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RESEARCH ARTICLE

Screening F_1 arabica hybrids for resistance to coffee berry disease (*Colletotrichum kahawae*): insights from field and controlled conditions

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ABSTRACT

Coffee berry disease (CBD), caused by *Colletotrichum kahawae*, remains one of the most destructive diseases of Arabica coffee, leading to substantial yield losses during high infection seasons in major coffee-growing regions, including Tanzania. Developing resistant varieties is a sustainable strategy for managing CBD, and breeding programs increasingly rely on host resistance to mitigate its impact. This study evaluated the response of eight F1 hybrid genotypes of Arabica coffee—F90/64/4660 × KP423, F89/64/4660 × KP423, F45/64/2049 × KP423, F24/64/902 × KP423, F45/64/2061 × KP423, F24/64/886 × KP423, VC 298, and KP423—against three *C. kahawae* isolates (2006/14 from Kibosho–Kombo, 2019/16 from Ugano-Mbinga, and 2019/11 from Maua Kilema). Coffee berries were inoculated under both field conditions and controlled environments using a spore suspension spray method. In controlled assays, berries were maintained in humidity boxes at 24 ± 2°C, while field inoculations required humid conditions and an optimum temperature of 30°C. Disease severity was assessed using a modified 0–4 scale, and incidence was recorded as the percentage of infected berries. Inoculated berries developed typical CBD symptoms, including brown spots and sunken lesions. Results revealed that two genotypes (F90/64/4660 × KP423 and F89/64/4660 × KP423) exhibited complete resistance, showing no infection across all isolates and environments. Among the isolates, 2006/14 from Kibosho–Kombo was the most aggressive, producing higher infection rates. These findings highlight the potential of resistant genotypes for incorporation into breeding programs and demonstrate the value of aggressive isolates as screening tools for developing durable resistance to CBD in Tanzania.

Keywords: F1 arabica hybrids, *Colletotrichum kahawae,* coffee, coffee berry disease.

INTRODUCTION

Arabica coffee in Tanzania is predominantly cultivated at altitudes above 1200 m.a.s.l., where low temperatures and prolonged moisture films on berry surfaces create favorable conditions for the development of coffee berry disease (CBD). This disease, caused by *Colletotrichum kahawae*, is highly destructive and has been reported to cause yield losses of up to 70–80% during severe epidemics (Silva et al., 2006). Effective management of CBD is therefore critical for stabilizing coffee yields. Current control strategies rely on timely fungicide application (Gichimu & Omondi, 2010), cultural practices, quarantine measures (Phiri et al., 2001), and host resistance (Omondi et al., 2000, 2001). However, fungicide use can sometimes exacerbate disease by reducing non-pathogenic microbial competitors (Derso et al., 2000), and continuous application of copper-based fungicides has raised environmental concerns. For instance, Lolland and Singh (2004) reported elevated copper concentrations in bean plants grown near coffee fields, suggesting potential soil and water contamination.

CBD epidemics depend on the susceptibility of Arabica varieties and the presence of virulent *C. kahawae* isolates. The pathogen's conidia are dispersed by rainfall and require free water or near 100% relative humidity for germination (Mouen Bedimo et al., 2010). Optimal temperatures for conidial germination, appressoria formation, and mycelial growth range between 21–23°C (Janardhan & Krishna, 2021), while temperatures above 30°C inhibit fungal growth (Chen et al., 2003). Conidia produced in acervuli are released and spread by rain or wind to nearby berries (Bedimo et al., 2007). In the absence of diseased berries, inoculum originates from fungal fruiting bodies on maturing bark, flower buds, and mummified berries, which sporulate after rainfall and infect young green fruits (Jayalakshmi et al., 2021). Green berries are most susceptible between four and fourteen weeks after flowering, while ripening berries remain vulnerable until maturity. Mature berries (16–25 weeks) develop resistance due to endocarp formation (Silva et al., 2006).

Given the limitations of chemical control and the environmental risks associated with fungicide use, breeding for host resistance remains the most sustainable strategy. The objective of this study was to evaluate the response of selected F1 Arabica hybrids to known CBD isolates, thereby enriching breeding programs aimed at developing resistant varieties.

MATERIALS AND METHODS

Location

This study was carried out both in the field and at the Pathology laboratory of Tanzania Coffee Research Institute in Lyamungu, Hai district; located at latitudes 03º24'49'' South and longitudes 37º24'46''East and 1268 meters above sea level (Figure 1).

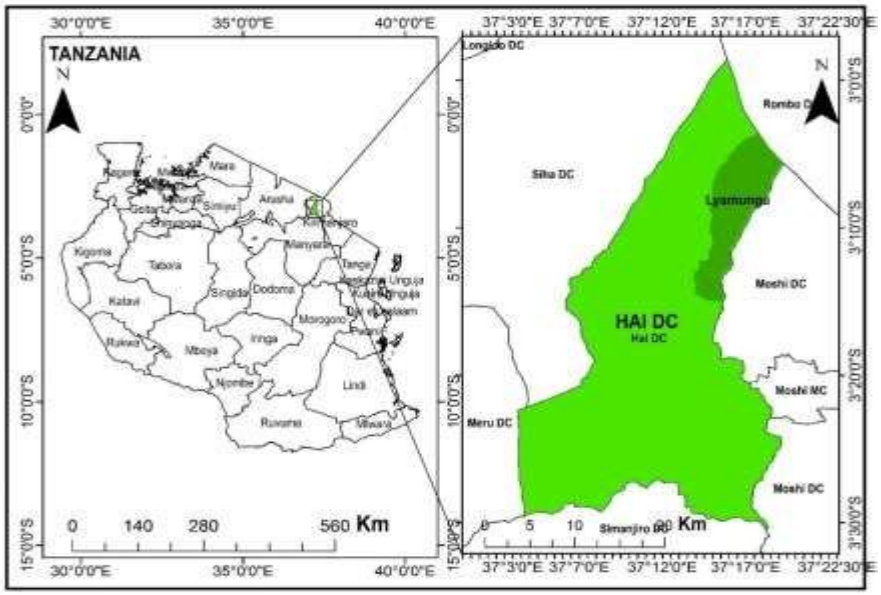

Figure 1. Map of Tanzania showing the location of study area in Lyamungu, Hai district - Kilimanjaro

Experimental plant materials

The experimental materials used were commercial coffee variety KP423, which is susceptible to CBD and VC 298 a resistant variety, as control checks. Six F1 populations, derivatives of Ethiopian coffee accessions, which are high yielding and KP 423, which has good cup quality (F45/64/2061 x KP 423, F90/64/4660 x KP 423, F45/64/2049 x KP 423, F24/64/902 x KP 423, F24/64/886 x KP 423, and F89/64/4660 x KP 423) were used.

Inoculum preparation and inoculation

For increasing the volume of collected and preserved C. kahawae isolates, the Malt Extract Agar (MEA) was prepared as described by Kilambo et al. (2008). These isolates 2006/14, 2019/16 and 2019/11 were obtained from TaCRI isolates collected from Kibosho-Kombo, Mbinga-Ugano and Maua-Kilema areas respectively. The ten months stored isolates were activated by inoculating on freshly green coffee berries in the field for sporulation, and then plated on solidified MEA in petri dishes kept in culture room for multiplication for a period of 14 days. Inoculum was then obtained by dislodging and harvesting the conidia by flooding the plate with 5 ml of sterile distilled water. The cell suspensions were made using sterile distilled water and its concentration of 2 x 10^6 conidia/ml as described by van der Vossen et al. (1976) were adjusted using a haemocytometer (Caligiore-Gei and Valdez, 2015). Detached coffee berries were inoculated with C. kahawae isolates using a hand sprayer, spraying them twice at 48 hours' interval with the inoculum of each isolate.

Experimentation

The laboratory condition was set at the temperatures of 19-21°C, and R.H of approximately 100%. A split plot under Randomized Complete Design was used with three replications whereby eight genotypes were the main plot and three *C. kahawae* isolates sub factors. A set of 20 detached green expanded berries were kept in a sandwich box having tissue paper with sterilized distilled water to prevent berries from shriveling. In sandwich boxes, berries were arranged at a spacing of 1.0 x 1.0 cm. One replication therefore contained a total of 24 sandwich boxes. The whole experiment consequently had a total of 72 sandwich boxes. And the field experiment was done using a split plot in Randomized Complete Block Design (RCBD) with three replications during long rain season on March, 2023. The eight coffee genotypes were inoculated with the three isolates of *C. kahawae*; 2006/14, 2019/16 and 2019/11. The main plots were the genotypes and subplots were the *C. kahawae* isolates. Every genotype consisted of three coffee trees. Spacing between coffee trees was 2.5 m and within rows 2.0 m. One inner plant was inoculated with three *C. kahawae* isolates by covering three different branches using polythene bag, each branch was inoculated with different C*. kahawae* isolate. The three branches used for CBD assessment had 5 to 6 berry clusters per branch (averaging 25 berries per cluster) of green expanding coffee berries 8-12 weeks old. The other two trees were used as guard rows. One tree in each genotype was inoculated with three different isolates in order to maintain uniformity. Inoculation was done twice at the interval of 48 hours for better infection (Kilambo *et al.,* 1999). During the experiment, rainfall, temperature and humidity were recorded (Appendix 1a, 1b and 1c) which were the main environmental factors for disease infection.

Procedure of assessment and data collection

The number of green coffee berries infected with CBD was recorded at 7, 11, and 15 days after artificial inoculations. Data collected were based on CBD symptoms such as: - number of lesions, type of lesions formed, active sunken dark lesions (A), scab lesions (S) and (N) for non-infected berries, size of lesions (mm^2) and days from inoculation to symptoms appearance. Disease incidence was calculated by counting the number of CBD infected berries against uninfected berries, and then the percentage berry infected calculated. Potential genotypes in terms of CBD resistance were identified based on the disease incidence; the ones with lower incidence were marked.

Means of analyzing data

Data were subjected to analysis of variance (ANOVA) for determination of statistical difference using GenStat software (16th version, VSN International) and Duncan Multiple Range Test were used for means separation. Resistance categories were then classified as; resistant (DIR 0 – 25), moderately resistant (DIR 26 – 50), moderately susceptible (DIR 51 – 75), and susceptible (DIR 76 – 100), as also applied by Kilambo et al. (2008). Disease incidence was performed as per Marasas et al. (1988) formula.

$$\text{Percent disease incidence} = \frac{Number\ of\ infected\ berries\ in\ the\ cluster}{Total\ number\ of\ berries\ in\ the\ cluster} \times 100$$

Active lesions (deep sunken black color) are indication of susceptible varieties and scab lesions (brownish color) as a sign of tolerance response (Appendix 2 and Appendix 3).

RESULTS

In both field and laboratory experiments, ANOVA mean squares for all variables tested on genotypes and *C. kahawae* isolates show significant variation (P<0.001) on percent infected berries, size of lesions, number of lesions and days to lesions appearance. Interaction of genotypes and isolates was significant (P<0.001) on size of lesions and number of lesions, respectively (Table 1).

Table 1. Analysis of variance table of mean squares

Source of Variation	Degree of freedom	% infected berries	Size of lesions (mm^2)	Number of lesions	Days to lesions appearance
Blocks	2	107.56 (92.36)	53.01 (1.377)	0.6007 (0.8528)	35.58 (77.42)
Genotypes (G)	7	7778.92 (71299.65)***	3106.13 (444.959)***	80.1673 (78.3016)***	1614.34 (1152.98)***
Isolates (I)	2	768.44 (300.69)***	584.86 (111.325)***	8.0617 (13.9382)***	491.77 (142.12)***
G x I	14	554.22 (382.64)	127.56 (64.386)***	4.5061 (4.6549) ***	23.00 (26.12)
Residual	1414	1310.22 (590.97)	14.32 (1.500)	0.697 (0.7520)	26.62 (24.75)

*** Significant at 0.001, ** Significant at 0.01, * Significant at 0.05; Values in brackets are for the laboratory conditions experiment (detached berries)

Effect of coffee berry disease on resistance level of the F1 population

Results on the Arabica coffee genotypes CBD resistance for the percentage infected berries, size of lesions, number of lesions and number of days to lesion appearance are presented in Table 2. F1 hybrid genotypes F90/64/4660 x KP423, F89/64/4660 x KP423 and the resistant check VC289 demonstrated higher resistance level to all *Colletotrichum kahawae* isolates as they had no (0.00) scores of CBD infection. Genotypes F45/64/2061 x KP423 and F24/64/886 x KP423 revealed significant difference at (P<0.001) high percentage infected berries (56.67) and (63.89) while Susceptible check KP423 indicated highest percentage level of infection which is 88.89. Results revealed significant difference at (P<0.001) of larger size of lesions (4.7mm^2), (1.8mm^2) and (1.4mm^2) in the check variety KP423, F24/64/886 x KP423 and F45/64/2061 x KP423, respectively. Some F1 hybrid genotypes F24/64/886 x KP423 and F45/64/2061 x KP423 were observed to have significant effect (P<0.001) on few days 8 and 9 to lesions appearance. Active type of lesion (A) was revealed by F1 hybrid genotypes F24/64/886 x KP423 and F45/64/2061 x KP423 upon infection. F1 hybrid genotypes F24/64/902 x KP423 and F45/64/2049 formed high percent of scab lesions (S) which indicated disease tolerance, therefore categorized as moderately resistance. Days to the first CBD symptoms appearance were noticed earlier on susceptible genotypes (KP423 and F1 hybrid F24/64/886 x KP423 that were inoculated with isolate 2006/14 and 2019/16 than isolate 2019/11.

Table 2. Effect of coffee berry disease on the Arabica coffee genotype tested

Genotypes	% infected berries	Size of lesions	Number of lesions	Number of days to lesions appearance	Type of lesions
F90/64/4660 x KP 423	0.00 (0.00)[a]	0.00 (0.00)[a]	0.00 (0.00)[a]	-	N
F89/64/4660 x KP 423	0.00 (0.00)[a]	0.00 (0.00)[a]	0.00 (0.00)[a]	-	N
VC 298	0.00 (0.00)[a]	0.00 (0.00)[a]	0.00 (0.00)[a]	-	N
F24/64/902 x KP423	34.22 (36.11)[b]	1.08[c] (0.94)[b]	0.66[b] (0.59)[b]	11 (11)	S
F45/64/2049 x KP423	36.00 (41.67)[c]	0.67[b] (0.73)[b]	0.88[c] (1.05)[c]	11 (11)	S
F45/64/2061 x KP423	52.89c (56.67)[d]	1.95d (1.38)[c]	4.4d (1.09)[c]	9 (9)	A
F24/64/886 x KP423	48.00c (63.89)[e]	1.77d (1.78)[d]	0.82c (1.36)[d]	9 (8)	A
KP 423	86.22d (88.89)f	4.16e (4.71)[e]	1.61e (1.63)[e]	5 (5)	A
Mean	32.17 (35.90)	1.20 (1.19)	0.64 (0.71)	9.08 (9)	
SE±	2.892 (1.387)	0.118 (0.054)	0.032 (0.042)	0.308 (0.302)	
CV%	9.0 (3.9)	9.8 (4.5)	5.0 (5.9)	3.4 (3.4)	
P-value	0.001	0.001	0.001	0.001	

Means with similar letter in the same column are not statistically different at P ≤ 0.05; A=Active lesions; S=Scab lesions; N=No lesion; [a]Cells in the table where there is no numerical value (-) is because no lesions were ever formed within the set observation period of maximum 15 days. Values in brackets are for the laboratory conditions experiment (detached berries)

Results on aggressiveness of *C. kahawae* isolates

Results in Table 3 show the mean values for the percentage of infected berries, size of lesions, number of lesions, type of lesions formed and number of days to lesion appearance caused by three different *C. kahawae* isolates. Isolates 2006/14, 2019/16 and 2019/11 had a significant effect (P<0.001) on size of lesions of 1.7, 1.2, and 1.0 mm^2 on the F1 hybrid genotypes. Moreover, isolates 2019/16 and 2006/14 induced lesions significantly earlier at (P≤0.05) on 9 and 8 days after inoculation respectively than isolate 2019/11 which induced lesion at 10 days after inoculation. Isolates 2006/14 and 2019/16 caused active lesions (A) on tested F1genotypes compared to isolate 2019/11 which revealed scab lesions (S). However, all tested isolates 2006/14, 2019/16 and 2019/11 caused significant disease effect at (P<0.001) whereby on percentage berries infection was 38.33, 36.04, and 33.33, respectively.

Table 3. Effect of *C. kahawae* isolates on F_1 genotypes

Isolates	% Infected berries	Size of lesions (mm^2)	Number of lesions	Number of days to lesion appearance	Type of lesions
2019/11	27.83[a] (33.33)[a]	0.80[a] (0.72)[a]	0.51[a] (0.52)[a]	13 (10)	S
2019/16	32.00[b] (36.04)[b]	0.99[b] (1.17)[b]	0.68[b] (0.79)[b]	12 (9)	A
2006/14	36.67[c] (38.33)[c]	1.82[c] (1.68)[c]	0.72[b] (0.83)[b]	11 (8)	A
Mean	32.17 (35.90)	1.20 (1.19)	0.64 (0.71)	12 (9)	
SE±	2.892 (1.387)	0.118 (0.054)	0.032 (0.421)	0.308 (0.302)	
CV%	9.0	9.8	5.0	3.4	

	(3.9)	(4.5)	(5.9)	(3.4)
Prob.	0.001	0.001	0.001	0.001

Means with similar letter in the same column are not significant different at P≤0.05; A=Active lesions; S=Scab lesions; N=No lesion. Values in brackets are for the laboratory conditions experiment (detached berries)

Interaction Effects of C. kahawae Isolates and F1 Arabica Genotypes

Table 4 shows interaction of genotypes and isolates on CBD evaluation parameters. Genotypes F90/64/4660 x KP423 and F89/64/4660 x KP423 and resistant check VC298 had no lesion appearance after inoculation, therefore, ranked with (R) while the susceptible check KP423 had high percent infected berries (86.67, 81.33 and 77.33) when inoculated with *C. kahawae* isolates (2006/14, 2019/16 and 2019/11), thus ranked with (S). Two F1 hybrid genotypes (F45/64/2049 x KP423 and F24/64/902 x KP423) revealed low percent infected berries when inoculated with the various isolates (2019/11, 2019/16 and 2006/14) and placed under moderately resistance class (MR). Genotypes F24/64/886 x KP423 and F45/64/2061 x KP423 ranked under moderate susceptibility (MS) after inoculated with *C. kahawae* isolate (2006/14).

Pathogenicity levels of three of *C. kahawae* isolates

Ability of *C. kahawae* isolates to cause infection on coffee genotypes is presented in Table 6. F1 genotypes F90/64/4660 x KP423 and F89/64/4660 x KP423 resist infection from all three isolates (2006/14, 2019/16 and 2019/11). Results of ability of the three isolates in causing lesions are summarized in Table 6. When the scored active lesions were more than 50% of infected berries, then the genotype was ranked under active type (A) while scab type of lesion (S) was ranked for the genotype which had more than 50% scabs from the total infected berries. Resistant varieties were ranked (N) which means not infected. All three isolates were pathogenic in susceptible genotype KP423 by causing active lesions (A) on green berries. Genotypes F45/64/2061 x KP423 and F24/64/886 x KP423 were weaker to isolates 2006/14 and 2019/16 by forming active lesions (A) upon infection, in contrast with isolate 2019/11 where they produce scab lesions (S) the indication of tolerating disease infection. For a susceptible check KP423 active lesions were developed due to its susceptibility to *C. kahawae* isolate used. The level of the pathogenicity of *C. kahawae* isolates is measured by the ability to cause active lesions and taking few days in causing infection (Kilambo et al. 2013).

Table 4. Mean values for the interaction effects of F1 Arabica genotypes and *C. kahawae* isolates on various coffee berry disease resistance parameters under field conditions

Genotypes	Isolates	%infected berries	No. of lesions	Size of lesions (mm2)	Days to lesion appearance[a]	Reaction Classification
F90/64/4660 x KP423	2006/14	0.00^{a}	0.00^{a}	0.00^{a}	-	R
F90/64/4660 x KP423	2019/16	0.00^{a}	0.00^{a}	0.00^{a}	-	R
F90/64/4660 x KP423	2019/11	0.00^{a}	0.00^{a}	0.00^{a}	-	R
F89/64/4660 x KP423	2006/14	0.00^{a}	0.00^{a}	0.00^{a}	-	R
F89/644660 x KP423	2019/16	0.00^{a}	0.00^{a}	0.00^{a}	-	R
F89/64/4660 x KP423	2019/11	0.00^{a}	0.00^{a}	0.00^{a}	-	R
VC298	2006/14	0.00^{a}	0.00^{a}	0.00^{a}	-	R
VC298	2019/16	0.00^{a}	0.00^{a}	0.00^{a}	-	R
VC298	2019/11	0.00^{a}	0.00^{a}	0.00^{a}	-	R
F24/64/902 x KP423	2006/14	40.00^{cd}	0.55^{b}	1.32^{de}	11	MR
F24/64/902 x KP423	2019/16	34.67^{bc}	0.53^{b}	1.09^{cd}	11	MR
F24/64/902 x KP423	2019/11	29.33^{b}	0.91^{def}	0.83^{bc}	12	MR
F24/64/886 x KP423	2006/14	54.67^{efg}	1.07^{ef}	2.80^{hi}	8	MS
F24/64/886 x KP423	2019/16	48.00^{ef}	0.76^{bcd}	1.73^{ef}	10	MR
F24/64/886 x KP423	2019/11	37.33^{bc}	0.63^{bcd}	0.77^{bc}	11	MR
F45/64/2061 x KP423	2006/14	57.33^{fg}	1.44^{gh}	2.81^{hi}	7	MS
F45/64/2061 x KP423	2019/16	48.00^{de}	1.17^{fg}	2.03^{fg}	9	MR
F45/64/2061 x KP423	2019/11	41.33^{cd}	0.73^{bcd}	1.00^{bcd}	10	MR
F45/64/2049 x KP423	2006/14	40.00^{cd}	1.19^{fg}	0.79^{bc}	10	MR

F45/64/2049 x KP423	2019/16	33.33^{bc}	0.88^{cde}	0.64^{bc}	11	MR
F45/64/2049 x KP42	2019/11	29.33^{b}	0.59^{bc}	0.57^{b}	11	MR
KP423	2006/14	86.67^{i}	1.55^{h}	6.81^{j}	3	S
KP423	2019/16	81.33^{hi}	2.11^{i}	2.43^{gh}	4	S
KP423	2019/11	77.33^{h}	1.19^{fg}	3.24^{i}	6	S
Mean		32.17	0.64	1.20		
SE±		2.892	0.032	0.118	9	
CV%		9.0	5.0	9.8	0.308	
P-value		0.151	0.001	0.001	3.4	

Means which share at least one similar letter are not statistically different, according to DMRT (P ≤ 0.05). A=Active lesions, S=Scab lesions N=No lesion. [a]Cells in the table where there is no numerical value (-) is because no lesions were ever formed within the set observation period of maximum 15 days

Table 5. The interaction effects of F1 Arabica genotypes and *C. kahawae* isolates on various CBD resistance parameters under laboratory conditions

Genotype	Isolates	% berry infection	Size of lesions mm^2	Number of lesions	Days to lesions appearance[a]	Reaction classification
F90/64/4660 x KP423	2006/14	0.00a	0.00a	0.00a	-	R
F90/64/4660 x KP423	2019/16	0.00a	0.00a	0.00a	-	R
F90/64/4660 x KP423	2019/11	0.00a	0.00a	0.00a	-	R
F89/64/4660 x KP423	2006/14	0.00a	0.00a	0.00a	-	R
F89/64/4660 x KP423	2019/16	0.00a	0.00a	0.00a	-	R
F89/64/4660 x KP423	2019/11	0.00a	0.00a	0.00a	-	R
VC298	2006/14	0.00a	0.00a	0.00a	-	R
VC298	2019/16	0.00a	0.00a	0.00a	-	R
VC298	2019/11	0.00a	0.00a	0.00a	-	R
F24/64/902 x KP423	2006/14	36.67bc	1.20cd	0.52bc	11	MR
F24/64/902 x KP423	2019/16	35.00b	0.63b	0.43b	11	MR
F24/64/902 x KP423	2019/11	36.67bc	0.98bcd	0.78cde	11	MR
F45/64/2049 x KP423	2006/14	45.00d	0.67b	1.33hi	10	MR
F45/64/2049 x KP423	2019/16	41.67cd	0.70bg	1.20ghi	11	MR
F45/64/2049 x KP423	2019/11	38.33bc	0.82bcd	0.62bcd	11	MR
F24/64/886 x KP423	2006/14	70.01h	2.98f	1.25hi	7	MS
F24/64/886 x KP423	2019/16	65.20gh	1.32d	1.13fghi	8	MS
F24/64/886 x KP423	2019/11	56.67ef	1.03bcd	0.88defg	9	MS
F45/64/2061 x KP423	2006/14	60.00fg	1.07bcd	1.82kl	9	MS
F45/64/2061 x KP423	2019/16	56.67ef	2.12e	1.467ij	9	MS
F45/64/2061 x KP423	2019/11	53.33e	0.95bcd	0.82cdef	10	MS
KP423	2006/14	95.00j	7.55h	1.75jk	4	S
KP423	2019/16	90.00j	4.60g	2.083i	5	S
KP423	2019/11	81.67i	1.98e	1.05efgh	6	S
Mean		35.90	1.192	0.714	8.84	
CV%		3.9	4.5	5.9	3.4	
SE(±)		1.387	0.0536	0.421	0.302	
p-value		0.028	0.001	0.001	0.393	

Means with the similar letter in the same column are not significant different, at P ≤ 0.05. [a]Cells in the table where there is no numerical value (-) is because no lesions were ever formed within the set observation period of maximum 15 days; R= Resistance; MR= Moderate resistance; MS= Moderate susceptible; S= Susceptible.

Table 6. Active and scab types of lesions record of berries infected with different isolates of *Colletotrichum kahawae*

Genotype	Isolate 2006/14			Isolate 2019/16			Isolate 2019/11		
	AcL %	ScL %	TpL	AcL%	ScL%	TpL	AcL %	ScL %	TpL
F45/64/2061 x KP423	42.22 (35)	19.12 (25)	A	35 (40.22)	17.32 (16.43)	A	6 (5)	38 (48.35)	S
F90/64/4660 x KP423	0 (0)	0 (0)	N	0 (0)	0 (0)	N	0 (0)	0 (0)	N
F45/64/2049 x KP423	10.32 (13)	31 (32)	S	8 (11.52)	28 (30.13)	S	7.68 (3.22)	23 (35.13)	S
F24/64/902 x KP423	6 (16.44)	35.32 (20.21)	S	5 (8)	27 (28)	S	9 (4.32)	20.32 (25)	S
F24/64/886 x KP423	40 (40)	17.32 (17.32)	A	25 (30)	23 (18)	A	8.55 (2.55)	30.13 (36.13)	S
F89/64/4660 x KP423	0 (0)	0 (0)	N	0 (0)	0 (0)	N	0 (0)	0 (0)	N
VC 298	0 (0)	0 (0)	N	0 (0)	0 (0)	N	0 (0)	0 (0)	N
KP423	92 (92)	0 (0)	S	86.68 (86.68)	0 (0)	A	80 (80)	0 (0)	A
Mean	23.82 (24.55)	12.85 (11.82)		19.96 (22.05)	11.92 (11.57)		13.9 (11.89)	13.93 (18.08)	

AcL = active lesions, ScL = Scab lesions, TpL = Type of lesions (A=active, S=scabs. N=nil/no infection).

Values in brackets are for the laboratory conditions experiment (detached berries)

DISCUSSION

The study in both field and controlled environments revealed genotypes F90/64/4660 x KP423 and F89/64/4660 x KP423 to be highly resistant to the infection of all *C. kahawae* isolates involved while genotypes F45/64/2049 x KP423 and F24/64/902 x KP423 were moderately resistant. These results are also supported by those of Leroy et al. (2006) and Bertrand et al. (2011) that, F1 hybrids of Arabica coffee have genetic and agronomic advantages such as heterosis disease resistance and good cup quality that are acceptable to coffee consumers. This study confirmed useful information for strengthening of the coffee breeding programme in Tanzania. It further confirmed that whether the experiments were done in the field or in the laboratory as the case of the detached berries, results are more or less the same. This is a great milestone for researchers to either carry out their research in the field or under laboratory conditions. Isolates 2006/14 and 2019/16 of *C. kahawae* should be used in research for screening resistance of different *C. arabica* varieties. Genotypes with no infection or low percent incidences were placed under resistant/moderately resistant, hence, to be involved in breeding program. This study revealed high relationship between the sizes of lesion, days from inoculation to lesion appearance and the percentage berry infection. Large size of lesions was observed where there was high percentage berry infection, also took few days from inoculation to symptoms appearance as observed on the interaction of susceptible variety KP423 with all three isolates.

Days to the first CBD symptoms appearance were noticed to be earlier on susceptible genotypes (KP423 and F1 hybrid F24/64/886 x KP423 that were inoculated with isolate 2006/14 and 2019/16. Previous findings documented close connection between pathogenicity and earliness in CBD symptom appearance (Kilambo et al., 2008; Varzea et al., 2002). A similar effect was reported earlier by Varzea et al. (1999; 1993); when studying pathogenicity variability of *C. kahawae* strains.

Number, size and type of lesions noticed to be caused by CBD isolates on the coffee genotypes, such as, on KP423 indicated susceptibility on its high percentage infected berries, high number of lesion, large size of lesion (mm^2) and few days to CBD symptoms appearance. The formation of scabs is an indication of tolerance mechanism to inhibit infection by *C. kahawae* pathogen, this is reported by Kilambo (2008); Chen et al. (2006) and Silva et al. (2006).

This study has brought added information that is very valuable for strengthening the coffee breeding programme and also coffee industry in Tanzania. The results revealed that *C. kahawae* isolate 2006/14 from Kibosho – Kombo was more aggressive in terms of infected berries followed by isolate 2019/16 from Ugano-

Mbinga. Isolates 2006/14, 2019/16 of *C. kahawae* should be used in future studies for screening resistance of *C. Arabica*. According to Vieira et al., (2019a) and Vieira et al., (2019b), *C. kahawae* aggressiveness is a genetically controlled traits, with a significant reliance on environmental factors.

Assessment of the interaction effect between the F1 Arabica coffee genotypes and *C. kahawae* isolates was significant on the size, number of lesions and days to lesion appearance. Since the assessed parameters are reportedly having consequential associations to the isolate's pathogenicity, it is overbearing to infer about pathogen's aggressiveness as a function of coffee genotype. This information set, ahead of CBD resistance assessments, the need for using multiple *C. kahawae* isolate when coffee genotypes are to be evaluated. This study was however conducted in one agro- ecological zone of Tanzania, namely Northern Zone, and so the inferences being made here are specific to this zone. Further studies on screening of CBD resistance on multi-location bases are recommended so as to sort out the effect of environment and/or interaction between environment and genotypes.

CONCLUSION

The study confirmed the resistance of four F1 hybrid genotypes to coffee berry disease, with two genotypes (F89/64/4660 x KP423 and F90/64/4660 x KP423) exhibiting high resistance (R), while the other two (45/64/2049 x KP423 and F24/64/902 x KP423) showed moderate resistance (MR). These genotypes displayed attributes such as low percentage berry infection, small lesion size, minimal lesion count, longer duration from inoculation to symptom appearance, and a higher percentage of scab lesions compared to active lesions on infected berries. These will be included in the TaCRI breeding programme, while the two *C. kahawae* isolates will be useful screening tools.

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AUTHORS CONTRIBUTION

GK performed the conception or design of the work, data collection, data analysis, interpretation and was a major contributor in writing the manuscript (drafting the article). SN and DM performed a critical revision of the article, providing critical comments concerning the discussion of results, conclusions, and recommendations. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not Applicable

CONSENT FOR PUBLICATION

Not Applicable

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AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

REFERENCES

Bedimo, J. A. M., Bieysse, D., Cilas, C., & Notteghen, J. L. (2007). Spatio-temporal dynamics of Arabica coffee berry disease caused by *Colletotrichum kahawae* on a plot scale. *Journal of Plant Disease, 91*, 1229-1236.

Bedimo, J. M., Njiayouom, I., Bieysse, D., Nkeng, M. N., Cilas, C., & Notteghem, J. L. (2008). Effect of shade on Arabica coffee berry disease development: Toward an agroforestry system to reduce disease impact. *Phytopathology*, *98*(12), 1320-1325.

Bertrand, B., Alpizar, E., Lara, L., Santacreo, R., Hidalgo, M., Quijano, J. M., & Etienne, H. (2011). Performance of *Coffea arabica* F1 hybrids in agroforestry and full-sun cropping systems in comparison with American pure line cultivars. *Euphytica, 181*(2), 147-158. https://doi.org/10.1007/s10681-011-0372-7

Caligiore-Gei PF, Valdez JG (2015). Adjustment of a rapid method for quantification of Fusarium spp. spore suspensions in plant pathology. *Revista Argentina de Microbiologia, 47*(2),152-154. https://doi.org/10.1016/j.ram.2015.03.002

Chen, Z. J., Ribeiro, A., Silva, M. C., Santos, P., Guerra- Guimaraes, L., Gouveia, M., & Fernandez, D. R. Jr., (2003). Heat shock induced susceptibility of green coffee leaves and berries to *Colletotrichum gloeosporioides* and its association to PRs and hsp 70 gene expression. *Physiological Molecular Plant Pathology, 63*,181-189.

Chen, Z., Liang, J. Zhang, C., & Rodriques, C. J. Jr. (2006). Epicatechin and catechin may prevent coffee berry disease by inhibition of appressorial melanization of *Colletotrichum hahawae. Biotechnology Letter 28*, 1637-1640.

Derso, E., Adugna, G., & Gebrezgi, T. (2000). Control of coffee berry disease (CBD) by fungicides in Ethiopia.

Gichimu, B.M., & Omondi, C.O. (2010). Early performance of five newly developed lines of Arabica Coffee under varying environment and spacing in Kenya. *Agriculture & Biology Journal of North America, 1*(1), 32.

Janardhan, S., & Krishna, G. S. (2021). Role of Biochar in Agriculture-Its Implications and Perspectives. *Agriculture & Food: E-Newsletter*.

Jayalakshmi, K., Raju, J., Raghu, S., & Sonavane, P. S. (2021). Important Diseases of Coffee (*Coffee Arabica* L.) and Their Management. Apple Academic Press. In *Diseases of Horticultural Crops.* p. 97-117.

Kilambo, D. L., Guerra-Guimarães, L., Várzea, V. M. P., Loureiro, A. M., Mabagala, R. B., & Teri, J. M. (2008). *Pathogenicity of Colletotrichum Kahawae Strains and their effect on Resistant Arabica Coffee Varieties in Tanzania*. Tanzania Coffee Research Institute, Kilimanjaro, Tanzania.

Kilambo, D., Swai, F., Nyange, N., Kipokola, T., Mtenga, D., & Charmetant, P. (1999). Techniques for screening resistance to CBD (Coffee Berry Disease *Colletotrichum kahawae* Waller and Bridge) In: *Proceedings of the 18th International scientific conference on coffee (ASIC)*, 2-6 Aug. 1999, Helsinki, Finland. p.508-511.

Leroy, T., Ribeyre, F., Bertrand, B., Charmetant, P., Dufour, M., Montagnon, C., & Pot, D. (2006). Genetics of coffee quality. *Brazilian Journal of Plant Physiology, 18*, 229-242.

Loland, J. O., & Singh, B. R. (2004). Copper contamination of soil and vegetation in coffee orchards after long-term use of Cu fungicides. *Nutrient Cycling in Agroecosystems, 69*, 203-211. https://doi.org/10.1023/B:FRES.0000035175.74199.9a

Marasas, W. F. O., Burgess, L. W., Anelich, R. Y., Lamprecht, S. C., & van Schalkwyk, D. J. (1988). Survey of *Fusarium* species associated with plant debris in South African soils. *South African Journal of Botany, 54*, 63-71. https://doi.org/10.1016/S0254-6299(16)31363-1

Mouen Bedimo, J. A., Bieysse, D., Nyassé, S., Notteghem, J. L., & Cilas, C. (2010). Role of rainfall in the development of coffee berry disease in Coffea arabica caused by Colletotrichum kahawae, in Cameroon. *Plant pathology*, *59*(2), 324-329. https://doi.org/10.1111/j.1365-3059.2009.02214.x

Omondi, C. O., Ayiecho, P. O., Mwang'ombe, A. W., & Hindorf, H. (2001). Resistance of Coffea arabica cv. Ruiru 11 tested with different isolates of *Colletotrichum kahawae*, the causal agent of coffee berry disease. *Euphytica*, *121*(1), 19-24. https://doi.org/10.1023/A:1012056622969

Omondi, C.O., Ayiecho, P. O., Mwang'ombe, A. W., & Hindorf, H. (2000). Reaction of some *Coffea arabica* genotypes to strains of *Colletotrichum kahawae*, the causal of Coffee Berry Disease. *Journal of Phytopathology, 148*, 61-63. https://doi.org/10.1046/j.1439-0434.2000.00464.x

Phiri, N., Kimani, M., Negussie, E., Simons, S., & Oduor, G. (2001). Management of Coffee Wilt Disease. *Coffee Wilt Disease*, 137.

Silva, M. C., Varzea, V., Guerra-Guimaraes, L., Azinheira, H. G., Fernandez, D., Petitot, A., Bertrand, B., Lashermes, P., & Nicole, M. (2006). Coffee resistance to the main diseases: leaf rust and coffee berry disease. *Brazilian Journal of Plant Physiology, 18* (1), 119-147. https://doi.org/10.1590/S1677-04202006000100010

Van der Vossen HAM, Cook RTA, Murakaru GNW (1976). Breeding for the resistance to coffee berry disease caused by *Colletotrichum coffeanum* in *Coffea arabica L.* I. Methods of preselection for resistance. *Euphytica, 25,* 733-745.

Varzea, V. M. P., Rodriques Jr C. J., Silva, M. C., Pedro, J. P., & Marques, D. M. (1999). High virulence of a *Colletotrichum kahawae* isolate from Cameroon as compared with other isolates from other regions. In: *Proceedings of the 18th International Conference on Coffee Science (ASIC),* Helsink, Finland. p. 516-519.

Varzea, V. M. P., Rodriques Jr. C. J., & Medeiros, E. (1993). Different pathogenicity of CBD isolates on coffee genotypes. In: *Proceeding of the 15th International Conference on Coffee Science.* Montpellier, France. p. 303 – 308.

Varzea, V. M. P., Silva, M. C., & Rogrigues, C. J. Jr., (Eds.) (2002). Resistencia a anthracnose os frutos do cafeeiro. (Resistance to anthracnose of green coffee berries). Estado da Arte de Tecnologias na Producao de Café. Universidade Federal Vicosa, Vicosa Brazil. p. 321-366.

Vieira, A., Diniz I., Loureiro A., Pereira, A.P., Silva, M.C., Varzea, V., & Batista, D. (2019a). Aggressiveness profiling of the coffee pathogen *Colletotrichum kahawae*. *Plant Pathology, 68*, 358-368. https://doi.org/10.1111/ppa.12950

Vieira, Ana., Silva, D. N., Varzea, V., Paulo, O. S., & Batista, D. (2019). Genome-wide signatures of selection in *Colletotrichum kahawae* reveal candidate genes potentially involved in pathogenicity and aggressiveness. *Frontiers in Microbiology*, *10*, 1-15. https://doi.org/10.3389/fmicb.2019.01374