Plant Pathology Journal

ISSN 1812-5387

science alert

ANSInet
an open access publisher
http://ansinet.com

Plant Pathology Journal 9 (3): 122-128, 2010
ISSN 1812-5387

Assessment of Irish Potato Cultivars' Field Tolerance to Bacterial wilt (*Ralstonia solanacearum*) in Kenya

[1]R. Felix, [1]O.J. Onyango and [2]O.M. Eliazer
[1]Department of Seed, Crop and Horticultural Sciences, Moi University, P.O. Box 1125-30100, Eldoret, Kenya
[2]School of Agriculture and Biotechnology, Kabianga University College, P.O. Box 1, Kabianga, Kenya

Abstract: Bacterial wilt (*Ralstonia solanacearum*) is the second most important biotic constraint to potato production after late blight in Kenya. The study was conducted to asses Irish potato cultivars' tolerance to bacterial wilt. Determination of potato reaction to bacterial wilt was carried out in fields infested with *R. solanacearum* in two sites in Kenya using five cultivars; Tigoni (CIP-381381.13), Asante (CIP-381381.20), Kenya Karibu, Kenya Sifa and Dutch Robjyn were used. The experiment was laid out as a randomized complete block design. Disease related data were then recorded during the study period. Tubers from plants that appeared healthy during the study period were sampled and tested for latent infection using the enzyme linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA). Data was subjected to analysis of variance and t-test. Subsequently, potato tolerance to bacterial wilt was determined by use of a regression model and ranking. None of the potato cultivars was found to be tolerant to bacterial wilt but some cultivars showed some level of tolerance. Reaction of potato cultivars' to bacterial wilt was variable in the two environments and even within the same environment. The cultivars Kenya Sifa was the most tolerant while Dutch Robjyn was the most intolerant. The use of these tolerant cultivars together with other control strategies could alleviate the disease problem significantly.

Key words: Regression, tolerant, *Solanum tuberosum,* latent infection

INTRODUCTION

Irish potato (*Solanum tuberosum*) ranks the second most important food crop after maize in Kenya (Guyton *et al*., 1994). The crop plays an important role as a staple food and the main source of income for low-income families. However, the yields are low averaging six to seven tonnes per hectare against the country's potential of 16 to 20 t ha^{-1} (MoA, 1998). Among the leading causes of the low yields are the lack of clean seed and its high price (Kinyua *et al*., 2001), land and food constraints resulting to intensified potato cultivation without crop rotation. This farming system leads to increased disease and pest build up and consequently low yields and poor quality tubers. Among the diseases attacking potato include bacterial wilt caused by *Ralstonia solanacearum* which is the second most important biotic constraint to potato production after late blight (Barton *et al*., 1997). Yield losses in Kenya due to bacterial wilt are estimated to be as high as 50% in ware and 75% in seed potato (Ajanga, 1993).

Bacterial wilt in Irish potatoes is basically caused by race 3 biovar 2 of *R. solanacearum*. This race has a narrow host range and can be successfully controlled by Integrated Disease Management (IDM). Among the important component of IDM is the use of disease tolerant cultivars (French *et al*., 1998). The use of tolerant cultivars can have a huge impact on ware potato production in areas where soils are highly infested with the pathogen if bacterial wilt-free seed can be provided (French *et al*., 1998). However, there are no known Irish potato cultivars that are resistant to bacterial wilt. Some 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, 1996). Breeding programmes to determine tolerant Irish potato cultivars have been 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). Some cultivars have been reported to exhibit variable reactions in different environments and in different seasons within the same environment (French, 1994). This study was therefore carried out to determine the reaction of selected Irish potato cultivars to bacterial wilt in two different agro-ecological zones in Kenya considering differences in the environment, soils and altitude.

Corresponding Author: Rotich Felix, Department of Seed, Crop and Horticultural Sciences, Moi University, P.O. Box 1125-30100, Eldoret, Kenya

MATERIALS AND METHODS

Experimental sites: The experiments were conducted in two locations, Kenya Agricultural Research Institute (KARI), Kitale and National Research Laboratories (NARL)-Nairobi, Kenya. The experiments were conducted during October to December 2007 in Nairobi and may to July, 2008 in Kitale.

Kitale is located 1890 metres above sea level (masl), with mean annual rainfall of 1143 mm and mean temperatures range from 9.05 to 26.85°C. Soils are classified as sandy clay loam. Nairobi is located 1737 masl, mean annual rainfall of 1295 mm and mean temperature range from 13.25 to 22.88°C. The soils here are classified as sandy loam.

The fields were naturally infested with *R. solanacearum* race 3 biovar 2A. At planting determination of *R. solanacearum* soil bacterial population was done using plate dilution technique (Englebrecht, 1994) at NARL-Nairobi laboratories. The mean *R. solanacearum* soil inoculum levels in the experimental fields was 1.6×10^5 and 2.14×10^5 bacteria per gram of soil in Nairobi and Kitale fields, respectively.

The experiment was established as a Randomized Complete Block Design with four replications. Planting was done on ridges spaced 75 cm apart with intra row spacing of 30 cm. 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. Once planted the crop was left for natural disease infestation to take place. Cultural practices, control of pests and diseases was carried out as necessary.

Planting materials. The Irish potato cultivars used were Tigoni (Potato International Centre-CIP 381381.13), Asante (CIP 381381.20), Kenya Sifa, Kenya Karibu and Dutch Robjyn (Golof). Tigoni, Asante Kenya Sifa and Kenya Karibu are CIP crosses selected in Kenya (Lungaho *et al*., 2006). The latter two cultivars are new and are documented to be superior than earlier varieties in terms of yield and tolerance to late blight (Lungaho *et al*., 2006), while Dutch robjyn is the oldest cultivar in Kenya. Clean seed tubers were sourced from KARI- Tigoni.

Data scored and statistical analysis. Upon emergence, the crop was monitored weekly for wilt symptoms. Plants were considered wilted when they showed 50% or complete wilting. Final wilt incidence for each variety was calculated as a percentage of the total number of emerged plants. The days to onset of wilting (DTOW) from the day of emergence and the days taken by infected plants to complete wilting (DTCW) upon development of wilt symptoms were recorded. Harvesting of tubers was done when 75% of the plants had reached senescence. Weights of the different qualities of tubers namely visibly infected and showing rotting or bacterial ooze in the tuber buds; ware (>45 mm diameter); seed (35-45 mm diameter) and the small (<35 mm diameter) were recorded separately at harvest. Weights of visibly infected and ware size tubers were expressed as a percentage of the total yield for each cultivar to give the proportion of the visibly infected (PVIT) and ware size tubers (PWT), respectively.

Tubers from plants not showing visible bacterial wilt symptoms during the experiment were sampled for testing latent infection (Priou *et al*., 1999). Latent Infection (LI) was tested by use of the enzyme linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA) kit developed and distributed by CIP.

ANOVA was performed on bacteria soil counts. Incidence, DTOW, DTCW, PVIT and PWT values were analysed using the additive main-effects and multiplicative interaction (AMMI) model (Gauch-Jnr, 2006) of the Genstat discovery edition (GenStat, 2003). Means were compared using the Least Significance Difference (LSD) ($p = 0.05$). Data on latent infection level were subjected to t-test.

Potato variety tolerance to bacterial wilt was subsequently determined using two methods; the ranking (Harahagazwe and Nzoyihera, 2000) with modification and the regression model (Van der Plank, 1963) modified by Arneson (2006) and Neher and Campbell (1992). In the regression model the independent variable was taken to be PWT because it is the variable that is mostly affected by the disease and hence would give the best indication of tolerance to disease. The dependent variables were DTCW, DTOW, incidence (Incid) and PVIT. In the ranking method, the mean values of DTCW, DTOW, Incid., PVIT, PWT and the latent infection (LI) levels were used to rank cultivars according to their tolerance.

RESULTS

Reactions of potato to bacterial wilt. Cultivars were significantly different ($p = 0.012$) in wilt incidence. Across environments the cultivar Dutch-Robjyn had the highest wilt incidence averaged at 62% with the lowest being the cultivar Kenya Karibu at 40% (Table 1). Environments were not significantly different ($p = 0.17$). There was a significant environment by cultivar interaction ($p = 0.006$).

Across environments, cultivars showed significant difference ($p = 0.045$) in DTOW. The cultivar Kenya Sifa took the longest time (49 days) while Dutch-Robjyn took the shortest time (41 days) to show wilt symptoms after emergence. Overall, cultivars took 14 days longer to show wilt symptoms in Kitale compared to Nairobi ($p<0.001$).

Table 1: Reactions of potato varieties in Kitale and Nairobi as evaluated using various variables: Incidence, DTOW, DTCW, PVIT and PWT. Values represent means

Cultivar	Incidence (%)	DTOW^{DAE1}	DTCW^{DAE}	PVIT	PWT
Dutch-Robjyn	61.64a[2]	40.65b	15.53b	51.08a	22.53b
Kenya Sifa	46.74b	48.64a	16.79ab	19.94c	48.37a
Asante	46.21b	41.80b	19.07ab	32.30bc	49.55a
Tigoni	43.86b	41.05b	15.53b	38.19ab	45.81a
Kenya Karibu	40.46b	44.25ab	20.24a	46.59a	26.54b
LSD (0.05)	11.78	5.70	3.82	13.60	16.84
Environment					
Kitale	54.43a	50.44a	19.67a	49.12a	29.13a
Nairobi	41.13b	36.12b	15.49b	26.12b	48.00b
LSD (0.05)	7.45	3.60	2.42	8.60	10.65

DAE: Days after emergence. Means followed by the same letter in a column are not significantly different (p = 0.05) according to LSD test

There was a significant environment by cultivar interaction (P = 0.014) in the days plants' DTOW. The cultivar Kenya Karibu took the longest time (20 days) (DTCW) upon development of wilt symptoms while Tigoni took the shortest time (16 days) (Table 1). However, cultivars did not vary significantly (p = 0.087) in the days infected plants' DTCW across environments.

There were significant (p = 0.005) differences in the PVIT between the cultivars in Kitale. The cultivar Kenya Karibu had the highest PVIT (70.0%) while Kenya Sifa had the least PVIT (22.7%). PVIT at Nairobi did not differ significantly (p = 0.096) between cultivars. Kitale had higher PVIT (49.2%) compared to Nairobi, which had 26.1% (Table 1). Overall there was a high significant difference (p<0.001) between cultivars in the PVIT across environments. The cultivar Dutch Robjyn had the highest PVIT (51.1%), while Kenya sifa had the lowest PVIT (19.94%) (Table 1). There was a significant interaction (p = 0.043) between environments and cultivars in the PVIT.

Cultivars were significantly different (p = 0.004) in the PWT obtained. The cultivar Asante had the highest PWT at 49.5%, while Dutch Robjyn had the lowest PWT at 22.5% (Table 1). Environments were also highly significant in the PWT (p<0.001). Nairobi had the highest amount of ware sized tubers at 48.0% against that of Kitale which had 29.1% of total yield as ware sized tubers. No interaction was observed between cultivars and environments on the PWT harvested.

Tuber latent infection. In spite of the high bacterial wilt incidence, latently infected tubers were found with high frequency in both Nairobi and Kitale. Latent infection levels in both Nairobi and Kitale ranged from 0% to 23%. Tuber samples from Nairobi for the cultivars Kenya Karibu and Dutch Robjyn tested negative for *R. solanacearum*. By the Tukeys student's t-test procedure, cultivars across environments did not differ significantly (p = 0.795) in their latent infection levels.

Table 2: Tolerance levels of potato varieties as derived from multiple regression model using various variables. PWT was used as the independent variable

Cultivar	Constant	DTCW	DTOW	Incid	PVIT	Total	Rank
K. Sifa	110.9	14.990	27.968	6.445	13.333	87.800	1
Asante	110.9	17.494	24.035	6.376	21.641	97.388	2
K.Karibu	110.9	17.973	25.444	5.589	31.222	104.294	3
Tigoni	110.9	13.791	23.604	6.058	25.594	105.158	4
D.Robjyn	110.9	14.457	23.374	8.501	34.237	115.808	5

Table 3: Potato varieties ranked according to their performance using several variables scored in the experiment: DTCW, DTOW, Incid, LI. (latent infection) PVIT and PWT

Cultivar	DTCW	DTOW	Incid.	LI	PVIT	PWT	Rank
K.Sifa	3	1	4	5	1	2	2
Asante	2	4	3	4	2	1	2
K.Karibu	1	2	1	2	3	4	1
Tigoni	4	3	2	3	4	3	4
D.Robjyn	4	5	5	1	5	5	5

Evaluation of potato tolerance to bacterial wilt. PWT was highly correlated negatively with DTOW (-0.769) and DTCW (-0.764). PWT was only slightly correlated with disease incidence (-0.413) but it had no correlation with PVIT.

A highly significant regression (p<0.001) was obtained when PWT was regressed against DTOW, DTCW, incidence and PVIT. These variables accounted for 62% of the variation in the curve obtained. When variety was included in the model the function accounted for 67% of the variation, although this inclusion did not bring about significant change (p = 0.072). Therefore, cultivar was left out of the model. Disease incidence (p = 0.256) and DTCW (p = 0.088) did not contribute significantly to the model. However they were retained in the model because physiologically the two are indicators of disease tolerance of a cultivar and signs of their coefficient changed to reflect this in the computations for disease tolerance.

Using the regression model Kenya Sifa was found to be the most tolerant cultivar followed by Asante but Tigoni and Dutch Robjyn were the least tolerant to bacterial wilt (Table 2).

However, using the ranking method the cultivar Kenya Karibu was rated as the most tolerant and Kenya Sifa as the second most tolerant while Dutch Robjyn remained the most susceptible cultivar to bacterial wilt disease (Table 3).

The ranking and the multiple regression methods found the cultivars Kenya Sifa and Kenya Karibu to be the most tolerant cultivars to bacterial wilt. Asante ranked as the second most tolerant cultivar while, Dutch Robjyn was the most susceptible followed by the cultivar Tigoni.

DISCUSSION

None of the five potato cultivars used in this study was found to be resistant to bacterial wilt. Reactions of potato to bacterial wilt varied from cultivar to cultivar and

from environment to environment and even within environments. Variation in potato reaction between environments showed the strong interaction between *R. solanacearum* and the environment. The interaction was exhibited in incidences, days to onset of wilting, days to complete wilting of infected plants, the proportion of visibly infected tubers and the proportion of ware tubers obtained. This is in agreement with previous observations that potato cultivars exhibit variable reaction to bacterial wilt in different environments or even within environments (French, 1994). Apart from cultivar differences, the different reactions exhibited by potatoes between environments could be due to both abiotic (temperature, pH, soil moisture content and soil type) and biotic factors (presence and activity of grazing protozoa and of antagonistic or competing organisms). The extent to which these factors affect survival of the pathogen can vary and the ultimate effect depends on the physiological and physical requirements for survival of the different bacterial types in the soil habitat, as well as on the interactions between the various factors acting on the habitat (Van Elsas *et al*., 2000).

Temperature conditions for the two environments during the study period did not vary widely. At the same time *R. solanacearum* soil inoculum counts in both environments did not vary significantly. Therefore other factors must have had a role in determining the reaction of the different potato cultivars to bacterial wilt. Nairobi received much lower rain compared to Kitale. The Kitale site showed higher disease incidence, days to complete wilting were shorter, higher proportions of visibly infected tubers and lower proportions of ware size tubers. All these were indicators of greater disease severity in Kitale compared to Nairobi, which could be attributed to higher soil moisture. High soil moisture and periods of wet weather are associated with high disease incidence and severity (Nesmith and Jenkins, 1985). This is because soil moisture is an important factor in the regulation of the *R. solanacearum* biovar 2 populations (Van Elsas *et al*., 2005). Low soil moisture conditions lead to reduced *R. solanacearum* populations in the soil. *Ralstonia solanacearum* is taken up and distributed throughout the plant with water necessitated by the transpiration flow. Hence, greater disease severity observed where there were high rains as the crop took up more of the pathogen load.

Soil types were different in the two environments, Kitale with sandy clay loams while Nairobi with sandy loams. Soil temperature and soil type have been indicated to play a role in the survival of *R. solanacearum* in the soil habitat (Van Elsas *et al*., 2000).

Ralstonia solanacearum biovar 2A found in both environments has a high temperature optimum of 27°C. The pathogen has been found to be most severe between the temperatures of 24 to 35°C and decreases in virulence when temperatures exceed 35°C or fall below 10°C (Stansbury *et al*., 2001). The temperatures in the study sites were near optimum which could have led to the high disease severity experienced in this study.

According to results obtained in this experiment infected plants took between 16 to 20 days to wilt completely upon development of wilt symptoms. Cultivar versus environment interaction was not significant in this factor but cultivar differences were observed. This means that environment may not play a role in the length of time plants survive upon infection. This has great implications on plants that are infected early in their growth stages in that when infected early, yields will be drastically reduced. The longer it takes plants to be infected by *R. solanacearum* is a better indicator of higher tolerance to the disease.

Latent infection results revealed that some of the plants that appeared healthy carried the disease and that these plants were able to tolerate development of visible bacterial wilt symptoms. Crop's tolerance to the expression of visible bacterial wilt symptoms but carrying the disease latently is unsafe as it helps to spread the disease with seemingly healthy material (Hayward, 1991). This constitutes the main path for international spread of the bacterial wilt pathogen. In all the tested cultivars, latent infections were encountered. The high incidence of latently infected tubers could be due to either unfavourable weather conditions, partly tolerant cultivars or low aggressiveness of the pathogen strain (Hayward, 1991). However, cultivars in the two environments did not differ significantly in their latent infection levels meaning that latent infection occurs regardless of the prevailing environmental conditions. Alternately, this finding could be suggesting that the two environments were the same in providing conditions conducive for latent infection development. Tubers of tolerant potato plants have been found to be less likely to be latently infected (Jill *et al*., 2004). This suggests that plant host resistance affects frequency of latent infection. However in most cases the cultivar may be susceptible but the disease remains unexpressed because of low temperature, as experienced at high altitudes in the tropics. Symptoms start to develop later on when harvested tubers are incubated at temperatures that favour disease expression (Graham *et al*., 1979; Nyangeri *et al*., 1984). Another theory advanced towards

understanding the biology of latency lie in the pathogen's gene expression. *Ralstonia solanacearum* is said to express a subset of genes specifically during wilt disease development (Brown and Allen, 2004). *In vivo* expression technology or microarray analysis has been used to show that different set of genes are expressed during latent infection than during symptomatic disease (Jill *et al*., 2004). On the other side of interaction, measuring expression of plant defense genes could reveal whether *R. solanacearum* living latently in plants trigger host defense responses (Jill *et al*., 2004).

The development and spread of plant diseases have been explained by mathematical models since (Van derPlank, 1963) and these functions emphasized the increase in inoculum levels. Logistic regression models have been used severally to explain growth and development in organisms. It has also been used to explain the seed germination process (Ochuodho and Modi, 2006), elucidate epidemiological framework for disease management (Gilligan, 2002) and temporal aspects of epidemiology (Arneson, 2006). Logistics models treat the classification variables (i.e., disease related data) as predictors rather than response variables (Cooke *et al*., 2006). However, it has been explained that the use of logistic models when maximum disease intensity is less than 100% leads to underestimation of rate of spread (Neher and Campbell, 1992). In this study multiple regressions was employed to determine potato plant performance indices that best explain tolerance to bacterial wilt. The result obtained agreed with the views of the breeders that the cultivar Tigoni is the most susceptible. Interestingly, percent disease incidence and days to complete wilting did not have a significant influence on cultivar tolerance to the disease. This suggests that any intervention in the control of bacterial wilt should be aimed at prolonging the days to onset of wilting. Recently other aspects of host reaction to pathogens have been used to quantify and qualify tolerance. The host plant reacts to pathogen invasion and disease establishment by limiting the size of necrotic spots and increasing activity of enzymes such as Hydrogen peroxide, phenylalanine, ammonia, lyase, chitinase, β-1, 3-glucanases, peroxidase and polyphenol oxidase in tolerant varieties (Sreeramanan *et al*., 2006).

Scientists have evaluated plant or seedling performance using several variables in order to determine tolerance or intolerance of genotypes against biotic or abiotic stress. In order to determine salinity tolerance levels of melon genotypes, seven seedling performance indices were used to rank the varieties (Ensoy *et al*., 2005). Elsewhere, when screening potato genotypes against bacterial wilt, varieties were ranked using only percent wilted plants, rotten tubers and marketable tubers (Harahagazwe and Nzoyihera, 2000). In this study, six variables were used to rank potato cultivars according to their reaction to bacterial wilt disease.

The two methods used to determine potato cultivar tolerance to bacterial wilt found the cultivars Kenya Sifa and Kenya Karibu to be the most tolerant to bacterial wilt, while Dutch Robjyn and Tigoni were the most susceptible. These findings agree with those (Ateka *et al*., 2001) who observed that cultivars Tigoni and Asante were highly intolerant to bacterial wilt. Tigoni was bred to tolerate late blight (Lungaho *et al*., 2006) but seem to lack tolerance to bacterial wilt. Dutch robjyn is the oldest variety in the country and has no tolerance to bacterial wilt. Kenya Sifa and Kenya Karibu are Potato International Centre (CIP) crosses selected in Kenya with improved resistance to late blight compared to Tigoni and Asante (Lungaho *et al*., 2006). The absence of potato tolerance to bacterial wilt could be attributed to the high genetic variability of strains within the *R. solanacearum* species complex (Hartman and Elphinstone, 1994).

ACKNOWLEDGMENTS

The authors would like to thank the Moi University Graduate Studies, Research and Extension Committee who partially funded this work through their University grant No. MU/GSREC/SAB/2/2008. The following KARI staff, Dr. Z. M. Kinyua, Dr. Kabira, T. Kwambai and J. Kinoti are highly thanked for their contributions towards the success of this work.

REFERENCES

Ajanga, S., 1993. Status of Bacterial Wilt in Kenya. In: Bacterial Wilt, Hartman, G.L. and A.C. Hayward (Eds.). ACIAR, Kaohsiung, Taiwan, pp: 338-340.

Arneson, P.A., 2006. Plant disease epidemiology: temporal aspects. Plant Health Instructor. 10.1094/PHI-A-2001-0524-01

Ateka, E.M., A.W. MwangOmbe and J.W. Kimenju, 2001. Reaction of potato cultivars to *Ralstonia solanacearum* in Kenya. Africa Crop Sci. J., 9: 251-256.

Barton, D., J.J. Smith and Z.M. Kinyua, 1997. Socio-economic inputs to biological control of bacterial wilt disease of potato in Kenya. ODA RNRRS Crop Protection Project ZA0085, United Kingdom.

Brown, D.G. and C. Allen, 2004. *Ralstonia solanacearum* genes induced during growth in tomato: An inside view of bacterial wilt. Mol. Microbiol., 53: 1641-1660.

Cooke, B.M., D. Gareth-Jones and B. Kaye, 2006. The Epidemiology of Plant Diseases. 2nd Edn., Springer, The Netherlands.

Englebrecht, M.C., 1994. Modification of a Semi-Selective Medium for the Isolation and Quantification of *Pseudomonas solanacearum*. In: Bacterial Wilt Newsletter, Hayward, A.C. (Ed.). Australian Center for International Agricultural Research, Canberra, Australia.

Ensoy, S., O. Turkmen, T. Kabay, C. Erd nc, M. Turan and M. Yildiz, 2005. Determination of salinity tolerance levels of melon genotypes collected from lake van basin. J. Biological Sci., 5: 637-642.

French, E.R., 1994. Strategies for Integrated Control of Bacterial Wilt of Potatoes. In: Bacterial Wilt: The Disease and its Causative Agent, *Pseudomonas solanacearum*, Hayward, A.C. and G.L. Hartman (Eds.). CAB International, Wallingford, Oxon, UK.

French, E.R., 1996. Integrated Control of Bacterial Wilt of Potato. International Potato Center, Lima, Peru.

French, E. R., R. Anguiz and P. Alley, 1998. The Usefulness of Potato Resistance to *Ralstonia solanacearum* for the Integrated Control of Bacterial Wilt. In: Bacterial Wilt Disease: Molecular and Ecological Aspects, Prior, P.C., C. Allen and J. Ephinstone (Eds.). INRA, Springer Verlag, Berlin, Germany, pp: 381-385.

Gauch-Jnr, H.G., 2006. Statistical analysis of yield trials by AMMI and GGE. Crop Sci., 46: 1488-1500.

GenStat, 2003. Genstat for Windows. VSN International Ltd., Hemel Hempstead, UK.

Gilligan, C.A., 2002. An epidemiological framework for disease management. Adv. Botanical Res., 38: 1-64.

Graham, J., D.A. Jones and A.B. Lloyd, 1979. Survival of *Pseudomonas solanacearum* race 3 in plant debris and in latently infected potato tubers. Phytopathology, 69: 80-82.

Guyton, B., F. Sogo, J. Mogire and R. Njuguna, 1994. Kenya Irish potato sub sector characteristics performance and participant's information needs. Government of Kenya Market Information System Report No. 94-01, Ministry of Agriculture, Nairobi.

Harahagazwe, D. and Z. Nzoyihera, 2000. Field screening of potato genotypes for resistance/tolerance to bacterial wilt. PRAPACE Final Report.

Hartman, G.L. and J.G. Elphinstone, 1994. Advances in the Control of *Pseudomonas solanacearum* Race 1 in Major Food Crops. In: Bacterial Wilt: The Disease and its Causative Agent, *Pseudomonas solanacearum*, Hartman, G.L. and J.G. Elphinstone (Eds.). CAB International, Wallingford, pp: 157-178.

Hayward, A.C., 1991. Biology and epidemiology of bacterial wilt caused by *Pseudomonas solanacearum*. Annu. Rev. Phytopathol., 29: 65-87.

Jill, K.S., Y. Jian, T.K. Julie and C. Allen, 2004. Behaviour of *R solanacearum* race 3 biovar 2 during latent and active infection of geranium. Phytopathology, 95: 136-143.

Kinyua, Z.M., J.J. Smith, C. Lungaho, M. Olanya and S. Priou, 2001. On-farm successes and challenges of producing bacterial wilt-free tubers in seed plots in Kenya. Afr. Crop Sci. J., 1: 279-285.

Lungaho, C., S.K.N. Nderitu, J.N. Kabira, R. El-Bedewy, O.M. Olanya and A. Walingo, 2006. Yield performance and release of four late blight tolerant potato varieties in Kenya. J. Agron., 5: 57-61.

MoA, 1998. Post harvest systems of potato and sweet potato in Kenya: Final report. Nairobi (Kenya). Ministry of Agriculture; Deusche Gessellschaft fur Technische Zusammenarbeit (GTZ). http://www.fao.org/wairdocs/x5420e/x5420e00.HTM.

Neher, D.A. and C.L. Campbell, 1992. Underestimation of disease progress rates with the logistic monomolecular and Gompertz models when maximum disease intensity is less than 100 percent. Phytopathology, 82: 811-814.

Nesmith, W.C. and S.F. Jenkins, 1985. Influence of antagonism and controlled matric potential on the survival of *Pseudomonas solanacearum* in four North Carolina soils. Phytopathology, 75: 1182-1187.

Nyangeri, J.B., E.M. Gathuru and D.M. Mukunya, 1984. Effect of latent infection on the spread of bacterial wilt of potatoes in Kenya. Tropical Pest Manage., 30: 163-165.

Ochuodho, J.O. and A.T. Modi, 2006. Statistical evaluation of the germination of *Cleome gynandra* L. seeds. South Afr. J. Plant Soil, 23: 310-315.

Priou, S., L. Gutara and P. Aley, 1999. Highly sensitive detection of *Ralstonia solanacearum* in latently infected potato tubers by post-enrichment ELISA on nitrocellulose membrane. EPPO/OEPP Bull., 29: 117-125.

Sreeramanan, S., M. Maziah, M. Sariah, M.P. Puad and R. Xavier, 2006. Bioassay method for testing Fusarium wilt disease tolerance in transgenic banana. Sci. Hortic., 108: 378-389.

Stansbury, C., S. McKirdy, A. Mackie and G. Power, 2001. Bacterial wilt: *Ralstonia solanacearum*-race 3 exotic threat to Western Australia. Factsheet No. 7/2001. Hortguard Initiative AGWEST, the Government of Western Australia. http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/ph/dis/veg/fs00701.pdf.

Van Elsas, J.D., L.S. van Overbeek, M.J. Bailey, J. Schonfeld and K. Smalla, 2005. Fate of *Ralstonia solanacearum* Biovar 2 as Affected By Conditions and Soil Treatments in Temperate Climate Zones. In: Bacterial Wilt Disease and the *Ralstonia solanacearum* Species Complex, Allen C., P. Prior and A.C. Hayward (Eds.). APS Press, St. Paul, MN., USA.

Van Elsas, J.D., P. Kastelein, J.M. van der Wolf, P.M. de Vries and L.S. van Overbeek, 2000. Survival of *Ralstonia solanacearum* biovar 2, the causative agent of potato brown rot in field and microcosm soils in temperate climates. Phytopathology, 90: 1358-1366.

Van der Plank, J.E., 1963. Plant Diseases: Epidemics and Control, 1st Edn., Academic Press, New York, ISBN: 0127114505, pp: 349.