Journal of Life Sciences 13 (2019) 34-47
doi: 10.17265/1934-7391/2019.01.004

Sources of Resistance to Blast Disease (*Pyricularia grisea L.*) in Finger Millet (*Eleusine Coracana*) Germplasm

C. M. Wekesa[1], P. K. Kimurto[1], C. O. Oduori[2], B. K. Towett[1], L. Jeptanui[1], H. Ojulong[3], E. Manyasa[3] and M. Siambi[3]

1. Department of Crops, Horticulture & Soils, Egerton University, P.O. Box 536-20115, Egerton, Kenya

2. Kenya Agricultural Research and Livestock Organization (KALRO), P.O. Box, 465 Kisii, Kenya

3. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Box 39063-00623, Nairobi, Kenya

Abstract: Blast has been a continuous threat to finger millet production in semi-arid tropics. The disease is economically important and widespread in finger millet major growing areas of western, Nyanza and Rift valley in Kenya. Host resistance is the most economical and effective means of controlling the disease as finger millet is grown by resource-poor farmers. This study evaluated a hundred finger millet genotypes for resistance to blast at KALRO (Kenya Agricultural Research and Livestock Organization) Kakamega and Alupe, Kenya for two seasons in 2011/2012 in a lattice square design for two seasons each. Data on blast incidence and severity were measured. Data were analyzed using ANOVA (analysis of variance) and means separated using Duncan multiple range test (DMRT) at $p < 0.005$. The results showed that disease severity was highest in early maturing varieties and lowest in the late maturing varieties. The most resistant genotypes were: GBK000702, GBK000513, GBK029869, GULU-E, GBK000752 and Busibwabo. Pearson correlation analysis between neck severity and physiological maturity was positively significant (r = -0.47). A strong positive correlation between finger severity and neck severity (r = 0.87) was observed. These tolerant genotypes could be utilized as donor parents for breeding durable blast resistant varieties.

Key words: *Eleusine coracana*, incidence, *Pyricularia grisea*, severity, mid altitude zones.

1. Introduction

Finger millet (*Eleusine coracana*) is the most important small millet grown for subsistence in Eastern Africa and Asia. The crop is believed to originate in Africa, Ethiopia and in Uganda along Western Kenyan border [1]. Worldwide finger millet production is estimated at 26,702,535 tons [2]. Africa is the second leading producer (16%) after India, the leading producer (8,810,000 tons) which is approximately 33% of world production [2]. In eastern Africa, it is produced in the lake region countries of Uganda, Kenya, Ethiopia, Tanzania, Ethiopia, Sudan, Rwanda, Burundi, Congo and Somalia [3]. In Kenya finger millet is grown mostly by smallholder farmers and the main production areas are Western 77,000 ha (29%), Nyanza 57,000 ha (15%) and Rift valley 65,000 ha (13%) [4]. Finger millet has witnessed an expansion in the last 5 year since to > 200,000 ha [5] due to combined research and promotion efforts that have provided new varieties, improved agronomy, and growing of the crop as an alternative to MLND (maize lethal necrosis disease) in many areas. In spite of this and its economic importance, finger millet is affected by several biotic and abiotic constraints. Abiotic constraints include drought, low soil fertility, flooding and poor production package [6]. Biotic constrains are mainly diseases such as blast, foot rot, smut, leaf blight, shoot fly (*Atherigona milliaceae*), pink stem

Corresponding author: Paul Kimurto, Ph.D, associate professor, research fields: crop breeding and crop physiology. E-mail: kimurtopk@gmail.com.

borer (*Sesamia inferens*), streak and mottling virus [7, 8]. Blast is the most devastating disease affecting different aerial parts of the plant at all stages of its growth [9, 10]. Average yield loss of about 28-36% is usually associated with kernel abortions and shriveled grains caused by damage of panicle during reproductive stage [11-13]. Since finger millet is an orphan crop grown mainly for subsistence, the disease management by chemical means is not economically feasible thus host plant resistance is the only promising method of blast disease control [14]. Use of resistant varieties is not only economical for minimizing the losses caused by the disease, it is also an environmentally friendly method. The significance of resistance and its durability for plant production especially in developing countries, justifies that breeding for resistance as top priority. The objective of the study was to determine the sources of resistance to blast in selected finger millet germplasm with a view to enhance host improving productivity amongst small holder farmers.

2. Material and Methods

2.1 Site Description

The experiment was conducted in two sites at Kenya Agriculture and Livestock Research Organization Kakamega and Alupe, in Western Kenya. Kakamega is located north-east of the Lake Victoria between latitudes of 00°10′ N and longitudes 34°47′ E and falls within the lower humid zone at an elevation of 1,800-1,900 m a.s.l. with mean annual precipitation of 2,147 mm concentrated in two seasons and temperature range of 21-24°C (16). Alupe lies at latitudes of 00°29′ N and 34°08′ E with mean annual temperature of 29.0°C (max) and 15.5°C (min). That area has annual mean rainfall of between 1,200-1,400 mm. The soils in Alupe are moderately deep with moderate natural fertility and high humus levels [17]. The high temperature and high humidity prevalent at Alupe are ideal conditions for the development of the blast pathogen. Western Kenya in general has favorable climatic condition that encourages epidemics and promotes elution of blast. Between the two sites, Kakamega has the highest potential and highest amount of seasonal rainfall, being located in the higher altitude unlike in Alupe with low rainfall and sandy soil infested with striga weed [15].

2.2 Plant Germplasm

In this study 100 finger millet genotypes were evaluated for high yield and blast tolerance/resistance (Table 1). The genotypes were sourced from KALRO Kakamega, ICRISAT and Gene bank of Kenya. Totally, 86 genotypes amongst these were sourced from Gene bank of Kenya, one commercial check (P-224), 10 advanced finger millet lines from KALRO Kakamega and ICRISAT and three local landraces from western (Ikhulule), Nakuru (Egerton) and Baringo (Koibatek). U-15 (resistant cultivar) and KNE 714 (a susceptible check) were included as checks. All germplasms have varied levels of resistance, phenology and maturity. The varieties were classified based on reaction to infection to pathogen as resistant, moderately resistant and susceptible.

2.3 Experimental Design and Treatments

The test germplasms were evaluated in simple lattice (10 × 10) design with three replications, 3 rows each row 2 m long and spacing of 30 cm and intra row spacing of 15 cm were maintained throughout the plots. The experiment was conducted in two seasons during short season of 2011 (August-December) and long rain 2012 (May-September). Experimental plots used had been previously been planted with finger millet to ensure that plots were sufficiently infested by inoculum. To enhance disease development, two rows of a blast susceptible variety KNE 741 were planted as guard rows. Five tillers were randomly tagged per plot and disease severity on the tagged tillers was recorded after every 10 days.

Table 1 List of finger millet genotypes evaluated in the study.

Germplasm	Phenology
Gulu-E	advanced line
U-15	commercial
Okhale-1	advanced line
P-224	commercial
IE4115	commercial
Busibwabo	advanced line
GBK000359	medium/purple
GBK000364	tall/white
GBK000453	medium/brown
GBK000463	tall/red
GBK000487	white
GBK000493	tall/brown
GBK000503	tall/brown
GBK000608	tall/white
GBK000621	medium/brown
GBK000638	tall
GBK000678	fist head/red
GBK000696	white
GBK000719	tall/
GBK000752	tall/red
GBK000766	tall/red
GBK000845	medium/brown
GBK000882	white
GBK000361	tall/black
GBK000409	tall/late maturity
GBK000410	early maturity
GBK000414	early maturity
GBK000449	tall/brown
GBK000458	medium/ brown
GBK000483	late maturity
GBK000506	early maturity
GBK000513	medium/brown
GBK000516	early maturity
GBK043185	tall/purple
GBK033433	early m/brown
GBK033548	red
GBK033332	red
GBK033410	short
GBK033551	brown
GBK033575	tall/white
GBK033569	medium/brown
GBK033592	white
GBK043258	medium
GBK043161	tall/brown
ACC#29	(commercial)
Acc#32	(commercial)
Acc#14	(commercial)
Koibatek	local
GBK000702	brown
GBK000780	tall/brown
GBK000815	early maturity
GBK000865	early maturity
GBK000904	tall/red
GBK011110	brown
GBK00119	early maturity
GBK011059	medium/red
GBK011098	tall/fist/brown
GBK011125	tall/red
GBK011127	tall/white
GBK011044	medium
GBK001115	short
GBK029713	short/early maturity
GBK029819	medium/brown
GBK029850	tall/white
GBK029739	early maturity
GBK029747	late m/brown
GBK029869	tall
GBK029875	early maturity
GBK027155	early maturity
GBK008294	early maturity
GBK008349	tall/large
GBK033418	tall/brown
GBK033464	red
GBK033474	early maturity
GBK033513	brown
GBK033520	tall/large head
GBK033576	medium/brown/
GBK033605	medium/white
GBK043115	red
GBK043145	short/early maturity
GBK043065	medium/brown
GBK043169	early m/ brown
GBK043124	medium
GBK043069	tall/large head
GBK031861	short-spreader
GBK031890	early maturity
GBK036839	medium height
GBK027076	tall/fist head
GBK027169	medium height,
GBK028567	short/brown
GBK036767	medium/white
GBK039367	short, red
GBK040468	medium height
KNE 714	(commercial)
KNE 629	(commercial)
Nakuru	local
Ikhulule	local

2.4 Data Collected

2.4.1 Data on Disease Infection

The following data were taken:

(i) DI (disease incidence)

DI was scored on 0-9 scale where 0 = no disease and 9 = more than 75% leaf area covered for leaf blast and 0 = no disease (all panicles have no disease on neck and finger) and 9 = 81-100% panicles severely infected for neck and finger blast. The three phases of the disease (leaf, neck and finger) were separately scored. Disease incidence scoring for leaf blast was done at seedling and booting stages whereas incidence scoring for finger and neck blast was carried out at physiological maturity and at harvest (Fig. 1).

(ii) DSR (disease severity rating)

DSR was determined as rate of percent damage on first four leaves (flag). Five tillers were randomly tagged per plot basis and disease severity on the tagged tillers was recorded every 10 days using the modified Cobb scale [18]. The scoring of infection type responses and disease severities started when the most susceptible entry showed approximately 5% of disease severity. *Pyricularia grisea* severity was evaluated as the percentage of the surface area infected. The mean disease severity was utilized for the calculation of the AUDPC and terminal severity data were used to compare cultivars.

Table 2 A quantitative severity scale for foliar blast disease on finger millet.

Scores	Reaction category	Appearance of genotypes
1	Very highly resistant	Free from any damage
2	Highly resistant	Less than 10% of the leaves damaged
3	Resistant	11-20% of the leaves damaged
4	Moderately resistant	21 to 30% of the leaves damaged
5	Intermediate	31 to 40% of the leaves damaged
6	Moderately susceptible	41 to 50% of the leaves damaged
7	Susceptible	51 to 70% of the leaves damaged
8	Highly susceptible	71 to 90% of the leaves damaged
9	Very highly susceptible	> 90% almost all leaves damaged

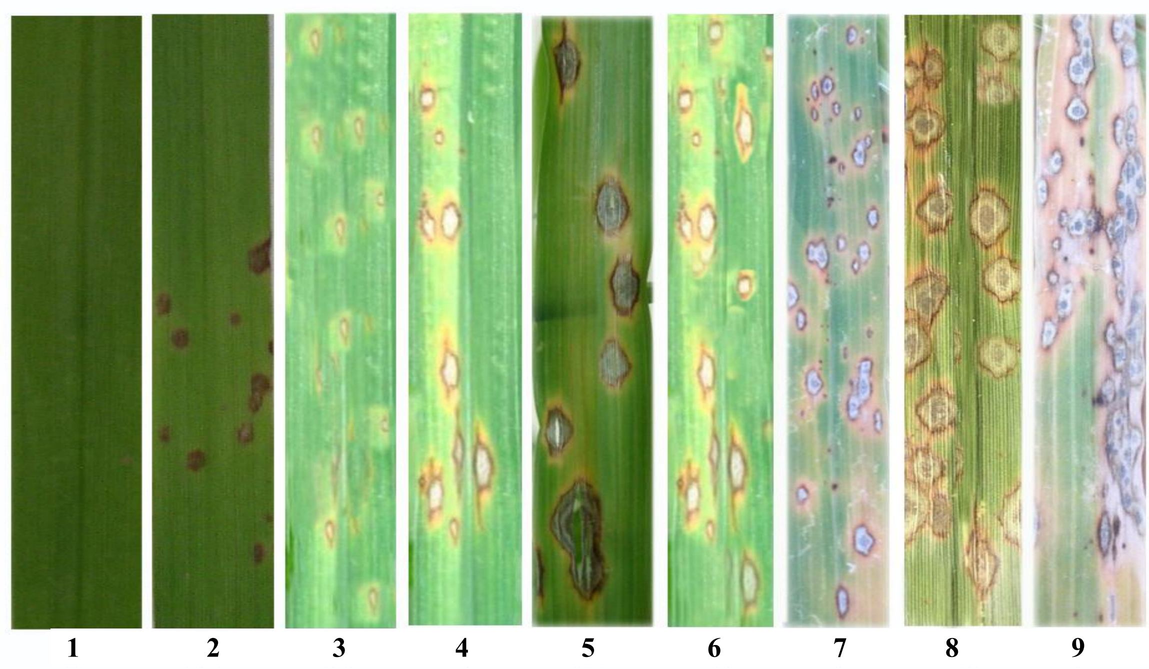

Fig. 1 Panicle showing flag leaf damage rating [19].

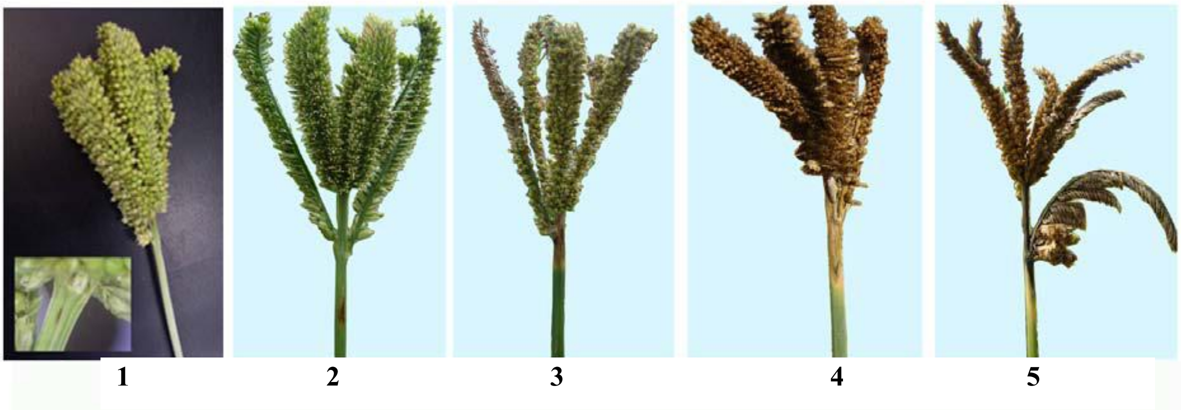

Fig. 2 Panicle showing neck damage rating.

(iii) Neck blast severity

Based on the relative lesion size on the neck a 1 to 5 progressive rating scale was 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 (Fig. 2). Data were recorded in field at the physiological maturity on 5 randomly selected and tagged individual plants of each accession.

2.4.2 Yield and Yield Parameters

The yield and yield components taken included:

(i) Tillers per plant

The number of tillers per plant was determined by physical counting five plants in the middle row picked at random at crop maturity.

(ii) Plant height

Average plant height (cm) was measured from base of the plant to the tip of the spike on five plants at dough stage on longest primary branch. This was determined at maturity in five plants selected randomly in the middle row.

(iii) DH (days to heading) and days to PM (physiological maturity)

DH was recorded when 50% of the plants in the middle row have headed and physiological maturity when 50% of the plants in the middle row have matured.

The weather data were recorded from weather station from an automatic weather station at KALRO Kakamega and Alupe (Table 3). This was necessary in determination of the amount of rainfall (mm) during the growing season (using a rain gauge), maximum and minimum air temperatures (°C) (using thermometers) and humidity (using a hygrometer).

2.5 Data Analysis

Data were subjected to ANOVA (analysis of variance) using Genstat release 14.1 and treatment means were separated using Least significance difference (LSD at $p \leq 0.05$. Simple correlation coefficient (r) was carried out using Pearson's correlation. Homogeneity of error variance was carried out before pooling the data across environments using Bartlett's test for homogeneity. Data on disease scores were transformed by dividing mean response by respective root MSE (mean square error) for respective environments [20]. Classification of test genotypes for resistance or susceptibility to blast was done based on disease severity (%) and genotypes were grouped into six categories which included: HR (highly resistant) with < 10% disease infection, R (resistant), 11-30% florets infected, 31-40% florets infected MR (moderately resistant), between 40-50% MS (moderately susceptible), 51-70% florets infected S (susceptible) and 71-100% floret infected as HS (highly susceptible).

The blast disease severity scores taken at different times were used to calculate AUPDC of each variety following method using the relationship (1975) below:

Table 3 Monthly temperature, rainfall and relative humidity in Alupe and Kakamega.

Kakamega											
2011						2012					
	Mean temp			Relative humidity			Mean temp.			RH	
Month	Max (°C)	Min (°C)	Rainfall	Max (%)	Min (%)	Month	Max (°C)	Min (°C)	Rainfall	Max (%)	Min (%)
AUG	25.8	14.2	233.2	87	61	MAY	26.5	14.9	268.1	83	66
SEP	26.7	14.1	132.1	83	61	JUN	26.5	14.5	212.9	88	57
OCT	27	14.7	191	76	60	JUL	25.9	14.1	27.3	89	58
NOV	26.1	15.1	233.9	81	70	AUG	26.3	13.9	281.6	86	60
DEC	27.5	13.9	94.3	75	52	SEP	26.9	13.9	266.4	81	61
JAN	30.1	12	7.7	63	29	OCT	27.4	14.8	142.9	73	63
FEB	31.3	13.8	21	57	27						
Alupe											
2011						2012					
AUG	29.3	16	9.3	80.8	73	MAY	29.1	20.9	10.8	74.9	70.6
SEP	29.5	16.4	12.5	77.3	69.9	JUN	30.5	15.2	12.1	75.3	71.9
OCT	29.2	16.4	5.4	76.6	69.6	JUL	22.1	13.9	6.2	71.4	68.6
NOV	29.4	16.7	12.9	90.1	72.5	AUG	29.2	14.7	4.9	72.5	67.2
DEC	27.1	15.6	9.8	76.8	71.4	SEP	30.7	15.9	9.3	82.4	71.5
JAN	32.1	15.7	7.2	78	71	OCT	32.4	15.6	10.8	76	70.8
FEB	34.2	17	2.9	64	57.6						

$$AUDPC = \sum_{i=1}^{n-1} 0.5\left(x_{i+1} + x_i\right)\left(t_{i+1} - t_i\right)$$

where, x_i is the cumulative disease severity expressed as a proportion at the i^{th} observation; t_i is the time (days after planting) at the i^{th} observation and n is total number of observations.

The model for field work: $y_{ijK} = \mu + T_i + \alpha_j + \beta_{jk} + \Sigma ijK$

$i = 1, 2, 3, \ldots, 100$, $j = 1, 2, 3$ and $k = 1, 2, \ldots, 10$

y_{ijk} = The yield/area under disease for the i^{th} treatment in the k^{th} block within j^{th} rep.

μ = Overall mean;

T_i = Effect of the i^{th} treatment;

α_j = Effect of the j^{th} rep (superblock);

β_{jk} = Effect of the k^{th} incomplete block within j^{th} rep;

ΣijK = Random error effect.

3. Results

3.1 Foliar Blast Severity and Incidence of Selected Finger Millet Varieties in Both Seasons

The findings showed significant genotypic variation for disease incidence and severity ($p \leq 0.05$) (Table 4). Genotype and the interactions between genotype and site (G×E), and genotype and season (G×S) (year) affected the disease components of tested finger millet germplasm in the two sites. In Alupe mean foliar severity was higher in season one (28.8%) than in season two (3%). In contrast, average foliar severity was higher in season two than season one in Kakamega (Table 4). During season one evaluation in Kakamega, 88 varieties showed significant tolerance to foliar blast with blast incidence scores of < 3.0 and an average severity percentage of < 8.1% (Table 4). Finger blast incidence mean was 2.26 and ranged from 1.7 to 3 while percentage severity ranged from 5 to 46.7% with a mean of 8.14% (Table 4). Varieties GBK033576 and GBK000458 had the lowest foliar blast incidence scores and percentage severity of severity 4% and severity 4.7%, respectively, which were lower than the tolerant check (U15) (Table 4). In contrast, season two foliar incidence ranged from 1.3 to 5 with a mean of 2.4 and foliar severity ranged from 4.3 to 53.3%. Varieties GBK043065 (foliar blast incidence 2.0 and severity 5%) GBK000845 (foliar blast incidence 2.0 and severity 5%) had the lowest foliar blast incidence scores and percentage severity. Busibwabo, Okhale, P224 and Ikhulule had severity less than 10% in seasons one and two. Overall in Kakamega the most resistant variety was ACC14 and GBK000719 with severity of 9.6 while susceptible genotypes were GBK027169, GBK033410 and GBK043115 with severity of (31.2%, 24.3%, and 24.2% respectively) (Table 4).

During season one evaluation in Alupe, the foliar incidence ranged from 1.7 to 3.7 with a mean of 3.2 and severity ranged from 8.5 to 23.8% with a mean of 28.8% (Table 4). Resistant check U15 had severity of

Table 4 Mean foliar severity and incidence in Alupe and Kakamega for season one and season two.

	Alupe					Kakamega			
	Season I		Season II			Season I		Season II	
Variety	F sev	F inc	F sev	F inc	Variety	F sev	F inc	F sev	F inc
GBK000621	15.0	2.3	2	2.7	GBK033576	4.0	2.0	6.0	1.6
GBK000865	16.7	2.7	2	1.3	GBK000458	4.7	2.7	11.7	2.3
GBK027076	16.7	2.3	2	1.3	GBK043065	5.0	2.3	5.0	2.0
GBK033520	18.3	2.7	2.3	1.3	IE4115	5.3	2.3	5.0	2.0
GULU-E	18.3	3.0	2	2.0	GBK011125	5.7	2.3	9.3	2.0
GBK000719	20.0	2.3	2.3	2.0	GBK000752	6.0	2.7	11.7	2.7
GBK011098	20.0	2.3	2	1.3	GBK000845	6.0	2.7	5.0	2.0
GBK033605	20.0	2.7	2	1.7	GBK033433	6.0	2.7	6.0	2.0
ACC 29	21.7	2.7	3.7	1.0	GBK033474	6.0	2.3	5.0	2.0
GBK000506	21.7	3.0	5.3	1.7	Okhale-1	6.0	2.3	9.3	2.3
GBK000592	21.7	3.0	2	1.3	GBK000409	6.3	2.7	8.7	2.3
GBK027169	21.7	2.7	4.7	1.7	GBK000487	6.3	2.7	8.7	2.0
GBK029747	21.7	3.0	2	2.3	GBK000696	6.3	2.0	11.7	2.3
GBK033576	21.7	2.7	2	1.3	GBK000815	6.3	2.0	8.7	2.3
GBK011125	23.3	2.8	3.3	2.0	Busibwabo	6.7	1.7	6.0	1.7
GBK011127	23.3	3.0	2	1.3	GBK000449	6.7	2.0	36.7	2.3
GBK043161	23.3	3.0	2.5	2.0	ACC 29	7.0	2.3	6.0	2.3
ACC 14	25.0	3.0	3.3	1.7	GBK000506	7.0	1.7	10.3	2.0
GBK000766	25.0	3.0	4.0	1.3	GBK029819	7.0	2.0	6.0	1.3
GBK029837	25.0	3.0	2.7	1.7	GULU-E	7.0	1.7	6.0	1.3
ACC 32	26.7	3.0	3.7	1.5	GBK029713	7.3	2.3	8.7	2.0
GBK029739	26.7	3.3	2.7	1.7	U-15(RC)	7.3	2.3	7.0	2.0
GBK033575	26.7	3.0	8.7	2.3	ACC 32	7.7	2.3	5.3	2.0
IE4115	26.7	3.0	2.7	1.7	GBK008349	7.7	2.3	5.0	2.0
Ikhulule	26.7	3.0	5.0	1.7	GBK027076	7.7	2.3	4.3	1.7
Okhale-1	26.7	2.7	3.3	1.0	GBK033520	7.7	2.3	5.0	1.7
KNE 741(SC)	41.7	3.7	6.0	2.0	GBK000780	12.3	2.7	10.0	2.3
U 15(RC)	33.3	3.3	3.3	1.8	KNE741(SC)	9.3	2.7	10.0	2.3
RANGE	8.5-23.8	1.7-3.7	2-8.7	1-3.7		5-46.7	1.7-3.3	4.3-53.3	1.3-5
MEAN	28.8	3.2	3.36	1.92		8.14	2.26	12.03	2.36
SE	5.24	0.72	0.32	0.48		1.74	0.46	3.01	0.57
CV	18.1	22.3	25.3	25.2		21.4	20.4	25.1	24.3
Var	***	***	***	***		***	ns	***	***
Rep	***	***	***	***		Ns	ns	ns	Ns

KEY: Var-variety; *, **, *** significant at 0.05, 0.01 and 0.001, respectively; F SEV = Neck severity; F INC = Neck incidence; SC = susceptible check; RC = Resistant check.

33.3% in season one and 3.3% while susceptible check KNE741 had severity of 41.7% and Busibwabo had severity of 33.3 (Table 4). Okhale had foliar severity of 26.7% in season one in contrast to season two that had severity of 3.3%. Similar trend was observed with U15 that had severity of 33.3% in season one and 3.3 in season two. Season two incidence ranged from 1 to 3.7 with average mean of 1.92 and severity ranged from 2 to 8.7 with mean of 3.36% (Table 4). Resistant check U15 had severity of 3.3% while susceptible check KNE741 had severity of 6% and Busibwabo had severity of 2.3%. Local variety Ikhulule had 26.7% and 5% in season one and two respectively. Overall in Alupe, most resistant varieties were ACC14, GBK029713, GBK000414 and GBK000638 with (14.1, 14.1, 14.3, 14.3% severity respectively) while the most susceptible variety was susceptible check GBK741 with 23.8% severity (Table 4).

3.2 Neck Blast Severity and Incidence of Selected Finger Millet Genotypes in Both Sites (Alupe and Kakamega)

The analysis of neck blast severity and incidence indicated significant ($p < 0.001$) variation among the varieties for neck blast reactions in both sites and seasons indicating high variation among the genotypes for neck blast resistance (Table 5). Genotypes, and the interactions between genotype and site, and genotype and season (year) affected the neck severity of tested finger millet germplasm. On average over all growing seasons, the highest mean neck severity was realised in Alupe (5%) compared with Kakamega (4.6%) (Table 5) with some genotypes being more tolerant than the check (U15). The neck blast infection severity was variable from 1 to 5 with a mean of 2.5% (Table 5). Genotype GBK033592 and recorded the highest neck blast infection while genotype GBK000503 and GBK027169 had the high percentage of neck blast as compared to genotype GBK000815, GBK029850 and GBK027076 which showed the lowest neck blast infection than resistant control (U15). These genotypes had less neck damage to blast disease (less than 10%).

The neck incidence ranged from 1.7 to 3.7 in season one with a mean of 3.2 (Table 5). In comparison to season two the incidence ranged from 1 to 3.7 (mean of 4.7) while severity ranged from 1 to 5 (mean of 4.4%) (Table 5). Based on mean neck blast severity, 43 accessions were resistant (score 1.0-2.0 on a 1-5 scale), 22 moderately resistant (score 2.1-3.0), 18 susceptible (score 3.1-4.0) and 17 highly susceptible (score > 4.0) in season one. In season two, 20 varieties were resistant, 15 moderately resistant, 18 susceptible and 47 highly susceptible. Tolerant/resistant check (U15) recorded good values of resistance in season one poor values of resistance (susceptible) in season two. Commercial varieties Busibwabo, P224, ACC32, GULU E and Okhale were all resistant in season one but in season two they were susceptible and highly susceptible (Table 5). Local varieties Ikhulule and Egerton were moderately resistant in all seasons. Average neck severity in Alupe was greatest in long rain in 2012 (4.4%) compared to short rain in 2011 (Table 5). This could be attributed to high relative humidity and high temperature during the heading stage.

Overall, 41 accessions were resistant, 47 moderately resistant, 10 susceptible and 2 highly susceptible in season one as compare to season two that had 87 accessions resistant, 3 moderately resistant, 6 susceptible and 4 highly susceptible in Kakamega (Table 5). Genotypes Busibwabo, ACC14, ACC29, P224 and ACC32 were all resistant in season one as compared to genotypes IE4115, KNE629, KNE741, U15 and GULU E which were moderately resistant in season one. However, all commercial varieties were resistant in season two (Table 5). However, no variety showed highly resistant reaction to neck blast in all sites. Genotype GBK027076, GBK000592 and GBK000865 were resistant in Kakamega and in Alupe. Generally disease incidence and severity was high in

Table 5 Mean neck severity and incidence in Alupe and Kakamega in both seasons.

Alupe					Kakamega				
	Season one		Season two			Season one		Season two	
Variety	Neck sev	Neck inc	Neck sev	Neck inc	Variety	Neck sev	Neck inc	Neck sev	Neck inc
GBK027076	1.0	1.0	1.0	1.0	GBK000815	1.0	1.7	1.3	1.0
GBK040468	1.0	2.0	3.7	1.7	GBK029850	1.0	1.0	1.0	1.7
GBK043065	1.3	2.0	1.7	2.0	GBK027076	1.0	1.0	1.3	1.7
Busibwabo	1.1	2.0	2.3	5.3	GBK000678	1.1	1.3	1.3	1.7
GBK000414	1.1	2.0	3.3	1.7	GBK029713	1.1	1.3	1.0	1.3
GBK000592	1.1	1.0	1.0	2.7	GBK039367	1.1	1.3	6.0	2.3
GBK000696	1.1	1.7	1.7	3.3	GBK043115	1.1	2.0	1.3	2.0
GBK000815	1.3	1.3	5.0	2.3	GBK000458	1.6	2.3	1.3	1.7
GBK011127	1.3	1.0	1.0	2.2	GBK000506	1.6	1.7	1.0	1.3
GBK029869	1.5	2.0	2.3	2.7	GBK029837	1.6	1.3	1.0	1.3
P 224	1.6	2.0	5.0	3.7	Egerton	1.6	1.3	1.0	1.3
GBK000780	1.7	2.3	3.7	4.3	Busibwabo	1.8	2.3	1.0	1.0
Ikhulule	1.7	1.7	2.8	2.7	GBK029869	1.8	2.3	1.0	1.0
Egerton	1.7	2.0	3.3	3.0	GBK033513	1.8	1.7	1.0	1.7
U-15(RC)	1.7	2.3	2	3.7	GBK033520	1.8	2.0	1.0	1.0
ACC 32	1.8	2.3	6.3	3.7	GBK033548	1.8	2.3	1.4	1.7
GBK029739	1.8	2.0	1.7	4.0	ACC 14	2.0	1.7	1.0	1.0
GBK033575	1.8	2.0	5.0	3.3	ACC 29	2.0	1.7	1.0	1.3
GULU-E	1.8	1.7	4.7	2.7	GBK000513	2.0	1.7	1.0	1.3
KNE 629	1.8	2.3	5.0	3.0	GBK000780	2.0	2.7	1.0	1.0
Okhale-1	1.9	1.7	2.3	4.3	GBK033605	2.0	1.7	1.0	1.0
GBK000678	2.0	2.3	2.3	5.3	Ikhulule	2.0	1.7	1.3	1.7
GBK000752	2.0	2.7	2.7	4.0	Okhale-1	2.0	2.0	1.3	1.7
GBK011110	2.0	1.7	2.3	2	P-224	2.0	1.7	1.0	1.0
GBK033332	2.0	1.0	1.7	4.7	ACC 32	2.1	2.0	1.0	1.3
GBK000458	2.3	2.3	4.8	5.3	IE4115	2.1	2.3	1.0	1.7
GBK000638	2.3	1.3	2.0	4.3	KNE 629	2.1	2.0	1.0	1.3
KNE 741 (SC)	3.7	3.0	5.0	5.2	U 15(RC)	2.6	2.3	1.0	1.0
Range	1-5	1.7-3.7	1-5	1-7		1-4.6	1-3.7	1-5	1-6.2
Mean	2.94	0.58	4.4	4.75		2.3	2.22	1.7	2.0
SE	5.075	26.8	7.22	0.98		4.7	0.45	2.27	0.55
% CV	19.6	0.935	17.8	20.7		20.6	20.6	29	27.4
Var	***	***	***	***		***	***	***	***

KEY: Var-variety; *, **, *** significant at 0.05, 0.01 and 0.001, respectively; NECK SEV = Neck severity; NECK INC = Neck incidences = susceptible check; RC = Resistant check.

Alupe than in Kakamega. The resistant lines retained their green color on the neck indicating resistance to the pathogen while the susceptible lines succumbed to the pathogen infection and expressed typical blast symptoms as shown in Figs. 1 and 2. For incidence, susceptibility to panicle blast disease for variety U-15 was 25.8% in Alupe whereas in Kakamega it was 7.8% while Gulu E had foliar severity of 10.1% in Alupe while in Kakamega it was 6.3%. Varieties Busibabwo, Okhale, GBK000702, GBK079869 and GBK 036839 were ranked best because they resist lodging and were tolerant to blast disease, white seeded varieties were generally more susceptible. Varieties ACC14, GBK029869, GBK029875, Okhale, GBK008294, Busibabwo, P224 and GBK027155 were adaptable for Alupe whereas GBK033569,

GBK000638, GBK000702, GBK000513, GBK029747 Busibwabo, and GBK011044 were not adaptable for Kakamega.

Similarly, the finger blast severity percentage was classified into resistant (1.0-10%), moderately resistant (10.1-20%), susceptible (20.1-30%) and highly susceptible (> 30%). The findings of this particular study showed that responses ranged from resistant for the immune finger millet to highly susceptible where the susceptible check (KNE 741) included in this experiment expressed 93.3% disease severity. In season one finger severity ranged from 5-63.3% (mean of 25.12%) as compared to season two that ranged from 3.8-99.3% (mean of 42%) in Alupe (Table 5). The mean finger incidence for season one was 2.17 while season two it was 4.65. This indicates season two had higher finger severity and incidence than season one which could be attributed to high humidity and high temperature in season two than in season one. Resistant check U15 had severity of 11.7% in season one and 33.3% in season two. Local accessions, Busibwabo, Ikhulule and Egerton had mean severity of 15.2%, 11.7% and 29.1% respectively (Table 5). Based on mean finger severity, 15 accessions were classified as resistant (score 1.0-10%), 28 moderately resistant (score 10.1-20%), 22 susceptible (score 20.1-30%.) and 35 highly susceptible (score > 30) in season one compared to season two with 5 accessions that were resistant, 16 moderately resistant, 23 susceptible and 56 highly susceptible. Kakamega generally recorded lower severity than Alupe. However, overall, average finger severity in Alupe was greatest in long rain in 2012 (42%) as compared with short rain in 2011 (25.12%) as compared to Kakamega 16.38% in short rain and 10.3% in long rains (Table 5).

4. Discussions

Based on results from this study, potential finger millet varieties with high productivity and low blast reaction in the fields were identified for major finger millet producing areas of Kenya. For instance, susceptibility to finger blast disease for variety U-15 was 25.8% in Alupe whereas in Kakamega it was 7.8% while GULU-E had foliar severity of 10.1% in Alupe while in Kakamega it was 6.3%. This indicates that blast disease incidence and severity was higher in Alupe than in Kakamega in both seasons. This could be attributed to environmental conditions especially high temperature and humidity in Alupe that favors development of blast. Similar genotypes which had dark colored seeds and compact heads were more resistant compared to white seeded and open headed varieties. This finding was also in agreement with the earlier findings [22, 23] which showed that dark and compact head are more resistant to blast than white and open headed varieties in Busia, Teso and Kisii districts in western Kenya.

Disease incidence and severity were significantly low in season one compared to season two in all sites. This could be attributed to low precipitation, low humidity and high temperature which do not encourage blast development. Neck blast could have more damage hence genotypes susceptible to neck blast compared to resistant varieties could be due to lesions coalescing into larger lesions that lead to leaf neck deformation thus poor transport system leading to poor growth due to blockage of vascular bundles leading to severe effects. These findings are similar to those earlier reported [24] that neck and finger blast are more destructive to many genotypes. The results also revealed that the virulence of the disease in finger millet was affected by days to maturity of the crop. Early maturing genotypes were more susceptible as compared to late maturing varieties as indicated by negative correlation between foliar severity with plant height and days to maturity. Tall and late maturing varieties might escape infection. The finding confirms the earlier reports in similar studies [25]. Significant genotypic variability ($p < 0.01$) observed across the trials shows there is wide diversity amongst the test genotypes evaluated. The findings of this study showed that none of finger millet variety could exhibit complete resistance to blast disease or evade the blast infestation completely in both sites and two seasons. The significant effect of the site and seasons that occurred in the leaf, neck and finger blast infection levels could be due to variable weather conditions in the two experimental sites. The significant effect of site and season occurred in leaf, neck and finger blast infection levels could be due to variable weather conditions in the two sites. Such difference in weather conditions influencing disease level is a known fact [26]. Environmental conditions, especially relative humidity and temperature could strongly affect the sporulation, release and germination of blast conidia [27]. It was observed that blast disease incidence and severity was higher in Alupe than in Kakamega in both seasons. This could be attributed to environmental conditions especially high temperature and humidity in Alupe that favors development of blast. It is well documented that the environmental conditions, especially relative humidity, are one of the most important factors affecting sporulation, release, and germination of blast conidia [28].

The experiment confirmed the strong influence of physiological maturity on the observed disease severity but not of the effect of tallness. A very high host plant damage rating was observed at flowering and maturity stage in Alupe as compared to Kakamega. This variation could have been caused by the difference in temperatures reported from the weather stations in the two sites probably with Alupe being a favorable environment for proliferation of this disease as compared to Kakamega. These agree with other study which indicated earlier that neck and panicle are more destructive than foliar blast.

Foliar blast occurred in a majority of accessions at the seedling stage, which did not correlate well with crop growth stages and maturity of the plants, probably because of the buildup of adult plant resistance. Significant moderate correlations between leaf blast with neck and, finger blast suggest that a high level of leaf blast severity may not result in severe neck or finger blast during the later stages of plant development. Poor correlation has been observed for leaf blast with neck blast (r = 0.04) and finger blast (r = 0.27) infection [29] on in finger millet. It has been reported that seedlings of finger millet are more susceptible to leaf blast than mature plant [30]. However, no relationship is known between the intensity of seedling infection and that of later neck and finger infection. Rather prevailing weather conditions at a particular stage of crop development determine the intensity of blast infection [31, 32]. Contrasting responses between the vegetative stage and reproductive stage often occur indicating differential gene expression for resistance to leaf, neck and/or finger blast infection. This shows that resistance to finger blast may be in some finger millet genotypes independent from resistance to leaf blast. The results agree with findings of earlier studies [33]. In rice similar results were reported in rice [34]. In contrast, finger blast severity did not correlate well with agronomic parameters measured probably because of the build-up of adult plant resistance. The negative correlations between plant height and foliar severity, neck severity and finger severity indicate that tall varieties might escape blast infection due to less favorable microclimatic conditions [35]. A significant negative correlation was found between blast severity and days to flowering suggesting that early flowering accessions are more susceptible than the late ones [36]. This reflects the susceptibility of early maturing varieties. From the weather data collected during the two growing seasons it shows that Alupe was warmer and humid compared to Kakamega during both the growing seasons, hence the reason for more disease development in this site.

There was however, a weak positive correlation between foliar blast severity and neck blast severity (0.021). Similarly panicle blast severity (0.0009) did not correlate well with agronomic parameters measured, probably because of the build-up of adult plant resistance. Hence, neck and panicle blast reactions that are more destructive than leaf blast were considered important parameters for blast resistance. The negative correlations between foliar and panicle blast severity and plant height indicate that tall and late maturing varieties might escape blast infection. A significant negative correlation (0.52) was found between blast severity and DF (days to flowering) suggesting that late flowering varieties are more resistant than the early ones as indicated by genotype KNE 741 which was early maturing but highly susceptible to blast disease. Significant positive correlation between neck and finger blast incidence has earlier been reported in finger millet [38]. The genotypes would do well in lowlands where disease incidence is low. The findings showed that genotypes GBK011127, GBK027076, GBK000865, GBK033520, GBK0333605, GBK000621, GBK029869, BK000592, GBK033513 and GBK029850 had general resistance for all the three different types of blast diseases and can be used as resistance sources. They could then be selected and promoted as important source of resistance. On the other hand, most of the varieties such as GBK033592, GBK036767, GBK027169, GBK000503 and GBK033418 were susceptible to blast with GBK036767 as the most susceptible to blast infection as depicted by terminal severity value and low yielding due presence of high disease pressure.

Thus a breeding program should be devised to cross the high yielding susceptible varieties with disease resistant varieties such as GBK00865 and GBK000592 having low terminal severity. A very high plant damage rating was observed at flowering and maturity stage. This finding was also in agreement with the earlier findings that noted that the neck and finger blast are more destructive than foliar blast. Highest susceptible variety in both sites was GBK036767. Varieties producing dark colored seeds and compact (fist) heads were more resistant to blast compared to white-seeded and open-headed varieties. The varieties identified can be utilized in breeding programs and some could be promoted for farmer productions.

5. Conclusion and Recommendation

The findings of this study showed that there is significant variation among the genotypes for disease resistance indicating high variation among the genotypes. Genotypes GBK011127, GBK027076, GBK000865, GBK033520, GBK0333605, K000621, GBK029869, GBK000592, GBK033513 and GBK029850 had general resistance for all the three phases (foliar, neck and finger) of blast diseases and can be used as resistance sources. They did better than the commercial varieties U15 and P224 and they could then be selected and promoted as important source of resistance. Thus a breeding program should be devised to cross disease resistant varieties such as GBK00865 and GBK000592 having low terminal severity with high yielding susceptible commercial varieties like U15 and P224. Breeding work on various aspects of the crop needs to be encouraged by breeders especially towards high yielding varieties that are resistant to blast disease. Also varieties producing dark coloured seeds and compact (fist) heads were more resistant to blast compared to white-seeded and open-headed varieties, hence these varieties could be utilized in breeding programs and mechanisms of resistance need further studies. These varieties could be promoted for production by the farmers after National performance trials.

Acknowledgement

This work was supported by HOPE finger millet Project funded by Gates Foundation through ICRISAT/Egerton University/KALRO collaborative project, hence they are highly acknowledged. We thank all ICRISAT and Egerton University research team for their assistance during period of project and all people who participated in this research work.

Reference

[1] Salasya, B. D. S., Oduori, C., Ambitsi, N., Onyango, E., Oucho, P. and Lumuli, J. 2009. The status of finger millet production in western Kenya. KARI Report, Nairobi, Kenya, 719-723.

[2] FAO 2009. Food and Agriculture Organization of the United Nations. http://www.fao.org.

[3] FAO 2005. Food and Agriculture Organization of the United Nations. http://www.fao.org.

[4] FAO 2012. Food and Agriculture Organization of the United Nations. http://www.fao.org.

[5] ICRISAT 2012. International Crops Research Institute for the Semi-Arid Tropics, Technical Reports on Status of Finger millet in ESA, Nairobi, Kenya.

[6] ICRISAT 2007. International Crops Research Institute for the Semi-Arid Tropics, Technical Reports on Status of Finger millet in ESA, Nairobi, Kenya.

[7] Oduori, C. O. 1998. Finger Millet Better Varieties, Better Crop Care-More Food DFID and GON Produced by DEVCOM and AIC, 67-71.

[8] Holt R.D. 2000. "The Population Genetics of Ecological Specialization in Evolving *Escherichia coli* Populations." *Nature 12: 407* (6805): 689-690.

[9] Mgonja, M. A., Lenne, J. M., Manyasa, E., and Sreenivasaprasad, S., eds. 2007. "Finger Millet Blast Management in East Africa: Creating Opportunities for Improving Production and Utilization of Finger Millet." *In Proceedings of the First International Finger Millet*, International Crops Research Institute for the Semi-Arid Tropics.

[10] Srivastava, R. K., Bhatt, R. P., Bandyopadhyay, B. B., and Kumar, J. 2009. "Fertility Status of *Magnaporthe grisea* Populations from Finger Millet." *Indian Journal of Science and Technology* 2 (9): 41-44.

[11] Sreenivasaprasad, S., Takan, J. P., Obilana, A. B., Manyasa, E., Brown, A. E., Bandyopadhyay, R., et al. 2004. *Finger Millet Blast in East Africa: Pathogen Diversity and Disease Management Strategies*. Final Technical Report, 118.

[12] Leen, J. M., Takan, J. P., Wanyera, N., Manyasa, E. O., Mgonja, M. A., Okwadi, J., Brown, A. E. and Sreenivasaprasad, S. (2007). "Finger millet blast management: a key entry point for fighting Malnutrion and poverty in East Africa", pp. 12-17.

[13] Nagaraja, A., Nanja, Y. A., Anjaneya, B., Patro, T. S. S. K., Kumar, B., Kumar, J., and Krishne, K. T. 2010. "Reaction of Finger Millet Recombinant Inbred Lines to Blast." *Crop Research* 39: 120-122.

[14] Sreenvasaprasad, S., Mgonja, M. A., Manyasa, E. O., Wanyera, N. W. M., Takan, J., Okwadi, J., et al. 2006. *Facilitating the Promotion of Improved and Blast Resistant Finger Millet Varieties to Enhance Production*. Technical Report, pp. 11-22.

[15] Jaetzold, R., and Schmidt, H. 1982. "Natural Conditions and Farm Management Information, Part A: Western Kenya." In *Farm Management Handbook of Kenya*. Volume II. Ministry of Agriculture in cooperation with GTZ, Nairobi, Kenya.

[16] Jaetzold, R., and Schmidt, H. 1982. "Natural Conditions and Farm Management Information, Part A: Western Kenya." In *Farm Management Handbook of Kenya*. Volume II. Ministry of Agriculture in cooperation with GTZ, Nairobi, KenyaAkonaay, H. B., Mushi, C. S., Ntundu, W., H and Millinga, L. P. 2004. *National Plant Genetic Resources Centre*. A Report on Baseline Survey of Neglected and Underutilized Crop Species in Tanzania, p. 65.

[17] Jaetzold, R., and Schmidt, H. 1982. "Natural Conditions and Farm Management Information, Part A: Western Kenya." In *Farm Management Handbook of Kenya*. Volume II. Ministry of Agriculture in cooperation with GTZ, Nairobi, Kenya

[18] Holt, J. 2000. Investigation into the biology, epidemiology and management of finger millet blast in low-input farming systems in East Africa. http://www.wisard.org/wizard/shared/asp/projectsummary.asp?Kennumer.

[19] ICRISAT 1997. International Crops Research Institute for the Semi-Arid Tropics, Technical Reports on Status of Finger millet in ESA, Nairobi, Kenya

[20] Snedecor, G. W. and Cochran, W. G. 1980. *Statistical Methods*. 7th Edition, Iowa State University Press, Ames.

[21] Barnett, H. L., and Hunter, B. B. 1960. "Illustrated Genera of Imperfect Fungi." Burgess Publishing Company, Morgantown, West Virginia, 71.

[22] Obilana, A. B., Manyasa, J. G., Kibuka, E. P., and Ajanga, S. 2002. Finger Millet Blast Samples Collection in Kenya: Passport Data, Analyses of Disease Incidence and Report of Activities. ICRISAT. Nairobi, Kenya.

[23] Takan, J. P., Akello, B., Esele, J. P., Manyasa, E. O., Obilana, A. B., Audi, P. O., et al. 2004. "Pathogen Diversity and Management of Finger Millet Blast in East Africa." *International Sorghum and Millets Newsletter* 45: 66-69.

[24] Nagaraja, A., Nanja, Y. A., Anjaneya, B., Patro, T. S. S. K., Kumar, B., Kumar, J., and Krishne, K. T. 2010. "Reaction of Finger Millet Recombinant Inbred Lines to Blast." *Crop Research* 39: 120-122.

[25] Nagaraja, A., Nanja, Y. A., Anjaneya, B., Patro, T. S. S. K., Kumar, B., Kumar, J., and Krishne, K. T. 2010. "Reaction of Finger Millet Recombinant Inbred Lines to Blast." *Crop Research* 39: 120-2.

[26] Kato, H., Yamaguchi, T., and Nishihara. N. 1977. "Seed Transmission, Pathogenicity and Control of Ragi Blast

Fungus and Susceptibility of Ragi to *Pyricularia* spp from Grasses, Cereals and Mioga." *Annals of the Phytopathological Society of Japan* 10: 20-28.

[27] Ou, S. H. 1985. *Rice Diseases* (2nd ed.). Surrey, England: Commonwealth Mycological Institute, Kew.

[28] Ou, S. H. 1985. *Rice Diseases* (2nd ed.). Surrey, England: Commonwealth Mycological Institute, Kew.

[29] Somashekhara, Y. M.., Viswanath, S., and Anilkumar, T. B. 1991. "Evaluation of Fingermillet (*Eleusine coracana* (L.) Gaertn) Cultivars for Their Reactions to Blast." *Tropical Agriculture* 68: 231–4.

[30] Rachie, O. K., and Peters, V. L. 1977. "*Tahe eleusines*: A Review of the World Literature." International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, AP, India.

[31] Esele J. P. 2002. Sorghum and Pearl millet diseases in horn of Africa In Leslie J.F. (Ed) Sorghum and Millets disease. Iowa State Press PP 383-366.

[32] Lubadde G., Tongoona P, Derera J. and Sabaya J. 2014. Major diseases of sorghum and pearl millet and their effects on-farm grain yield in Uganda. African Journal of Agricultural Research 9 (39): 2911-2018.

[33] Bennetzen, J. L., Dida, M. M., Manyara, N. W. M and Devos, K. M. (2003). Characterization of genetic Diversity in finger millet. Online: http://www.cerealsgenomics.org/document/BennetzenProp.doc (Accessed on 2011, Aug. 10).

[34] Chaudhary, B., Shrestha S. M., and Sharma, R. C. 2005. "Resistance in Rice Breeding Lines to the Blast Fungus in Nepal." *Nepal Agric. Res. J.* 6: 49-56

[35] Babu, T. K., Thakur, R. P., Upadhyaya, H. D., Reddy, P. N., Sharma, R., Girish, A. G., et al. 2012. "Resistance to Blast (*Magnaporthe grisea*) in a Mini-Core Collection of Finger Millet Germplasm." *European Journal of Plant Pathology* 135 (2): 299-311.

[36] Mgonja, M. A., Lenne, J. M., Manyasa, E., & Sreenivasaprasad, S. Eds. 2007. Finger millet blast management in East Africa: creating opportunities for improving production and utilization of finger millet: proceedings of the first International finger millet stakeholder workshop, Nairobi.

[37] Mgonja M. A., Chandra S, Gwata E. T., Obilana A. B., Monyo E. S., Rohrbach D. D., Chisi M., Kudita S., Saadan H. M. 2005. "Improving the Efficiencies of National Crop Breeding Programs through Region-Based Approaches: The Case of Sorghum and Pearl Millet in Southern Africa." *J Food, Agriculture Environment* 3: 124-129.

[38] Pande S., Mukuru S. Z., King, S. B., and Karunakar, R. I. 1995. *Biology of, and Resistance to Finger Millet Blast in Kenya and Uganda in Eighth EARSAM Regional Workshop on Sorghum and Millets*, 30 October-5 November 1992.

[39] Kumar, A., Kumar, S., Kumar, R., Kumar V., Prasad, L., Kumar, N., and Singh, D. 2010. "Identification of Blast Resistance Expression in Rice Genotypes Using Molecular Markers (RAPD and SCAR)." *African Journal of Biotechnology* 9: 3501-3509.