of BLS on field inoculated rice genotypes is given in Fig. 3. For all the genotypes, disease severity was initially low at 15 DAI, ranging from 1% in Nerica 1 to 20% in Jaribu. For Agoro, Du 363 and Jaribu, disease severity increased steadily, eventually peaking at 80%, 45 DAI. Severity remained steady and high at 80% for Jaribu and Du 363 at 55 DAI but slightly decreased for Agoro to 75% at 55 DAI. For Nerica 1 and Namche 2, BLS severity remained low throughout the growing season.
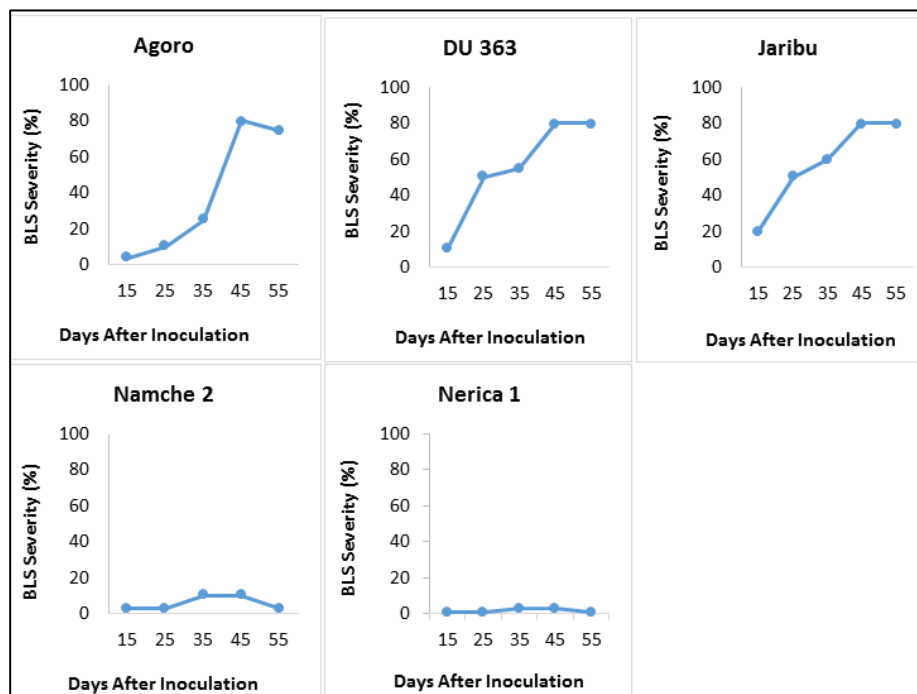


**Fig. 3.** Severity of BLS on field inoculated rice genotypes 15 to 55 days after inoculation.

*Relationship between BLS AUDPC and grain yield loss*

Analysis of variance for 1000 grain weight between the five genotypes revealed a significant (P < 0.001) genotype effect. Inoculum had a significant effect (P < 0.001) on the 1000 grain weight as well the interaction of the genotype with the inoculum (P < 0.001). Fig. 6 gives a graphical representation of the linear relationship between BLS AUDPC and grain yield loss. The regression of percent yield loss and AUDPC was strong and significant (P = 0.002, $R^2$ = 0.98). The linear model for the prediction of yield loss due to BLS at a given AUDPC was given by the equation:

Y = 0.61606 + 0.0076x

The genotype Jaribu had the highest AUDPC of 2475 and suffered the highest loss in yield at 19.2%, Du 363 had the second highest AUDPC of 2425 and suffered a yield loss of 17.4% while Agoro had AUDPC 1725 and suffered a yield loss of 13.6%. Namche 2 had an area under disease progress curve of 282.5, resulting into a 3.5% yield loss while Nerica 1 had the lowest AUDPC of 87.5 and suffered the least loss in yield at 0.8% (Table 1).
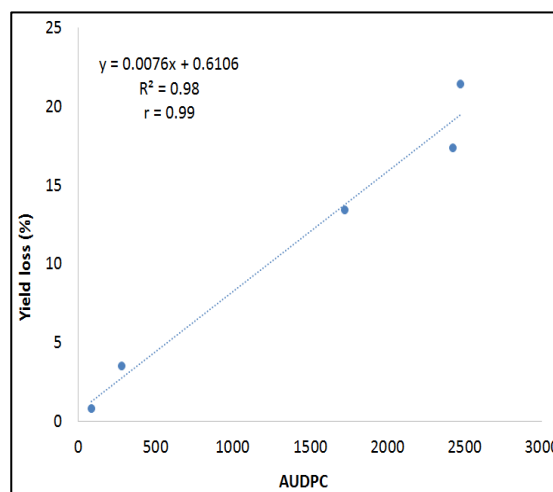


**Fig. 4.** Relationship between AUDPC and yield loss.

**Table 1.** Loss in 1000-grain weight in BLS and water field inoculated rice genotypes.

| Genotype | 1000 grain weight (g) Inoculum | | Weight loss (g) | Weight loss (%) | AUDPC |
|---|---|---|---|---|---|
| | SDW | BLS | | | |
| Agoro | 29.58 | 25.57 | 4.01 | 13.56 | 1725 |
| Du 363 | 32.53 | 26.88 | 5.65 | 17.37 | 2425 |
| Jaribu | 30.56 | 24.70 | 5.86 | 19.18 | 2475 |
| Namche 2 | 30.70 | 29.64 | 1.06 | 3.45 | 282.5 |
| Nerica 1 | 27.11 | 26.90 | 0.21 | 0.77 | 87.5 |

LSD (Inoculum) = 0.552 LSD (genotype) = 0.873 CV = 2.9 % SDW- Sterile distilled water BLS – Bacterial leaf streak.

*Effect of BLS on spikelet fertility*

Analysis of variance for the number of empty grains per panicle revealed that there were significant differences (P < 0.001) in the number of empty grains among genotypes. The inoculum source effect for number of empty grains was also significant (P < 0 .001). The interaction effect of genotypes and inoculum was not significant (P = 0.983) (Table 2).

**Table 2.** Analysis of variance for number of empty grains per panicle.

| Variate: Average streak length | | | | |
|---|---|---|---|---|
| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
| Season | 1 | 20161. | 20161. | 2.93 | |
| Genotype | 4 | 284003. | 71001. | 10.32 | <.001 |
| Inoculum | 1 | 85412. | 85412. | 12.42 | <.001 |
| Genotype.Inoculum | 4 | 2658. | 664. | 0.10 | 0.983 |
| Residual | 69 | 474610. | 6878. | | |
| Total | 79 | 866843 | | | |

CV = 38.9%

Table 3 gives the number of filled and empty grains per genotype when separately inoculated with BLS and with distilled water. When inoculated with distilled water only, the genotype Du 363 had the highest loss in spikelet fertility at 24.41%, closely followed by Namche 2 and Agoro at 22.64% and 21.65% respectively. Jaribu had fertility loss of 18.64% while Nerica 1 suffered the least fertility loss at 15.78% when inoculated with distilled water.

Overall, plots inoculated with BLS registered significantly higher (P < 0.001) losses in spikelet fertility compared to the water inoculated plots (Table 6). Jaribu suffered the greatest loss at 32.24% while Nerica 1 recorded the lowest loss at 17.91%. Spikelet fertility losses due to BLS were computed as the difference in fertility loss between BLS and water inoculated plots.

Jaribu had the highest loss in fertility due to BLS at 13.59%, followed by Agoro at 8.7% and Du 363 at 6.72%. Namche 2 had a fertility loss of 4.06% while Nerica 1 had the least loss in spikelet fertility attributable to BLS at 2.13% (Table 3).

**Table 3.** Effect of BLS on spikelet fertility among field inoculated rice genotypes.

| Inoculum Genotype | Namulonge-BLS | | | | Distilled water | | | | Fertility loss due to BLS (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Filled grain | Empty grain | Total grain | Fertility loss (%) | Filled grain | Empty grain | Total grain | Fertility loss (%) | |
| Agoro | 692.00 | 302.30 | 994.30 | 30.40 | 881.00 | 243.40 | 1124.40 | 21.65 | 8.76 |
| Du 363 | 712.00 | 321.70 | 1033.70 | 31.12 | 757.00 | 244.40 | 1001.40 | 24.41 | 6.72 |
| Jaribu | 741.00 | 352.50 | 1093.50 | 32.24 | 1187.00 | 272.00 | 1459.00 | 18.64 | 13.59 |
| Namche 2 | 660.00 | 240.50 | 900.50 | 26.71 | 619.00 | 181.20 | 800.20 | 22.64 | 4.06 |
| Nerica 1 | 786.00 | 171.50 | 957.50 | 17.91 | 643.00 | 120.50 | 763.50 | 15.78 | 2.13 |

*Agronomic performance the BLS field inoculated rice genotypes*

Table 4 gives a summary of the agronomic performance of the genotypes when inoculated with BLS under field conditions. Analysis of variance in number of productive tillers, plant height, panicle number, panicle length, flag leaf width and panicle dry weight revealed that there were very significant differences (P < 0.001) among the genotypes.

ANOVA further revealed that in as much as there were differences in all these parameters between the BLS and water inoculated plots, these differences were not statistically significant (P = 0.937 for number of productive tillers, P = 0.181 for plant height, P = 0.250 for panicle number, P = 0.827 for panicle length, P = 0.809 for flag leaf width and P = 0.177 for panicle dry weight).

Jaribu had the highest reduction in panicle number at 12.13%, followed by Agoro at 9.52% and Nerica 1 at 5.33%. Namche 2 had the least reduction in tiller number at 1.2%. Jaribu had the highest reduction in panicle dry weight at 5.43%, followed by Du 363 at 3.58%. Namche 2 suffered the least reduction in panicle dry weight at 0.88%. Agoro suffered the greatest reduction in plant height at 5.53%, followed by Namche 2 at 5.24%. Nerica 1 suffered the least reduction in plant height at 0.15%. Agoro had the highest reduction in tiller number at 9.39%, followed by Nerica 1 at 9.04% and Namche 2 at 4.90%. Jaribu had the least reduction at 0.39%. For panicle length, Namche 2 and Nerica 1 suffered the greatest reductions at 5.92% and 4.22% respectively while Agoro suffered the least reduction at 0.39%. For flag leaf width, Nerica 1 and Namche 2 registered the greatest reductions at 5.65% and 3.05% respectively. Du 363 had the least reduction in flag leaf width at 0.54% (Table 4).

**Table 4.** Agronomic performance of five rice genotypes inoculated with BLS under field conditions.

| Trait | Panicle number | | | Panicle dry weight (g) | | | Plant height (cm) | | | Tiller number | | | Panicle length | | | Flag leaf width | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotype | Inoculum BLS | Water | % Reduction | BLS | Water | % Reduction | BLS | Water | % Reduction | BLS | Water | % Reduction | BLS | Water | % Reduction | BLS | Water | % Reduction |
| Agoro | 14.44 | 15.96 | 9.52 | 36.39 | 37.96 | 1.57 | 84.58 | 89.53 | 5.53 | 14.76 | 16.29 | 9.39 | 22.86 | 22.95 | 0.39 | 1.29 | 1.32 | 2.27 |
| Du 363 | 11.78 | 12.20 | 3.44 | 31.54 | 35.12 | 3.58 | 89.44 | 91.43 | 2.18 | 12.30 | 12.56 | 2.07 | 22.27 | 22.78 | 2.24 | 1.83 | 1.84 | 0.54 |
| Jaribu | 12.24 | 13.93 | 12.13 | 28.49 | 33.92 | 5.43 | 88.40 | 90.61 | 2.44 | 15.34 | 15.40 | 0.39 | 23.15 | 23.52 | 1.57 | 1.39 | 1.41 | 1.42 |
| Namche 2 | 9.84 | 9.96 | 1.20 | 26.80 | 27.68 | 0.88 | 113.29 | 119.55 | 5.24 | 8.73 | 9.18 | 4.90 | 23.69 | 25.18 | 5.92 | 1.59 | 1.64 | 3.05 |
| Nerica 1 | 9.24 | 9.76 | 5.33 | 22.36 | 24.60 | 2.24 | 102.49 | 102.64 | 0.15 | 6.64 | 7.30 | 9.04 | 21.34 | 22.28 | 4.22 | 1.67 | 1.77 | 5.65 |
| Lsd | 1.30 | | | 5.53 | | | 5.28 | | | 1.79 | | | 6.73 | | | 0.14 | | |
| CV (%) | 33.00 | | | 27.80 | | | 13.30 | | | 25.2 | | | 10.8 | | | 13.5 | | |

% Percentage.

## Discussion

All inoculated plots had plants showing symptoms typical of BLS by the seventh day after inoculation, indicating that the inoculum consisted of a virulent isolate of BLS. The incidence of BLS was initially low for all genotypes, increasing rapidly as the season progressed in the genotypes Du 363, Agoro, Jaribu and Namche 2 as the bacterial cells rapidly multiplied in the leaf tissues. The production of the bacterial exudate in these genotypes is thought to have aided the rapid dispersal of the pathogen between plants within in the plots as leaves rubbed against each other (Swings *et al.,* 1990). Despite the high incidence and severity observed on the genotypes Agoro, Du 363 and Jaribu, the yield loss is not proportionately as high as plants were able recover by replacing some of the dead or diseased leaves with new ones given that the infection occurred early on in the season (Ou, 1985). The high incidence of BLS in the inoculated plots is attributed to having a virulent BLS isolate under favorable conditions of temperature and humidity on susceptible rice plant hosts. Indeed (Ou, 1985) observed that under favorable conditions, the disease may affect entire fields. A strong positive correlation (r = 0.99) was found to exist between BLS disease area under disease progress curve and grain yield loss which was determined as the difference in loss in 1000 grain weight between BLS inoculated plots and water inoculated plots. The coefficient of determination ($R^2$ = 0.98) indicates that 98% of the loss in the 1000 grain weight in the BLS inoculated plots can be attributed to BLS. Regression models have been established as a useful approach in predicting crop yield loss due to a disease, especially if they have a high coefficient of determination ($R^2$) value (Bonman *et al.*, 1991; Mousanesad *et al.*, 2010). A similar relationship was established for rice blast disease (Chuwa *et al.*, 2013). The high $R^2$ observed in this study shows the importance of BLS in yield reduction in rice.

Genotypes showed highly significant variation (P < 0.001) in number of productive tillers, plant height, flag leaf width, panicle length and dry panicle weight. The differences in these traits however were not statistically significantly different (P = 0.937 for number of productive tillers, P = 0.181 for plant height, P = 0.250 for panicle number, P = 0.827 for panicle length and P = 0.809 for flag leaf width and P = 0.177 for panicle dry weight) for plots treated with BLS and those treated with sterile distilled water. The observed differences in agronomic traits could therefore be attributed to differences in the inherent genetic capacity of the genotypes. Golam *et al.* (2003)

made similar observations on agronomic traits of rice varieties when they studied the influence of stomatal characteristics on yield and yield attributes of rice. The susceptible genotypes Jaribu, Agoro and Du 363 had the highest loss in spikelet fertility at 13.59%, 8.76% and 6.72%. This was due to the high numbers of empty grains in the BLS inoculated plots in these genotypes. The high number of empty grains per panicle among the three susceptible genotypes in BLS inoculated plots can be explained by the fact that these allowed rapid multiplication and accumulation of *Xoc* in the intracellular spaces and parenchyma tissue (Wonni *et al.,* 2015). This could have limited carbondioxide movement in the leaf tissues thus limiting the plants' photosynthetic ability and their capacity to accumulate assimilates for grain filling. The extra - cellular polysaccharide (EPS) exudate which was visible as yellow droplets of bacterial ooze on the leaf lamina could have blocked stomata, thus similary limiting the amount of carbondioxide available to the leaves for photosynthesis. Blocking of the stomata by the extra -cullular polysaccharide could also have resulted into suppression of transpiration in the affected plants. Transpiration is vital in the uptake of water and soluble salts by plants as it creates a suction force (Agrios, 2004). This could have limited the amount of water and soluble salts effectively available to the plants for photosynthesis and other physiological functions. Still among these three susceptible genotypes; the yellowing, browning and eventually death of otherwise photosynthetically active leaves lead to low rates of photosynthesis resulting into limited availability of photosynthates for grain filling.

Diseases of cereals have been reported to cause loss in grain yield through reduction in dry matter production either by reducing the leaf area index (Aggarwal *et al.*, 2006) or by reducing the leaf chlorophyll content (Rosyara *et al.*, 2007). Ibeagha *et al.* (2005) while working on wheat reported that the entire leaf tissue may be invaded by a pathogen, leading to reduced carbondioxide concentration in cells sorrounding the stomata. This would in turn result into reduced rates of photosynthesis (Zuckerman *et al.*, 1997). Agrios (2004) reported that when plants are infected by pathogens, respiration increases such that affected tissues use up their energy reserves faster than they would when healthy. In resistant varieties, respiration increases rapidly as plants mobilise their defense machinery to counter the attack but declines quickly after reaching maximum, such that the plant is not under stress for elongated periods. For susceptible plants, respiration rate increases slowly after inoculation but continues rising and remains high for longer periods, imposing considerable stress on the plant. In addition, infection by pathogens in plants tends to activate the alternate respiration pathway; the pentose pathway over a level it would operate at in a healthy plant. Unlike the energy efficient glycolytic pathway, the pentose pathway is not linked directly to ATP production and therefore fails to produce sufficient energy for the plant to perform all its physiological functions (Agrios, 2004). The combined effect of all these is disruption of the plant's normal physiological processes such that the plant's machinery functions at less than optimal rates.

The ability of *Xoc* to block stomal openings due the bacterial exudate, block intrecellular spaces due to bacterial accumulation and potential to cause leaf discolouration and death result into reduced photosynthesis and impairement of the plant's ability to accumulate photosynthates that could be partioned for grain filling. These very factors are responsible for the depression in 1000 grain weight observed among the susceptible BLS inoculated genotypes in this study. The high incidence and severity of BLS on the susceptible genotypes Agoro, Jaribu and Du 363 between the maximum tillering and grain filling growth stages observed in the inoculated plots indeed lend credence to the contribution of BLS to poor grain filling and loss in the 1000 grain weight.

## Conclusion

Bacterial leaf streak disease caused yield losses of 0.8 – 19.2% and losses in panicle fertility of 2.1 – 13.6%. BLS reduces the agronomic performance of susceptible genotypes through reduced spikelet fertility, resulting into poor grain filling and ultimately yield losses.

Researchers should pay ample attention to this emerging threat and initiate a breeding program so as to address the risk to food security that is being presented by BLS disease.

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