Int.J.Curr.Res.Aca.Rev.2021; 9(03): 97-110

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 9 Number 03 (March-2021)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2021.903.010

Relationship of Coffee Wilt Disease (*Gibberella xylarioides Heim* and Saccas) Resistance and Morphological Traits in Selected Arabica Coffee (*Coffea arabica* L.) Genotypes

Admikew Getaneh*

Department of Coffee Breeding and Genetics at Jimma Agricultural Research Center, Ethiopian Institute of Agricultural Research, Jimmy

**Corresponding author*

Abstract

Understanding the association between coffee wilt disease (CWD) resistance and morphological traits are important in designing appropriate resistant breeding approaches. The study was conducted to estimate the relationship among characters and to determine path coefficient analysis (direct and indirect effects) of the characters on resistance in 17 selected genotypes (experiment 1); and eight parents with 28 F1 crosses (experiment 2) using randomized complete block design (RCBD) with three replications in artificial seedling inoculation test at the greenhouse, Jimma Agricultural Research Center (JARC). The analyses of variance showed that highly significant differences ($p<0.01$) among the genotypes for wilted seedling percentage, incubation period, number of defoliated leaves, and all seedling growth characters (height, stem diameter, average inter-node length, petiole length, leaf area, number of nodes and leaves) for both experiments. Wilted seedling percentage revealed a highly significant negative genotypic correlation with the incubation period, leaf area, and stem diameter in both experiments; while it showed a positive association with the number of defoliated leaves. The incubation period, leaf area, and stem diameter observed high negative direct effects on CWD resistance. Additionally, seedling height also showed a direct negative effect, but low in magnitude. The indirect effect of average internodes length found mainly through leaf area, and seedling height through incubation period and stem diameter. We concluded that emphasis should be given to the incubation period and stem diameter along with the number of defoliated leaves for the indirect selection of resistance Arabica coffee genotypes. These traits could be used as a selection criterion to improve resistance in Arabica coffee; however, it is not the only factors that contributes to selection. Therefore, further study is important on the association of CWD resistance to these morphological and vascular discoloration traits atnatural field conditions (multi-locations).

Article Info

Accepted: 15 February 2021
Available Online: 20 March 2021

Keywords

Arabica coffee, coffee wilt disease, correlation, path coefficient analysis, resistance.

Introduction

Coffee is the most exported and traded agricultural commodity in the world. The production and consumption have risen over the past 50 years. Some coffee producing countries have seen considerable benefits through higher yield and growing volumes of sales. However, many, especially small producers who produce the majority of the world's coffee are facing growing challenges from climate change and more difficult natural growing conditions (FAO, 2015). Additionally, the production is low due to the widespread of coffee diseases such as, coffee berry disease (CBD), coffee leaf rust (CLR), coffee wilt disease along with other limiting factors (Eshetu *et al.*, 2000; Girma *et al.*, 2009a).

Coffee wilt disease (CWD) is a fungal disease that causes a vascular disease in coffee; caused by *Gibberella xylarioides*or *Fusarium xylarioides* (Heim and Saccas, 1950; Geiser, *et al.*, 2005). The fungus invades the coffee tree and colonizes the xylem system. Successive surveys by different scholars on the occurrence and prevalence of the pathogenin major coffee-growing regions ascertained the existence of the disease with varying intensity (Van der Graaff and Pieters, 1978; Merdassa, 1986; Girma, 1997; Eshetu *et al.,* 2000; Sihen *et al.,* 2012). The prevalence and importance of CWD has been markedly increasing throughout coffee producing areas of the country (Girma *et al.*, 2001; CABI, 2003; Girma, 2004).

A host-pathogen association involves a three-dimensional interaction between host varieties, pathogen strains and environmental variables that can affect disease expression. To be able to limit the effect of these factors on host-pathogen interactions, standard artificial screening protocols that discriminate between resistant and susceptible genotypes have developed (Flood, 2006). Different inoculation procedures, such as stem nicking, root dipping and syringe injection have to screen and identify resistant genotypes by different countries (Pieters and Van der Graaff, 1980; Girma and Mengistu, 2000; Musoli, *et al.,* 2001; Musoli, 2005). Stem nicking method of young coffee seedlings with inoculum suspension 2×10^6 spore per milliliter of *Gibberella xylarioides* isolate at cotyledon stage (2 to 2.5 months old) using a scalpel has adopted as the preferred standard practice on Arabica coffee. Thus**,** standardizing the inoculation protocols (methodologies), identifying proper growth stages of the seedlings (host) that show differential reactions, selection of aggressive strain/isolate and conditions that favor infection and wilt disease development are paramount important in designing an effective screening and breeding program for CWD management (Girma *et al.,* 2009b).

Correlation is a measure of the degree of association between traits and the association may be based on genetics or non-genetic between two or more traits (Hallauer and Miranda, 1988). If a genetic association exists, selection for one trait will cause the changes on other traits. This response to change by genetic association is called correlated response; it may be caused by pleiotropism or linkage disequilibrium. Pleiotropism is the multiple effect of a single gene (i.e., a single gene simultaneously affects several physiological pathways). In a random mating population, the role of linkage disequilibrium in correlated response is only important if the traits of interest are closely linked (Acquaah, 2012).

Several studies have suggested that morphological traits (height, basal diameter of the axis, and the number of branches) of Japanese pines are associated with resistance to pine wilt nematodes (PWN) (Toda *et al.*, 1986; Toda and Fujimoto, 1987; Kuroda,2004).These morphological traits showed different levels of relevance among individuals. Yamanobe (2009) supposed that a thicker basal diameter well survived. Pine trees can survive as long as there is a partial passage for xylem and phloem transport, even if almost no transport occurs (Kuroda, 1999). Trees with a wider diameter at the base may have a greater potential to retain functional passages than thinner trees. With respect to the number of branches, subjects with more branches would survive better as long as there are more branches below the inoculation position. For upland cottons, significant negative correlations observed between foliar damage or vascular discoloration with number of nodes and plant height. These significant correlations indicated that the reduction in plant growth related to symptoms (Ulloa *et al.*, 2006).

Agrios (2005) stated that inoculation of *Fussarium wilt* resulted in clogging of xylem vessels by mycelia, spores and tyloses. Crushing of vessels by proliferating adjacent parenchyma cells also observed, which hamper the translocation of water on the infected plants. The leaves of infected plants transpire more water than the roots and stem can transport, resulting in wilting symptoms. That is why growth and transpiration reduced in fussarium wilt infected plants. Glasshouse experiments conducted to assess the effects of wilt fungus on growth and transpiration of chickpea. Results showed inoculation of *Fussarium oxysporum* reduced plant growth, transpiration and caused severe wilting (Siddiqui and Singh, 2004). Walyaro and Van der Vossen (1979) also studied on 16 Arabica coffee varieties and they reported phenotypic correlation is generally much lower than the genotypic ones, indicating that the inherent association between characters strongly influenced by environmental cause. The girth at the base of the main stem is genotypic-ally correlated with height. According to El-bramawy *et al.*, (2009), the regression analysis of branch number and seed color in sesame showed significantly correlated with *Fusarium wilt* and charcoal rot diseases infection percentages. Therefore, these traits might use for direct selection of sesame accessions that are resistant to fusarium wilt and charcoal rot disease. The associations between characters are important selection parameters for plant breeder to select the required traits (Panwar *et al.,* 2015). So far, information has been lacking in correlation of CWD resistance with other characters. Therefore, the study conducted to determine the association and path coefficient analysis(direct and indirect) of resistance with other wilt and seedling growth characters.

Materials and Methods

Coffee genotypes and experimental design

The study was conducted on two interrelated experiments at JARC (in greenhouse), Southwest Ethiopia. The first experiment consisted of 17Arabica coffee genotypes with different CWD resistance reactions based on artificial inoculation test or naturally infested soils(Table 1).The genotypes obtained from Jimma and Gera Agricultural Research Centers.

Then, eight promising coffee parents (from experiment one), namely 75227 (P1), 971 (P2), 74110 (P3), 8136 (P4), 79233 (P5), Arbagugu (P6), 974 (P7), 370 (P8) and one susceptible check (Geisha) were selected based on the first experiment, yield and some other agronomic traits.

These parental lines were generated from different CWD reaction groups; parental lines 971 (P2) and 974 (P7) resistant; 79233 (P5), 370 (P8), 8136 (P4), 74144A (P6) moderately resistant; 75227 (P1) and 74110 (P3) susceptible parents (Table 1). Then, eight parents were crossed in 8 x 8 half diallel mating design using Griffing (1956) method 2 and model I at Gera, southwest of Ethiopia in 2014. The resulting 28 F1 crosses along with eight parents and one susceptible check were studied in experiment two from 2015 to 2016. The above symbols and designation of the parental lines are the same throughout this study. Both experiments were laid out in randomized complete block design (RCBD) with three replications at greenhouse using heat sterilized and moistened sandy soil on disinfected plastic pots (each has 5652 cm^3 capacity). Five seedlings from 20 inoculated seedlings in each pot sampled and the growth traits recorded for each genotype. The methods and procedures used for coffee seedling raising, inoculum preparation, seedlings inoculation, management, disease assessment and types of data collected were the same for both experiments based on Pieters and Van der Graaff (1980); (Girma and Mengistu, 2000). Selfing and crossing techniques were made based on Carvalho (1988) procedures.

Data recorded on a plot (pot) basis for wilted seedling Percentage and incubation period. In addition, numbers of yellow and defoliated leaves per seedling recorded per seedling and analyzed for average of five sampled seedlings at four months old seedling. On the other hand, seedling growth characters: stem height, stem diameter, average inter node length on stem based on Walyero(1983), number of stem nodes per seedling, number of leaves per seedling, leaf petiole length and leaf area were measured and analyzed for average of five sampled seedlings at four months old seedling stage.

Data analysis

Data was analyzed using SAS program version 9.2 (SAS, 2008). Fisher's least significant difference (LSD) mean separation test was performed to identify and comparison of genotypes means that were significantly different from each other. Wilted or dead seedling percentage calculated from cumulative number of wilted over total number of seedlings (wilted plus healthy) after six months of inoculation as follow;

$$\text{Wilted seedling Percentage} = \frac{\text{cumulative number of dead seedlings}}{\text{total number of seedlings (dead plus healthy)}} * 100$$

Estimates of correlation and path coefficient analysis

The associations between wilted seedling percentage and incubation period, number of yellow and defoliated leaves per plant and seedling growth characters were calculated as Singh and Chaudhary (1985):

$$r_p = \frac{pcovx.y}{\sqrt{\delta^2 px.\delta^2 py}},$$

$$r_g = \frac{gcovxy}{\sqrt{\delta^2 gx.\delta^2 gy}}$$

Where; rp and rg are phenotypic and genotypic correlation coefficients, respectively, pcovx.y and gcovx.y are phenotypic and genotypic covariance between variables x and y, respectively, δ^2pxand δ^2gxare phenotypic and genotypic variances for variable x, and δ^2pyand δ^2gyare phenotypic and genotypic variances for the variable y, respectively. The significance of phenotypic and genotypic correlation coefficient was tested at 5 % and 1 % significance level by comparing the computed '**r**' value to the tabular 'r' value at n-2degree of freedom. Path coefficient analysis and residual effect were estimated for wilted seedling percentage and morphological traits following the method described by Dewey and Lu (1959).

rij = Pij + ΣrikPkj

Residual effect (R) = $\sqrt{1-R^2}$ Where: - $R^2=\Sigma pij.rij$

Where, rij=Mutual association between the independent character (i) and dependent Character (j) as measured by genotypic correlation coefficient; Pij=Component of direct effects of the independent character (i) on dependent character (j) as measured by genotypic path coefficient; Σrikpkj=Summation of components of indirect effect of a given independent character (i) on the given dependent character (j) via all other independent character (k) and R= residual effect

Results and Discussion

Analysis of variance

In both experiments, analysis of variance (ANOVA)mean squares for four CWD parameters and seven seedling morphological characters are presented in Table 1.ANOVA mean squares showed that highly significant differences (p<0.01) between 17 genotypes for all characters in experiment one. Genotypes also showed variable reaction to wilted seedling percentage in area under disease progress curve (AUDPC).

Moreover, ANOVA mean squares showed significant different (p<0.01or p<0.05) between genotypes for wilted seedling percentage, incubation period, number of defoliated leaves, seedling height, seedling stem diameter (girth), average inter-node length, number of nodes, petiole length, leaf area and number of leaves when compared 28 F1 crosses with eight parents in experiment two. However, number of yellow leaves exhibited non-significant differences.

Correlation among characters

Phenotypic and genotypic correlation estimates between characters for experiment one is shown in Table 2. The genotypic correlation coefficient was higher than their corresponding phenotypic correlation in all characters, which indicated that the association was largely due to genetic factors. Wilted seedling percentage showed negative and significant phenotypic and genotypic association with incubation period (r_p = -0.88, r_g= -0.93), seedling height (r_p = -0.73, r_g= -0.76), average inter node length (r_p = -0.50, r_g= -0.52), stem diameter (r_p = -0.072, r_g= -0.78) and leaf area (r_p = -0.54, r_g= -0.60) in experiment one (Table 2). However, it showed positive and significant association with number of yellow leaves. In contrary, incubation period manifested significant, but reverses relationship with the above-mentioned characters. Both correlations were also detected positive and significant between seedling height with seedling diameter, average inter node length, petiole length and leaf area; while, negative and significant (p<0.01) association with number of yellow leaves. Moreover, seedling diameter had positive and significant correlation with average inter node length, petiole length and leaf area; whereas, seedling diameter and leaf area showed negative and significant association with number of yellow leaves for both types of correlations. But, number of nodes and leaves had positive and significant relationship with number of defoliated leaves per seedling.

This significant correlation of traits may be caused by pleiotropism (multiple effect of a single gene) or linkage disequilibrium (different traits genes linked or closely connected; and during segregation and recombination they pass together to the next generation). In order to select CWD resistance (primary trait of interest) and other CWD and growth characters (secondary traits) simultaneously, it is clear that the effectiveness of indirect selection depends on the magnitude of genetic correlation and the heritability of the secondary traits being selected. Therefore, such a situation would occur when the secondary trait is less sensitive to environmental change (or can be measured under controlled conditions) and it is easier to measure. Generally, low wilted seedling percentage (CWD resistance) had a desirable association with incubation period, seedling height, stem diameter, leaf area and average inter node length; but it showed negative correlation with number of yellow leaves, defoliated leaves, number of leaves and number of nodes (undesirable association). Therefore, such interrelationships of characters with wilted seedling percentage and between each other aid to identify CWD resistant and suggest to plan efficient selection.

The estimates of phenotypic and genotypic correlation between and among characters for experiment two are shown in Table 3. There were found highly significant ($p<0.01$) and negative correlation between wilted seedling percentage and incubation period (rp= -0.86, r_g = -0.91) and following components: leaf area (r_p = -0.59, r_g= -0.64) and stem diameter (r_p = -0.34, r_g= -0.41) in experiment two. While, it was positive and highly significant correlation with number of defoliated leaves (rp = +0.86, r_g = +1.00). Therefore, these correlations indicated that wilted seedling percentage showed strong negative correlation with incubation period; while strong positive associations with number of defoliated leaves. Longer incubation period of CWD was positive and highly significance ($p<0.01$) phenotypic and genotypic association with leaf area, but negative and highly significant correlation with number of defoliated leaves. Furthermore, incubation period showed positive and non-significant association with the rest quantitative characters, except seedling diameter and number of leaves for genotypic correlation (significant association). Therefore, low wilted seedling parentage (CWD resistance) could be improved by considering direct selection of longer incubation period, wide stem diameter and leaf area with minimum number of defoliated leaves and number of nodes. Selections for characters based on its positive and significant association are very useful for simultaneous improvement of the associated characters. On the other hand, characters manifesting negative association, simultaneous improvement of characters could be quite difficult and independent selection may have to be carried out to improve the characters (Sylva and Carvalho, 1997).

The current wilted seedling percentage or CWD resistance with other characters associations result supported by Toda *et al.*, (1986); Toda and Fujimoto (1987); Kuroda (2004); they studied in Japanese pines resistant to Pine wilt nematodes and suggested that height, basal diameter of the axis and the number of branches increment are associated with PWN resistance. According to Yamanobe (2009) on pine tree also a thicker pine basal diameter and more branches increase survival to PWN, considered as resistance factors. Furthermore, a thicker basal diameter predicted to survive better and also trees can survive as long as there is a partial passage for xylem and phloem transport. Likewise, Siddiqui and Singh (2004) conducted an experiment to assess the effects of wilt fungus on the growth and transpiration of chickpea at glasshouse. Results showed that inoculation of *Fussarium oxysporum* reduced plant growth, transpiration and caused severe wilting. The existing quantitative characters correlation results are in agreement with Olika *et al.*, (2011) and Yonas *et al.*, (2014). Different scholars also confirmed the positive association between seedlings vigorous, such as height and stem diameter at the nursery with a better growth and yield performance in the field condition. Walyaro (1983) reported a positive correlation between three-year average yield and early record of seedling leaf area, seedling girth, height, number of leaves, number of laterals and longest lateral branch length. He also noted a positive relationship between height at the nursery and field. Likewise, Mesfin (1982) reported a desirable association between 21 months old seedling growth and three years old F1 plants girth, number of primary nodes and height. According to Fernie (1970), noted positive and highly significant correlation between stem girth and six years mean yield in F1 hybrids. Walyaro and Van der Vossen (1980) also reported highly significant genotypic correlation between three-year yield with height and girth in Arabica coffee. In most studies stem girth had a good association with yield. Therefore, the current good seedling vigorous and CWD resistant genotypes might also have good growth and yield production in the field.

Path coefficient analysis

Path coefficient analysis is an extension of correlation analysis and it has been used to evaluate selection criteria in several plants. This technique is useful in determining the direct influence of one variable on another (Lenka and Misra, 1973). The genotypic and phenotypic correlation coefficients were further divided into direct and indirect effects using path coefficient analysis.

Such analysis leads to the identification of important component traits useful in indirect selection of complex traits like CWD resistance. In this study, CWD resistance was considered as a complex dependable trait (resultant) while the rest of the variables that were negatively correlated with it were used as causal (independent) traits.

Table.1 Description of Arabica coffee genotypes used for the study

No.	Coffee Genotypes	Origin	Released or collection year	Some characters description
1	75227	Gera, Jimmy	1980/81	Open growth habit, good yielder, CBD resistant, susceptible to CWD (DemelashandKifle., 2015)
2	971	Gelana Abaya, Borena	2010	Resistant to CWD (Chala*et al*., 2012)
3	74110	Metu, Illubabor	1978/79	Resistant to CBD, susceptible to CWD, good yielder, compact growth habit (DemelashandKifle., 2015)
4	8136	Gera, Jimmy	2006	High yielding potential, resistant to CBD &CLR, moderately resistant to CWD (Girma, 2004)
5	79233	International collection	1979	CWD resistant under natural infested soil (personal observation)
6	Arbagugu	Arsi, Oromia	1978/79	Moderately resistant to CWD under natural infested soil, susceptible to CBD(personal observation)
7	974	Gelana Abaya, Borena	2010	Resistant to CWD (Chala*et al*., 2012)
8	370	Seka-Chekorsa, Jimmy	_	Resistant to CWD, susceptible to CBD(Demelash, 2013)
9	Catimor J-19	International collection	1998	Resistant to CWD (Girma, 2004)
10	CatimorJ-21	International collection	1998	Resistant to CWD (Girma, 2004)
11	7440	Washi, Kaffa	1979/80	Moderately resistant to CWD (Girma, 2004)
12	279/71	Sokoru, Jimmy	2013	CWD resistant, CBD susceptible (Demelash, 2013)
13	B-64/04	Balle, Oromia	2004	CWD resistant (Kifle*et al.*, 2015)
14	B-70/04	Balle, Oromia	2004	CWD resistant (Kifle*et al.*, 2015)
15	74144B	Arsi, Oromia	1978/79	Moderately susceptible to CBD (personal observation)
16	Geisha*	International collection	2002	Highly susceptible to CWD (Demelash, 2013)
17	SN-5*	Kaffa, SNNPR		Susceptible to CWD (Girma, 2004)

*= susceptible check, Source: JARC / Coffee Breeding and Genetics division database for genotypes origin and some characters description; breeding method is pure line selection

Table.2 Analysis of variance mean squares and probability levels for CWD and growth characters

Characters	Characters mean squares and p'					
	Experiment 1			Experiment 2(F1 crosses & parents)		
	Block (df=2)	Genotypes (df=16)	Error (df=32)	Block (df=2)	Genotypes (df=35)	Error (df=70)
Disease parameters						
Wilted coffee seedlings Percentage	1000.98** (666.29**)	2161.31** (1179.73**)	103.11 (58.35)	**1065.19** (801.08**)**	**1743.23** (823.29**)**	**204.48 (118.02)**
Incubation period	456.37^{ns}	1290.27**	**157.77**	**397.34****	**610.80****	**52.69**
Number of Defoliated leaves per seedling	0.01 ^{ns}	0.24**	**0.03**	**8.22****	**1.73****	**0.66**
Number of yellow leaves per seedling	**0.04 ns**	**0.26****	**0.05**	**1.58****	**0.14ns**	**0.10**
Morphological characters						
Seedling height (cm)	0.89 ^{ns}	**6.31****	**0.40**	**9.97****	**2.62****	**0.44**
Seedling stem diameter (mm)	0.024*	**0.039****	**0.005**	**0.01 ns**	**0.022***	**0.013**
Number of nodes	0.04 ^{ns}	0.27**	0.01	**0.03***	**0.17****	**0.009**
Average internode length (cm)	0.42*	1.83**	0.10	**0.18 ns**	**1.16****	**0.16**
Number of leaves	0.54*	0.77**	0.13	**2.85****	**0.57****	**0.18**
Leaf area (cm2)	1.06 ^{ns}	9.49**	0.97	**24.11****	**18.02****	**1.80**
Petiole length (cm)	**0.002***	**0.005****	**0.0005**	**0.0065****	**0.0032****	**0.0004**
AUDPC	**5110325.2**	**16205358.7****	**784550.8**	–	–	–

Data in bracket is arcsine transformed value of wilted seedlings percentage
df= degree of freedom of block, genotypes and error, ** = highly significant at P <0.01, * = significant at p<0.05 and ns =non-significant

Table.3 Phenotypic (r_p) (above diagonal) and genotypic (r_g) (below diagonal) correlation of 11 characters for experiment 1

	WS (%)	IP (days)	SH (cm)	SSD (mm)	AINL (cm)	NN (no.)	PL (cm)	LA (cm2)	NL (no.)	NDL (no.)	NYL (no.)
WS (%)		-0.88**	-0.73**	-0.72**	-0.50*	0.23	-0.17	-0.54*	0.17	0.40	0.62**
IP (days)	-0.93**		0.75**	0.57*	0.55*	-0.26	0.11	0.53*	-0.18	-0.43	-0.76**
SH (cm)	-0.76**	0.81**		0.81**	0.75**	-0.27	0.59*	0.73**	-0.25	-0.19	-0.68**
SSD (mm)	-0.78**	0.64**	0.82**		0.51*	0.05	0.48*	0.66**	-0.02	0.03	-0.50*
AINL (cm)	-0.52*	0.63**	0.80**	0.53*		-0.66**	0.54*	0.81**	-0.71**	-0.48	-0.63**
NN (no.)	0.24	-0.30	-0.30	0.05	-0.68**		-0.15	-0.38	0.93**	0.62**	0.31
PL (cm)	-0.21	0.12	0.61**	0.48*	0.58*	-0.18		0.71**	-0.21	0.24	-0.20
LA (cm^2)	-0.60*	0.60*	0.74**	0.69**	0.87**	-0.42	0.74**		-0.47	-0.32	-0.53*
NL (no.)	0.23	-0.27	-0.35	-0.09	-0.76**	1.00**	-0.28	-0.62**		0.63**	0.33
NDL (no.)	0.41	-0.46	-0.20	0.07	-0.50*	0.66**	0.26	-0.36	0.75**		0.34
NYL (no.)	0.68**	-0.85**	-0.74**	-0.54*	-0.70**	0.40	-0.23	-0.56*	0.48	0.41	

cm= cent meter, cm2= cent meter square, mm= mill meter
AINL= average inter node length, IP = incubation period, LA =leaf area,NDL = number of defoliated leaves, NL= number of leaves, NN = number of nodes NYL =number of yellow leaves, PL= petiole length, SH = seedling height, SSD = seedling stem diameter, WS = wilted seedling percentage

Table.4 Phenotypic (rp) (above diagonal) and genotypic (rg) (below diagonal) correlation among characters for experiment two

	WS (%)	IP (days)	SH (cm)	SSD (mm)	AINL (cm)	NN (no.)	PL (cm)	LA (cm2)	NL (no.)	NDL (no.)	NYL (no.)
WS (%)		-0.86**	-0.18	-0.34*	-0.22	0.08	-0.22	-0.59*	-0.10	0.86**	-0.17
IP (days)	-0.91**		0.17	0.29	0.19	0.02	0.16	0.68**	0.28	-0.74**	0.15
SH (cm)	-0.17	0.20		0.44**	0.89**	-0.41*	0.58**	0.60**	-0.08	-0.33*	-0.05
SG (mm)	-0.41**	0.44**	0.52**		0.36*	0.10	0.26	0.51**	0.30	-0.28	0.23
AINL (cm)	-0.25	0.23	0.97**	0.57**		-0.58**	0.55**	0.65**	-0.24	-0.34*	-0.03
NN (no.)	0.08	0.01	-0.44**	0.18	-0.60**		-0.13	-0.18	0.68**	0.23	0.02
PL (cm)	-0.23	0.18	0.61**	0.27	0.64**	-0.15		0.46**	0.25	-0.33*	0.39*
LA (cm2)	-0.64**	0.75**	0.66**	0.69**	0.72**	-0.17	0.48**		0.20	-0.51**	0.16
NL (no.)	-0.09	0.34*	-0.24	0.25	-0.29	0.83**	0.23	0.19		0.002	0.28
NDL (no.)	1.00**	-0.96**	-0.31	-0.02	-0.43**	0.27	-0.35*	-0.58**	0.13		-0.06
NYL (no.)	-0.37*	0.30	-0.03	0.55**	-0.02	0.004	0.76**	0.27	0.57**	0.01	

Note: Values without asterisk (*) are non-significant; cm= centimeter, cm2 = centimeter square, mm=millimeter
AINL= average inter node length, IP = incubation period, LA= leaf area, NL= number of leaves, NDL= number of defoliated leaves per seedling, NN= number of nodes, PL= petiole length, SH= seedling height, SSD= seedling stem diameter, WS%= Wilted coffee seedling percentage

Table.5 Direct (diagonal) and indirect effects of path coefficient analysis for wilted seedling percentage by different traits for experiment 1

	IP	SH	SSD	AINL	NN	PL	LA	NL	NDL	NYL	Total genotypic correlation with WS%
IP	-0.71	**-0.78**	**0.07**	**0.74**	**-0.01**	**0.07**	**-0.53**	**-0.15**	**0.15**	**0.22**	-0.93
SH	**-0.58**	-0.96	**0.09**	**0.94**	**-0.01**	**0.34**	**-0.66**	**-0.19**	**0.06**	**0.19**	-0.76
SSD	**-0.45**	**-0.79**	0.11	**0.63**	**0.00**	**0.27**	**-0.61**	**-0.05**	**-0.02**	**0.14**	-0.78
AINL	**-0.45**	**-0.77**	**0.06**	1.18	**-0.02**	**0.32**	**-0.77**	**-0.41**	**0.16**	**0.18**	-0.51
NN	**0.21**	**0.29**	**0.01**	**-0.80**	0.03	**-0.10**	**0.37**	**0.54**	**-0.21**	**-0.10**	0.24
PL	**-0.09**	**-0.59**	**0.05**	**0.68**	**-0.01**	0.56	**-0.66**	**-0.15**	**-0.08**	**0.06**	-0.21
LA	**-0.43**	**-0.71**	**0.08**	**1.03**	**-0.01**	**0.41**	-0.89	**-0.33**	**0.12**	**0.15**	-0.60
NL	**0.19**	**0.34**	**-0.01**	**-0.90**	**0.03**	**-0.16**	**0.55**	0.54	**-0.24**	**-0.12**	0.22
NDL	**0.33**	**0.19**	**0.01**	**-0.59**	**0.02**	**0.15**	**0.32**	**0.41**	-0.32	**-0.11**	0.41
NYL	**0.60**	**0.71**	**-0.06**	**-0.83**	**0.01**	**-0.13**	**0.50**	**0.26**	**-0.13**	-0.26	0.67

Residual effect = 0.246374
AINL= average inter node length, IP = incubation period, LA= leaf area, NDL= number of defoliated leaves per seedling, NL= number of leaves, NN= number of nodes, NYL= number of yellow leaves, PL= petiole length, SH= seedling height, SSD= seedling stem diameter, WS%= Wilted coffee seedling percentage

Table.6 Direct (diagonal) and indirect effects of path coefficient analysis for wilted seedling percentage by different traits for experiment 2

	IP	SH	SSD	AINL	NN	PL	LA	NL	NDL	NYL	Total genotypic correlation with WS%
IP	-0.69	**0.09**	**-0.15**	**0.07**	**0.00**	**-0.10**	**-0.17**	**0.32**	**-0.27**	**-0.01**	-0.90
SH	**-0.14**	0.43	**-0.18**	**0.30**	**0.20**	**-0.32**	**-0.15**	**-0.23**	**-0.09**	**0.00**	-0.17
SSD	**-0.30**	**0.22**	-0.34	**0.18**	**-0.08**	**-0.14**	**-0.15**	**0.24**	**-0.01**	**-0.02**	-0.41
AINL	**-0.16**	**0.42**	**-0.19**	0.31	**0.27**	**-0.34**	**-0.16**	**-0.27**	**-0.12**	**0.00**	-0.24
NN	**-0.01**	**-0.19**	**-0.06**	**-0.19**	-0.45	**0.08**	**0.04**	**0.78**	**0.08**	**0.00**	0.08
PL	**-0.12**	**0.26**	**-0.09**	**0.20**	**0.07**	-0.53	**-0.11**	**0.22**	**-0.10**	**-0.02**	-0.23
LA	**-0.52**	**0.28**	**-0.23**	**0.22**	**0.08**	**-0.25**	-0.22	**0.18**	**-0.16**	**-0.01**	-0.64
NL	**-0.23**	**-0.10**	**-0.09**	**-0.09**	**-0.37**	**-0.12**	**-0.04**	0.94	**0.04**	**-0.02**	-0.09
NDL	**0.66**	**-0.13**	**0.01**	**-0.13**	**-0.12**	**0.19**	**0.13**	**0.12**	0.28	**0.00**	1.00
NYL	**-0.21**	**-0.01**	**-0.19**	**-0.01**	**0.00**	**-0.40**	**-0.06**	**0.54**	**0.00**	-0.03	-0.37

Residual effect = 0.214709

AINL= average inter node length, IP = incubation period, LA= leaf area, NDL= number of defoliated leaves per seedling, NL= number of leaves, NN= number of nodes, NYL= number of yellow leaves, PL= petiole length, SH= seedling height, SSD= seedling stem diameter, WS%= Wilted coffee seedling percentage

The path analysis was done among 10genotypic correlated traits with wilted seedling percentage. Direct and indirect effects of these traits determined on resistance and their contribution ratios are summarized in table 4 and 5.Incubation period (-0.71), seedling height (-0.96) and leaf area (-0.89) in experiment one, and Incubation period (-0.69), petiole length (-0.53), number of nodes (-0.45), and seedling stem diameter (-0.34) in experiment two showed the highest negative direct effect on resistance genotypes selection. Average internode length and number of leaves showed positive direct effect on resistance at both experiments; which is insignificant traits as a selection criterion.

Alternatively, seedling height and number of defoliated leaves showed negative direct effect in experiment one, but positive direct effect in experiment two. However, petiole length exhibited positive and negative direct effect, but closer in magnitude in experiment one and two, respectively. Generally, petiole length, number of leaves, average internodes length, seedling height number of yellow and defoliated leaves were not the stronger traits used as a selection criterion for CWD resistance variety development.

These traits varied in the two experiments and it may be due to the presence of genotypic variabilities in these two experiments. Overall, incubation period and leaf areas were the best selection criterion with considering other traits in resistance genotypes selection. The indirect effect of average internodes length found mainly through leaf area, and seedling height through incubation period and stem diameter.

In this study, the genotypic correlation coefficients were higher in magnitude than the corresponding phenotypic correlation coefficients for all traits. These results indicated that the traits are predominantly governed by genetics factor rather than environmental factors.

In both experiments, CWD resistant genotypes were significantly associated with extended incubation period, wide stem diameter, extensive leaf area and minimum number of defoliated leaves than the susceptible genotypes.

As a result, CWD resistance could be improved by indirect selection of these correlated characters. Traits such as, Incubation period and leaf areaobserved negative direct effects on CWD resistance. Therefore, incubation period and leaf areas traits were the best selection criterion with considering other traits in resistance genotypes selection. The indirect effect of average internodes length found mainly through leaf area, and seedling height through incubation period and stem diameter.

Acknowledgment

The necessary facilities and finance were supported by the Ethiopian Institute of Agricultural Research (EIAR), Jimma Agricultural Research Center.

Conflict of Interest

The author has declared that there is no conflict of interest.

References

Acharya, S. N. and H. C. Huang, 2003. Breeding alfalfa for resistance to *verticillium wilt*: A sound strategy. *Advances in Plant Disease Management*, 345-371.

Acquaah, G., 2012. Principles of plant genetics and breeding. John Wiley & Sons. 740p.

Agrios, G. N., 2005. Plant pathology. Elsevier Academic Press, USA. 922p.

Allard, R.W., 1999. Principles of plant breeding. John Wiley and Sons, New York. 254p.

Anthony, F., B. Bertrand, O. Quiros, A. Wilches, P. Lashermes, J. Berthaud and A. Charrier, 2001. Genetic diversity of wild coffee (*Coffea arabica* L.) using molecular markers. *Euphytica*, 118(1):53-65.

Anthony, F., M.C. Combes, C. Astorga, B. Bertrand, G. Graziosi and P. Lashermes, 2002.The origin of cultivated *Coffea arabica* L. varieties revealed by AFLP and SSR markers. *Theoretical and Applied Genetics*, 104(5):894-900.

Arega, Z., 2006. Diversity of Arabica coffee population in afro-mountain rainforests of Ethiopia in relation to coffee berry disease (C*olletotrichum kahawae*) and coffee wilt disease (*Gibberella xylarioids*). An MSC Thesis presented to the school of graduate studies of Addis Ababa University. 81p.

Bayetta, B. and A. Mesfin, 1986.Variation among national coffee collections for some agronomic characters. First Ethiopian coffee symposium. Addis Ababa, Ethiopia, August, 1986.

Bayetta B., 1991. Nursery evaluation of heterosis and combining ability in reference to origin and morphology of parents in coffee (*Coffea arabica* L.). An MSC Thesis presented to the school of graduate studies of Alemaya University. 128p.

Bayetta B., 2001. Arabica coffee breeding for yield and resistance to coffee berry disease (*Colleototrichum kahawae sp*. Nov). Doctoral dissertation submitted to the Wye University, London. 272p.

Beckman, C. H., 1987. The nature of wilt diseases of plants. APS Press, USA. 175p.

CABI, 2003. Surveys to assess the extent of coffee wilt disease in East and Central Africa. Final technical report. CABI Regional Center, Nairobi, Kenya. 49p.

Carvalho, A., 1952. *Coffea arabica* L. Taxonomy VI: morphological characters of haploid. *Bragantia*, 12 (4-6): 201-212.

Carvalho, A., F. P. Ferwerda, J. A. Frahm-leliveld, D. M. Medina, A. J. I. Mendes and L. C. Monaco, 1969. Coffee (*C. arabica* L. and *C. canephora* Pierre ex froehner). pp. 186-244. In: F.P. Ferwerda and F. Wilt (eds). Outlines of perennial crop breeding in the tropics. Landbouwhoge school (Agricultural University) Wageningen, Netherland.

Carvalho, A., 1988. Principles and practice of coffee plant breeding for productivity and quality factors: coffeaarabia. pp. 129-165. In: R.G. Clarke and R. Macrae (eds). Coffee: Agronomy. Elsevier applied science publishers Ltd, London.

Chala, J., A. Girma, T. Demelash, Z. Arega, B.Sihen, and A. Adem, 2012. Development and release of coffee berry disease resistant varieties to specialty coffee producing regions in Ethiopia. pp.637-644. Proceedings of 24thinternational scientific colloquium on coffee (ASIC). Costa Rica, 12-16 November 2012, Jimma Agricultural Research Centre.

Changaya, A. G., R. Melis, J. Derera, M. Laing, V. W. Saka, 2012. Inheritance of resistance to fusarium wilt and yield traits in pigeon pea. *Euphytica*, 186:883–896.

Cook R. J., W. L. Bruckart, J. R. Coulson, M. S. Goettel, R. A. Humber, R. D. Lumsden, J. V. Maddox, M. L. McManus, L. Moore, S. F. Meyer, P. C. Quimby, J. P. Stack, and J.L. Vaughn, 1996. Safety of microorganisms intended for pest and plant disease control. A frame work for scientific evaluation. *Biol. Control*,7: 333-351.

Central Statistical Agency (CSA), 2016.The Federal Democratic Republic of Ethiopia Agricultural sample survey report on area and production of major crops, volume, I. statistical bulletin, 584.

Davenport, C. B., 1908. Degeneration, albinism and inbreeding. *Science*, 28(718):454-455.

Davis, A.P., F. Rakotonasolo and P. De Block, 2010. *Coffeatoshii sp. nov*. (Rubiaceae) from Madagascar. *Nordic Journal of Botany*, 28(2):134-136.

Demelash, T., 2013.Evaluation of Arabica coffee (*coffea arabica* L.) germplasm for major coffee disease with special emphasis to coffee wilt disease (*Gibberella xylarioids*) at Jimma, Ethiopia. An MSC Thesis presented to the school of graduate studies of Jimma University.

Demelash, T. and B. Kifle, 2015. Evaluation of released Arabica coffee varieties (*Coffea arabica* L.) for major coffee diseases with special emphasis to coffee wilt disease (*Gibberella xylarioides*) at Jimma, Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 5 (15).

Charrier, A. and J. Berthaud, 1985.Botanical classification of coffee. pp. 13-47. In: M. N. Clifford and K. C. Wilson (eds.). Coffee Botany, Biochemistry and Production of Beans and Beverage. Croom Helm, London.

El-Bramawy, M.A.E.H.S., S.E.S. El-Hendawy and W. I. Shaban, 2009.Assessing the suitability of morphological and phenotypical traits to screen sesame accessions for resistance to *Fusarium wilt* and charcoal rot diseases. *Plant Protect. Sci*. 45: 49–58.

Epinat, C. M. Pitrat, 1994. Inheritance of resistance to downy mildew (*Pseudoperonosporacubensis*) ´in muskmelon (*Cucumis melo*). I. Analysis of 8 x 8 diallel table. *Agronomie, EDP Sciences*, 14 (4):239-248.

Eshetu, D., 1997. Coffee diseases and their significance in Ethiopia.*ASIC.*17(I): 723-726.

Eshetu, D., G. Teame and A. Girma, 2000. Significance of minor diseases of *Coffeaarabica*L. In Ethiopia: review. pp. 58–65. Proceedings of the workshop on control of coffee berry disease (CBD) in Ethiopia. Addis Ababa, Ethiopia.

Falconer, D.S. and T.F.C. Mackay, 1996.Introduction to quantitative genetics.Longman and Scientific and technical, London. 438p.

FAO, 2006. Food and Agriculture Organization Corporate Statistical data base (FAOSTAT). Available from: http://faostat.fao.org.

FAO, 2014. Analysis of price incentives for coffee in Ethiopia. Technical notes series, MAFAP, by KumaWorako, T., MasAparisi, A. and Lanos B., Rome.

Fehr, W.R., 1987. Principles of cultivar development: theory and techniques. Macmillan Publishing Company, New York. 536p.

Fernie, L.M., 1970. The improvement of arabica coffee in East Africa. Crop Improvement in East Africa.*Techn. Comm*, 19:231-249

Flood, J., 2006. Reviews of Fusarium wilt of oil palm caused by *Fusarium oxysporum f. sp. elaeidis*. *Phyto-pathology*.96:660–662.

Gardner, C. O. and S. A. Eberhart, 1966. Analysis and interpretation of the variety cross diallel and related populations. *Biometrics*,22: 439–452.

Geiser, D. M., M. L. L. Ivey, G. Hakiza, J. H. Juba and S.A. Miller, 2005.*Gibberella xylarioides* (anamorph: *Fusarium xylarioides*), a causative agent of coffee wilt disease in Africa, is a previously unrecognized member of the *G. fujikuroi* species complex. *Mycologia*, 97: 191-201.

Gharderi, A., M. W. Adams and A. M. Nassib, 1984.Relationship between genetic distance and heterosis for yield and morphological traits in dry edible bean and fababean. *Crop sci*. 24:32-34.

International Plant Genetic Resource Institute (IPGRI), 1996. Descriptors for coffee (*coffea spp*. and *psilanthusspp*). International plant Genetic Resources Institute., Rome, Italy. 38p.

Girma A., 1997. Characterization of *Gibberella xylarioides* Heim and Saccas (*Fusarium wilt*) of coffee (*Coffee arabica* L.). An MSc Thesis presented to the school of graduate studies of Alemaya University. 100p.

Girma, A. and H. Mengistu, 2000. Cultural characteristics and pathogenicity of *Gibberella xylarioides* isolates on coffee. *Pest management Journal of Ethiopia*, 4:11-18.

Girma A., H. Mengistu and H. Hindorf, 2001.Incidence of tracheomycosis, *Gibberella xyilarioides* (*Fusarium xylarioides*), on Arabica coffee in Ethiopia. *J. Plant Dis. and Pro*. 108 (2): 136-142.

Girma A., 2004. Diversity in pathogenicity and genetics of *Gibberella xyilarioides* (*Fusarium xylarioides*) population and resistance of coffee spp. in Ethiopia. Doctoral Dissertation presented to University of Bonn, Germany. 81p.

Girma A., H. Hindorf, U. Steiner, H. I. Nirenberg, H. W. Dehne and K. Schellander, 2005. Genetic diversity in the coffee wilt pathogen (*Gibberella xyilarioides*) populations: differentiation by host specialization and RAPD analysis. *J. Plant Dis. and Pro*. 112 (2):134-145.

Girma, A. and J. Chala, 2008. Resistance levels of Arabica coffee cultivars to coffee berry disease, coffee wilt and leaf rust diseases in Ethiopia. pp.92–103. Proceedings of the 12th conference of the crop science society of Ethiopia (CSSE). Addis Ababa, Ethiopia, 22-24 may 2006, Ethiopian Institute of Agricultural Research.

Girma A., A. Million, H. Hindorf, Z. Arega, T. Demelash and J. Chala, 2009a. Coffee wilt disease in Ethiopia. pp. 50-68. In: J. Flood (eds). Coffee wilt disease. Typeset by MTC, Manila and Philippines, UK.

Girma A., D. Biyesse and P. C. Musoli, 2009b. Host - pathogen interaction in Coffea- *Gibberella xylariodes* pathosystem. pp.120-136. In: J. Flood, (eds). Coffee wilt disease. Typeset by MTC, Manila and Philippines, UK.

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Aust. J. Biol. Sci*. 9: 463–493.

Hallauer, A. R. and J. B. Miranda., 1988.Quantitative genetics in maize breeding.Iowa State University press, Ames.

Heim, R. and A. Saccas, 1950.Tracheomycosis of *Coffeaexcelsa* and *robusta* in the plantations of Oubangui-Chari. CompteRendu de l'Academie des Sciences, 231(11):536-538.

Holland, J. B., W. E. Nyquist and C. T. Cervantes-Martinez., 2003. Estimating and interpreting heritability for plant breeding. In: J. Janick, (eds). Plant Breeding Reviews. John Wiley and Sons Inc., New York.

Huber, D. A., 1993. Optimal mating designs and optimal techniques for analysis of quantitative traits in forest genetics. Doctoral Dissertation presented to University of Florida. 151p.

Hurtl, D. L., 1994. Genetics. Jones and Bartlett Publishers, Boston.

Jeger, M. J., and S. L. H. Viljanen-Rollinson, 2001.The use of the area under the disease-progress curve (AUDPC) to assess quantitative disease resistance in crop cultivars. *Theor. Appl. Genet*. 102:32-40.

Kambal, A. E. and O. S. Webster., 1965.Estimates of general and specific combining ability in grain sorghum.*Crop Sc*. 5: 521-523.

Kangire, A., 2014. Enhancing resistance to coffee wilt disease in Uganda–the conventional way. Viewpoints: Africa's Future... Can Biosciences Contribute, p.41.

Kassahun, H. and G. Getnet, 2008.Performance, structure and prospects of coffee marketing in Ethiopia. pp. 416–423. In: Girma, A., B. Bayetta, S. Tesfaye, K. Taye and T. Endale (eds). Coffee Diversity and Knowledge: Proceedings of a national workshop four decades of coffee research and development in Ethiopia. Addis Ababa, Ethiopia, 14-17 August 2007.

Kifle, B., T. Demelash and G. Gabisa, 2015.Screening of some coffee Arabica genotypes against coffee wilt diseases (*Gibberella xylarioides* Heim and Saccus).*International Journal of Sustainable Agricultural Research*, 2(3): 66-76.

Kilambo, D. L., N. M. Ng'homa, D. J. Mtenga, J. M. Teri, and N. Phiri, 2012. Progress in breeding for resistance to coffee wilt disease (tracheomycosis) in Ttanzania. *World research journal of agricultural & bio-systems engineering*, 1: 12-16.

Kilambo, D. L., N. M. Ng'homa, J. Mtenga, J. M. Teri, T. Nzallawahe, R. Mike, and L. Masumbuko1, 2007. Progress towards searching for durable resistance to Fusarium wilt (*Fusarium xylarioides*) in *Coffeacanephora* germplasm in Tanzania. pp. 1386–1389. Proceedings of the 20th International Scientific Conference on Coffee Science (ASIC). Bangalore, India.

Kranz, J. and M. Mogk, 1973.*Gibberella xylarioides* Heim and Saccas on Arabica coffee in Ethiopia. *Phytopath. Z.* 78: 365-366.

Krug, C. A. and A. Carvalho, 1951.The genetics of Coffea. *Advances in genetics*, 4:127-158.

Kuroda, K., 1999. Which factor decides dead or alive in tree? pp. 81–82. In: K. Suzuki (eds). Tree health. AsakuraShoten, Tokyo.

Kuroda, K., 2004. Inhibiting factor of symptom development in several Japanese red pine (*Pinus densiflora*) families selected as resistant to pine wilt. *Journal of Forest Research*, 9: 217–224.

Lamkey, K. R. and J. W. Edwards, 1999.Quantitative genetics in heterosis. pp. 31-48. In: Coors, G. J. and S. Pandey, (eds.). Genetics and exploitation heterosis in crops. Amer. Soci. of Agron. Wisconsin, USA.

Lenka, D. and Misra, B. (1973) Path Coefficient Analysis of Yield in Rice Varieties. Indian Journal of Agricultural Science, 43, 376-379.

Lashermes, P., M. C. Combes, J. Robert, P. Trouslot, A.D'hont, F. Anthony and A. Charrier, 1999.Molecular characterization and origin of the *Coffea arabica* L. genome.*Molecular and General Genetics MGG*, 261(2):259-266.

Lüders R. R., R. Galbieri, M. G. Fuzatto1, and E. Cia, 2008. Inheritance of resistance to Verticillium wilt in cotton. *Crop Breeding and Applied Biotechnology*,8: 265-270.

Manu, D. G., B. V. Tembhurne, B. Kisan, D. S. Aswathnarayanaand J. R. Diwan, 2014. Inheritance of *Fusarium wilt* and Qualitative and Quantitative Characters in Chilli (*Capsicum Annuum* L).*Journal of Agriculture and Environmental Sciences*, 3(2):433-444.

Mathur P. N. and J. R. Mathur, 1983.Combining ability for yield and its components in pearl millet. *Indian J. Genet.Pl. Breeding*.43:299-303.

Melaku, W., 1984.Coffee genetic resources in Ethiopia conservation and utilization particular reference to CBD resistance. pp. 203-211. Proceedings of the first regional workshop on coffee berry disease. Addis Ababa, Ethiopia, 19-23 July 1982.

Merdassa, E., 1986. A review of coffee diseases and their control in Ethiopia. pp. 187–195. In: A. Tsedeke, (eds). Proceedings of the first Ethiopian crop protection symposium. Addis Ababa, Ethiopia, 4–7 February 1986, Institute of Agricultural Research.

Mert M., S. Kurt, O. Gencer, Y. Akiscan, K. Boyaci and F. M. Tok, 2005. Inheritance of resistance to Verticillium wilt (*Verticillium dahliae*) in cotton (*Gossypium hirsutum* L.).*Plant Breeding*,124:102-104.

Mesfin, A., 1982. Heterosis in crosses of indigenous coffee (*Coffee arabica* L.) selected for yield and resistance to CBD at first bearing stage. *Ethiopian Journal of Agricultural Science*, 4: 33-43.

Mesfin, A. and B. Bayetta, 1983. Heterosis in crosses of indigenous coffee selected for yield and resistance to coffee berry disease: II-First three years. *Ethiopian Journal of Agricultural Science*, 5:13-21.

Meyer, F. G., 1965. Notes on wild *Coffea arabica* from Southwestern Ethiopia, with some historical considerations, *Economic Botany*, 19:136–151.

Ministry of Agriculture (MOA), 2015.Plant Variety Release, Protection and Seed Quality Control Directorate. Crop Variety Register, Issue N. 18, Adiss Ababa, Ethiopia.

Mugiira, R. B., P. F. Arama, J. M. Macharia, and B.M. Gichimu, 2011. Antibacterial activity of foliar fertilizer formulations and their effect on ice nucleation activity of *Pseudomonas syringarpvgarcae* Van Hall; the causal agent of Bacterial Blight of Coffee. *Int. J. Agric. Res*. 6(7): 550 –561.

Musoli, P. C., S. Olal, A. Nabaggala and C. Kabole, 2001.Screening Robusta coffee germplasm for resistance against coffee wilt disease. CORI Progress Report on Coffee Wilt Disease Research and Development, 1997–2000, Uganda.

Musoli, P. C., 2007. Sources of resistance against coffee wilt disease caused by *Fusarium xylarioides*in Uganda. Doctoral Thesis of Montpellier II University, France.

Musoli, P. C., A. Girma, G. J. Hakiza, A. Kangire, F. Pinard, C. Agwanda and D. Bieysse, 2009. Breeding for resistance against coffee wilt disease.pp.180-197. In: J. Flood, (eds). Coffee Wilt Disease. Typeset by MTC, Manila, Philippines, Printed and bound in UK.

Musoli, P. C., C. Cilas, D. Pot, A. Nabaggala, S. Nakendo, J. Pande, A. Charrier, L. Thierry and D. Bieysse, 2013.Inheritance of resistance to coffee wilt disease (*Fusarium xylarioides* Steyaert) in Robusta coffee (*Coffeacanephora* Pierre) and breeding perspectives. *Tree Genetics & Genomes*, 9:351–360.

Mwanga, R. O. M., G. C. Yenchoand J. W. Moyer, 2002. Diallel analysis of sweet potatoes for resistance to sweet potato virus disease. Euphytica, 128: 237–248.

Nelson, P. E., 1981. Life cycle and epidemiology of *Fusarium oxysporium*. pp. 51-80. In: M. E. Mace, A. A. Bell and C. H. Beckman (eds). Academic Press: London.

Olika, K., A. Sentayehu, K. Taye and G. Weyessa, 2011.Variability of quantitative traits in limmu coffee (*Coffea arabica* L.) in Ethiopia. International Journal of Agricultural Research, 6(6):482-493.

PBTools, version 1.4., 2014.Biometrics and breeding Informatics, PBGB Division.

International Rice Research Institute, Los Baños, Laguna.

Panwar I. S., R. K. Arya, D. Phougat and S. K. Pahuja, 2015.Use of combining ability, heritability and genetic advance in breeding programmes. *Forage Res*.41 (3):164-169.

Patel, P. B. and H. C. Pathak, 2011. Genetics of resistance to wilt in castor caused by *Fusarium oxysporum f. sp*. ricini Nanda and Prasad. *Agricultural Science Digest*, 31(1):30-34.

Pieters, R. and N. A., Van der Graaff, 1980. *Gebberrella xyilarioides* on Arabica coffee: evaluation of testing methods and evidence for the horizontal nature of Resistance. *Neth. J. Pl. Path*. 86:37-43.

Phiri, N. and P. Baker, 2009. Coffee Wilt disease in Africa. Final Technical Report of the Regional Coffee Wilt Program.CABI, 2009.

Poehlman, J. M., and D. A. Sleper, 1995.Breeding field crops. Iowa state university press, Ames, Iowa50014, India. 494p.

Rutherford, M. A., 2006. Current knowledge of coffee wilt disease, a major constraint to coffee production in Africa. Symposium on Fusarium induced diseases of tropical perennial crops. *Phytopathology,*96: 663–666.

Russel, A. J., 1978. Plant breeding for pest and disease resistance. Butterworth Ltd, London. 485p.

Rood, S. B., 1986.Heterosis and the metabolism of [3H] gibberellin A1 in maize. Canadian *journal of botany*, 64(9):2160-2164.

Statistical analysis system (SAS). 2008.SAS user's guide (version 9.2).SAS Institute, Cary, NC., USA.

Seyoum, S., 2003.Genetic divergence for seedling parameters and associations among agronomic traits in the Ethiopian coffee (*Coffea arabica* L.) germplasm. An MSc thesis submitted to the School of graduate studies of Alemaya University. 91p.

Schlegel, R. H. J., 2003. Encyclopedic dictionary of plant breeding and related subjects. Food Products Press and the Haworth Reference Press, imprints of the Haworth Press, Inc. Alice Street, Binghamton. 563p.

Sharma, P. D., 2004. Plant pathology: a text book for university students. Rackesh Kumar Rastogi publications, New Delhi, India.

Shull, G. H., 1908. The composition of a field of maize. *Journal of Heredity*, 1:296-301.

Shull, G. H., 1952. Beginning of the heterosis concept. pp. 14-48. In: J. W. Gowen (eds). Heterosis. Hafner publishing, New York.

Siddiqui, Z.A. and L. P. Singh, 2004.Effects of soil inoculants on the growth, transpiration and wilt disease of chickpea.*Journal of Plant Diseases and Protection*, 111(2): 151-157.

Sihen, B., A. Girma, L. Fikre and H. Hindorf, 2012.Coffee wilt disease (*Gibberella xylarioides* Heim and Saccas) in forest coffee systems of Southwest and Southeast Ethiopia. *PlantPathol. J*. 11(1): 10-17.

Singh, B. D., 1993. Plant breeding. Kalyani Pub. New Delhi, India. 896p.

Singh, R. K. and B. D. Chaudhary, 1985.Biometrical methods in quantitative genetic analysis.Kalyani publishers, New Delhi. 318p.

Sleper, D. A. and J. M. Poehlman, 2006.Breeding field crops. Wiley-Blackwell, India. 424p.

Sprague, G.F. and L.A. Tatum, 1942.General versus specific combining ability in single crosses of corn. *J.Am.Soc.Agron*. 34:923-932.

Stangland, G. R., W. A. Russel and O. A. Smith, 1983. Evaluation of the performance and selected lines derived from improved maize population. *Crop sci*.18:224-226.

Stewart, R. B., 1957. Some plant diseases occurring in Kaffa province. Imperial Ethiopian College of Agriculture and Mechanical Arts, Alemaya, Ethiopia.

Strange, R. N., 1993.Plant Disease Control.Towards environmentally acceptable methods. Chapman and Hall, New York.

Stuber, C. W., Lincoln, S. E., Wolff, D. W., Helentjaris, T. and E. S. Lander, 1992. Identification of genetic factors contributing to heterosis in a hybrid from two elite maize inbred lines using molecular markers. *Genetics*, 132(3): 823-839.

Sylvian, P. G.,1955. Some observation on *Coffea arabica* L. in Ethiopian.*Turrialba*,5:37-53.

Toda, T., Y. Fujimoto, K. Nishimura, H. Yamate& T. Maeta, 1986. Resistance to the nematode in hybrid pines (*P. thunbergii* × *P. massoniana*). Proceedings of Kyushu

Branch Congress of Japanese Forest Society, 39: 67–68.

Toda, T. & Y. Fujimoto, 1987. Resistance to the pine wood nematodes in *Pinus densiflora* (Kirishima-matsu).*The Japanese Forest Society Congress*, 98:261–262.

Toole, E. R., 1941. Fusarium wilt of mimosa tree (*Albiziajulibrisin*). *Phyopath*.31: 599-616.

Ulloa, M., R.B. Hutmacher, R.M. Davis, S.D. Wright, R. Percy and B. Marsh, 2006. Breeding for Fusarium wilt race

4 resistance in cotton under field and greenhouse conditions. *J. Cotton Sci*, 10(11):114–127.

Van der Graaff, N. A. and R. Pieters, 1978. Resistance levels in *Coffea arabica* to *Gibberellaxylarioides*and distribution pattern of the disease. *Neth. J.Pl. Pathol*.84: 117-120.

Van der Graaff, N.A., 1981. Selection for Arabica coffee types resistant to CBD in Ethiopia. A Doctoral Dissertation presented to Wageningen University, Netherland. 110pp.

Van der Graaff, N. A., 1983. Durable resistance in perennial crops. pp. 263-276. In: L. Lamberti, J. M. Waller and N. A. Van der Graaff (eds). Durable resistance to crops. Plenum Press, New York.

Vanderplank, J. E., 1984.Disease resistance in plants. Academic Press, INC. 194p.

Van der Vossen, H. A. M. and D. J. A. Walyaro, 1980. Breeding for resistance to coffee berry disease in *Coffeaarabica* II. Inheritance of the resistance. *Euphytica*, 29:777-791.

Van der Vossen H. A. M. •and D. J. Walyaro, 2009.Additional evidence for oligogenic inheritance of durable host resistance to coffee berry disease (*Colletotrichum kahawae*) in Arabica coffee (*Coffea arabica* L.).Euphytica. 165(1):105-111.

Van der Vossen, H. A. M., 1985. Coffee selection and breeding. pp. 49-96. In: M. N. Clifford and K. C. Willson (eds). Coffee: Botany, biochemistry and production of beans and beverages. Croom Helm Ltd, London.

Van der Vossen, H. A. M., 2005. A critical analysis of the agronomic and economic sustainability of organic coffee production.*Exper. Agri*. 41: 449-473.

Verma, P. S. and V. K. Agarwal, 1982.Genetics.Chad,S. and Co. Ltd, Ramnagar, New Delhi. 580p.

Viands, D. R., 1985.Comparison of *Maris Kabul* with *Vertus* alfalfa for resistance to *verticillium wilt*. *Crop Sci*. 25:1096-1100.

Walyaro, D. J. A., 1983. Considerations in breeding for improved yield and quality in Arabica coffee (*Coffea arabica* L.). Doctoral Thesis presented to Wageningen University, Netherland. 119pp.

Yamanobe, T., 2009. Relationships between morphological traits and resistance to pine wood nematode in two Japanese pines. *Eur. J. Plant. Pathol*.124:543–552.

Yonass, B., Bayetta, B. and F. Chemeda, 2014. Performance evaluation of indigenous Arabica coffee genotypes across different environments. *Journal of Plant Breeding and Crop Science*, 6(11):171-178.

How to cite this article:

Admikew Getaneh. 2021. Relationship of Coffee Wilt Disease (*Gibberella xylarioides Heim* and Saccas) Resistance and Morphological Traits in Selected Arabica Coffee (*Coffea arabica* L.) Genotypes. *Int.J.Curr.Res.Aca.Rev*. 9(03), 97-110. doi: https://doi.org/10.20546/ijcrar.2021.903.010