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Screening of Finger Millet Genotypes for Resistance to *Pyricularia Grisea* under Varied Agro-Ecologies in Kenya

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Abstract

Pyricularia grisea is the most destructive fungal pathogen causing blast disease in finger millet hence screening for resistance across multiple locations for identification of resistant and high-yielding genotypes is the safest way of controlling the disease. Twenty five (25) selected genotypes were screened in a 5 x 5 *alpha* lattice design with 3 reps in three sites (ATC- Koibatek, Bomet and Nakuru) in two seasons: 2019 short rain season and 2020 Long rain season . To determine resistance to blast and yield performance, four checks were used: NKRFM1, U-15 and P-224 as resistant checks while KNE 741 was susceptible. Data were collected on yield, yield components and disease severity index and analyzed using SAS version 20 and disease data subjected to Area Under Disease Progress Curve (AUDPC). Results showed that seasons, sites, environment and their interactions were significant ($P<0.05$) in expression of neck blast, however, site was not significant in expression of leaf blast recurrence ($P<0.05$), indicating the prevalence of the disease in the regions. In both seasons and sites, genotypes resistant to both leaf and neck blast included: Snapping-Purple, IE-2183, GBK-127189A, Gulu-E, KatFm1xU15-1.6.6.3.1.1, KNE-1124xKNE-796. Commercial checks NKRFM-1, and U-15 had average yields ranging from 2.05 and 1.83 t ha^{-1} while P224 was among highest yielding variety with 2.68 t ha^{-1} as compared to susceptible check KNE-741 had lower yield of 0.55 t ha^{-1}. Correlation analysis showed that an increase in leaf blast significantly increases the chances of neck blast infections by 37% in the field conditions. The study showed a considerable variation in response to blast disease indicating that the resistant varieties could be used for further improvement through breeding. Genotypes Snapping-Purple, IE-2183, GBK-127189A, KatFm1xU15-1.6.6.3.1.1, Gulu-E and KNE-1124xKNE-796 could further be evaluated in multiple locations for possible release as commercial varieties.

Keywords: Finger Millet Varieties, Leaf and Neck Blast, Yield Performance

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INTRODUCTION

Finger millet (*Eleusine coracana* L. Gaertn.) is a staple food crop in Asia and sub-Saharan Africa and perhaps the oldest domesticated cereal grain in Africa. The crop ranks third amongst dryland cereals in importance to the world that is; sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) (Onyango, 2016). Annual world production of finger millet is at 4.5 million tons. India is the largest producer of finger millet with 8.8 million tons. Africa accounts for 2 million of the production (FAOSTAT, 2015). East African production covers 800,000 ha with 470,000 ha in Uganda, 350,000 ha in Tanzania and 77,880 ha in Kenya (Onyango, 2016). It is highly resilient with a special ability to withstand extreme weather conditions of 1000-2000 in East and Southern Africa and 2500-3000 in Himalayas. It has a wide adaptability to soils of pH ranging from 5-7, well-drained sandy-loam soils to black heavy vertisols and can also to erate saline conditions. Rainfall requirement can also vary from 500-1000 mm well distributed throughout the growing season (Green life Crop Protection Africa, 2018). According to FAO 2019, although finger millet production has been increasing with 4.5 million tons in 2018 production growth does not meet demand for finger millet because of the rapidly increasing human population and industrialization. To overcome the challenge, finger millet production has to be increased by at least 40% like other major cereals (Kumar et al*.,* 2016). To date, there is no published data on economic loss due to blast disease in finger millet (Mbinda & Masaki, 2021)

Broadly, finger millet is an important cereal crop in southern Asia and Eastern Africa with excellent nutraceutical properties, a long storage period and a unique ability to grow under arid and semi-arid environmental conditions (Mbinda & Masaki, 2021). The crop is also an important millet crop and has greater nutritional value due to its methionine containing protein which is not found in rice, maize and sorghum. It is one of the novel crops containing a wide range of nutrients from including calcium 358 mg/kg, iron 46 mg/kg, proteins 7.4%, zinc 0.22% and fiber. It is considered as a staple food for pregnant and lactating mothers, children, diabetics and the sick (Takan *et al.,* 2012; Lansakara *et al.,* 2016).

Despite the mentioned benefits, *E.coracana* production and productivity is declining due to a number of biotic stresses such as blast disease (*Magnaporthe grisea* (anamorph *Pyricularia grisea*), downy mildew *Sclerospora graminicola*, rust *Puccinia substriata* and seedling leaf blight *Helminthosporium nodulosum* and insect pests. Improving crops to withstand single and combined stresses remains a major challeng in Kenya causing substantial yield losses. The disease infects the crop from the seedling stage until the harvest period (Mgonja *et al.,* 2007; Srivastaya *et al.,* 2009). Small, spindle-shaped white spots appear at the initial stage of infection which later turns to grey or white with a brown or black margin at the point of infection. Infection of the panicle is the most severe with yield losses above 80% reported. It leads to no seed formation or the formation of shriveled seeds on the panicle leading to a total loss in yield. Infection starts from tips downwards. Due to the importance of finger millet blast disease, which may reduce the crop grain yield to levels of up to 100%, effective disease control measures are needed to ensure global food security, especially in arid and semi-arid regions of Africa and Asia where the crop is majorly cultivated. Over the years, various efforts have been made to develop new cultivars that are resistant to the disease for control and management for example the development of U-15 and P-224 in Uganda (Manyasa *et al.,* 2019) diseases largely depends on chemicals which are usually costly to the marginal farmer.

Understanding the how rainfall, temperature, and relative humidity influence disease infection and development is important (Takan *et al.,* 2013). Blast has caused yield losses of 90% and

provision of knowledge on the host-pathogen and environment is important (Babu *et al.,* 2016). Furthermore, the frequent breakdown of blast resistance because of the susceptibility to rapidly evolving virulent genes of the pathogen causes yield instability in all finger millet growing areas (Mbinda and Masaki, 2021). Therefore the deployment of novel and efficient strategies that provide dynamic and durable resistance against many biotypes of the pathogen and across a wide range of agro-ecological zones guarantees future sustainable production of finger millet. Because to interest and priority in Rese finger millet has received less research attention than maize and rice the limited genomic resources of finger millet have greatly hampered studies of the genetics of resistance to the blast disease compared with other major cereals (Mbinda and Masaki, 2021). As a result, of these shortcomings, the knowledge of broad-spectrum resistance to finger millet blast disease remains limited.

On the other hand, HPR is a mechanism triggered upon pathogen attack that prevents the attack of the pathogen from attacking host tissues therefore offering resistance. It is an effective method in terms of cost, environmental friendly for the control of diseases and pest with inclusion of *P. grisea*. HPR has been successful in management of head blight (*Fusarium graminearium*) in wheat (Rudd *et al.,* 2001), rice blast (*Magnaporthe grisea*) in rice (*Oryza sativa*) (Sharma *et al.,* 2012), and zebra chip disease (*Candidatus* Liberibacter solanacearum) in potato. It has been recommended for the management of finger millet blast (*Pyricularia grisea*) since marginal farmers who cannot be able to access the expensive chemicals can be able to adopt and use new and improved varieties that are resistant to the disease as well as high-yielding (Manyasa *et al.,* 2019). Although screening and selection of finger millet cultivars or new advanced lines toward selected strains of blast fungi have been successful in many breeding programs, caution is needed to avoid risk of limited success since the method relies primarily on the phenotypic features and virulence tests using various hosts which are extremely variable due to the genetic instability of the blast pathogen (Que et al*.,* 2019; Rasool et al., 2020). Additionally, the studies are influenced by environmental and G x E interactions in addition to a long time and high cost for breeders to develop new varieties with broad spectrum resistance to blast disease when these strategies are adopted. Hence the knowledge of the pathogen and host plant resistance of diverse genotypes of finger millet across different geographical locations helps identify multi-location and controlled environment offers resistant lines with stable and durable resistance. The objective of the study was to screen for host plant resistance to blast disease of selected finger millet genotypes under different agro-ecological conditions.

MATERIALS AND METHODS

Site Description

This study was conducted at three sites in Kenya: Agricultural Training Centre (ATC)-Koibatek, Baringo County. ATC Longisa, Bomet County, ATC Soilo, Nakuru County. Koibatek ATC is located at longitude 35° 58’ 0.01” E and latitude 0° 28’ 0.01” N. It has low agricultural potential, with a low-altitude region at 1890 meters above sea level in agro-ecological zone UM4. Mean annual rainfall is 767 mm and mean temperature ranges between 18-24.3°C. Soils are *Vitric Andosols* with moderate to high fertility, well-drained, deep, sandy soils with a pH of 5.2. . ATC Bomet, the experiment was done at ATC Longisa, which lies at longitude 35°20’29.62” E and latitude of 0° 46’52.64” N. It is a medium altitude zone with evenly distributed rain throughout the year and a mean rainfall of 1000-1400 mm. The mean monthly temperature is 17.2 °C. ATC Soilo lies at a longitude of 36°04'0.01" E and a latitude

of 0°16'59.99" N with a mean annual rainfall of 1012mm, well distributed and temperature ranges of 15°C-20°C respectively. Soils are *Molliac Andosols*, well drained dark reddish brown. (Jaetzold and Schmist, 2012).

Plant Genotypes

Twenty-five (25) finger millet genotypes were screened for resistance to *Pyricularia grisea* under field conditions. The genotypes were sourced from ICRISAT, Egerton Seed Unit, KALRO, Genebank of Kenya and Local varieties. NKRFM1, U15 and P224 are commercial varieties that were used as resistant checks while KNE-741 was used as a susceptible check since they have varied levels of resistance, phenology and maturity (Table 1).

Table 1: List of Finger millet genotypes evaluated ATC Bomet, Koibatek and Nakuru.

No	Genotype	Source	Description
1	P-224	Kenya Seed	Commercial variety, medium maturity
2	U-15	KALRO	Commercial, Red early maturing
3	NKRFM1	Egerton	Commercial Red early maturing
4	KatFm1×U15-1.7.8.2.1	KALRO	Advanced breeding line
5	IE 615	ICRISAT	Advanced breeding line
6	KNE1034	ICRISAT	Advanced breeding line
7	GBK027189A	Gene Bank	Advanced breeding line
8	IE 2183	ICRISAT	Advanced breeding line
9	IE 2872	ICRISAT	Advanced breeding line
10	Kal Dokolo	Local	Local land race
11	Otiyo brown	Local	Local land race
12	Kal 2 Pader	Local	Local land race
13	KNE 628	ICRISAT	Advanced breeding line
14	Kal pader	Local	Local land race
15	Snapping purple	Egerton	Commercial variety
16	KAT FM1	KALRO	Commercial variety
17	EUFM 2 (KNE 741)	Egerton	Early maturing and escapes drought
18	Ikhulule	Local	Moderately tolerant to blast
19	Gulu E	ICRISAT	Moderately tolerant to blast
20	EUFM4	Egerton	Newly released commercial for lowlands
21	EUFM1 (KNE 629)	ICRISAT	High tillering and late maturing
22	Snapping green early	Egerton	Early maturing, easy for harvesting
23	KATFM1×U15 1.6.3.3.1	KALRO	Advanced breeding line
24	KNE 1124×KNE 796	ICRISAT	Advanced breeding line
25	KATFM1×U15 1.6.6.3.1.1.	KALRO	Advanced breeding line

Experimental Design and Treatments

Field Experimental Layout, Design and Agronomic Procedures

Land preparation as recommended. In order to achieve good soil tilth for finger millet planting and for fast germination of small seeded grain, a fine tilth was obtained by thorough harrowing. The experiment was laid out in an alpha lattice design (5 x 5) with three replications. A plot of 2 m by 2 m with four rows spaced 0.3 m apart with a plant to plant distance of 0.15 m was used. The experiment was conducted in two seasons. June-December 2019 and March-September 2020. The susceptible genotype (KNE 741) was planted in all the three sites around each plot as disease spreader to enhance disease development and spread to the test genotypes. Planting was done using recommended 50 kg/ha nitrogenous fertilizers; NO_3 of 19.36 kg/Ha and NH_4^{2-} of 5.62 kg/Ha with DAP of 18.46.0 as a source and NO_3 at a rate of 25 kg/Ha with 26% N CAN as a source which was the top-dresser. Data were taken on five plants randomly selected and tagged in all the plots at the two center rows to avoid the border effect at all sites.

Data Collection

Disease Data Collection

Disease severity rating (DSR) (% damage) was done on the first four leaves (flag) where five plants were randomly tagged per plot. Disease severity on tagged plants was recorded at tillering, flowering, and physiological maturity stages on 5 randomly selected and tagged individual plants on each plot and each plant in the field and the greenhouse respectively using modified Cobb scale (Kiran *et al.,* 2017). Leaf blast was scored based on percent surface area of the infected leaves was evaluated as *P. grisea* severity was used as an indication of severity (Table 2). Neck blast severity was based on the relative lesion size on the neck. A 1 to 5 progressive rating scale will be used where, 1 = no lesions to pin head size of lesions on the neck region, 2 = 0.1 to 2.0 cm size of typical blast lesion on the neck region, 3 = 2.1 to 4.0 cm, 4 = 4.1 to 6.0 cm, and 5 = >6.0 cm size of typical blast lesion on the neck region (Figure 1). The data were then subjected to AUDPC and terminal severity data were used to compare cultivars as resistant, moderately resistant, susceptible and moderately susceptible.

Table 2: A Quantitative Severity Scale for Foliar Blast Disease on Finger Millet.

Scores	Reaction Category	Appearance of Genotypes
1	Highly resistant	Less than 10% of the leaves damaged
2	Resistant	11-20% of the leaves damaged
3	Intermediate	31 to 40% of the leaves damaged
4	Susceptible	51 to 70% of the leaves damaged
5	Highly susceptible	71 to 100% of the leaves damaged

Source: *(Babu et al., 2015)*



Figure 1: Panicle showing peduncle damage rating where 1- no symptom and 5- severe symptom.
Source: *(Babu et al., 2015)*

Agronomic Data Collection

Data on yield and yield parameters taken in all three (Bomet, Nakuru and Koibatek) included measurements of the five tagged plants.

The number of tillers was counted on five plants. Plant height was measured using a 100 cm ruler from the base level to the tip of the panicle on the five tagged plants selected randomly in the middle row. At 50% flowering dates were recorded. When the crop had 50% DTM (Days to Maturity), the number of fingers per panicle was counted and the length of the panicles was measured using a 30cm ruler for the straight type of fingers and a string was used to measure the folded fingers and the string was placed on a ruler.

Grain yield was measured by harvesting the heads from the net plot area ($1m^2$) (2 middle rows) manually using a knife. They were then sun-dried for 7 days, threshed using sticks and cleaned by winnowing. After obtaining the seeds they were further sun-dried to 15% moisture content. Each plot was weighed separately and the plot yield was converted to (Kg/ha). 1000 KW and 100 KW seed weight was measured using an electronic seed counter Contador.

Weather data was recorded periodically at all ATC sites during both seasons. Rainfall was measured using a rain gauge, maximum and minimum temperatures were measured using a thermometer, and humidity used using a hygrometer (Table 3).

Table 3: Temperature, rainfall and relative humidity recorded in ATC- Nakuru, Baringo and Bomet counties during the short rain season (2019) and the long rain season (2020).

NAKURU 2019						NAKURU 2020					
	Temperature		Rainfall (mm)	Relative humidity			Temp		Rainfall (mm)	Relative humidity	
Month	Max (ºC)	Min (ºC)		Max (%)	Min (%)	Month	Max (ºC)	Min (ºC)		Max (%)	Min (%)
JUN	24.23	14.06	104.5	65	35	MAR	27.87	14.19	120.4	70	55
JULY	24.22	12.71	98.05	66	29	APR	25.76	14.5	228.9	79	75
AUG	24.45	11.29	44.06	63	25	MAY	25.70	14.12	89.4	75	69
SEPT	26.00	12.23	62.06	60	25	JUNE	24.7	13.6	113.5	72	65
OCT	24.16	13.19	197.66	60	28	JULY	23.61	13.35	137.3	76	68
NOV	24.90	13.60	86.27	62	39	AUG	24.87	13	105.1	57	23
DEC	24.22	13.45	236.45	58	10	SEPT	26	12.48	86.8	60	21
BARINGO 2019						**BARINGO 2020**					
	Temperature		Rainfall (mm)	Relative humidity			Temp		Rainfall (mm)	Relative humidity	
Month	Max (ºC)	Min (ºC)		Max (%)	Min (%)	Month	Max (ºC)	Min (ºC)		Max (%)	Min (%)
JUN	27.3	19.00	101.1	93	48	MAR	28.96	18.51	235.4	45	0
JUL	27.8	17.74	145	90	45	APR	28.93	19.1	215.2	75	9
AUG	28.96	17.64	39	93	45	MAY	28.09	18.96	90.0	89	15
SEPT	29.13	17.76	326	81	30	JUN	27.3	18	77.1	79	10

OCT	28.51	18.16	299.9	83	35	JUL	27.25	17.80	200.3	98	20
NOV	28.46	18.56	230.2	87	39	AUG	28.38	17.25	87.9	45	0
DEC	27.45	18.25	181.9	65	29	SEPT	28.55	17.52	80.9	45	5
	BOMET 2019						**BOMET 2020**				
	Temperature		**Rainfall (mm)**	**Relative humidity**			**Temp**		**Rainfall (mm)**	**Relative humidity**	
Month	**Max (ºC)**	**Min (ºC)**		**Max (%)**	**Min (%)**	**Month**	**Max (ºC)**	**Min (ºC)**		**Max (%)**	**Min (%)**
JUN	24.20	14.03	231.73	59	30	JAN	25.8	13	36.3	39	31
JULY	24.19	12.67	126.40	80	21	FEB	27.65	13	41.3	32	30
AUG	24.39	11.29	87.17	74	20	MAR	27.87	14	120.4	60	35
SEPT	25.93	12.36	72.64	77	20	APR	25.77	15	228.9	82	60
OCT	24.16	14.22	229.19	80	25	MAY	26	14	113.5	83	58
NOV	24.90	13.60	99.52	67	39	JUN	24.7	14	137.3	55	30
DEC	24.19	13.77	248.81	40	25	JULY	23.6	13	105.1	30	21

Data Analyses

Area Under Disease Progress Curve (AUDPC) was used to estimate the severity of leaf and head blast disease in finger millet. It was computed using Wilcoxson *et al.* (1975) formula (Equation 1).

$$\text{AUDPC}= \sum_{i=1}^{n}\left(\frac{(yi+yi+1)}{2}\times(t_{i+1}-ti)\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 1$$

Where: yi = disease severity % on the ith scoring, ti = number of days from sowing to ith scoring, n= total number of scoring t_{i+1} is second assessment date of two consecutive assessment and y_{i+1} is disease severity on assessment date ($i+1$).

All the data collected were subjected to homogeneity test using Barlet's test . Analysis of variance (ANOVA) with locations, seasons and replications as random effects genotypes as fixed effects was computed using Statistical Analysis software version 9.2 (SAS institute Inc; Cary 2002) with the following model;

$$Y_{ijklm} = \mu + L_i + S_j + LS_{ij} + B_k + V_l + LV_{il} + VS_{jl} + VLS_{ijl} + \varepsilon_{ijkl} \ldots\ldots\ldots Equation\ 2$$

Where;

Y_{ijklm} is the overall observation, L_i is the i^{th} effect due to location, S_j j^{th} effect due to season, LS_{ij} the interaction between the i^{th} location effect and j^{th} season effect, B_k k^{th} block effect, V_l is the l^{th} variety effect and LV_{il} is the interaction between the i^{th} variety effect and l^{th} location, VS_{jl} is the interaction between the j^{th} season effect and l^{th} variety effect, VLS_{ijl} is the interaction of the i^{th} location effect j^{th} season effect and l^{th} variety effect, ε_{ijkl} is the random error.

Means were compared using the Duncan Multiple Range Test to detect detect true differences among group means at 5% level of significance given by the following formula;

$$Rp = rp\sqrt{\frac{MSE}{r}} \quad \text{.....Equation 3}$$

Where *Rp* - DMRT at 5% level of significance q= Number of treatment means, *fe* =degrees of freedom of error, α= Level of significance, *MSE*= mean square error and *r* =Number of replicates.

Pearson's correlation analysis was performed to determine the relationship between leaf and head AUDPC and yield and yield components of finger millet using the following formula;

Pearson's Correlation= $r = [n\Sigma xy - (\Sigma x)(\Sigma y)] / \sqrt{\{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]\}}$

Where;

r = Pearson correlation coefficient.

n = Number of paired observations.

x = Observations of the first variable.

y = Observations of the second variable.

Σxy = Sum of the products of paired observations.

Σx and Σy = Sums of observations for variables X and Y, respectively.

Σx^2 and Σy^2 = Sums of squared observations for variables X and Y, respectively. (Herrero *et al.,* 2011).

RESULTS

Host Plant Resistance to Leaf Blast in of Finger Millet Genotypes across Agro-Ecologies (Nakuru, Bomet and Koibatek)

The combined ANOVA showed that there was significant differences ($P<0.05$) in site, season, genotype (G) and their interactions; genotype (G) x site (S), genotype (G) x season (Year) and site x season x genotype effects on the severity of both foliar and neck blast test genotypes as shown in Table 4. The significant difference ($P<0.05$) in seasons showed that long rain season (2020) had a significantly ($P<0.05$) higher leaf severity (72.99) compared to the short rain season (2019) (39.42) (Table 5).

Overall means leaf severity value (AUDPC) were 56.2 with Koibatek having the highest mean of 59.6 (35.36%) while Nakuru and Bomet did not differ significantly ($P<0.05$) with a mean value of 55.2 (31.75%) and 53.76 (31.88%) respectively (Table 5). The results further indicated that during short rain season one (2019), the interaction between site and variety had a strong influence on leaf blast severity ($P\leq0.001$), however, site had no significant effect on leaf severity (Table 5). Bomet had a significantly ($P<0.01$) higher value of 39.89 (33.71%) followed by Nakuru 39.77 (33.60%) and Koibatek 38.67 (32.67%) (Table 5). In general, season 2 had high infection rates of blast compared to season one (Figure 2).

In general, during season one, mean separation of varieties from combined analysis revealed that KNE-741, P-224, KNE-1034, Kat-Fm1 were susceptible to leaf blast with mean severity values of ≥ 64 in all the sites in contrast to GBK-127189A, Snapping-Purple, KNE-1124 x KNE-796, Gulu-E and U-15 which were resistant to leaf blast with mean severity values of ≤ 49 (Table 6).

In season two, long rain season (2020), the interaction G x S had a strong influence on leaf blast severity. Comparison of sites indicated that Koibatek had a significantly ($P<0.05$) higher mean severity of 82.73 while Nakuru and Bomet did not differ significantly ($P<0.05$) with 70.39 and 68.94 respectively (Table 5). Mean separation of varieties in season two revealed genotypes resistant to leaf blast during this season included GBK-127189A, Kal Pader, Kal Dokolo, IE-615, Kat Fm1xU15 1.6.6.3.1.1 and KNE1124 x KNE796 had severity values ≤ 66 and were therefore rated as resistant. In contrast, genotypes P224, Kal 2 Pader, Snapping green early, KatFm1x U15 1.6.3.3.1, KNE 1034 and SDFM-1702 with severity values of ≥83 were susceptible to leaf blast (Table 6).

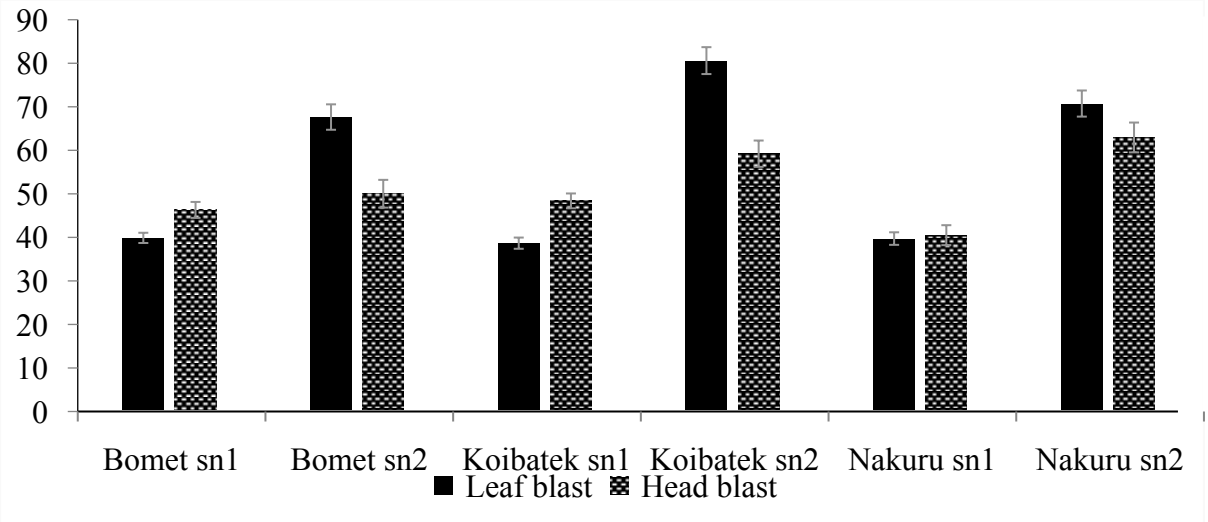


Figure 2: Leaf and neck blast severity during the first and second seasons of the three sites

Table 4: Combined ANOVA table for finger number, finger length, height, tillers, days to maturity, kernel weight, Biomass, yield, harvest index, leaf and neck blast AUDPC of 25 finger millet genotypes for the short rain season (2019) and long rain season (2020).

Source of variation	d.f	Finger number	Finger length	Height	Tillers	Days to maturity	Kernel weight
Site	2	77.53^{***}	85.16^{***}	38507.35^{***}	126.38^{***}	636.19^{*}	0.39^{*}
Season	1	214.37^{***}	110.58^{***}	2938.79^{***}	2312.23^{***}	6550.77^{***}	58.84^{***}
Site x Season	2	125.28^{***}	123.82^{***}	11787.96^{***}	142.28^{***}	728.86	23.06^{***}
Variety	24	4.58^{***}	8.55^{***}	226.15^{*}	15.68^{***}	233.67^{***}	0.65^{***}
Site x Variety	48	4.34^{***}	5.56^{***}	190.74^{*}	10.85^{***}	380.44	0.32^{***}
Season x Variety	24	5.54^{***}	5.14^{***}	26.72^{*}	17.29^{***}	207.12	0.59^{***}
Site x Season	48	5.24^{***}	5.59^{***}	180.49	9.08^{***}	164.35	0.29^{***}

x Variety							
Rep(block)	14	1.52	3.31***	269.58*	10.16***	205.69	0.08
Error		1.49	1.07	130.87	1.70	165.27	0.12
CV		20.1	15.90	17.87	23.89	13.63	12.58
R^2		76.9	82.33	79.07	85.69	52.73	83.48

Table 5: Combined DMRT table for the sites and seasons; season 1- short rain season (2019) and season 2-long rain season (2020) showing finger number, finger length, height, tillers, days to maturity, kernel weight, Biomass, yield, harvest index, leaf and neck blast AUDPC of 25 finger millet genotypes.

Site	Finger number	Finger length	Height	Tillers	Laudpc	Naudpc	Days to maturity	Kernel weight	Biomass	Yield t/ha	HI
Nakuru	5.87^{b}	6.76^{b}	82.69^{a}	8.15^{a}	55.23^{b}	51.73^{a}	92.33^{b}	2.84^{a}	1.87^{a}	1.53^{b}	1.25^{b}
Koibatek	5.45^{c}	5.69^{c}	54.72^{b}	6.63^{b}	59.63^{a}	53.81^{a}	96.69^{a}	2.73^{b}	1.73^{b}	1.47^{c}	1.29^{b}
Bomet	6.91^{a}	7.13^{a}	54.68^{b}	6.56^{b}	53.76^{b}	48.71^{b}	94.06^{ab}	2.85^{a}	1.86^{a}	2.06^{a}	1.58^{a}
DMRT (P<0.05)	0.2796-0.2943	0.2359 - 0.2483	2.615-2.747	0.3761 - 0.3959	3.154-3.320	3.106-3.270	2.951-3.107	0.0821 - 0.8676	0.0510-0.0537	0.0419-0.0444	0.0436 - 0.0459
Season											
1	6.75^{a}	7.02^{a}	61.47^{b}	9.37^{a}	39.42^{b}	45.06^{b}	98.01^{a}	3.18^{a}	1.83^{a}	1.38^{b}	1.18^{b}
2	5.38^{b}	6.03^{b}	66.60^{a}	4.83^{b}	72.99^{a}	57.40^{a}	90.35^{b}	2.42^{b}	1.81^{a}	1.99^{a}	1.56^{a}
DMRT (P<0.05)	0.2283	0.1928	2.1350	0.3071	2.571	2.551	2.409	0.6732	0.0416	0.0342	0.0355

**F.N=Finger number, F.L= Finger Length, LAUDPC= Leaf blast severity, NAUDPC= Neck Blast severity, DTM=Days to maturity, Yieldt= Yield t Ha-1, HI= Harvest Index. Means under the same letters are not significantly different (p<0.05).*

The combination of both seasons showed that genotypes including Snapping-Purple, IE-2183, GBK-127189A, Gulu E and Kal 2 Pader were resistant to leaf blast with AUDPC values ≤ 33 in Nakuru. P-224, IE-2183, Snapping green, GBK-127189A and SDFM-1702 were resistant in Koibatek with ≤31. Snapping-Purple, IE2183, GBK127189A, GULUE, IE2872 and Kal Pader were resistant in Bomet with ≤33. Resistant check P224 had mean AUDPC values of 36, 24.5 and 44 in Nakuru, Koibatek and Bomet respectively (Table 6).

Overall, genotypes resistant to leaf blast in all sites combined included GBK-127189A (40.88), Snapping-Purple (45.13), KNE 1124 x KNE796 (42.27), Gulu E (48.93) and U15 (49.93) while varieties KNE 741 (70.11), P224 (66.72), KNE 1034 (65.14), KatFm1 (64.23) were susceptible to leaf blast across all sites and seasons (Table 7).

Table 6: Leaf and neck AUDPC of 25 varieties planted in varied agro-ecologies (Nakuru, Koibatek and Bomet ATC regions).

	NAKURU ATC				KOIBATEK ATC				BOMET ATC			
	LAUDPC		HAUDPC		LAUDPC		HAUDPC		LAUDPC		HAUDPC	
	SN1	SN2	SN1	SN2	SN1	SN2	SN1	SN2	SN1	SN2	SN1	SN2
GBK 127189A	30.3	31.4	22.1	29.8	28.0	33.8	33.8	30.8	31.5	30.3	29.1	22.1
GULU E	31.5	31.5	21.0	29.5	36.1	56.0	56.0	44.6	31.5	31.0	35.0	21.0
IE 2183	31.5	29.1	21.0	29.1	22.1	33.8	33.8	35.6	29.7	31.5	29.7	21.0
IE 2872	33.8	38.7	40.8	38.5	37.3	39.6	39.6	42.8	33.8	32.6	38.5	47.5
IE 615	31.5	35.0	26.8	35.0	36.1	39.6	39.6	34.5	35.0	36.5	35.0	25.4
IKHULULE	33.8	42.0	43.1	40.8	43.1	54.8	54.8	68.1	42.0	39.6	40.3	54.8
KAL 2 PADER	35.0	31.4	31.5	35.0	37.3	46.6	46.6	42.8	29.1	38.5	35.0	31.5
KAL DOKOLO	42.0	46.6	43.1	57.1	37.3	43.1	43.1	72.3	46.6	42.0	57.1	34.8
KAL PADER	35.0	35.7	36.1	44.3	56.0	69.1	67.6	36.5	38.5	47.1	44.3	42.8
KATFM1	47.8	54.1	52.5	70.0	49.0	66.5	66.5	62.5	54.8	57.8	70.0	52.5
KATFM1× U15.1.6.3.3 .1	38.5	30.3	54.8	29.1	40.8	32.6	66.5	44.6	42.0	40.8	46.6	42.0
KATFM1× U15 1.6.6.3.1.1	40.8	39.9	42.0	46.6	29.1	66.5	32.6	36.5	30.3	38.5	29.1	54.8
KATFM1 × U15 1.7.8.2.1	43.1	43.1	47.8	53.6	32.6	44.3	44.3	38.3	43.1	43.1	53.6	47.8
KNE 1034	38.5	51.3	29.1	65.4	40.8	63.0	63.0	58.6	51.3	38.5	63.0	29.1
KNE 1124 × KNE 796	31.5	37.3	33.8	47.8	31.5	39.6	39.6	40.9	38.5	30.3	47.8	33.8
KNE 628	51.3	41.9	71.1	43.1	43.1	60.6	60.6	77.1	45.5	51.3	43.1	71.1
KNE 629	36.1	41.1	33.8	49.0	38.5	47.8	47.8	44.6	39.6	36.1	49.0	33.8
KNE 741	68.8	60.7	78.1	77.0	66.5	77.0	77.0	78.6	60.6	65.4	77.0	78.1
NKR FM1	38.5	54.6	59.5	65.3	49.0	59.5	59.5	36.5	56.0	38.5	65.3	59.5
OTIYO BROWN	49.0	37.3	52.5	49.0	43.1	45.0	46.6	53.5	37.3	49.0	49.0	52.5
P-224	44.3	29.1	40.8	29.1	24.5	19.8	19.8	27.4	29.1	44.3	29.1	29.4
SDMF 1702	33.8	34.4	25.6	50.1	26.8	36.1	36.1	46.5	36.1	32.6	50.1	25.6
Snapping-Green-Early	39.6	37.4	57.1	52.5	29.1	29.1	39.6	40.6	36.1	39.6	52.5	57.1

Snapping-Purple	29.1	24.5	21.0	23.8	35.0	35.0	33.8	39.3	24.5	28.0	31.5	21.0
U-15	32.6	57.6	37.3	66.5	49.0	49.0	60.6	61.8	57.1	28.9	66.5	22.9
Means	**39.7**	**40.5**	**70.3**	**66.2**	**38.6**	**48.3**	**82.7**	**60.8**	**39.8**	**46.3**	**68.9**	**50.7**

Neck Blast Resistance of Selected Genotypes in Varied Agro Ecologies (Nakuru, Bomet and Koibatek).

Results from combined ANOVA indicated that site, season, site x season, variety, site x variety, season x variety and the interaction of site, season and variety had a significant effect ($P \leq 0.01$) on severity of neck blast on the selected finger millet genotypes (Table 4). Long rain season (2020) had a significantly ($P<0.05$) higher neck blast severity compared to short rain season (2019) (Table 5). All sites differed significantly, Nakuru had a high neck blast severity differ significantly ($P<0.05$) with AUDPC mean severity in the two sites with 53.81 and 51.73 AUDPC values respectively (Table 9)

During the short rain season (2019), Nakuru had a high occurrence of blast diseases with 64.77 in contrast to Koibatek and Bomet with AUDPC mean severity of 59.27 and 48.94 respectively 46.52 respectively while Nakuru had the lowest mean of 41.89 (Table 10). All sites were significantly different ($P<0.01$) with higher head infection in Nakuru than in Koibatek and Bomet and AUDPC mean values of 64.77, 59.27 and 49.55 respectively (Table 10).

In both seasons, when compared to the resistant and commercial check P224, genotypes Snapping-Purple, IE-2183, GBK-127189A, Gulu E, Kal 2 Pader and IE-2183 were resistant to neck blast with AUDPC mean severity values of ≤33 in Nakuru KATFM1 x U15 1.6.6.3.1.1, IE-2872, Snapping-Purple and KATFM1x U15 1.7.8.2.1 were resistant in Koibatek with mean severity of ≤36. Genotypes Snapping-Purple, IE2183, GBK127189A, GULUE, P224 and IE-615 were resistant in Bomet with AUPDC mean severity of ≤30 (Table 6; Table 7)

In general, genotypes AUDPC values showed that NKRFM1 (71.43), KNE-628 (66.16), Etiyo Brown (64.96), Kal Dokolo (61.10) and KATFM1 (61.10) were susceptible to neck blast while genotypes resistant to neck blast included Snapping-Purple (33.19), GBK-127189A (35.37), SDFM-1702 (40.64), P224 (41.86), Kat Fm1xU15 1.6.6.3.1.1 (43.02), IE-2183 (43.94) and GuluE (44.70) in all the sites and seasons (Table 7).



Figure 3: Genotype KNE 741 showing its susceptibility to both leaf and neck blast.

Table 7: Combined mean table for varieties, yield and yield parameters.

No.	Variety	F.N	F.L	Height	Tillers	Laudpc	Naudpc
1	KatFm1×U151.6.6.3.1.1	4.84^{g}	6.07^{e-h}	60.36^{b-d}	6.33^{e-g}	48.27^{f-h}	43.02^{f-i}
2	KatFm1 × U15 1.6.3.3.1	5.50^{e-g}	6.09^{e-h}	59.21^{cd}	6.12^{e-g}	60.84^{a-e}	51.74^{c-f}
3	KatFm1 × U15 1.7.8.2.1	6.29^{a-e}	6.70^{c-f}	65.41^{a-c}	6.85 $^{c-g}$	59.08^{b-e}	51.59^{c-g}
4	KNE 1124 × KNE 796	6.11^{b-f}	7.09^{bc}	65.26^{a-c}	6.14^{e-g}	48.27^{gh}	51.16^{c-g}
5	Snapping Green Early	5.87^{c-e}	5.79^{gh}	57.95^{cd}	5.95^{fg}	60.74^{a-e}	60.22^{b-d}
6	KNE 629	5.65^{d-g}	6.06^{e-h}	68.92^{ab}	6.65^{c-g}	51.15^{d-h}	47.59^{e-f}
7	P-224	5.82^{c-e}	6.64^{c-f}	63.03^{a-c}	6.73^{c-g}	66.72^{ab}	41.86^{f-i}
8	SDFM-1702	6.16^{b-e}	6.92^{b-d}	61.17^{c-d}	10.45^{a}	58.99^{b-f}	40.64^{g-i}
9	KNE 1034	6.04^{c-e}	6.99^{c-d}	67.15^{a-c}	5.58^{g}	65.14^{a-c}	50.93^{c-g}
10	NKR FM1	7.16^{a}	9.26^{a}	66.83^{a-c}	6.87^{c-g}	61.11^{a-d}	71.43^{a}
11	Gulu E	6.09^{b-f}	5.69^{h}	63.93^{a-c}	7.59^{c-d}	48.93^{f-h}	44.70^{f-h}
12	Ikhulule	6.71^{a-c}	6.20^{e-h}	60.83^{c-d}	7.36^{c-e}	61.88^{a-d}	47.96^{e-g}
13	KNE 741	6.77^{a-c}	6.62^{c-g}	65.80^{a-c}	6.29^{e-g}	70.11^{a}	61.00^{bc}
14	U-15	6.32^{a-e}	5.95^{f-h}	64.82^{a-c}	7.74^{c}	49.94^{e-h}	46.78^{fg}
15	KAT FM1	5.61^{d-g}	6.05^{e-h}	63.36^{a-c}	7.54^{cd}	64.23^{a-c}	61.10 ^{bc}
16	Snapping-Purple variety	7.05^{ab}	6.79^{b-e}	62.68^{bc}	9.24^{b}	45.14^{gh}	33.19^{i}
17	KNE 628	6.18^{b-e}	6.08^{e-h}	61.45^{c-d}	7.25^{c-f}	60.04^{a-e}	66.16^{ab}
18	Kal Pader	6.07^{c-e}	6.30^{c-h}	69.76^{ab}	7.52^{cd}	52.95^{d-g}	50.09^{d-g}
19	Kal 2 Pader	5.16^{fg}	5.95^{f-h}	67.07^{a-c}	6.71 $^{c-g}$	58.35^{b-f}	45.96^{fg}
20	GBK 027189A	6.55^{a-d}	6.83^{b-e}	72.24^{a}	7.56^{cd}	40.88^{h}	35.37^{h-i}
21	IE-615	6.31^{a-e}	6.78^{b-f}	67.03^{a-c}	7.93^{c}	54.55^{c-g}	48.62^{e-g}
22	Otiyo Brown	5.91^{c-f}	6.30^{c-h}	63.77^{a-c}	6.89^{c-g}	58.89^{b-f}	64.96^{ab}
23	IE-2183	5.69^{d-g}	7.56^{b}	53.83^{d}	6.68^{c-g}	54.16^{c-g}	43.94^{f-h}
24	IE 2872	6.08^{c-e}	5.96^{f-h}	63.63^{a-c}	7.60^{cd}	54.02^{c-g}	57.50^{b-e}
25	Kal Dokolo	5.81^{c-e}	6.48^{c-h}	64.25^{a-c}	6.30^{e-g}	51.61^{d-g}	63.31^{ab}
	DMRT (P<0.05)	0.81-1.02	0.68-0.86	7.55-9.52	1.12-1.41	9.09-11.46	9.02-11.37

*F.N=Finger number, F.L= Finger Length, LAUDPC= Leaf blast severity, NAUDPC= Neck Blast severity.

Table 7 continued…

No.	Variety	DTM	KW	Biomass	YieldT	HI
1	KatFm1×U151.6.6.3.1.1	100.44^{a}	3.00^{a-c}	1.86^{b-e}	1.66^{h}	1.30^{d}
2	KatFm1 × U15 1.6.3.3.1	93.66^{ab}	2.53^{h-j}	1.83^{b-e}	2.89^{ab}	1.42^{a-d}
3	KatFm1 × U15 1.7.8.2.1	99.94^{a}	2.93^{a-e}	1.83^{b-e}	2.34^{b-e}	1.35^{cd}
4	KNE 1124 x KNE 796	90.41^{a-c}	2.73^{c-i}	1.98^{ab}	1.91^{e-f}	1.33^{cd}

5	Snapping Green Early	94.94^{b}	2.93^{a-e}	1.73^{ef}	1.87^{e-h}	1.35^{b-d}
6	KNE 629	94.17^{ab}	2.94^{a-e}	1.80^{b-f}	2.26^{c-g}	1.38^{b-d}
7	P-224	90.70^{a-c}	2.64^{f-i}	1.86^{b-e}	2.68^{a-c}	1.36^{b-d}
8	SDFM-1702	97.05^{ab}	2.98^{a-c}	1.74^{ef}	1.76^{f-h}	1.33^{cd}
9	KNE 1034	91.61^{a-c}	2.94^{a-e}	1.79^{c-f}	2.01^{d-h}	1.41^{b-d}
10	NKR FM1	93.11^{ab}	2.96^{a-d}	2.11^{a}	2.05^{d-h}	1.38^{b-d}
11	Gulu E	91.11^{a-c}	2.30^{j}	1.77^{d-f}	2.58^{a-d}	1.46^{a-c}
12	Ikhulule	98.33^{a}	2.73^{c-i}	1.85^{b-e}	2.94^{a}	1.42^{a-d}
13	KNE 741	82.65^{c}	2.91^{a-c}	1.80^{b-f}	0.55^{i}	1.43^{a-d}
14	U-15	94.00^{ab}	3.01^{a-c}	1.79^{c-f}	1.83^{f-h}	1.35^{cd}
15	KAT FM1	94.00^{ab}	3.15^{a}	1.78^{c-f}	1.83^{f-h}	1.33^{cd}
16	Snapping-Purple variety	95.71^{ab}	2.80^{b-f}	1.64^{f}	1.57^{h}	1.33^{cd}
17	KNE 628	94.17^{ab}	2.88^{a-f}	1.93^{b-d}	2.05^{e-h}	1.34^{cd}
18	Kal Pader	95.94^{ab}	2.94^{a-e}	1.79^{c-f}	1.71^{gh}	1.33^{cd}
19	Kal 2 Pader	99.88^{a}	2.72^{c-i}	1.96^{a-c}	1.80^{f-h}	1.32^{cd}
20	GBK 027189A	99.88^{a}	2.66^{e-i}	1.93^{b-d}	1.81^{f-h}	1.31^{cd}
21	IE-615	93.33^{ab}	2.56^{g-j}	1.76^{d-f}	2.44^{a-e}	1.45^{a-d}
22	Otiyo Brown	96.44^{ab}	3.05^{ab}	1.70^{ef}	2.33^{b-e}	1.38^{b-d}
23	IE-2183	94.05^{ab}	2.45^{ij}	1.69^{ef}	1.81^{f-h}	1.31^{cd}
24	IE 2872	88.05^{bc}	2.67^{e-i}	1.72^{ef}	2.63^{a-c}	1.51^{ab}
25	Kal Dokolo	92.11^{ab}	2.81^{b-f}	1.86^{b-e}	2.76^{a-c}	1.55^{a}
	DMRT (P<0.05)	8.50-10.72	0.2389-0.3011	0.6271-0.7905	0.4923-0.6207	0.1260-0.1589

*D.T.M=Days to maturity, KW= Kernel weight, YiledT= Yield t Ha $^{-1}$, H.I= Harvest Index

Genotypic Variation in Yield and Yield Traits of Finger Millet Varieties

Results from the combined ANOVA across seasons and sites indicated that site, season, site x season, variety, site x variety, season x variety, site x season x variety had a significant (P<0.05) effect on yield and yield traits of finger millet genotypes (Table 4). The grand mean yield from the two seasons (2019-2020) in all three sites was 1.68 t ha^{-1}. Season two (2020) had the highest mean yield of 1.99 t ha^{-1} while season one had 1.38 t ha^{-1} (Table 9). Bomet had the highest yield across all seasons with a mean of 2.06 t ha^{-1}, followed by Nakuru with 1.53 t ha^{-1} while Koibatek recorded the lowest yield of 1.46 t ha^{-1} (Table 5).

When comparing seasons and sites, Bomet season two had high performance compared to season one with 2.72 and 1.39 t ha^{-1} respectively (Table 5). Overall, the high yielding genotypes in Bomet included Kal Dokolo, IE-615, KNE 741, Ikhulule, IE-2872, P224, KatFm1 × U15 1.6.3.3.1 with yields ≥ 2.2 t ha^{-1} respectively (Table 7: Figure 4) .

In Koibatek, season two performed highly compared to season one with 1.67 and 1.25 t ha^{-1} respectively. Yield was generally lower in season one ranging from 1.12-1.48 t ha^{-1} in the first season in contrast to season two which ranged from 1.43-1.90 t ha^{-1}. Generally, the high

yielding genotypes in Koibatek included KatFm1×U151.6.6.3.1.1, KNE 1034, Kal-Dokolo and Kal-Pader with 1.57, 1.58, 1.60 and 1.64 t ha^{-1} (Figure 5).

In Nakuru, season two had a slightly higher yield than season one with 1.56 and 1.50 t ha^{-1} respectively while season two had yields ranging from 1.16-1.75 t Ha^{-1}. Genotypes such as Ikhulule, KAT FM1, GBK 027189A and Gulu E were high yielding genotypes in Nakuru with yields of 1.70, 1.72, 1.72 and 1.82 t ha^{-1} respectively (Figure 6).

In general, genotypes performed differently across all sites and seasons. Mean separation of varieties across all sites and season showed that Kal Dokolo, Ikhulule, KAT-FM1, P-224, IE-2872, Gulu E, IE-615 recorded yield values of 1.83, 1.81, 1.79, 1.78, 1.76 and 1.76 t ha^{-1} respectively (Table 7).

The response on yield showed that there was variation among the genotypes in yield components which included the number of tillers, number of fingers, length of fingers, days to maturity, 1000KW, biomass and harvest index. The comparison of sites showed that Koibatek, Bomet and Nakuru had various maturity periods of 96.69, 94.06 and 92.23 days after planting respectively. In Bomet, genotype days to maturity ranged from 62 to 106 days while in Koibatek maturity days ranged from 88 to 105, in contrast to the range of 79 to 103 in Nakuru. The susceptible genotypes such as the check KNE-741 had the earliest maturity of 62, 91 and 93 days in Bomet, Koibatek and Nakuru respectively. The number of tillers differed among the genotypes with a range of 5 - 9 tillers per plant. The high tillering varieties with >7 tillers included SDFM 1702, Snapping-Purple, IE-615, U-15, IE-2872, Gulu-E, GBK-127189A, KAT-FM1 and Kal-Pader. Finger length varied from 4-7 cm with Snapping-Purple variety and NKR FM1 having the highest finger length (7 cm) while genotypes KATFM1×U151.6.3.3.1, Kal 2 Pader and KATFM1×U15-1.6.6.3.1.1 had small finger lengths of > 5.5 cm (Table 7)

Biomass of finger millet varieties planted in all sites ranged from 1.7 kg to 3.6 kg. The biomass of KNE-628, Kal-2-Pader KNE-1124×KNE-796 and NKRFM1 genotypes was high with >2.8 kg while Snapping-Purple variety had the lowest biomass of 1.72 kg. 1000 kernel weight (KW) had mean values ranging from 2.3 g to 3.1 g, genotypes KATFM1×U151.6.3.3.1, U-15, Otiyo-Brown and KAT-FM1 having > 3.0 g weight. The harvest index (HI) of finger millet varieties across regions varied from 0.7 to 1.5. High HI was measured in genotypes P-224, Otiyo Brown, KNE-1034, NKR-FM1, KNE-741, and IE-615, KATFM1×U15-1.6.6.3.1.1, Ikhulule, Gulu E, IE-2872 and Kal Dokolo. These genotypes had >1 total harvest index ratio (Table 7). The genotypes with lowest harvest index included Snapping Purple Variety, KAT-FM1, Kal-Pader, IE-2183, GBK-127189A and KATFM1×U15-1.6.6.3.1.1 which had > 0.9 HI ratio (Table 7).

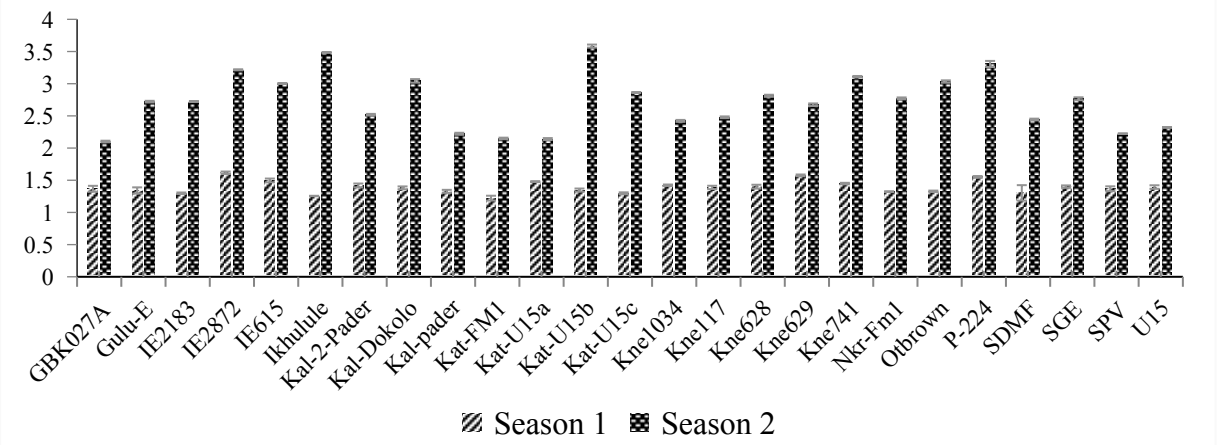


Figure 4: Yield performance of selected finger millet genotypes in Bomet season 1 and 2

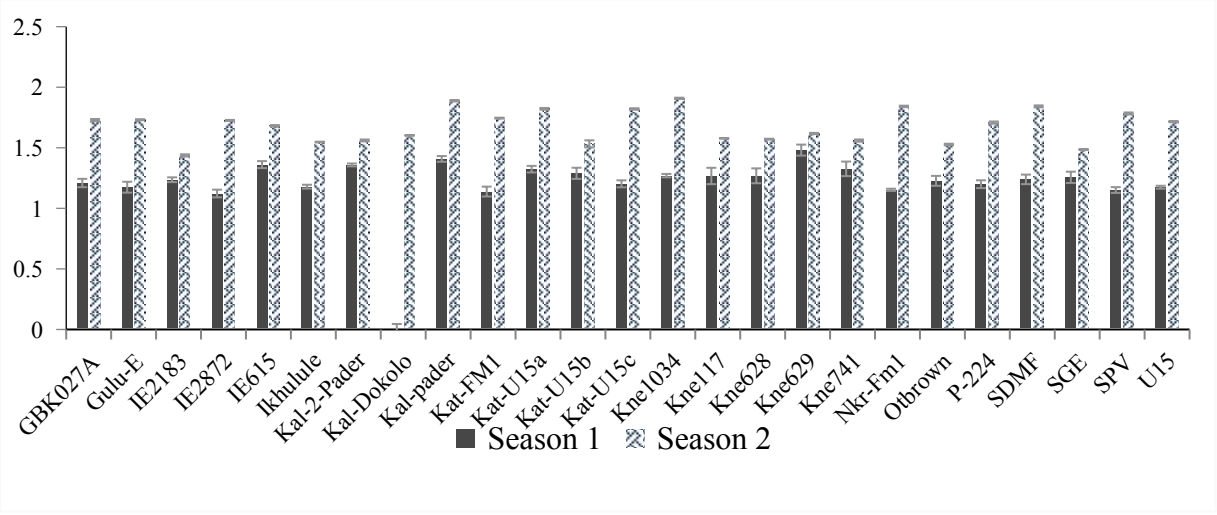


Figure 5: Yield performance of selected finger millet genotypes in Koibatek season 1 and 2.

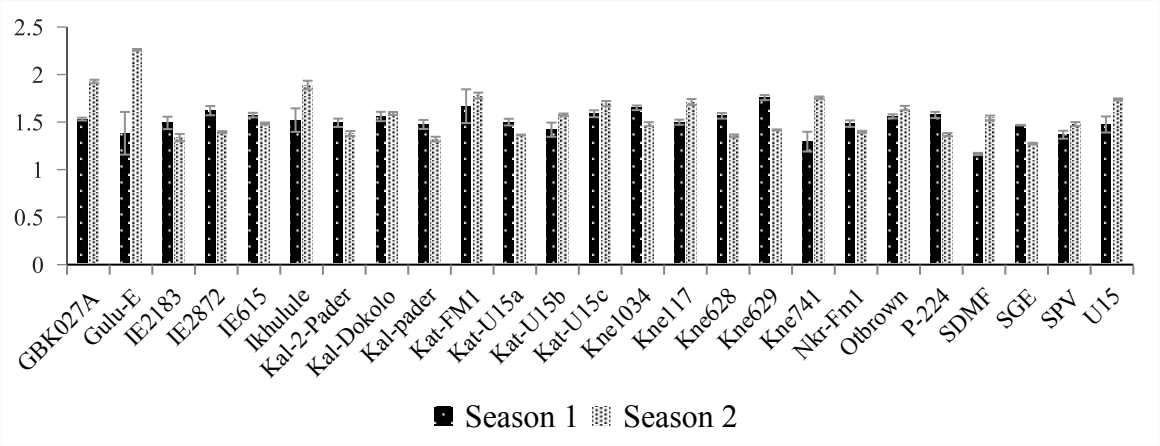


Figure 6: Yield performance of selected finger millet genotypes in Nakuru season 1 and 2

Pearson's correlation between yield, disease scores and yield components

Correlation analysis of yield, disease scores and yield components showed that disease severity of both leaf and head had a negative effect on finger length, finger number, tillers and days to maturity. Leaf blast severity had a significant positive correlation ($P<0.001$ $r= 0.372^{***}$) with neck blast, however it was negatively correlated with biomass (r=-0.037). Neck blast had a negative correlation with biomass and yield but was significant only for 1000KW ($P<0.05$ r=-0.026, -0.041 and -0.104^{*} respectively). Maturity had a significant negative ($P<0.01$) correlation with leaf blast, neck blast, harvest index and yield ($r= -0.168^{**}$, -0.2011^{***}, -0.137^{**}, -0.159^{***}), however, a significant positive correlation ($P<0.01$ $r= 0.209^{***}$) was noted with 1000 KW. Plant height had a significant positive correlation with leaf blast ($P<0.05$ $r=0.094^{*}$) but was negatively correlated with neck blast (r=-0.066) however it was positively correlated with finger length and finger number ($r = 0.167^{***}$, $r = 0.021$). The number of fingers per panicle had a significant ($P<0.05$) positive correlation with tillers, 1000 KW and biomass while it was significantly negatively correlated with leaf blast ($P<0.01$), harvest index and yield (Table 8).

Table 8: The relationship of leaf and head blast severity expressed in AUDPC, yield and yield traits of selected finger millet genotypes

	Height	F.L	F.N	Tillers	DTM	LAUDPC	NAUDPC	1000 KW	Biomass	H.I	Yieldt
Height	1										
F.length	0.167***	1									
F. no	0.021	0.536***	1								
Tillers	0.154**	0.279***	0.449***	1							
Maturity	-0.153**	-0.027	0.043	0.043	1						
Leaf Blast	0.094*	-0.129**	-0.204***	-0.426***	-0.168**	1					
Neck blast	-0.066	-0.037	-0.034	-0.228***	-0.2011***	0.372***	1				
Kw	0.151**	0.144**	0.225***	0.392***	0.209***	-0.272***	-0.104*	1			
Biomass	0.225***	0.153**	0.102*	0.074	-0.011	-0.037	-0.026	0.151**	1		
Harvest index	-0.149**	-0.202***	-0.227***	-0.419***	-0.137**	0.296***	0.009	0.218***	-0.247***	1	
Yieldt	-0.111*	-0.179***	-0.210***	0.415***	-0.159***	0.301***	-0.041	-0.207***	0.027	0.883***	1

Table 9: Season 1; DMRT table for height, finger length, finger number, tillers, no of days to maturity, LAUDPC, HAUDPC, KW, biomass and yield of finger millet varieties evaluated under field conditions in the three sites;

Site	LAUDPC	NAUDPC	Height	F.L	F.N	Tillers	DTM	KW	Biomass	Yieldt	HI
Nakuru	39.77a	41.89b	85.37a	6.59b	5.45c	11.14a	98.44ab	3.57a	2.78a	1.29a	1.22a
Koibatek	38.67a	48.39a	41.87c	5.67c	6.18b	7.68c	100.24a	2.69c	1.92c	0.57c	1.15c
Bomet	39.89a	46.52a	57.22b	8.74a	8.69a	8.75b	95.76b	3.25b	2.56b	0.94b	1.18b
DMRT (P<0.05)	2.21-2.32	3.68-3.87	3.50-3.68	0.31-0.32	0.42-0.45	0.82-0.86	3.15-3.31	0.09-0.10	0.09-0.10	0.078-0.082	0.0157-0.0166
Mean	39.44	45.49	61.47	6.98	6.75	9.21	98.10	3.18	2.42	0.942	1.183

**F.N=Finger number, F.L= Finger Length, LAUDPC= Leaf blast severity, NAUDPC= Neck Blast severity, DTM=Days to maturity, Yieldt= Yield t Ha^{-1}, HI= Harvest Index. Means under the same letters are not significantly different at p<0.05.*

Table 10: Season 2; DMRT table for height, finger length, finger number, tillers, no of days to maturity, LAUDPC, HAUDPC, KW, biomass and yield of finger millet varieties.

Site	LAUDPC	NAUDPC	Height	F.L	F.N	Tillers	DTM	KW	Biomass	Yieldt	HI
Nakuru	70.39b	64.77a	85.37a	5.07a	5.47a	6.72a	88.89b	2.07c	1.82a	2.72a	1.92a
Koibatek	82.73a	59.27b	41.87c	5.32a	5.32a	5.78b	94.40a	2.78a	1.09b	1.68b	1.08b
Bomet	68.94b	49.55c	57.22b	3.68b	5.08b	5.33c	92.42a	2.43b	1.80a	1.46c	1.24c
DMRT (P<0.05)	4.89-5.15	4.06- 4.28	3.50-3.68	0.31-0.33	0.21-0.22	0.35-0.36	2.71-2.85	0.11-0.12	0.05-0.06	0.083-0.087	0.059-0.063
Mean	74.02	57.87	66.61	4.69	5.29	5.94	91.24	2.43	1.57	1.95	1.41

**F.N=Finger number, F.L= Finger Length, LAUDPC= Leaf blast severity, NAUDPC= Neck Blast severity, DTM=Days to maturity, Yieldt= Yield t Ha^{-1}, HI= Harvest Index. Means under the same letters are not significantly different at p<0.05.*

DISCUSSION

Response of Selected Genotypes to both Leaf and Neck Blast Disease

The results indicate genotypes respond distinctly when infected with *Pyricularia grisea* under different environments and seasons. In the year 2019, disease severity was low compared to 2020. This is because of the corresponding weather differences in the years. This is similar to Onega and Asea (2016); Titone *et al.,* 2015 who evaluated leaf and neck blast and showed that variability in weather which changed the magnitude which therefore increased the severity. The occurrence of blast disease in these areas is highly dependent on weather. *Pyricularia grisea* requires temperatures ranging from 25-30 ºC and humidity above 80% for maximum production of spores (Sreenivasaprasad *et al.,* 2004). Koibatek had higher leaf and neck blast occurrence compared to Nakuru and Bomet. These high occurrence of infections could be due to the temperature of 17-29 ºC and humidity of 65-93%, conditions favorable for the multiplication of the spores of *P. grisea*. Bevitori and Ghini, 2014 observed that formation of appressorium and multiplication of spores occurs at an average temperature of 24 ºC to 27 ºC and favorable humidity of above 80%. The variation in severity among the genotypes is dependent on the genotype susceptibility to both leaf and neck blast. Genotypes such as NKR-FM1, KNE 629, P-224 and Snapping-Purple are resistant to neck blast but are shown to be susceptible to leaf blast in sites like Bomet.

The host plant resistance is evident in these genotypes because the spread of the pathogen does not affect the productive fingers; therefore, they have mechanisms to resist diseases. This would include, shedding off their leaves and hypersensitive reactions to avoid disease spread to other parts of the plant as explained by Preisig and Kuć, (1985). From the comparison, there is stability in the resistance of some genotypes such as SDFM-1702, IE-2183, Snapping Purple variety, Gulu-E, KatFM1x U15 1.6.6.3.1.1 as the results showed that genotypes resistant to the field had the same resistance in the greenhouse on both leaf and neck blast. The high resistance of these genotypes could be due to their genetic makeup. The R genes contained in these genotypes maybe specific to *Pyricularia grisea* pathogen. The R gene will recognize the host interference through infection by the pathogen which then encodes with protein molecules such as the nucleotide binding protein and leucine rich proteins (Marone *et al*., 2013). The pathogen avirulent gene (Avr) will match specifically with the R gene to confer resistance. Specific recognition leads to an immediate response of the plant against the pathogen such as the hypersensitive reaction (HR) (Balint-Kurti, 2019).

Variations in Yield and Yield Components among Finger Millet Genotypes

Higher yields were achieved in the year 2020 as compared to 2019. This is because of the favorable weather conditions experienced during the long rain season in contrast to the short rain season. The ideal rainfall received during the long rain season which runs from March to August facilitates uptake of nutrients and healthy growth of the plants in most parts of the country explains the high yields (Guan *et al.,* 2015). Wekesa *et al*. (2019) also pointed out that under well rain fed conditions such as the long rain season there is high grain filling due to adequate moisture provided while during the short rains, little grain filling is evident due to moisture stress. Early maturity achieved during the short season could be explained by the short rains received during the season. Plants mature faster when exposed to low moisture content due to high metabolic processes, competition from weed species, less photosynthetic assimilates and availability of nutrients leading to a substantial loss in grain production hence yield (Osakabe *et al.,* 2015). Maturity of the genotypes affected the severity of both leaf and neck blast. Genotypes such as Snapping green early and KNE 741 recorded early maturity time, therefore exposing them to attacks from pests such as blast disease and birds leading to low yields.Among the genotypes, Snapping-Purple, IE-615, U-15, IE-2872, GuluE, KAT FM1 and Kal Pader had a higher number of tillers, this led to a corresponding higher yield of > 90% that is > 2 t ha^{-1}. This is because a high number of tillers leads to more head count and therefore more yield. Furthermore, when the birds attack the mother plant the surviving tillers would still compensate for the loss. Varieties such as P-224 and Gulu-E had high levels of Neck blast as well as high yields. Neck blast resistance is the most damaging type leading to over 80% losses. When genotypes such as P-224 and Gulu-E resist the attack of blast, they are prone to yielding higher since the formation of seed is not interfered with.

Correlation Between Disease Severity, Yield and Yield Components

In Pearson's correlation analysis, an increase in leaf blast by 0.51 significantly increases the chances of neck blast infections by 37%. Similar to these findings, Owere *et al.,* 2015; Nagaraja *et al.,* 2007 who reported a 27.1% positive correlation between leaf and neck blast with some genotypes resisting blast infection in rice. Babu *et al.,* 2013 found a correlation of 92% of leaf and neck blast. This meant that the genotypes that were most susceptible to leaf blast could also be infected by neck blast. However, this contrasts with the resistant checks U-15 and NKRFM1, which were both susceptible to leaf blast but resistant to neck blast. This is because the genotypes have resistance genes which limit blast spread to the neck region.

The relationship of height and blast disease is evident in both leaf and neck blast severity. Height had a positive correlation with occurrence of leaf blast. Leaf blast seemed to occur more irrespective of other agronomic aspects. This is because of the favorable climatic conditions that promoted the occurrence of the disease and spread, however, neck blast had a negative correlation with height meaning shorter genotypes were more susceptible to neck blast than the taller genotypes. Wekesa *et al.,* 2019 in a study of 100 genotypes in Alupe and Kakamega revealed that greater plant height showed less neck blast severity with lower AUDPC values. Genotypes such as GBK-127189A, Kal Pader and KNE 629 were found to be tall and hence resistant to neck blast. These genotypes can be selected as parent material for provision of genes through crossing to boost the resistance mechanism of genotypes such as KNE 741. Similar to this findings is Bregaglio *et al.,* 2017 who showed that variation in seasons and genotypes are important factors in blast disease development and therefore growing of finger millet genotypes under natural conditions is an efficient way of assessing resistance of a genotypes.

Maturity was significantly negatively correlated with both neck and leaf blast, harvest index and yield. This is because the early maturing genotypes such as KNE 741 (88 days) were most susceptible to both leaf and neck blast because of the favorable microclimate while the late maturing genotypes KATFM1xU15-1.6.6.3.1.1 (100 days) escaped attack of the disease because of the weather conditions prevailing at harvest period. These disease attacks had a negative impact on both yield and harvest index of the crop leading to a corresponding decrease. A decrease in harvest index due to the occurrence of leaf and neck blast is a clear indication of reduced assimilates accumulation in productive tissues hence a decrease in yield (Unkovich *et al.,* 2010). Similar to these findings, Babu *et al.,* 2013; Nagaraja *et al.,* 2007 who also pointed out that the genotypes that mature early are easily affected by both leaf and neck blast disease. There was a significant positive correlation of height, finger length and finger number. Upadhyaya *et al.,* 2006 evaluated 610 genotypes of finger millet and found similar results and further suggested that it is important to select such traits for improvement of finger millet genotypes.

Finger number did not seem to have an influence on leaf and neck blast severity however it was positively correlated to the number of tillers, 1000KW and biomass. Increase in the number of tillers would possibly increase the biomass of the plant. As biomass increased the weight of the seeds also increases. This is because of the build-up of sufficient photosynthetic assimilates for growth and development of the plant itself (Smidansky *et al.,* 2003). The negative correlation of finger number with leaf and blast could be explained by the genotype response to attack by blast as opposed to the plant characteristics. Increase in the number of tillers increased yield of finger millet. Similar findings were reported by Nandini *et al.,* 2010 who found a positive correlation of tillers and 1000KW with yield. Contrary to studies such as Nandini *et al.,* (2010) and Grando *et al.,* (2001) 1000 KW, finger length and finger number were negatively correlated to yield. This could be due to the huge variability shown within the genotypes across various varied environmental conditions. Neck blast results from the field and greenhouse both showed a positive correlation with 1000 KW, leaf blast and panicle weight. This is because the attack of finger millet on the neck region by *Pyricularia grisea* leads to the formation of shriveled grains which are light in weight, some will not form grains on the panicle hence leading to lower weight of panicle.

CONCLUSION AND RECOMMENDATION

The aim of this experiment was to determine host plant resistance in selected finger millet genotypes across three major growing areas of Kenya in different growing conditions. There was variation in expression of the disease yearly with an increase in disease progressively from 2019 to 2020. Genotypic variability in resistance against attack, yield and yield components differs with the different environmental conditions and seasons with some showing greater levels of performance compared to others despite the disease. *Pyricularia grisea* growth, development and expression is highly dependent on weather conditions Genotypes GBK-127189A, Snapping-Purple, KNE 1124 x KNE796, Gulu E and U15 were resistant to leaf blast across all sites while Snapping-Purple, GBK-127189A, SDFM-1702, SDFM-1702, P224, Kat Fm1xU15 1.6.6.3.1.1, IE-2183 and GuluE were resistant to neck blast across all seasons and sites. These genotypes can easily be up-scaled and used as parent sources for resistance to blast disease.

All these varieties that have good resistance and provide high yields can be used by breeders for the improvement of other genotypes through selection, genetic improvement and crossing.

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