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Response of Potato Genotypes to Bacterial Wilt Caused by *Ralstonia Solanacearum* (Smith)(Yabuuchi et al.) In the Tropical Highlands

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Abstract Potato varietal resistance to bacterial wilt disease caused by *Ralstonia solanacearum* Yabuuchi et al., (Microbiology and Immunology 39:897–904, 1995) is the best management of the disease. Because the causal pathogen exhibits strong host-pathogen-environment interaction, screening the potential parents for resistance under the target growing environmental conditions is the first important step for effective resistance breeding. The objective of this study was to determine the response to bacterial wilt of selected potato genotypes currently grown by farmers in Kenya and candidate clones from the International Potato Center to identify parents that can be used in the local breeding program to develop resistant cultivars. A study was carried out at Kabete, Kenya for three consecutive seasons between November 2011 and February 2013. Thirty six potato genotypes were planted on an inoculated field at the Kenya Agricultural Research Institute (KARI), Kabete using alpha lattice experimental design with three replications. Data collected were days from planting to onset of wilting (DTOW), bacterial wilt incidence (BWI), total tuber weight (ton ha^{-1}) (TTW), total tuber numbers/hectare (TTN), proportion of ware sized tubers (PWTTW), proportion of symptomatic tubers based on weight (PSTTW), proportion of symptomatic tubers based on tuber numbers (PSTTN) and latent infection (LI) of the tubers. Almost, all the potato genotypes evaluated in this study were susceptible to bacerial wilt. Ranking of genotypes based on resistance differed among the three seasons. On average, the three most resistant genotypes were Kenya Karibu, Kenya Sifa and Ingabire. The study identified eight potato genotypes (Meru, Ingabire, Kenya Karibu, Sherekea, Kihoro, Tigoni, Bishop Gitonga and Cangi) to be used as promising parents for subsequent crosses. The chosen genotypes are prolific in pollen production and popularly grown by Kenyan farmers.

Resumen La Resistencia varietal de la papa a la enfermedad de la marchitez bacteriana, causada por *Ralstonia solanacearum* Yabuuchi et al., (Microbiology and Immunology 39:897–904, 1995), es el mejor manejo de la enfermedad. Considerando que el agente patógeno causal presenta una interacción fuerte hospedante-patógeno-ambiente, las pruebas de padres potenciales para resistencia bajo condiciones ambientales de crecimiento enfocadas, es el primer paso importante para el mejoramiento efectivo para la resistencia. El objetivo de este estudio fue determinar la respuesta a la marchitez bacteriana de genotipos de papa selectos que actualmente se cultivan por productores en Kenia y clones candidatos del Centro Internacional de la Papa, para identificar padres que pudieran usarse en el programa local de mejoramiento para desarrollar variedades resistentes. Un estudio se efectuó en Kabete, Kenia, durante tres ciclos consecutivos entre noviembre de 2011 y febrero de 2013. Se plantaron 36 genotipos de papa en un campo inoculado en el Instituto de Investigaciones Agrícolas de Kenia (KARI). En Kabete se usó un diseño de látice alfa con tres repeticiones. Los datos tomados fueron los días desde la siembra hasta el establecimiento del marchitamiento (DTOW), incidencia de la marchitez bacteriana (BWI), peso total de tubérculo (ton ha^{-1}) (TTW), número total de tubérculos/ha (TTN), proporción de tubérculos de tamaño comercial (PWTTW), proporción de tubérculos sintomáticos con base en

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Table 1 List and sources of potato genotypes used in the study

Genotype	Source/pedigree	Year of release
Desiree	The Netherlands	1972
Tigoni	CIP	1998
Kenya Sifa	CIP	2002
Kihoro	Farmers' variety	-
Meru	Farmers' variety	-
Nyayo	Farmers' variety	-
Ingabire	CIP	1998
Roslin Tana	Scotland	1974
Kenya Baraka	Scotland	1973
Kenya Furaha[1]	CIP	1998
393385.57	CIP	Not yet released
Tigoni Long[1]	Farmers' variety	-
Arka	The Netherlands	-
Kerr's Pink	Scotland	1927
Dutch Robyjn	The Netherlands	1945
Roslin Bvumbwe	Scotland	1974
Sterling		-
Bishop Gitonga	Farmers' variety	-
Annete	Germany	1972
Purple Gold	CIP	2010
Pimpernel	The Netherlands	-
Kenya Mpya	CIP	2010
B53	Scotland	1953
Sherekea	CIP	2010
Ngure[1]	Farmers' variety	-
Asante	CIP	1998
Kenya Mavuno	CIP	2002
Saturna[1]	Germany	-
396286.6	CIP	Not yet released
394906.6	CIP	Not yet released
387164.4	CIP	Not yet released
394903.3	CIP	Not yet released
394034.7	CIP	Not yet released
394905.8	CIP	Not yet released
394895.7	CIP	Not yet released
394904.17	CIP	Not yet released
Cangi[2]	Farmers' variety	-
Romano[2]	The Netherlands	-
Kenya Karibu[2]	CIP	2002
393382.44[2]	CIP	Not yet released

[2] =Not included in the first season. [I] =Not included in the second and third seasons. - Not available

el peso (PSTTW), proporción de tubérculos sintomáticos con base en el número de tubérculos (PSTTN) e infección latente (LI) de los tubérculos. Casi todos los genotipos de papa evaluados en este estudio fueron susceptibles al marchitamiento bacteriano. La clasificación de los genotipos con base en la resistencia varió entre los tres ciclos de cultivo. En promedio, Los tres genotipos más resistentes fueron Kenya Karibu, Kenya Sifa, e Ingabire. El estudio identificó ocho genotipos de papa ((Meru, Ingabire, Kenya Karibu, Sherekea, Kihoro, Tigoni, Bishop Gitonga y Cangi) para usarse como progenitores prometedores para cruzas subsecuentes. Los genotipos seleccionados son prolíficos en producción de polen y se cultivan popularmente por los productores kenianos.

Keywords Bacterial wilt · Potato · Resistance breeding

Introduction

Potato (*Solanum tuberousm* L.) production in Kenya has not achieved its potential due to several constraints including low soil fertility, inadequate supply of certified seed potatoes, use of unimproved low yielding varieties, and diseases. The most common diseases in the country include late blight, viral infections and bacterial wilt (Kaguongo et al. 2008). Bacterial wilt, caused by *Ralstonia solanacearum* (Yabuuchi et al. 1995),is the second most important potato disease after late blight locally and globally (Kaguongo et al. 2008). The disease has been estimated to affect about 1.7 million hectares in approximately 80 countries worldwide, with global damage estimates of over USD 950 million per annum (Champoiseau et al. 2009). Bacterial wilt has been reported to cause yield losses of between 50 and 100 % in Kenya (Otipa et al. 2003), while in Uganda, losses of up to 30 % (Alacho and Akimanzi 1993), with occasional losses of up to 100 %, have been reported (Kakuhenzire et al. 1993). This disease has no effective means of control because crop protection chemicals and biological controls are ineffective and expensive (Smith et al. 1998; Champoiseau et al. 2010). In addition, phytosanitary methods such as quarantine are either expensive or difficult to apply (Martin and French 1985; Muthoni et al. 2010), and cultural methods such as crop rotations are largely impractical because the farms are too small to allow effective rotation. Furthermore, the pathogen has a wide host range and it persists for a long time in the soil (Kaguongo et al. 2008; Muthoni et al. 2010).

Development of resistant cultivars is currently the best option for managing bacterial wilt, however, there are no known potato cultivars with resistance. Cultivars such as Cruza 148 and Molinera have been found to have some degree of tolerance to bacterial wilt but still transmit latent infection to their progeny tubers (French 1994). In addition, the resistance has been shown to be very unstable due to its strong host-pathogen-environment interaction (French and Lindo 1982; Tung et al. 1990, 1992a; Tung 1992). Therefore, a pathogen race at one location may overcome the resistance effective at another location (Grimsley and Hanson 1998); more than one race may occur in a given field (Martin and French 1985). Due to this, an essential step in the

Table 2 Rainfall and temperatures in the experimental site during the experimental period

	2011			2012												2013	
Month	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Total rainfall (MM)	154.4	351	96.2	9.4	75.6	49.1	686.6	3746.6	456	26	96.8	33.5	416.1	252.1	289.4	89.2	6
Number of rainy days	16	12	4	1	3	3	21	23	11	3	2	2	12	15	12	7	2
Mean temp.	16.8	17.8	18.4	19.4	16.9	19.7	18.0	16.2	14.9	14.8	16.24	23.1	24.6	23	22	23.1	25.2

Table 3 Analysis of variance on colony forming units (cfu) per gram of soil sampled during the three seasons at KARI Kabete

Source of variation	DF	MS	Fpr.
Block	2	2249000000000.00	
Season	2	24570000000000.00	<.001*
Sampling time	2	281100000000000.00	<.001*
Season * Sampling time	4	10470000000000.00	<.001*
Residual	205	801700000000.00	
Total	215		

*=significant at $P \leq 0.05$

development of resistant varieties is screening of the germplasm at the target production environment to identify promising clones for breeding (Martin and French 1985).

Breeding programs to develop resistant cultivars were initiated in many parts of the world, but acceptable cultivars with good tolerance to bacterial wilt are yet to be identified in Kenya (Ateka et al. 2001). Resistant potato clones have recently been identified by International Potato Centre (CIP) scientists. This resistance needs to be incorporated into the popular but susceptible Kenyan potato cultivars so as to increase potato production in Kenya. Screening the clones for resistance under local environmental conditions is the first important step for effective resistance breeding. This study was carried out to determine the reaction to bacterial wilt of the potato genotypes currently grown by farmers in Kenya as well as other clones from CIP so as to identify parents that can be used in the local breeding program to develop resistant cultivars.

Table 4 Mean colony forming units (cfu) per gram of soil sampled during the three seasons at KARI Kabete

Sampling time	Season 1	Season 2	Season 3	Mean
Before planting	855000a	832500a	1936250a	1207917a
60 days after planting	3352500c	5361250c	5556667b	4756806c
After harvesting	1373750b	1490000b	1568333a	1477361a
Mean	1860417a	2561250b	3020417c	2480694
LSD(0.05) for Seasons= 294213.1				
LSD(0.05) for Sampling time=294213.1				
LSD(0.05) for Seasons * Sampling time =509592.0				

Within each column, values followed by the same letter are not significantly different at $P \leq 0.05$

Materials and Methods

Study Site

The experiment was carried out at National Research Laboratories (NARL), Kabete Station of the Kenya Agricultural Research Institute (KARI). The KARI-Kabete station is located 7 km N.W. of Nairobi at an altitude of 1795 m above sea level, latitude of 1°15' 31.64" S and longitude 36° 46' 17. 96"E (Jaetzold et al. 2006a). The average

Table 5 Analysis of variance: Days to onset of wilting and final BWI of 36 potato genotypes planted at KARI Kabete for three consecutive seasons

Source of variation	DF	DTOW		FINAL BWI	
		MS	Fpr.	MS	Fpr.
Season I					
Block	2	295.85		166.07	
Genotype	35	142.57	0.011*	305.79	<.001*
Residual	70	74.93		75.71	
Season II					
Block	2	41.61		457.2	
Genotype	35	48.22	0.738	207.2	0.007*
Residual	70	58.84		104.1	
Season III					
Block	2	123.15		0.2	
Genotype	35	248.78	<.001	989.1	0.057
Residual	70	66.96		634.0	

DTOW days to onset of wilting, *FINAL BWI* bacterial wilt incidence at 120 days after planting

*=significant at $P \leq 0.05$

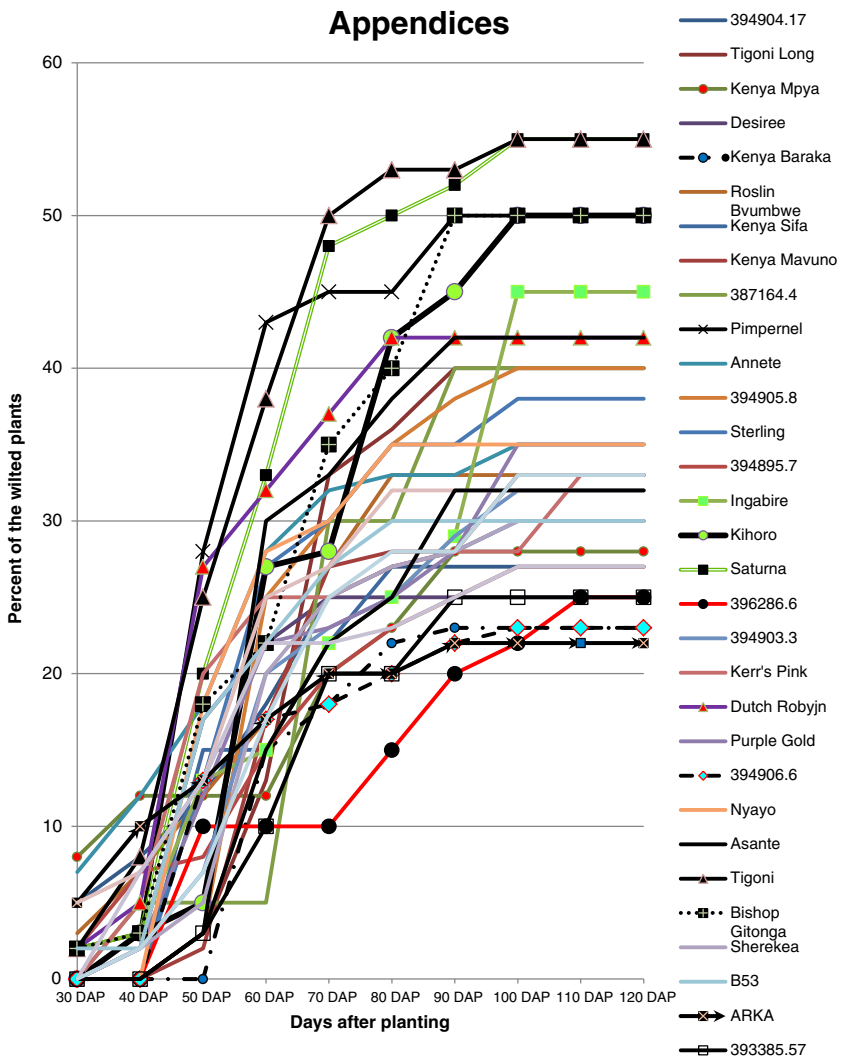

Fig. 1 Percent of the wilted plants 30 to 120 days after plating during the first season at KARI Kabete

annual rainfall is 1295 mm with a bimodal distribution. A long rain season occurs between March and May while a short rain season is between October and December (Jaetzold et al. 2006a). The mean air temperature ranges from 13.3 to 22.9 °C. The soil type is humic nitosol (alfisol) derived from quartz trachyte (UNESCO 1977) and is locally referred to as the Kikuyu Red Clay. The experiment was carried out for three consecutive seasons; 11 November 2011 to 24 February 2012 (first season), 7 April 2012 to 15 August 2012 (second season), and 16 October 2012 to 8 February 2013 (third season).

Field Layout, Inoculation and Crop Management

Thirty six bacterial wilt free potato genotypes were sourced from KARI Tigoni. The list and sources of the potato genotypes used in the study are described in Table 1. The same genotypes were used in the second and third seasons; in the first season, four genotypes were different. Genotypes were planted at KARI, Kabete Station for screening for bacterial wilt resistance. The same field was used for three consecutive seasons; randomization was different for each season. The experimental design was an alpha lattice with four blocks each having nine plots with three replications. Each genotype was planted in four rows, and spacing was 75 cm (inter-row) and 30 cm (intra-row) giving a total of 20 plants. Di-ammonium phosphate (18:46:0) fertilizer was applied at the rate of 500 kg ha^{-1} in furrows and thoroughly mixed with soil before planting.

To ensure uniform inoculum distribution, a susceptible tomato cultivar, Moneymaker, was transplanted in the field at a spacing of 30 cm x 60 cm. Two weeks after transplanting, the tomato plants were inoculated by spraying a bacterial suspension (3.0 x 10^9 cfu/ml) at the base of each stem. About 6 weeks after inoculation, when at least 80 % of the plants had wilted, the tomato plants were ploughed under. Thereafter, the first-season potato evaluation trial was established on the same field. In the second and third seasons, a bacterial suspension concentrated at 3.0 x 10^9 cfu/ml was

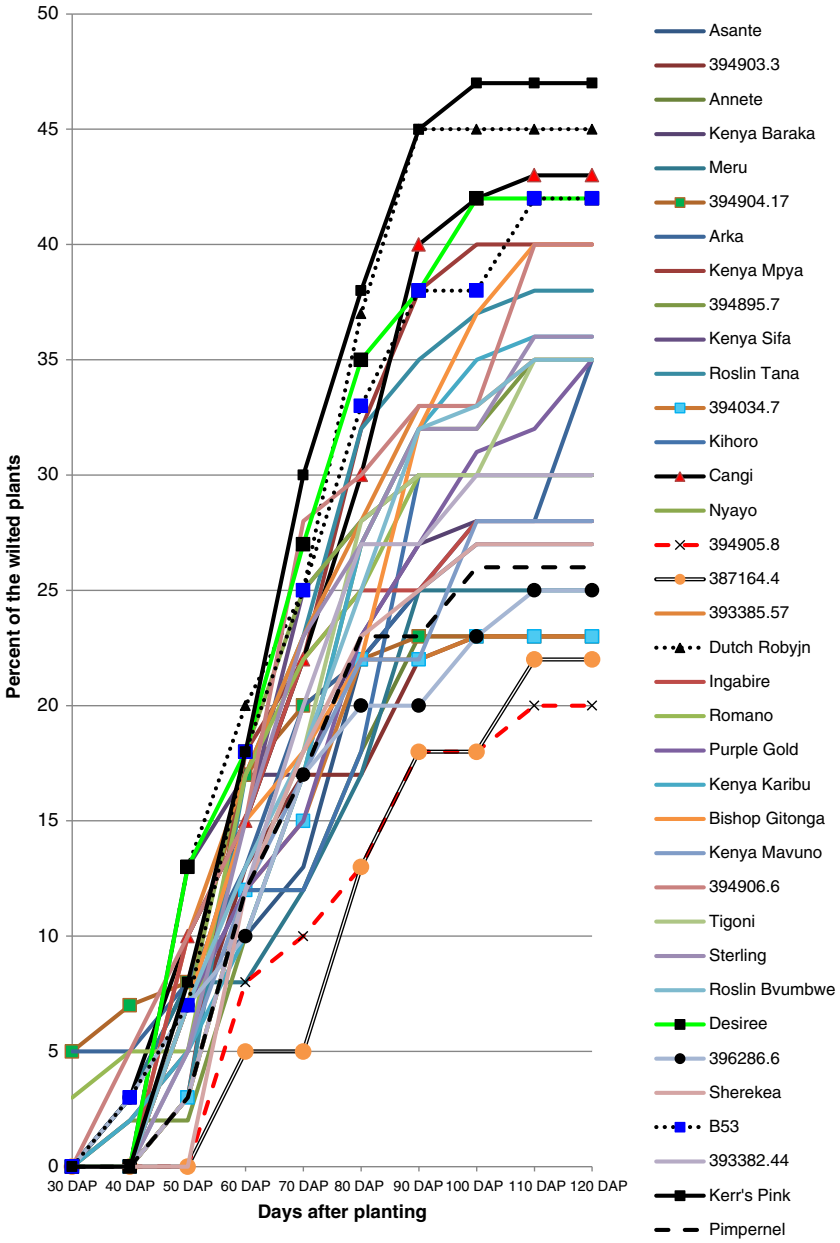

Fig. 2 Percent of the wilted plants 30 to 120 days after plating during the second season at KARI Kabete

poured into the planting furrows (during planting potato tubers but before covering them) at a rate of 400 ml per plot to boost the inoculum concentration in the soil. Weeding and other cultural management practices were carried out according to recommendations for potato production in Kenya(Kabira et al. 2006). To ensure disease progression, supplemental irrigation was provided during the dry times. In addition, workers' shoes as well as working tools were disinfested by dipping in a footbath containing 1 % sodium hypochlorite when entering and leaving the field.

The minimum and maximum air temperatures were taken daily at 12.00 p.m. throughout the experimental period. This was done using a thermometer hung in a Stevenson screen near the experimental plots. The daily values were averaged on a monthly basis to give the mean monthly temperature. Daily total rainfall was captured using a rain gauge in the KARI-Kabete centre while the number of rainy days per month were recorded at the same site.

Data Collection

The potato plants were first observed for wilt symptoms 30 days after planting and then after every 10 days. At each evaluation date, all the wilting plants on each plot were counted. This was then expressed as a percentage of all the plants in the plot to give wilt incidence (BWI). Final BWI was

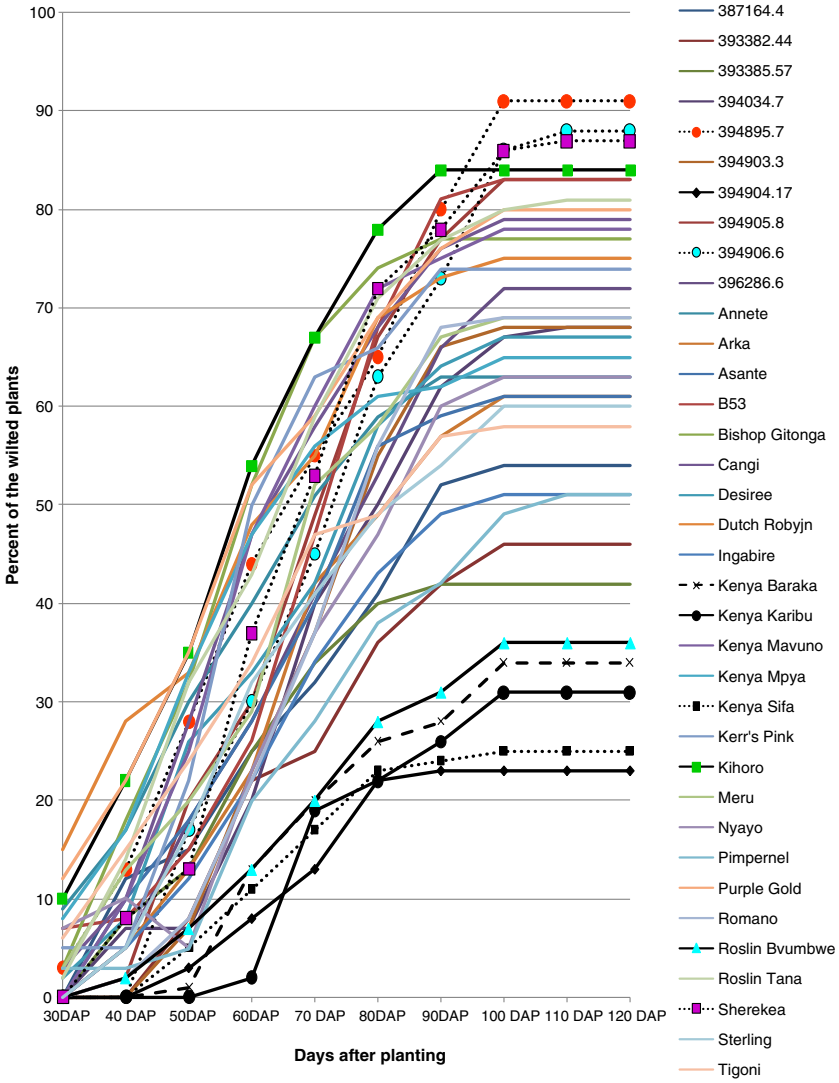

Fig. 3 Percent of the wilted plants 30 to 120 days after plating during the third season at KARI Kabete

taken at 120 days after planting. Other data collected were days from planting to onset of wilting (DTOW). In each season, populations of *R. solanacearum* in the soil were determined using a modified SMSA method (Englebrecht 1994) before inoculating the field, at 60 days after planting, and after harvesting the crop. At each sampling time, 8 soil samples were evenly collected from each replicate. From each soil sample, 10 g were placed into a sterile conical flask and 30 ml of sterile distilled water added. This was mixed thoroughly for 30 min and then allowed to stand for 5 min. Thereafter, 1 ml was drawn from the supernatant solution using a micro-pipette and put in a sterile Eppendorf tube. This formed the stock solution (10^0 cfu/ml). From the stock solution, 0.1 ml was drawn and put in sterile Eppendorf tube which already contained 0.9 ml of sterile distilled water. This formed the first dilution of the stock solution (10^{-1}). This serial dilution was continued up to 10^{-3}. From 10^{-3} dilution, 0.1 ml of the suspension was drawn and plated on semi-selective media for *R.solanacearum*. The plates were incubated at 30^0C for 48 h after which the bacterial colonies were counted. The experiment was duplicated and the mean number of bacterial colonies was reported.

Harvesting of potato tubers was done when the latest maturing genotype had reached 75 % senescence. During harvest, the 6 middle plants per plot were harvested, each plant separately. The total number of tubers was counted from each of the six plants. In addition, the number of symptomatic tubers (i.e. showing rotting or bacterial ooze in the tuber eyes or soil adhering to the eyes of the tubers) and healthy looking tubers (asymptomatic) were determined. The healthy looking tubers were then categorized based on size i.e. ware (>45 mm diameter) and, seed and chatts (45>mm diameter). Their number and weights were recorded. The weights of symptomatic and ware tubers were expressed as percentage of the total yields. The percent of symptomatic tubers were expressed as a weight, a value which is useful to determine yield loses (tons ha^{-1}), and as

Table 6 Latent infection of tubers among potato genotypes tested for three consecutive seasons at KARI Kabete

Season I			Season II			Season III		
Genotype	% LI	Rank	Genotype	% LI	Rank	Genotype	% LI	Rank
394904.17	40.00	8.0	394904.17	40.00	26.5	394904.17	25.00	8.5
Tigoni Long	33.33	3.5	Kenya Mpya	33.33	20.0	Kenya Mpya	33.33	17.0
Kenya Mpya	46.67	13.0	Desiree	30.00	16.0	Desiree	26.00	11.5
Desiree	40.00	8.0	Kenya Baraka	60.00	35.5	Kenya Baraka	6.67	2.0
Kenya Baraka	50.00	15.5	Roslin Bvumbwe	46.67	31.5	Roslin Bvumbwe	50.33	29.0
Roslin Bvumbwe	40.00	8.0	Asante	16.00	6.0	Asante	26.00	11.5
Kenya Sifa	33.33	3.5	Kenya Mavuno	20.00	10.0	Kenya Mavuno	23.33	6.0
Kenya Mavuno	53.33	20.5	387164.4	40.00	26.5	387164.4	20.33	5.0
387164.4	60.00	28.5	Annete	20.00	10.0	Annete	45.00	24.5
Annete	53.33	20.5	394905.8	50.00	34.0	394905.8	25.00	8.5
394905.8	60.00	28.5	Sterling	20.00	10.0	Sterling	33.00	16.0
Sterling	53.33	20.5	394895.7	33.33	20.0	394895.7	26.67	14.0
394895.7	66.67	34.5	Ingabire	20.00	10.0	Ingabire	13.67	3.0
Ingabire	60.00	28.5	Kihoro	20.00	10.0	Kihoro	50.00	28.0
Kihoro	40.00	8.0	396286.6	40.00	26.5	396286.6	26.33	13.0
Saturna	60.00	28.5	394903.3	26.67	14.5	394903.3	30.00	15.0
396286.6	40.00	8.0	Kerr's Pink	40.00	26.5	Kerr's Pink	60.00	33.0
394903.3	60.00	28.5	Dutch Robyjn	0.00	1.5	Dutch Robyjn	60.53	34.0
Kerr's Pink	53.33	20.5	Purple Gold	33.33	20.0	Purple Gold	53.33	31.0
Dutch Robyjn	40.00	8.0	394906.6	46.67	31.5	394906.6	35.00	18.5
Purple Gold	53.33	20.5	Nyayo	33.33	20.0	Nyayo	53.33	31.0
394906.6	53.33	20.5	Kenya Sifa	40.00	26.5	Kenya Sifa	15.00	4.0
Nyayo	53.33	20.5	Bishop Gitonga	6.67	3.5	Bishop Gitonga	66.67	35.0
Asante	46.67	13.0	Sherekea	33.33	20.0	Sherekea	40.00	20.5
Tigoni	20.00	2.0	B53	33.33	20.0	B53	46.67	27.0
Bishop Gitonga	40.00	8.0	Arka	20.00	10.0	Arka	25.00	8.5
Sherekea	60.00	28.5	393385.57	60.00	35.5	393385.57	40.00	20.5
B53	46.67	13.0	Meru	6.67	3.5	Meru	76.67	36.0
Arka	60.00	28.5	Roslin Tana	46.67	31.5	Roslin Tana	53.33	31.0
393385.57	60.00	28.5	Pimpernel	40.00	26.5	Pimpernel	45.00	24.5
Ngure	66.67	34.5	Kenya Karibu	0.00	1.5	Kenya Karibu	5.00	1.0
Meru	66.67	34.5	394034.7	26.67	14.5	394034.7	25.00	8.5
Roslin Tana	53.33	20.5	Cangi	13.33	5.0	Cangi	43.33	22.0
Kenya Furaha	66.67	34.5	Romano	33.33	20.0	Romano	35.00	18.5
Pimpernel	50.00	15.5	Tigoni	20.00	10.0	Tigoni	45.00	24.5
394034.7	0.00	1.0	393382.44	46.67	31.5	393382.44	45.00	24.5
Mean	49.44			30.44			36.93	

% LI=% Latent infection

a number of infected tubers, a value which is used for the calculation of infection tuber rates.

Only healthy-looking tubers selected above were analyzed for latent infection by *R. solanacearum.* For each genotype across all the replications, 30 healthy-looking tubers were placed in khaki paper and delivered to the laboratory for latent infection analysis. In the laboratory, the tubers were washed and disinfested. They were then divided into five groups of six tubers each. In each group, each potato tuber had a thin slice of the tuber removed and discarded from around the stolon end using a flame-sterilized scalpel. Then strips of tuber flesh were removed with a flame-sterilized cuticle remover along the vascular ring (= 3 mm wide and 3 mm deep); strips from the six tubers were put in a plastic bag to constitute a composite

Table 7 Analysis of variance for some tuber yield traits of 36 potato genotypes planted at KARI Kabete for three consecutive seasons

Source of variation	DF	TTN		PSTTN		TTW		PSTTW		PWTTW	
		MS	Fpr.	MS	Fpr.	MS	Fpr.	MS	Fpr.	MS	Fpr.
Season I											
Block	2	2.633E+10	<0.001*	103.6	0.379	953.15	0.014*	65.1	0.046*	165.8	0.244
Genotype	35	7.526E+09		116.7		80.95		225.1		123.6	
Residual	70	2.348E+09		107.7		43.41		140.1		102.0	
Season II											
Block	2	2.759E+09	0.616	15673.4	0.131	479.6	0.561	12010.7	0.191	5668.0	0.210
Genotype	35	8.704E+09		247.0		163.8		279.9		266.2	
Residual	70	9.589E+09		180.0		173.1		212.6		212.6	
Season III											
Block	2	4.401E+09	0.108	4564.0	<.001*	487.4	0.017*	3693.6	<0.001*	3227.5	0.035*
Genotype	35	9.076E+09		656.3		182.2		572.4		348.8	
Residual	70	6.407E+09		151.1		100.5		187.8		208.8	

DF degrees of freedom, *MS* means squares, *Fpr* F probability, *TTN* total tuber number per hectare; *PSTTN* percent of symptomatic tubers (% of total tuber number per hectare); *TTW* total tuber weight (ton ha^{-1}), *PSTTW* percent of symptomatic tubers (% of total tuber weight in ton ha^{-1}); *PWTTW* percent of ware sized tubers (% of total tuber weight in ton ha^{-1})

*=significant at $P \leq 0.05$

sample (Priou et al. 1999). The composite sample was then analyzed for latent infection using the post-enrichment enzyme-linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA) test as described by Priou et al. (1999).

Data analysis

Data on soil bacterial count (SBC), days to onset of wilting (DTOW), final BWI, total tuber numbers (TTN), total tuber weight in tons ha^{-1} (TTW), proportion of symptomatic tubers based on total tuber numbers (PSTTN), proportion of symptomatic tubers based on total tuber weight (PSTTW), and proportion of ware sized tubers based on total tuber weight (PWTTW) values were subjected to analysis of variance using Genstat statistical package, 14th edition (Payne et al. 2011). Data on TTN, TTW, PWTTW, PSTTN and PSTTW were first averaged on plot basis; the average value was then used to extrapolate values per hectare. The total tuber weight (TTW) was given in tons/ha. Where analysis of variance showed significant differences, mean separation was done using Fisher's protected LSD (Steel and Torrie 1980). Data on latent infection (LI) level were subjected to Kruskal-Wallis non-parametric test procedure using SPSS for Windows Release Version 18.0 (SPSS Inc., 2009). Data for different seasons were analysed separately. Potato genotypes were also ranked based on % latent infection (% LI), final BWI, DTOW, TTN, TTW, PWTTW, PSTTW and PSTTN. Resistance of geneotypes to bacterial wilt was determined using ranking based on % LI, final BWI, DTOW, PSTTW and PSTTN.

Results

Weather Data

The second season experienced much higher rainfall and slightly lower temperatures than the first season (Table 2). This was expected because the second season coincided with the long rains season (March-June) while the first season coincided with the short rains season (October-December). The third season experienced much higher temperatures than the first two.

Soil Bacterial Counts

There were significant differences ($P \leq 0.05$) in soil bacterial counts between seasons, among sampling times and in the seasons x sampling time interaction (Table 3). The third season had the highest number of soil bacteria counts followed by the second season while the first season had the least (Table 4).

Bacterial Wilt Incidence and Days to Onset of Wilting

The final BWI was significantly different among potato genotypes in the first and second seasons while DTOW was significant in the first and third seasons (Table 5). For most genotypes, percent wilting increased rapidly from 60 days after planting and levelled off at 90–100 days after planting (Figs. 1, 2 and 3). The highest final BWI (indicated by % of wilted plants) in the first season was in genotype Tigoni

Table 8 Mean response and ranks among 36 potato genotypes for agronomic traits" during the first season

GENOTYPE	DTOW		PWTTW		TTW		PSTTW		TTN		PSTTN		FINAL BWI	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Kenya Baraka	60.0	1.0	30.0	7.0	39.7	12.5	29.6	4.0	330861	8.0	33.3	6.0	23.33	5.5
Tigoni Long	56.7	4.0	22.7	20.5	37.0	24.0	37.8	21.5	31851	36.0	31.4	4.0	40.00	30.0
Kenya Mavuno	56.7	4.0	19.8	31.0	41.3	9.5	33.6	12.0	335799	6.0	30.5	3.0	28.33	18.0
Sterling	56.7	4.0	22.9	19.0	33.3	31.0	50.7	32.0	224689	34.0	46.9	32.0	30.00	21.5
393385.57	56.7	4.0	21.5	25.0	38.7	17.0	38.3	23.0	325923	9.0	36.5	9.5	25.00	9.5
Meru	56.7	4.0	34.5	2.0	41.3	9.5	31.7	8.0	308639	15.5	36.5	9.5	31.67	24.0
394905.8	54.1	7.0	23.0	18.0	29.8	34.0	35.8	17.0	224694	33.0	40.0	19.5	30.78	23.0
Kihoro	53.3	10.0	26.0	11.0	47.0	3.0	39.9	26.0	358021	3.0	43.8	29.0	45.00	32.5
394903.3	53.3	10.0	28.7	9.0	52.3	1.0	30.1	5.0	437033	1.0	36.1	7.0	25.00	9.5
394906.6	53.3	10.0	20.4	29.0	29.7	35.0	52.3	33.0	234566	31.5	50.8	33.0	23.33	5.5
Nyayo	53.3	10.0	21.5	25.0	37.3	22.5	32.9	9.0	348144	4.0	36.9	13.0	35.00	27.5
Asante	53.3	10.0	22.7	20.5	37.3	22.5	37.4	18.0	264195	24.0	52.8	34.0	33.33	25.5
Desiree	50.0	14.5	33.0	5.0	33.3	31.0	30.5	6.5	259257	26.0	32.3	5.0	25.00	9.5
Kenya Sifa	50.0	14.5	22.2	23.0	39.3	14.5	20.9	2.0	338268	5.0	29.7	2.0	23.33	5.5
Purple Gold	50.0	14.5	23.4	16.0	38.3	19.5	37.8	21.5	298763	19.0	36.5	9.5	30.00	21.5
Sherekea	50.0	14.5	23.1	17.0	31.7	33.0	30.5	6.5	256787	28.0	45.1	30.5	28.33	18.0
394034.7	47.3	17.0	23.8	15.0	38.5	18.0	37.7	19.5	295677	20.0	40.0	19.5	2.56	1.0
396286.6	46.7	18.0	20.0	30.0	28.4	36.0	54.5	34.0	178266	35.0	54.0	36.0	17.49	2.0
B53	46.7	19.5	24.2	14.0	43.7	6.0	47.6	31.0	311108	13.5	41.0	26.0	23.33	5.5
Kenya Furaha	46.7	19.5	30.7	6.0	43.3	7.0	35.1	15.0	316046	10.5	38.5	14.0	28.33	18.0
Kenya Mpya	43.3	23.5	21.2	25.0	36.7	25.0	37.7	19.5	256788	27.0	40.2	21.5	28.33	18.0
Saturna	43.3	23.5	20.6	27.5	33.7	28.5	34.1	13.0	274071	23.0	40.7	23.0	50.00	35.0
Kerr's Pink	43.3	23.5	17.0	33.0	44.0	5.0	33.4	11.0	333330	7.0	43.1	27.5	28.33	18.0
Bishop Gitonga	43.3	23.5	22.6	22.0	39.0	16.0	26.2	3.0	313577	12.0	40.9	24.5	50.00	35.0
Arka	43.3	23.5	28.3	10.0	38.3	19.5	39.6	25.0	293824	21.0	43.1	27.5	21.67	3.0
Roslin Tana	43.3	23.5	25.4	13.0	40.0	11.0	34.7	14.0	303701	18.0	40.9	24.5	26.67	13.5
394904.17	40.0	30.0	29.6	8.0	33.3	31.0	43.2	29.0	254319	29.0	40.2	21.5	26.67	13.5
Pimpernel	40.0	30.0	35.5	**1.0**	44.7	4.0	40.2	27.0	288886	22.0	39.7	18.0	45.00	32.5
Annete	40.0	30.0	33.2	4.0	35.7	28.5	40.5	28.0	261726	25.0	53.2	35.0	35.00	27.5
Ingabire	40.0	30.0	13.3	34.0	41.7	8.0	33.0	10.0	308639	15.5	36.5	9.5	25.00	9.5
Dutch Robyjn	40.0	30.0	12.6	35.0	39.7	12.5	43.4	30.0	316046	10.5	39.3	17.0	38.33	29.0
Tigoni	40.0	30.0	25.7	12.0	39.3	14.5	38.4	24.0	311108	13.5	39.0	16.0	55.00	35.0
Ngure	40.0	30.0	18.2	32.0	36.3	26.0	57.9	36.0	306170	17.0	38.8	15.0	26.67	13.5
387164.4	36.8	34.0	5.5	36.0	48.3	2.0	20.7	**1.0**	385243	2.0	29.4	**1.0**	42.44	31.0
Roslin Bvumbwe	36.7	35.5	34.1	3.0	37.7	21.0	35.5	16.0	237035	30.0	36.8	12.0	33.33	25.5
394895.7	36.7	35.5	20.6	27.5	36.0	27.0	54.7	35.0	234566	31.5	45.1	30.5	26.67	13.5
Mean	47.26		23.82		38.49		37.70		295674		40.00		30.79	
LSD (0.05)	14.10		16.44		10.73		19.28		78914.1		16.90		14.17	
SED	7.07		8.24		5.38		9.66		39567.1		8.47		7.10	
%CV	18.30		42.4		17.1		31.40		16.4		26.00		28.30	

DTOW days to onset of wilting, *FINAL BWI* bacterial wilt incidence at 120 days after planting, *PWTTW* proportion of ware sized tubers (% of total tuber weight in ton ha^{-1}), *TTW* total tuber weight (ton ha^{-1}), *TTN* total tuber number per hectare, *PSTTW* proportion of symptomatic tubers (% of total tuber weight in ton ha^{-1}), *PSTTN* proportion of symptomatic tubers (% of total tuber number per hectare)

followed by Saturna, Pimpernel, Bishop Gitonga and Kihoro in that order. In the second season, final BWI was highest in Kerr's Pink followed by Dutch Robyjn while Cangi was third (Fig. 2). In both seasons, the latest clones from the International Potato Centre had the lowest BWI: clones 394905.8 and 387164.4 had the lowest BWI in the second season while

Table 9 Mean response and ranks among 36 potato genotypes for agronomic traits¨ during the second season

GENOTYPE	FINALBWI		DTOW		TTW		TTN		PWTTW		PSTTW		PSTTN	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Sherekea	30.00	18.5	60.00	1.0	63.3	8.5	513575	1.0	28.9	27.0	49.8	22.0	56.2	23.0
394905.8	18.33	1.0	59.61	2.5	51.5	29.0	440374	13.0	14.1	36.0	70.0	36.0	70.6	34.0
387164.4	20.00	2.0	59.61	2.5	**45.5**	36.0	351510	32.0	25.6	29.0	59.7	32.0	61.8	30.0
Roslin Tana	38.33	26.0	56.67	7.5	55.7	22.5	370367	26.0	38.8	12.0	42.7	10.5	49.5	15.0
Pimpernel	26.67	8.5	56.67	7.5	47.7	35.0	286417	36.0	21.1	34.0	60.4	34.0	68.5	33.0
Kerr's Pink	46.67	34.0	56.67	7.5	62.0	11.0	429625	17.0	38.7	13.0	50.7	23.0	57.5	25.5
Tigoni	36.67	23.5	56.67	7.5	53.0	27.0	439502	14.0	19.1	35.0	69.4	35.0	71.6	35.0
Bishop Gitonga	43.33	30.5	56.67	7.5	69.7	3.5	474069	5.0	38.1	14.0	54.0	26.0	54.0	20.0
Annete	23.33	4.0	56.67	7.5	61.0	12.0	454316	8.5	31.2	22.0	56.1	28.0	55.9	22.0
394034.7	23.33	4.0	56.67	7.5	60.7	13.0	459255	6.0	22.0	32.0	54.3	27.0	52.4	18.0
393382.44	36.67	23.5	56.67	7.5	54.0	26.0	345676	34.0	40.8	9.0	40.5	8.0	47.6	10.0
Sterling	40.00	28.5	53.33	16.0	51.3	30.0	353083	30.0	40.0	11.0	40.3	7.0	42.6	3.0
Purple Gold	26.67	8.5	53.33	16.0	59.0	18.0	449378	11.0	29.0	26.0	57.3	29.0	60.5	29.0
Nyayo	30.00	18.5	53.33	16.0	63.3	8.5	451847	10.0	44.1	4.0	46.7	18.0	50.3	16.0
Kihoro	30.00	18.5	53.33	16.0	57.7	19.5	410490	19.0	34.2	17.0	43.5	13.0	46.2	9.0
Kenya Sifa	30.00	18.5	53.33	16.0	69.3	5.0	385181	25.0	60.8	1.0	33.6	2.0	43.2	5.5
Kenya Mpya	46.67	34.0	53.33	16.0	65.7	6.0	488884	4.0	31.4	21.0	47.2	19.0	48.8	13.0
Kenya Mavuno	26.67	8.5	53.33	16.0	63.0	10.0	454316	8.5	28.0	28.0	49.2	21.0	58.0	27.0
Roslin Bvumbwe	33.33	21.0	53.33	16.0	78.0	1.0	490859	3.0	47.0	2.0	34.6	4.0	41.8	2.0
394895.7	35.00	22.0	53.33	16.0	55.3	24.0	330861	35.0	45.9	3.0	38.7	6.0	44.3	7.0
Kenya Karibu	26.67	8.5	50.00	26.5	57.7	19.5	429626	16.0	35.8	15.0	42.7	10.5	47.7	11.0
Romano	28.33	14.0	50.00	26.5	50.3	32.0	370366	27.0	31.1	23.0	44.3	15.0	53.5	19.0
Kenya Baraka	28.33	14.0	50.00	26.5	71.3	2.0	498760	2.0	33.9	19.0	57.5	30.0	57.5	25.5
Ingabire	28.33	14.0	50.00	26.5	59.7	16.0	385675	24.0	43.7	5.0	31.7	1.0	38.0	1.0
Dutch Robyjn	45.00	32.0	50.00	26.5	69.7	3.5	351757	31.0	41.5	8.0	35.3	5.0	44.7	8.0
Desiree	38.33	26.0	50.00	26.5	54.7	25.0	358021	28.5	40.1	10.0	42.9	12.0	48.6	12.0
Cangi	43.33	30.5	50.00	26.5	55.7	22.5	404934	20.5	25.2	30.0	58.5	31.0	57.2	24.0
B53	46.67	34.0	50.00	26.5	64.0	7.0	444440	12.0	32.2	20.0	44.0	14.0	42.9	4.0
396286.6	28.33	14.0	50.00	26.5	48.7	34.0	404934	20.5	23.9	31.0	60.1	33.0	72.9	36.0
394906.6	48.33	36.0	50.00	26.5	56.3	21.0	422218	18.0	34.4	16.0	52.9	25.0	65.8	32.0
394903.3	26.67	8.5	50.00	26.5	50.7	31.0	392589	22.0	30.6	24.0	52.8	24.0	61.9	31.0
393385.57	38.33	26.0	50.00	26.5	60.0	15.0	358021	28.5	43.4	6.0	34.3	3.0	43.2	5.5
Meru	40.00	28.5	46.67	34.0	49.7	33.0	350614	33.0	21.3	33.0	45.8	16.0	52.2	17.0
Asante	26.67	8.5	46.67	34.0	59.3	17.0	434564	15.0	42.3	7.0	46.6	17.0	55.0	21.0
Arka	28.33	14.0	46.67	34.0	52.7	28.0	387650	23.0	34.1	18.0	40.6	9.0	49.3	14.0
394904.17	23.33	4.0	43.33	36.0	60.3	14.0	456785	7.0	29.9	25.0	48.5	20.0	59.8	28.0
Mean			52.66		58.50		411959		34.00		48.50		53.70	
LSD (0.05)			12.49		21.42		159460.80		23.74		23.74		21.85	
SED			6.26		10.74		79952.80		11.90		11.90		10.96	
%CV			14.60		22.80		23.50		42.90		30.20		25.00	

DTOW days to onset of wilting, *FINAL BWI* bacterial wilt incidence at 120 days after planting, *PWTTW* proportion of ware sized tubers (% of total tuber weight in ton ha^{-1}), *TTW* total tuber weight (ton ha^{-1}), *TTN* total tuber number per hectare, *PSTTW* proportion of symptomatic tubers (% of total tuber weight in ton ha^{-1}), *PSTTN* proportion of symptomatic tubers (% of total tuber number per hectare)

clones 396286.6, 394906.6 and 393385.57 had low BWI in the first season. In addition, cultivars Arka and Kenya Baraka had low BWI in the first season (Fig. 1). In the third season, however, final BWI was highest in clone 394895.7 followed by clone 394906.6, then sherekea while Kihoro was fourth (Fig. 3). In the same season, clone 394904.17 had the least

Table 10 Mean response and ranks among 36 potato genotypes for agronomic traits¨ during the third season

GENOTYPE	FINAL BWI		DTOW		PWTTW		PSTTW		TTW		TTN		PSTTN	
	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK
Ingabire	51.0	9.0	60	2.5	62.20	1.0	25.9	5	73.00	1.0	404942	23	20.6	3
Kenya Sifa	25.3	2.0	57	5.0	60.40	2.0	16.7	3	60.67	5.0	394646	26	22.3	4
Kenya Baraka	34.3	4.0	60	2.5	55.60	3.0	11.6	2	66.33	2.0	496485	4	19.8	2
394906.6	87.7	35.0	50	13.5	47.80	4.0	27.7	8	53.67	14.5	426898	19	31.7	11
394034.7	67.3	19.0	53	9.0	46.30	5.0	29.2	9	54.33	12.0	452789	12	36.4	12
393382.44	45.7	7.0	53	9.0	44.00	6.0	31.0	10	47.33	23.5	343090	35	38.3	13
Kenya Karibu	31.3	3.0	67	1.0	43.70	7.0	11.4	1	53.00	17.0	465156	9	14.8	1
393385.57	42.0	6.0	43	20.0	41.70	8.0	25.7	4	54.67	11.0	397541	24	27.9	7
Roslin Bvumbwe	35.7	5.0	40	25.5	39.70	9.0	37.0	15	58.33	8.0	490088	5	41.2	15
394895.7	91.3	36.0	43	20.0	38.40	10.0	35.2	14	49.33	21.0	365827	30	29.6	8
394903.3	68.0	20.0	53	9.0	36.60	11.0	27.5	7	46.67	25.5	394521	27	46.3	20
396286.6	72.3	23.0	47	16.5	33.70	12.5	26.0	6	46.33	27.5	413858	21	31.6	10
Sterling	60.0	12.0	50	13.5	33.70	12.5	53.8	32	47.33	23.5	357842	32	45.8	19
394905.8	83.3	33.0	50	13.5	33.30	14.0	32.7	11	46.67	25.5	427670	18	24.8	6
Annete	63.3	15.5	37	30.0	33.10	15.0	35.0	13	53.67	14.5	473686	8	54.8	29
Kenya Mavuno	78.3	28.0	43	20.0	31.80	16.0	47.8	20	59.33	6.0	456580	11	51.4	26
Nyayo	63.3	15.5	40	25.5	31.40	17.0	49.9	24	41.33	34.0	440923	15	60.6	32
394904.17	22.7	1.0	53	9.0	30.80	18.0	33.9	12	52.67	18.0	443887	14	24.4	5
Romano	69.3	22.0	47	16.5	30.30	19.0	45.3	19	36.67	36.0	375242	29	52.8	27
Asante	61.0	14.0	40	25.5	30.20	20.0	59.0	35	56.00	10.0	459900	10	44	16
Kenya Mpya	65.0	17.0	43	20.0	29.30	21.0	49.5	23	62.00	3.0	511682	3	48.9	21
Kerr's Pink	74.3	24.0	37	30.0	28.80	22.0	42.6	17	53.67	14.5	433481	17	49.3	23
Kihoro	76.3	26.0	33	33.5	27.30	23.0	52.4	30	45.00	29.0	422287	20	69	35
Sherekea	87.3	34.0	50	13.5	26.40	24.0	51.3	26	57.00	9.0	519960	1	40.8	14
Tigoni	58.3	11.0	33	33.5	25.80	25.0	50.9	25	52.00	19.0	514773	2	71.8	36
Arka	60.7	13.0	53	9.0	25.60	26.0	43.6	18	46.33	27.5	396743	25	49.7	24
Desiree	67.0	18.0	43	20.0	25.40	27.0	48.3	21	41.00	35.0	363547	31	44.4	17
B53	82.7	32.0	57	5.0	25.30	28.0	52.2	28.5	53.67	14.5	433996	16	45.7	18
Meru	69.0	21.0	40	25.5	24.70	29.0	39.1	16	43.33	31.5	355682	33	53.3	28
387164.4	53.7	10.0	57	5.0	24.10	30.0	49.0	22	44.00	30.0	344817	34	30.7	9
Roslin Tana	80.7	31.0	33	33.5	24.00	31.0	57.0	34	42.67	33.0	379220	28	49.8	25
Cangi	79.3	29.0	37	30.0	23.90	32.0	52.2	28.5	50.67	20.0	406765	22	49.2	22
Pimoernel	50.7	8.0	40	25.5	23.60	33.0	51.7	27	43.33	31.5	288855	36	64.1	34
Purple Gold	79.7	30.0	33	33.5	22.90	34.0	53.8	31	48.00	22.0	446832	13	62.8	33
Bishop Gitonga	77.3	27.0	40	25.5	21.60	35.0	56.2	33	61.67	4.0	477053	7	60.1	31
Dutch Robyjn	74.7	25.0	30	36.0	19.70	36.0	66.9	36	58.67	7.0	487847	6	58.9	30
Mean	63.6		45.74		33.40		41.1		51.68		424031		43.50	
LSD (0.05)	41.0		13.32		23.53		22.3		16.32		130343.6		20.02	
SED	20.6		6.68		11.80		11.2		8.18		65353.6		10.04	
% CV	39.6		17.90		43.20		33.4		19.40		18.9		28.20	

DTOW days to onset of wilting, *FINAL BWI* bacterial wilt incidence at 120 days after planting, *PWTTW* proportion of ware sized tubers (% of total tuber weight in ton ha^{-1}), *TTW* total tuber weight (ton ha^{-1}), *TTN* total tuber number per hectare, *PSTTW* proportion of symptomatic tubers (% of total tuber weight in ton ha^{-1}), *PSTTN* proportion of symptomatic tubers (% of total tuber number per hectare)

final BWI followed by Kenya Sifa then Kenya Karibu and Kenya Baraka in that order while Roslin Bvumbwe was the fifth. In the third season, many genotypes had higher final BWI than in the first two seasons.

Table 11 Overall ranking of the genotypes in the three seasons

Genotype	First season		Second season		Third season	
	Sum of ranks	Overall rank	Sum of ranks	Overall rank	Sum of ranks	Overall rank
Kenya Baraka	**59.5**	**1**	179	26	21.5	**1**
Tigoni Long	143.5	16				
Kenya Mavuno	104	4	139	13	133.0	14
Sterling	194	30	145.5	14	160.5	22
393385.57	125.5	10	170.5	22	100.5	7
Meru	107	6	201.2	31	220.0	33
394905.8	180	29	201.5	32	129.5	12.5
Kihoro	122.5	8	132	9	224.5	34
394903.3	71	3	193.7	28	134.5	15
394906.6	197.5	31	221.2	34	123.5	9
Nyayo	131.5	12	124.3	8	194.0	28
Kenya Sifa	70	2	113	4	51.0	4
Desiree	105.5	5	170	21	180.5	25.5
Asante	167.5	24	135.5	12	142.0	16.5
Purple Gold	142	15	170.8	23	227.5	35
Sherekea	176	28	134.3	11	142.0	16.5
394034.7	111	7	134.2	10	86.5	6
396286.6	199	33	235	36	129.5	12.5
B53	128.5	11	150.8	17	169.0	23
Kenya Furaha	124.5	9				
Kenya Mpya	172.5	27	146.3	15.5	125.0	10
Saturna	202	34				
Kerr's Pink	145.5	19	171	24	180.5	25.5
Bishop Gitonga	144	17	113.2	5	197.5	29
Arka	158	23	160	18	151.0	20
Roslin Tana	138	14	166.2	20	246.5	36
394904.17	170	25	174	25	85.5	5
Pimpernel	150	21	228	35	219.5	32
Annete	198.5	32	124	7	149.5	19
Ingabire	145	18	107.5	3	47.5	**3**
Dutch Robyjn	172	26	114	6	210.0	31
Tigoni	147	20	197	29	176.0	24
Ngure	204	35				
387164.4	135.5	13	203.5	33	145.0	18
Roslin Bvumbwe	151	22	95.7	1	111.5	8
394895.7	235	36	146.3	15.5	153.0	21
393382.44			164.7	19	128.0	11
Romano			189.8	27	187.0	27
Kenya Karibu			107	2	40.0	**2**
Cangi			198.3	30	205.5	30

Latent Infection

There were significant differences ($P \leq 0.05$) among genotypes for latent infection (chi square=67.72). The mean % LI was higher in the first season than in the other two seasons (Table 6).

Tuber Yield Traits

Genotypes exhibited significant differences ($P \leq 0.05$) in total tuber number per hectare (TTN) and total tuber weight (TTW) (tons ha^{-1}) in the first season (Table 7). Proportion of symptomatic tubers (PSTTN and PSTTW) as well as proportion of

Table 12 Ranking for bacterial wilt resistance in the first season

GENOTYPE	Rank (DTOW)	Rank (PSTTW)	Rank (PSTTN)	Rank (Final BWI)	Rank LI	Average Rank	Overall Rank
Kenya Baraka	1.0	4.0	6.0	5.5	16.5	6.4	**2.0**
Tigoni Long	4.0	21.5	4.0	30.0	4.5	12.6	7.0
Kenya Mavuno	4.0	12.0	3.0	18.0	2.0	11.5	4.0
Sterling	4.0	32.0	32.0	21.5	21.0	22.0	30.0
393385.57	4.0	23.0	9.5	9.5	28.5	14.9	8.0
Meru	4.0	8.0	9.5	24.0	34.5	16.0	9.5
394905.8	7.0	17.0	19.5	23.0	28.5	19.0	14.5
Kihoro	10.0	26.0	29.0	32.5	9.0	21.1	27.0
394903.3	10.0	5.0	7.0	9.5	28.5	12.0	6.0
394906.6	10.0	33.0	33.0	5.5	21.0	20.4	25.5
Nyayo	10.0	9.0	13.0	27.5	21.0	16.0	9.5
Asante	10.0	18.0	34.0	25.5	14.0	20.1	22.5
Desiree	14.5	6.5	5.0	9.5	9.0	8.7	3.0
Kenya Sifa	14.5	2.0	2.0	5.5	4.5	5.5	**1.0**
Purple Gold	14.5	21.5	9.5	21.5	21.0	17.5	11.5
Sherekea	14.5	6.5	30.5	18.0	28.5	19.6	20.5
394034.7	17.0	19.5	19.5	1.0	1.0	11.6	5.0
396286.6	18.0	34.0	36.0	2.0	9.0	19.6	20.5
B53	19.5	31.0	26.0	5.5	14.0	19.0	14.5
Kenya Furaha	19.5	15.0	14.0	18.0	34.5	20.2	24.0
Kenya Mpya	23.5	19.5	21.5	18.0	14.0	19.1	16.5
Saturna	23.5	13.0	23.0	35.0	28.5	24.6	32.5
Kerr's Pink	23.5	11.0	27.5	18.0	21.0	20.1	22.5
Bishop Gitonga	23.5	3.0	24.5	35.0	9.0	18.8	13.0
Arka	23.5	25.0	27.5	3.0	28.5	21.5	29.0
Roslin Tana	23.5	14.0	24.5	13.5	21.0	19.2	18.0
394904.17	30.0	29.0	21.5	13.5	9.0	20.4	25.5
Pimpernel	30.0	27.0	18.0	32.5	16.5	24.6	32.5
Annete	30.0	28.0	35.0	27.5	21.0	28.2	35.0
Ingabire	30.0	10.0	9.5	9.5	28.5	17.5	11.5
Dutch Robyjn	30.0	30.0	17.0	29.0	9.0	22.8	31.0
Tigoni	30.0	24.0	16.0	35.0	3.0	21.4	28.0
Ngure	30.0	36.0	15.0	13.5	34.5	25.8	34.0
387164.4	34.0	**1.0**	**1.0**	31.0	28.5	19.1	16.5
Roslin Bvumbwe	35.5	16.0	12.0	25.5	9.0	19.4	19.0
394895.7	35.5	35.0	30.5	13.5	34.5	29.8	36.0

ware-sized tubers (PWTTW) were not significant. In the second season, all the five characters were not significant. In the third season, only TTN was not significant (Table 7, Table 8). On average, the second season gave the highest yields (TTW) (Table 9) followed by the third season (Table 10) while the first season had the least (Table 8). The PWTTW followed the same trend.

Ranking of Genotypes Based on Various Traits

When ranking was done based on % LI, final BWI, DTOW, TTN, TTW, PWTTW, PSTTW, and PSTTN, the top ten genotypes were Kenya Baraka, Kenya Sifa, clone 394903.3, Kenya Mavuno, Desiree, Meru, clone 394034.7, Kihoro, Kenya Furaha and clone 393385.57 in that order during the first season (Table 11). In the second season, the top ten genotypes were Roslin Bvumbwe, Kenya Karibu, Ingabire, Kenya Sifa, Bishop Gitonga, Dutch Robyjn, Annet, Nyayo, Kihoro and clone 394034.7 in that order (Table 11). In the third season the top ten genotypes were Kenya Baraka, Kenya Karibu, Ingabire, Kenya Sifa, clone 394904.17, clone 394034.7, clone 393385.57, Roslin Bvumbwe, clone 394906.6 and lastly Kenya Mpya (Table 11). Potato genotype resistance to bacterial wilt as determined by ranking based on

Table 13 Ranking for bacterial wilt resistance in the second season

GENOTYPE	DTOW	PSTTW	PSTTN	FINAL BWI	% LI	Average Rank	Overall Rank
Sherekea	1.0	22.0	23.0	18.5	33.33	19.57	16.0
394905.8	2.5	36.0	34.0	1.0	50.00	24.70	30.0
387164.4	2.5	32.0	30.0	2.0	40.00	21.30	20.5
Roslin Tana	7.5	10.5	15.0	26.0	46.67	21.13	19.0
Pimpernel	7.5	34.0	33.0	8.5	40.00	24.6	29.0
Kerr's Pink	7.5	23.0	25.5	34.0	40.00	26.00	33.0
Tigoni	7.5	35.0	35.0	23.5	20.00	24.20	27.5
Bishop Gitonga	7.5	26.0	20.0	30.5	6.67	18.13	11.0
Annete	7.5	28.0	22.0	4.0	20.00	16.30	6.0
394034.7	7.5	27.0	18.0	4.0	26.67	16.63	8.0
393382.44	7.5	8.0	10.0	23.5	46.67	19.13	14.0
Sterling	16.0	7.0	3.0	28.5	20.00	14.90	4.0
Purple Gold	16.0	29.0	29.0	8.5	33.33	23.17	25.0
Nyayo	16.0	18.0	16.0	18.5	33.33	20.37	17.0
Kihoro	16.0	13.0	9.0	18.5	20.00	15.30	5.0
Kenya Sifa	16.0	2.0	5.5	18.5	40.00	16.40	7.0
Kenya Mpya	16.0	19.0	13.0	34.0	33.33	23.07	24.0
Kenya Mavuno	16.0	21.0	27.0	8.5	20.00	18.50	13.0
Roslin Bvumbwe	16.0	4.0	2.0	21.0	46.67	17.93	10.0
394895.7	16.0	6.0	7.0	22.0	33.33	16.87	9.0
Kenya Karibu	26.5	10.5	11.0	8.5	0.00	11.30	**1.0**
Romano	26.5	15.0	19.0	14.0	33.33	21.57	22.0
Kenya Baraka	26.5	30.0	25.5	14.0	60.00	31.20	35.0
Ingabire	26.5	1.0	1.0	14.0	20.00	12.50	**2.0**
Dutch Robyjn	26.5	5.0	8.0	32.0	0.00	14.30	**3.0**
Ddesiree	26.5	12.0	12.0	26.0	30.00	21.30	20.5
Cangi	26.5	31.0	24.0	30.5	13.33	25.07	31.0
B53	26.5	14.0	4.0	34.0	33.33	22.37	23.0
396286.6	26.5	33.0	36.0	14.0	40.00	29.90	34.0
394906.6	26.5	25.0	32.0	36.0	46.67	33.23	36.0
394903.3	26.5	24.0	31.0	8.5	26.67	23.33	26.0
393385.57	26.5	3.0	5.5	26.0	60.00	24.20	27.5
Meru	34.0	16.0	17.0	28.5	6.67	20.43	18.0
Asante	34.0	17.0	21.0	8.5	16.00	19.30	15.0
Arka	34.0	9.0	14.0	14.0	20.00	18.20	12.0
394904.17	36.0	20.0	28.0	4.0	40.00	25.60	32.0

% LI, final BWI, DTOW, PSTTW and PSTTN showed that the five most resistant genotypes were Kenya Sifa, Kenya Baraka, Desiree, Kenya Mavuno and clone 394034.7 in the first season (Table 12). In the second season, the most resistant genotypes were Kenya Karibu, Ingabire, Dutch Robyjn, Sterling and Kihoro in that order (Table 13) while in the third season, the most resistant genotypes were Kenya Karibu, Kenya Baraka, Kenya Sifa, Ingabire and clone 394904.17 in that order (Table 14). When the most resistant genotypes across the seasons were ranked, Kenya Karibu was the most resistant followed by Kenya Sifa while Ingabire was third (Table 15).

Correlations Among Traits

Correlations between DTOW and final BWI were negative and non-significant in the first and second season (Table 16) and negative and significant in the third season (Table 17). Correlations between DTOW and PSTTW and between DTOW and PSTTN were negative and non-significant in the first season and, positive and non-significant in the second season (Table 16). The same applied to correlations between final BWI and PSTTW and between final BWI and PSTTN (Table 16). Correlation between DTOW and PSTTW was

Table 14 Ranking for bacterial wilt resistance in the third season

GENOTYPE	DTOW	PSTTW	PSTTN	FINAL BWI	% LI	Average Rank	Overall Rank
Ingabire	2.5	5	3	9.0	3.0	4.5	4
Kenya Sifa	5.0	3	4	2.0	4.0	3.6	**3**
Kenya Baraka	2.5	2	2	4.0	2.0	2.5	**2**
394906.6	13.5	8	11	35.0	18.5	17.2	14
394034.7	9.0	9	12	19.0	8.5	11.5	7.5
393382.44	9.0	10	13	7.0	24.5	12.7	9
Kenya Karibu	1.0	1	1	3.0	1.0	1.4	**1**
393385.57	20.0	4	7	6.0	20.5	11.5	7.5
Roslin Bvumbwe	25.5	15	15	5.0	29.0	17.9	16
394895.7	20.0	14	8	36.0	14.0	18.4	17
394903.3	9.0	7	20	20.0	15.0	14.2	11
396286.6	16.5	6	10	23.0	13.0	13.7	10
Sterling	13.5	32	19	12.0	16.0	18.5	18
394905.8	13.5	11	6	33.0	8.5	14.4	12
Annete	30.0	13	29	15.5	24.5	22.4	25
Kenya Mavuno	20.0	20	26	28.0	6.0	20	20
Nyayo	25.5	24	32	15.5	31.0	25.6	29
394904.17	9.0	12	5	1.0	8.5	7.1	5
Romano	16.5	19	27	22.0	18.5	20.6	22
Asante	25.5	35	16	14.0	11.5	20.4	21
Kenya Mpya	20.0	23	21	17.0	17.0	19.6	19
Kerr's Pink	30.0	17	23	24.0	33.0	25.4	28
Kihoro	33.5	30	35	26.0	28.0	30.5	33
Sherekea	13.5	26	14	34.0	20.5	21.6	23
Tigoni	33.5	25	36	11.0	24.5	26	30
Arka	9.0	18	24	13.0	8.5	14.5	13
Desiree	20.0	21	17	18.0	11.5	17.5	15
B53	5.0	28.5	18	32.0	27.0	22.1	24
Meru	25.5	16	28	21.0	36.0	25.3	27
387164.4	5.0	22	9	10.0	5.0	10.2	6
Roslin Tana	33.5	34	25	31.0	31.0	30.9	34
Cangi	30.0	28.5	22	29.0	22.0	26.3	31
Pimpernel	25.5	27	34	8.0	24.5	23.8	26
Purple Gold	33.5	31	33	30.0	31.0	31.7	35
Bishop Gitonga	25.5	33	31	27.0	35.0	30.3	32
Dutch Robyjn	36.0	36	30	25.0	34.0	32.2	36

negative and significant in the third season (Table 17). Correlation between % LI and all the other traits were positive and non-significant in the first two seasons. In the third season, correlation between % LI and DTOW was negative and significant while between % LI and final BWI, was positive and significant (Table 17). From the evaluations eight potato genotypes were selected to be used as pollen donors (males) in subsequent crossing. These are Meru, Ingabire, Kenya Karibu, Sherekea, Kihoro, Tigoni, Bishop Gitonga and Cangi. The choice of these genotypes was also determined by pollen production (a good male needs to produce a lot of pollen), and popularity of the genotype with the Kenyan farmers.

Discussion

The high soil bacterial count at 60 days after planting was probably due to the fact that this coincided with periods of high rainfall. The aggressiveness of the pathogen is affected mainly by temperature and moisture; high temperature and high soil moisture promote survival, reproduction, infectivity,

Table 15 Overall ranks of the most resistant potato genotypes across the three seasons at KARI Kabete

Genotype	Ave. Ranks				
	Season 1	Season 2	Season 3	Ave rank	Overall Rank
Kenya Sifa	5.5	16.4	3.6	8.50	2
Kenya Baraka	6.4	31.2	2.5	13.37	5
Desiree	8.7	21.3	17.5	15.83	6
Kenya Mavuno	11.5	18.5	20	16.67	7
394034.7	11.6	16.63	11.5	13.24	4
Kenya Karibu		11.3	1.4	6.35	1
Ingabire	17.5	12.5	4.5	11.50	3
Dutch	22.8	14.3	32.2	23.10	11
sterling	22	14.9	18.5	18.47	9
Kihoro	21.1	15.3	30.5	22.30	10
394904.17	20.4	25.6	7.1	17.70	8

and spread of the bacterium, and hence disease development (Harris 1976; Martin and French 1985). This high soil bacterial population combined with the vigorous vegetative plant growth probably led to the rapid increase in the disease incidence (number of wilting plants) in the field (Figs. 1, 2 and 3). At around flowering time, the plants' water demand is very high and they wilt rapidly due to the blockage of the xylem tissue by the bacterial mass. In addition, due to high transpiration rates, the plants take up a lot of water (together with bacteria in the soil water) and hence wilt rapidly. The higher soil bacterial population in the third season compared to the other two seasons could be due to accumulation of bacterial population in the soil over time (the same piece of land was used for three consecutive seasons), the high temperature and rainfall experienced in that period (Table 2) or a combination of all. Although the soil bacterial population was higher in the second season than in the first season, final BWI was higher in the first season. This is most likely due to lower temperatures experienced

Table 16 Pearson correlation coefficients for various agronomic traits for 36 genotypes during season I (top diagonal) and season II (bottom diagonal)

Trait	% LI	DTOW	FINAL BWI	PSTTN	PSTTW	PWTTW	TTN	TTW
% LI	1	0.037 ns	0.062 ns	0.048 ns	0.063 ns	−0.082 ns	0.181 ns	0.071 ns
DTOW	0.210 ns	1	−0.146 ns	−0.121 ns	−0.153 ns	0.052 ns	0.015 ns	−0.220*
FINAL BWI	−0.108 ns	−0.025 ns	1	−0.086 ns	−0.180 ns	0.083 ns	0.170 ns	0.157 ns
PSTTN	0.175 ns	0.129 ns	0.135 ns	1	0.424*	0.004 ns	−0.393*	−0.296*
PSTTW	0.095 ns	0.187 ns	0.100 ns	0.939*	1	−0.175 ns	−0.357*	−0.128 ns
PWTTW	0.071 ns	−0.080 ns	−0.015 ns	−0.767*	−0.833*	1	0.066 ns	0.234*
TTN	0.041 ns	0.030 ns	−0.006 ns	−0.032 ns	0.006 ns	0.074 ns	1	0.743*
TTW	0.029 ns	−0.041 ns	0.137 ns	−0.359*	−0.372*	0.524*	0.708*	1

% LI % latent infection, *DTOW* days to onset of wilting, *FINAL BWI* bacterial wilt incidence at 120 days after planting, *TTN* total tuber number per hectare, *PSTTN* percent of symptomatic tubers (% of total tuber number per hectare), *TTW* total tuber weight (ton ha^{-1}), *PSTTW* percent of symptomatic tubers (% of total tuber weight in ton ha^{-1}), *PWTTW* percent of ware sized tubers (% of total tuber weight in ton ha^{-1})

*=significant at $P \leq 0.05$

Table 17 Pearson correlation coefficients for various agronomic traits for 36 genotypes during the third season

Trait	% LI	DTOW	FINAL BWI	PSTTN	PSTTW	PWTTW	TTN	TTW
% LI	1							
DTOW	−0.654*	1						
FINAL BWI	0.455*	−0.433*	1					
PSTTN	0.524*	−0.609*	0.531*	1				
PSTTW	0.473*	−0.478*	0.241 ns	0.291 ns	1			
PWTTW	−0.428*	0.325 ns	−0.169 ns	−0.223 ns	−0.387*	1		
TTN	−0.009 ns	0.108 ns	−0.122 ns	−0.370*	0.222 ns	0.196 ns	1	
TTW	−0.184 ns	0.221 ns	−0.270 ns	−0.477*	−0.016 ns	0.571*	0.713*	1

% LI % latent infection, *DTOW* days to onset of wilting, *FINAL BWI* bacterial wilt incidence at 120 days after planting, *TTN* total tuber number per hectare, *PSTTN* percent of symptomatic tubers (% of total tuber number per hectare), *TTW* total tuber weight (ton ha^{-1}), *PSTTW* percent of symptomatic tubers (% of total tuber weight in ton ha^{-1}), *PWTTW* percent of ware sized tubers (% of total tuber weight in ton ha^{-1})

*=significant at $P \leq 0.05$

during the second season compared to the first season (Table 2). Disease expression in the field is favoured by high temperatures (Hayward 1991; French 1994; EPPO 2004). The high total tuber weight (TTW) in the second season was likely due to the heavy rainfall and lower temperatures experienced in that season. The heavy rains and cool conditions favoured crop growth because potato is a cool season crop. These conditions also led to the high PWTTW and TTN.

In terms of resistance, the genotypes ranked differently in all the seasons (Table 12, 13 and 14). This could be due to differences in weather among the seasons especially with regards to temperature and rainfall. Resistance to *R. solanacearum* available in *Solanum tuberosum* originated mainly from the cultivated diploid, *Solanum phureja* (Martin and French 1985). This resistance is very unstable due to strong host-pathogen-environment interaction; hosts resistant to the disease in 1 year/environment or location may succumb to the disease in the other year/environment or location (French and Lindo 1982; Tung et al. 1990, 1992b, 2006; Tung 1992). Previously, varieties Kenya Dhamana (CIP-800228), Kenya Sifa, Kenya Karibu, Mauritius clone (89016), and Cruza-148 (CIP-720118) were rated as resistant to bacterial wilt, while varieties Asante (CIP-381381.20), Tigoni (CIP-381381.13), Nyayo, and Dutch Robyjin were highly susceptible (Ateka et al. 2001). In a later study it was found that Kenya Sifa and Kenya Karibu were the most resistant to bacterial wilt while Dutch Robjyn and Tigoni were the most susceptible (Felix et al. 2010). The present study found Kenya Karibu to be the most resistant followed by Kenya Sifa while Ingabire was third. The negative correlation between final BWI and DTOW means that genotypes that took long before onset of wilting had a lower final BWI. Correlation between latent infection and all the other traits was not consistent. According to some reports, *R. solanacearum* expresses different sets of genes during latent infection and during symptomatic disease development (Jill et al., 2004).

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