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Occurrence, distribution and severity of finger millet blast caused by *Magnaporthe oryzae* in Kenya

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Finger millet is a food crop that provides nutritional security and is climatically resilient for farming and agricultural diversification. However, its quality and yield remain low due to biotic and abiotic factors, the greatest of which is blast disease caused by *Magnaporthe oryzae*. We surveyed the occurrence, distribution and severity of finger millet blast in five counties, namely, Busia, Bungoma, Kisii, Machakos and Makueni, in Kenya. Blast disease occurrence was determined by observing disease symptoms of different plant parts on each farm, and symptoms were recorded as either present or absent. Severity was evaluated based on the disease symptoms on plant fingers, leaves and necks and generally at the whole farm scale. Distribution was assessed based on the number of farms sampled for blast per county, and global positioning systems coordinates were recorded. Blast occurrence was 100%, with a uniform distribution pattern on all the farms surveyed across all the counties. Busia County had the highest disease severity at 82.3%, while Makueni had the lowest severity at 61%. Pearson's correlation test revealed no statistically significant correlation between blast severity and plant parts infected ($p < 0.05$), with Busia (74.2%) having the highest number of plants showing symptoms of blast on fingers, followed by Bungoma (57.1%), Makueni (57%), Machakos (56%) and Kisii, 53.3%. This study reveals that finger millet blast is rampant in all the counties surveyed and is widely distributed in Kenya. This information is helpful in understanding the geographical distribution, occurrence and severity of *M. oryzae*.

Key words: Finger millet blast, occurrence, severity, distribution, *Magnaporthe oryzae*.

INTRODUCTION

Crop transformation and diversification are an ideal mechanism for transforming agriculture from a stable system to a more useful system. At present, the area under which some cereal crops such as finger millet

[*Eleusinecoracana* (L.) Gaertn.] are cultivated is rapidly declining; yet this crop plays a significant role in meeting both the dietary and economic needs of most subsistence farmers living in arid and semiarid areas in sub-Saharan

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Africa and Asia (Babu, 2011). In addition, this traditional food crop acts as an important plant genetic resource for agriculture that provides a resource for food-security deprived farmers living in such areas (Lata, 2015). Finger millet is an excellent source of minerals and nutrients such as methionine, iron and calcium (Patro et al., 2018) that are especially useful to expectant women, nursing mothers and children (Manyasa et al., 2019). Despite its importance as a staple crop, finger millet production is still low compared with that of other cereals. Globally, the production of finger millet accounts for a minimal 30.73 million tonnes of millet; 37% of which is produced by India. Among other small millets, finger millet production only accounts for 11%. In India, finger millet production accounts for an estimated 81% of millet production with an annual production turnover of approximately 2.78 tons (Babu, 2011; Sakamma et al., 2018). Among the main finger millet growing regions in India, Karnataka State is the leading producer of finger millet, but this production only accounts for 58% of the global production. Despite this scenario, only a few Indians are aware of its health benefits and nutritional value (Chandra et al., 2016). In East Africa, cultivation of this crop accounts for more than 50% of the area of small millet, which only reflects a 25% increase over 30 years within the region. This expansion, though minimal, is due to increased domestic demand, improved regional trade and increased market prices in comparison to those of other cereals (Manyasa et al., 2019). Studies in East Africa have shown that finger millet is grown on over 800,000 ha; 470,000 ha in Uganda, 350,000 ha in Tanzania, and 77,890 ha in Kenya (Mwema et al., 2013). In Kenya, this crop is mainly grown in low input subsistence systems on 0.5 to 1 ha farms, with western regions being the highest producers of this crop. Having been replaced by maize in the 20th century finger millet is perceived more like the “poor-man-crop” or ‘bird seed thus it is not a priority crop for most of the farmers (Handschuch and Wollni, 2016).

Finger millet crop production and productivity are impeded by both abiotic and biotic factors such as drought, high temperatures, nutrient stress, declines in land fertility, high labor requirements for weeding and low-yielding disease-susceptible varieties (Saha et al., 2016). Insects also damage this grain only slightly due to the minute size of the seed, but birds and striga weed pose significant threats (Mgonja et al., 2007). However, worldwide, blast disease caused by *M. oryzae* is the major biotic constraint that affects finger millet production and productivity, leading to low grain quality and poor yields. The disease was first reported in Asia more than 3,000 years ago, and it has now spread to several countries across the globe. This disease is highly adaptable to different environmental conditions, such as irrigated lowlands, rain-fed uplands or even deep water rice paddies (Srivastava et al., 2014). Substantial yield losses have frequently occurred due to this blast fungus since it infects different parts of the plants. Extensive

damage to the aerial parts of plants, especially the panicle, leading to withered or blasted finger, neck and head portions of the crop have been observed. This greatly lowers the positive agronomic traits exhibited by the crop eventually causing losses of between 28-36% whereas in endemic areas this could rise up-to 80-90% (Ramakrishnan et al., 2016)

This situation is worsened by the fact that *M. oryzae* is able to produce mycelia on infected living leaves or survive in dead plant debris in the soil for a long time. In addition, preexisting environmental conditions, such as high mean temperatures with relatively high humidity and damp leaves exacerbate this situation. Additionally, the presence of infected related weed hosts such as *Eleusine indica*, *E. africana*, *Digitaria* spp., *Setaria* spp. and *Doctylocterium* spp. may act as disease reservoirs for the next crop thus intensifying disease spread (Gashaw et al., 2014). On top of this, high amount of nitrogen content either in the plant or soil as a result of nitrogenous fertilizer application increases blast incidence thus predisposes the crop to blast infection. Disease incidence and severity are more intense during heavy rainy seasons and highly humid months than during the hot dry seasons (Onyango, 2016). Blast disease management involves practices such as plant quarantine, pathogen inoculum elimination and implementation of good agricultural practices that include intercropping, rotating crops, implementing good farm hygiene, understanding and fighting virulence mechanisms of pathogens, using biological control methods and using biotechnological techniques to improve plant performance. Chemical control methods are also employed but may be too expensive for poor farmers (Shittu, 2018).

Since the identification of blast disease in 1933 in Kenya, information on finger millet blast pathogen diversity and characteristics in East Africa has remained insufficient (Takan et al., 2012). Currently in Kenya, most of the studies have not provided a quantitative measurement of finger millet blast occurrence, distribution and severity, although blast disease has been established as the greatest constraint on finger millet production. These disease assessment techniques would be critical in determining the geographical distribution and disease status throughout the country to prioritize research. This study was therefore carried out with the aim of determining the occurrence, distribution and severity of finger millet blast caused by *M. oryzae* in five counties in Kenya. This knowledge will be a good resource for the determination of effective and sustainable disease management strategies, blast epidemiology and varietal selection procedures against blast for different geographic regions in Kenya.

MATERIALS AND METHODS

Study area and survey methodology

A survey of finger millet blast disease was conducted in the five

counties of Busia, Bungoma, Kisii, Machakos and Makueni in Kenya in May 2018 and February and June 2019. These counties represent some of the main finger millet growing areas. The location of each farm was recorded using a GPS device.

Sampling and survey methodology

Purposeful sampling was adopted, and both symptomatic and asymptomatic plants were collected. Finger millet crops were physically examined for the presence of diamond-shaped lesions on the leaves and neck, while a rusty brown appearance was observed on the finger. The finger millet samples collected included leaf, finger and neck, which were then stored in brown sugar bags to avoid contamination. Three plants were collected per farm: 1 asymptomatic plant and 2 severely infected plants at random. The number of farms sampled per county depended on the availability of finger millet.

Disease intensity was evaluated on the basis of occurrence, distribution and severity. Disease occurrence was based on the presence or absence of disease on the farms surveyed. Disease severity was based on the symptoms of blast on the plant parts (finger, leaf and neck) as well as disease symptoms spread on the whole farm. Disease severity data were recorded and scored as less severe (0-25%) = 1, moderately severe (30-60%) = 2 and very severe (70% and above) = 3. The identity of the *M. oryzae* was determined using PCR. GPS data were used to determine farm locations and disease density per county.

Data analysis

Survey data were analyzed using the Pearson product-moment correlation coefficient with SPSS version 25 software (IBM Corp, NY, USA) to assess the extent of the statistical relationship between the linearly related variables using the following equation:

$$r = \frac{N\sum xy - (\sum x)(\sum y)}{\sqrt{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]}}$$

where r = Pearson r correlation coefficient; N = number of observations; $\sum xy$ = sum of the products of the paired scores; $\sum x$ =sum of the x scores; $\sum y$ = sum of the y scores; $\sum x^2$ = sum of the x squared scores; $\sum y^2$ = sum of the y squared scores. x and y represent the county-level severity on the whole farm and severity per plant part, respectively.

Maps were designed to show the extent of disease spread within the different counties surveyed to portray disease distribution within the counties.

RESULTS

Farming practices

Finger millet farming practices across the five counties were somewhat similar. The crop was grown for subsistence where low-input cropping systems were utilized. The farms were mostly managed by female farmers, with the highest number of farmers in Kisii(77%), Busia (65%), Bungoma (61.5%) and Machakos, and Makueni had the least number of farmers at 50% (Table 1).

Soil fertility was enhanced on most of the farms

surveyed by farm yard manure with Busia and Machakos having the highest fertility at 90%, Bungoma and Makueni at 85% and Kisii with the lowest fertility at 80%. A few farmers, however, used compost manure and inorganic fertilizers as well (Table 1). According to farmer interviews, organic fertilizers were applied prior to crop planting to avoid scorching. Kisii County had the highest percentage (92%) of farmers using seeds carried forward from the previous harvest, followed by that of Bungoma (Table 1). Machakos County had zero percentage carryover of seeds because the farms were undergoing a pilot research program from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), so the seeds were supplied by the organization. The fields surveyed varied in size, but the majority of farms with finger millet crops were less than an acre (0.404 ha), as was observed during sampling.

Intercropping finger millet with other crops was a key cultural practice among the farmers in all the counties visited. The predominant crops used in intercropping were cereals such as maize, beans and cowpeas; fruits such as mangoes, oranges, guavas and pawpaw; and tubers such as cassava and sweet potatoes. Makueni County was the farm with the most intercropping at 90% of the farms being intercropped with cereals, and Busia and Bungoma had the next highest about of farms with intercropping at 85%. Machakos had the least number of farms with intercropping at 60%. Farms intercropped with fruits were mainly in Makueni with 85% implementing intercropping and Machakos with 80% implementing intercropping and no intercropping in Kisii, Bungoma and Busia (Table 1). Farmers across the counties agreed that the reason for growing finger millet was mainly for food with 90% of the farmers in Kisii and Bungoma counties in agreement and 85% of the farmers in Machakos, Busia and Makueni in agreement. In addition, some farms in Busia, Bungoma and Kisii grew this crop for cultural reasons at 30, 10 and 10% of the farms, respectively (Table 1). With regard to soil fertility practices, farm yard manure application was the key method used by the farmers. Busia and Machakos had 90% of the farms using this method, followed by those in Makueni and Bungoma at 85% and Kisii at 80%. Inorganic fertilizer application was not a common practice across the counties with 10% of farms using inorganic fertilizer in Makueni and Kisii and 5% in Machakos, Bungoma and Kisii (Table 1).

Finger millet waste was fed to livestock, burnt, left on the farm to dry or placed in cowsheds. In Busia, 80% of the farmers fed waste to the animals; in Bungoma, Kisii and Machakos 75% of the farmers implemented this practice; and in Makueni, 70% of the farmers in Makueni implemented this practice. The amount of water burned in decreasing order per county was as follows: Kisii 18%, Bungoma and Makueni 10%, Busia and Machakos 5%. Most farmers across the counties also laid the waste in the livestock shed as follows: Busia 10%, Bungoma 10%,

Table 1. Finger millet farming patterns in Busia, Bungoma, Kisii, Machakos and Makueni counties in Kenya.

Parameter (in %)	Busia	Bungoma	Kisii	Machakos	Makueni
Female farmers	65	61.5	77	50	50
Male farmers	35	38.5	33	50	50
Farming as main source of income	80	77	85	100	70
Formal employment as source of income	20	33	15	0	30
Seeds obtained from owner	80	85	92	0	80
Seeds obtained from neighbors	0	0	0	0	2
Seeds bought from market	0	0	0	0	10
Seeds bought from agricultural organizations	33	15	8	100	8
Source of food	85	90	90	85	85
Farms with very severe blast symptom	84.6	71.4	58.3	80	30
Farms with moderately severe blast symptom	15.4	14.3	41.7	20	70
Farms with less severe blast symptom	0	14.3	0	0	0
stable crop for climate variability	0	0	0	15	10
storage friendly	0	0	0	0	3
cultural reasons	30	10	10	0	0
commercial use	0	0	0	0	2
intercropped with other cereals	85	85	80	60	90
intercropped with Fruits	0	0	0	80	85
intercropped with tubers	85	85	85	60	65
mixed crop farming only	10	0	0	0	10
mixed farming	100	100	100	100	90
fertilizer application	5	5	10	5	10
compost manure application	10	10	10	5	5
Farm yard manure application	90	85	80	90	85
wastes fed to livestock	80	75	75	70	75
wastes left on farm	5	5	5	10	10
wastes laid in livestock shed	10	10	2	10	5
wastes burnt	5	10	18	5	10

Machakos 10%, and Makueni 10%, while Kisii County had the least number of farmers using this method. Most farmers across the counties left the waste on the farms to dry as a last resort. The percentage values of the farms using this method were as follows: Busia 5%, Bungoma 5%, Kisii 5% and Makueni 10%, and Machakos 10% (Table 1).

Blast disease occurrence and distribution

Finger millet blast disease occurred on all the farms visited in Busia, Machakos, Makueni, Bungoma and Kisii, representing a 100% disease occurrence on all the farms visited (Table 2). Finger millet blast disease was sampled from two main agro-ecological zones (western and eastern) represented by Bungoma, Busia, Kisii, Machakos and Makueni counties as shown in the spatial analytical map (Figure 1). According to the results of the

surveyed areas, finger millet blast disease was distributed across all the counties surveyed. However, the density of disease distribution varied across the counties. In Busia and Bungoma counties, the farms were closely distributed; consequently, the disease distribution followed the same pattern. In Machakos and Makueni, the farms were far apart, and as a result, the disease also tended to follow a spatial distribution pattern. Although in Kisii County, the farms were fairly far apart, blast disease was present at a high density.

The distribution of diseased plants followed a uniform pattern on the farms visited across all the counties surveyed. However, in some farms that were intercropped with large fruit trees, more blast symptoms were observed than those on other farms. In addition, farms that were on the windward side had more blast symptoms than those that were on the leeward side. Regarding the plant parts infected, the fingers were more infected than the leaves and neck. The number of farms

Table 2. Finger millet blast disease occurrence in sampled Kenyan counties in 2018 and 2019.

Agro-ecological zone	County	Number of farms surveyed	Blast occurrence	Percentage blast disease occurrence
Western	Busia	>200	+	100
	Bungoma	13	+	100
	Kisii	13	+	100
Eastern	Machakos	5	+	100
	Makueni	10	+	100

(+) sign indicates presence of blast disease.

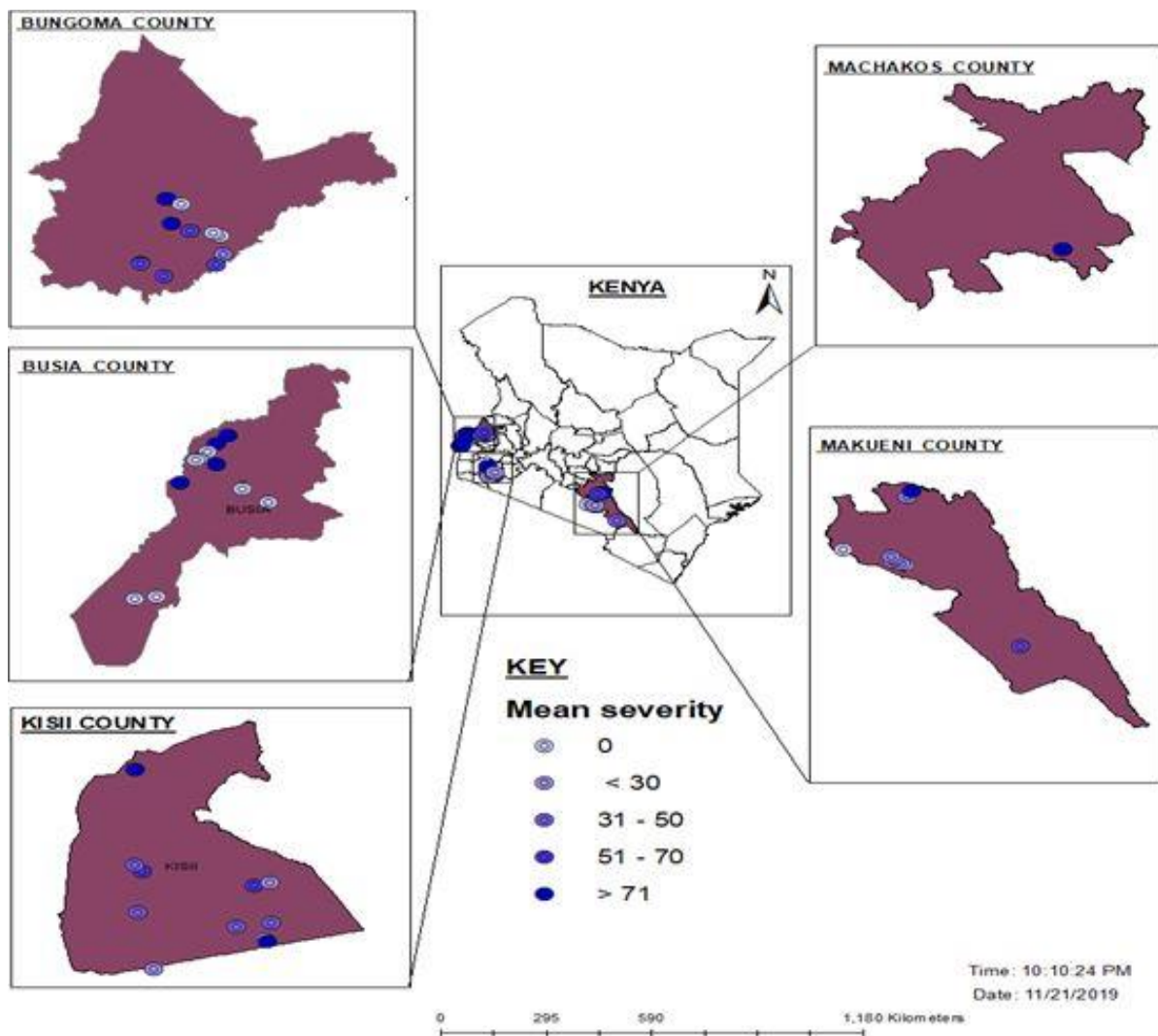


Figure 1. Finger millet blast disease sampling sites in Kenya. The surveyed areas represent the major finger millet growing areas. The blue spots with different shades represent sampled areas with varying blast disease severity.

surveyed varied among the counties, with Busia having the highest number of farms sampled (>200), followed by Bungoma (13) and Kisii (13), Makueni (10) and Machakos (5) (Table 2).

Blast severity

Busia county recorded the highest finger millet blast severity (82.3%), based on the symptoms of the whole

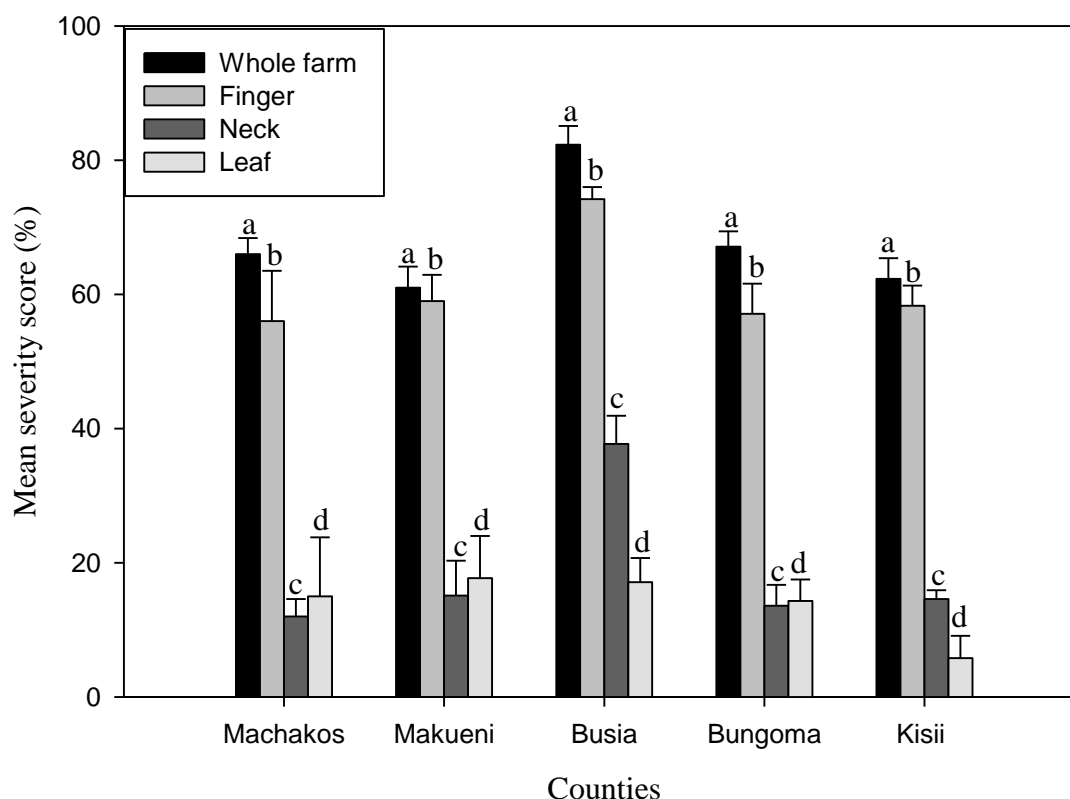


Figure 2. Percentage finger millet blast severity across the five counties for the whole farm and individual plant parts affected. Means \pm standard error followed by different alphabets in each column are significantly different ($P \leq 0.05$) using Fishers LSD.

Table 3. Pearson correlation table for finger millet blast severity.

County	Whole farm mean severity	Finger severity	Neck severity	Leaf severity
Machakos	66 ^a \pm 2.4	56 ^{ab} \pm 7.5	12 ^b \pm 2.6	15 \pm 8.8
Makueni	61 ^a \pm 3.14	59 ^{ab} \pm 3.9	15.1 ^b \pm 5.2	17.7 \pm 6.3
Busia	82.3 ^a \pm 2.8	74.2 ^{ab} \pm 1.8	37.7 ^b \pm 4.2	17.1 \pm 3.6
Bungoma	67.1 ^a \pm 2.3	57.1 ^{ab} \pm 4.5	13.6 ^b \pm 3.1	14.3 \pm 3.2
Kisii	62.3 ^a \pm 3.1	58.3 ^{ab} \pm 3	14.6 ^b \pm 1.3	5.8 \pm 3.3

^aMeans are significantly correlated at $p < 0.05$; ^b means are significantly correlated at $p < 0.01$.

farm, followed by Bungoma and Machakos (67 and 66%, respectively), while Makueni had the lowest severity (61%) (Supplementary Material 1 and Figure 2). In terms of infected plant parts, Busia County also had the highest severity of infected fingers at 74.2%, neck at 37.7% and leaves at 17.1% (Supplementary material 1 and Figure 2). Pearson's correlation test revealed a statistically significant correlation of whole farm finger millet blast disease symptoms between the counties surveyed (Table 3). A significant association ($p < 0.01$) existed between blast severity on a whole farm and severity on

plant parts infected in the different counties surveyed. The whole farm blast severity symptoms were significantly higher in Busia than in Makueni. The blast disease symptoms were most severe in Busia but decreased across the counties with 67% in Bungoma, 66% in Machakos, 62.5% in Kisii and 61% in Makueni (Supplementary Material 1).

Pearson's correlation test also showed that blast severity was significantly associated with plant parts infected ($p < 0.05$) (Supplementary material 1). The blast disease symptoms on fingers decreased in severity

across the counties, with Busia (74.2%) having the highest number of plants showing symptoms of blast on fingers, followed by Bungoma (57.1%) and Makueni (57%), Machakos (56%) and Kisii 53.3%. Within Busia County, in comparison to other counties, Teso South sub-county had more farms with plants showing blast symptoms on fingers at 80%, Bunyala at 77.5% and Nambale at 66.7% (Table 2). In Bungoma, Kanduyi sub-county had the highest number of plants with blast symptoms on fingers (72%), Kabuchai (70%) and Webuye west (60%). In Kisii County, Nyaribarichache sub-county had the highest number of plants with blast symptoms on fingers at 66.7%, Bomachogechache at 62% and Bobasi at 60%. In Machakos County, Mwalasub-county had 66% of its plants with blast symptoms on the finger. In Makueni County, the Kibwezi East and Mbooni East sub-counties had the highest percentages, with 70% of plants showing symptoms of blast on fingers, Kibwezi West and Nzau with 60%, Makueni with 56.7% and Kilome with 50% (Supplementary material 1).

Generally, there was a positive correlation among blast symptom severity on the whole farm and blast symptoms on the fingers of the crop on all the farms surveyed. On farms with higher blast disease symptoms on the whole farm, the fingers of the crop also showed a higher level of infection (0°08'50.2"N 34001'56.4"E Bunyala sub-county 90% severity on the whole farm and 80% severity on the fingers) compared with those on farms with lower percentages (0°54'09.4"S 34°53'08.2"E Bobasi 40% severity on the whole farm and 40% severity on the fingers) (Supplementary material 1). The Pearson correlation tests further revealed a positive correlation ($p < 0.05$) between finger blast severity and neck blast severity (Table 3). Plants with higher severity on the finger than on the other parts also had higher severity on the neck (Supplementary material 1). However, there was no correlation between severity on finger and severity on leaf.

There was a significant difference ($p < 0.01$) in neck blast severity across the different counties surveyed. Similarly, there was a significant statistical correlation of neck blast severity with the different counties surveyed (Table 3). Neck blast symptom severity decreased across the counties. Busia had the highest severity at 37.7%, Makueni at 15%, Kisii at 14.6%, and Bungoma at 13.6% and Machakos at 12% (Supplementary material 1). However, there was variation in the severity within the different sub-counties. Teso south had the highest severity at 40%, Bunyala at 37.7% and Nambale at 31.7% in Busia county. In Bungoma, Kabuchai sub-county had the highest at 18.3%, Kanduyi at 16% and Webuye West at 11%. In Kisii, the Nyaribarichache sub-county had the highest neck severity, at 15%, Bomachogechache at 11% and Bobasi at 9%. Mwalasub-county in Machakos had a severity of 12%. In Makueni, Mbooni east had the highest neck blast

symptom severity at 50%, with Nzau at 21%, Kibwezi east at 15%, Kibwezi west and Kilome at 10% each and Makueni at 4.7% (Table 2). No significant correlation was found between neck blast symptom severity and leaf blast symptom severity.

DISCUSSION

The occurrence of finger millet on all the farms surveyed across different counties suggests that blast disease is highly prevalent in the main finger millet growing areas in Kenya. This scenario is consistent with the results of earlier studies by Oduori (2008) and Gashaw et al. (2014), who revealed that the disease was highly prevalent in Busia, Teso and Kisii districts, causing 10-80% yield losses in both Kenya and Uganda. Similarly, Owere (2013) showed that finger millet blast in Uganda is endemic to all finger millet growing areas with the disease severity being higher in some areas than in others depending on weather conditions. Zhang et al. (2016) have equally shown that blast disease is highly prevalent in areas where host plants are cultivated worldwide. Over 85 countries in both developing and developed nations have reported the incidence of blast especially on finger millet and rice: the key hosts for *M. oryzae*. Although the disease is widespread in all finger millet growing areas, farmers still have limited knowledge about it, thus posing a great challenge to management of the disease.

We observed that finger millet blast distribution varied from farm to farm and county to county. Based on these results, finger millet blast distribution was clustered into two main categories, densely and sparsely distributed. In the western agro-ecological zone (Busia, Bungoma and Kisii counties), the disease distribution was denser than that in the eastern zone (Machakos and Makueni counties), which exhibited a relatively sparse distribution. This observation could be attributed to the different farm management practices and agroclimatic conditions prevalent on the farms and/or counties. Onyango (2016) revealed that appropriate ecological requirements including adequate rainfall that is well distributed all through the year play a significant role in profiling blast disease distribution. Machakos and Makueni counties are semiarid regions and thus receive lower annual rainfall amounts (830 and 834 mm, respectively) and have lower humidity levels than those in Busia (1691 mm), Bungoma (1628 mm) and Kisii (1922 mm). High rainfall conditions with higher humidity levels are favorable conditions for blast fungi survival. Another possibility for the increased blast disease distribution within the western agro-ecological zone could be related to the origin of the finger millet pathogen. *M. oryzae* populations that colonize finger millet and rice in sub-Saharan Africa have shown unique patterns of genetic diversity, mating-type distribution, fertility status and host compatibility. This pattern emulates the different histories and patterns of

cultivation of these crops within East Africa (Takan et al., 2012). Shittu (2018) also confirmed that the frequency of occurrence of *M. oryzae* isolates possessing the transposable DNA elements such as *grh* element varied significantly due to difference in lineage. The study further revealed that the presence of these elements among the rice blasts isolates corresponded to gene flow between rice and other *M. oryzae* hosts. This has provided good knowledge in the understanding of the population dynamic patterns of *M. oryzae* from different hosts. This is supported by earlier studies on the genetics of finger millet blast fungus which revealed a repetitive DNA element grasshopper (*grh*) only in populations of *M. oryzae* from finger millet in Japan, Nepal and India as well as some in West African countries (Viji et al., 2000; Tanaka et al., 2007). However, PCR analysis showed that some indigenous blast populations did not have this element and were unique from the Asian blast populations. The *M. oryzae* isolates that had the *grh* element were recent introductions, and most of the pathogen population in East Africa lacked the *grh* repeat element (Takan et al., 2012; Shittu, 2018). There is thus a high likelihood that the blast pathogen could have been an introduction through the western route possibly through cross-border transfer of finger millet seeds given that finger millet originated from Uganda and that Busia is a border point. This scenario could explain why Busia tends to have a higher disease distribution compared to that of the remaining regions. The presence of certain haplotypes in various locations within Kenya and Uganda further confirms that pathogen movement is highly likely linked to environmental human impacts (Lenne et al., 2007). Furthermore, the disease spread within the western region of Kenya could have occurred through the purchasing of seeds from the market and borrowing from neighbors.

Our results on blast disease severity also revealed that there were variations from farm to farm and county to county due to the different farm management practices and geographical and environmental conditions prevalent in each county. As with the blast disease distribution, severity also followed a similar trend, and the western agro-ecological zones had more farms with severe infections compared with those in the eastern zone. The surveyed farms in Busia County are between altitudes of approximately 1000-1300 m above sea level, with a mean temperature of 22°C. This county is a humid lower midland zone with well-drained soils that are suitable for agriculture. *M. oryzae* infestation tends to be more severe in this area because of high humidity conditions. Furthermore, because of the proximity of Busia to Uganda, there is the possibility of cross-border infection (Onziga, 2015). Bungoma (1200-1400 m above sea level) and Kisii (1500-1800m above sea level) have similar agroclimatic conditions to those of Busia County. Bungoma and Busia counties are within close proximity, so the chances of farmers sharing diseased seeds are

higher. Kisii County may be further away, but the climatic conditions of Kisii, Bungoma and Busia are similar. Besides Kisii county experiences cloudy skies with frequent rains and drizzles: conditions that allow dew accumulation on leaves for a longer period. Such conditions increase blast incidence thus predisposes the plant to blast infection. All three counties experience high humidity, which is a favorable condition for blast fungus to thrive. Moreover, the tropical climate favors the accumulation of blast spores in the air throughout the year which favors continuous disease development (Onyango, 2016).

Machakos (1000-1600 m above sea level) and Makueni (1200-1600 m above sea level) counties are both semiarid regions experiencing low rainfall with low humidity. The extent of disease severity within the farms in these two counties was not substantially different from that in Kisii and Bungoma. In addition to climatic conditions, farm management practices also contributed to disease spread. Most finger millet farms in these two counties had large fruit trees surrounding the farms or near the finger millet farms. Such trees reduce the much needed light intensity and instead increase humidity within the farms, creating favorable microclimatic conditions for the blast pathogen. Whereas the essence of intercropping is to maximize supplementary resource utilization including canopy and root architecture, nutrient fixation and resource sharing on the other hand these can be at the detriment of the plant (Daryanto et al., 2020) as observed by the presence of the large fruit trees present in the finger millet farms. According to Gashaw et al. (2014), presence of microclimatic conditions such as increased humidity due to large tree canopies in the farms predisposes the finger millet plants to blast infection. In addition, most of the farms were on the windward side so that when the wind blows, it facilitates the spread of the pathogen spores thus exposing more plants to blast infection.

Good farm management practice is a gateway to a good harvest and reduced disease infection rates (Meena et al., 2017). Some farmers, especially in Kisii, Makueni and Bungoma, employed appropriate management practices, such as proper spacing, crops rotation, enhancing soil fertility a few months before planting with organic fertilizer and timely weeding. On such farms, there was notably lower disease severity at the whole farm level. There is thus a need to train farmers on finger millet farm proper management techniques to minimize the severity of disease.

Conclusion

Finger millet blast caused by *M. oryzae* occurred throughout the counties in this study; thus, this pathogen is widely distributed in Kenya at high severity levels. However, both the distribution pattern and severity differed across the counties surveyed. The majority of

farmers were not aware that blast infection is a disease. Thus, there is an urgent need to increase farmers' awareness about blast disease. In addition, the development of an integrated disease management strategy that includes resistant varieties and good agronomic practices is needed to safeguard the livelihood of subsistence farmers in Kenya. We are currently performing genetic diversity of the fungi and the finger millet grown in the study areas to relate our results.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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SUPPLEMENTARY MATERIAL

Finger millet blast symptom severity and plant part infected in sampled farms in Kenyan sub counties in 2018-2019.

County	latitude	longitude	Sub county	Severity score		% blast severity in the whole farm	Main part of plant infected	% blast severity per plant part			Level of severity
				Scale	1-3			finger	Neck	leaf	
Busia	0°27'26.8"N	34°07'07.6"E	Teso south	3		90	f, n, l	80	60	30	very severe
	0°33'41.0"N	34°11'12.3"E	Teso south	3		90	f, n, l	80	60	20	very severe
	0°34'59.9"N	34°12'32.3"E	Teso South	2		80	f & n	70	50	10	moderately severe
	0°34'60.0"N	34°12'26.1"E	Teso south	3		90	f, n, l	80	50	25	very sever
	0°32'26.3"N	34°10'11.0"E	Teso south	2		90	f & l	80	10	40	very severe
	0°31'17.9"N	34°09'13.4"E	Teso south	2		80	f & n	80	35	10	very severe
	0°31'03.9"N	34°08'57.1"E	Teso south	2		80	f& n	70	15	40	very severe
	0°26'40.7"N	34°14'23.1"E	Nambale	2		60	f, n	70	30	10	moderately severe
	0°26'26.7"N	34°14'07.7"E	Nambale	2		70	f, n	60	35	5	very severe
	0°24'20.6"N	34°17'11.6"E	Nambale	2		70	f, n	70	30	5	very severe
	0°30'19.2"N	34°11'11.9"E	Teso south	3		90	f, n, l	70	40	20	very severe
	0°08'50.2"N	34°01'56.4"E	Bunyala	2		90	f & n	80	40	5	very severe
0°09'10.1"N	34°04'30.4"E	Bunyala	2		90	f& n	75	35	5	very severe	
Mean						82.31±2.8		74.2±1.8	37.7±4.2	17.1±3.6	
Bungoma	0°31'49.6"N	34°34'44.9"E	Kanduyi	2		70	f & n	70	35	5	very severe
	0°31'40.1"N	34°34'44.8"E	Kanduyi	2		70	f& n	70	25	5	very severe
	0°37'02.3"N	34°40'29.3"E	Kanduyi	1		80	f	60	10	5	very severe
	0°37'07.0"N	34°40'29.3"E	Kanduyi	2		70	f & l	70	5	30	very severe
	0°29'39.5"N	34°37'29.3"E	Kanduyi	2		70	f & l	60	5	30	very severe
	0°33'16.6"N	34°44'20.8"E	Webuye west	1		60	f	50	5	5	moderately severe
	0°31'29.6"N	34°43'29.6"E	Webuye west	1		70	f	40	5	5	very severe
	0°31'29.6"N	34°43'28.6"E	Webuye west	3		70	f,n&l	70	30	10	very severe
	0°36'10.4"N	34°43'58.4"E	Webuye west	1		50	f	40	5	5	less severe
	0°36'40.7"N	34°43'09.5"E	Webuye west	1		50	l	20	5	30	less severe
	0°42'10.4"N	34°37'41.9"E	Kabuchai	2		70	f&l	70	5	30	very severe
	0°42'14.8"N	34°37'45.8"E	Kabuchai	2		80	f& n	70	20	5	very severe
	0°41'28.7"N	34°39'25.9"E	Kabuchai	1		50	l	40	5	30	moderately severe
0°38'09.8"N	34°38'17.9"E	Kabuchai	3		80	f & n	70	30	5	very severe	
Mean						67.1±2.3		57.1±4.5	13.6±3.1	14.3±3.2	

Supplementary material contd.

	0°54'09.4"S	34°53'08.2"E	Bobasi	1	40	f	40	5	2	moderately severe	
	0°54'27.0"S	34°53'18.6"E	Bobasi	3	80	f,n&l	70	40	20	very severe	
	0°52'26.0"S	34°53'33.7"E	Bobasi	1	60	f	50	10	5	moderately severe	
	0°52'51.2"S	34°50'51.0"E	Bobasi	2	60	f & n	50	20	2	moderately severe	
	0°46'37.6"S	34°43'27.5"E	Bomachogechache	2	70	f & n	70	20	5	very severe	
Kisii	0°46'00.5"S	34°42'50.8"E	Bomachogechache	1	60	f	60	5	5	moderately severe	
	0°51'14.8"S	34°43'09.1"E	Bomachogechache	1	60	f	50	5	5	moderately severe	
	0°57'29.2"S	34°44'22.2"E	Bomachogechache	2	70	f & n	60	20	5	very severe	
	0°57'28.8"S	34°44'20.8"E	Bomachogechache	1	50	f	50	5	5	very severe	
	0°35'19.7"S	34°42'50.4"E	Nyaribarichache	1	80	f	60	5	5	very severe	
	0°48'19.4"S	34°52'12.0"E	Nyaribarichache	2	70	f & n	70	30	5	very severe	
	0°47'57.8"S	34°53'27.2"E	Nyaribarichache	1	50	f	70	10	5	very severe	
	Mean					62.3±3.1		58.3±3	14.6±1.3	5.8±3.3	
		1°30'40.7"S	37°36'18.2"E	Mwala	1	60	f	50	10	5	moderately severe
		1°30'40.7"S	37°36'18.2"E	Mwala	1	60	f	60	10	5	moderately severe
Machakos	1°30'40.7"S	37°36'18.2"E	Mwala	1	70	l	30	5	50	very severe	
	1°30'40.7"S	37°36'18.2"E	Mwala	1	70	f	70	15	5	very severe	
	1°30'40.7"S	37°36'18.2"E	Mwala	1	70	f	70	20	10	very severe	
Mean					66±2.4		56±7.5	12±2.6	15±8.8		
	1°55'09.5"S	37°13'10.5"E	Kilome	1	50	f	50	10	5	moderately severe	
	2°00'48.0"S	37°28'51.3"E	Nzau	3	70	f,n&l	60	40	20	very severe	
	2°00'48.0"S	37°28'51.3"E	Nzau	1	50	f	50	2	30	moderately severe	
	2°00'19.4"S	37°28'05.8"E	Kibwezi west	1	60	f	50	10	10	moderately severe	
Makueni	1°59'09.6"S	37°25'51.3"E	Makueni	1	50	f	60	4	11	moderately severe	
	1°58'35.0"S	37°26'05.7"E	Makueni	2	60	f&l	50	5	5	moderately severe	
	1°57'50.9"S	37°25'28.7"E	Makueni	2	60	f & l	60	5	10	moderately severe	
	2°29'56.9"S	37°58'38.8"E	Kibwezi East	3	70	f, n&l	65	15	11	very severe	
	1°36'26.5"S	37°29'27.2"E	Mbooni East	2	60	f & l	55	10	5	moderately severe	
	1°33'53.1"S	37°30'35.0"E	Mbooni East	3	80	f, n&l	90	50	70	very severe	
	Mean					61±3.1		59±3.9	15.1±5.2	17.7±6.3	