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Full Length Research Paper

Evaluation of different potato variety and fungicide combinations for the management of potato late blight (*Phytophthora infestans*) in Southern Ethiopia

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ABSTRACT
Late blight caused by *Phytophthora infestans*, is one of the most significant constraints to potato production in Ethiopia and other regions of the world. Fungicides and host plant resistance are among the most efficient control options available to growers. Field trials were conducted in 2010, in Hawassa and Shashemene, Southern Ethiopia to evaluate the effectiveness of fungicide application regimes on four potato varieties. A factorial experiment with four types of fungicide applications (Ridomil, Pencozeb, Chlorothanoil, and no spray) in weekly intervals, and four potato varieties having different level of resistance were established. Late blight infection was prevalent in the experiment year, and a significant amount of disease was detected ($P< 0.05$). Application of fungicide treatments considerably reduced late blight progress, with a corresponding increase in tuber yields. Based on late blight disease occurrence, application of Ridomil MZ 63.5%WP fungicide reduced disease development and increased tuber yield in all varieties as compared to the other two fungicides.

Key words: Fungicide, Host resistance, Late blight, *Solanum tuberosum*

INTRODUCTION
Potato (*Solanum tuberosum L.*) is an important food source globally. The tuber is known to supply carbohydrate, high quality protein, and substantial amounts of essentials vitamins, minerals, and trace elements (Horton and Sawyer, 1985). Like many other countries in the world, potato is a very important food and cash crop especially on the highland and mid altitude areas of Ethiopia (Borgal *et al*., 1980). Late blight, caused by the oomycete *P. infestans*, is a devastating disease of potato worldwide (Hijmans *et al*., 2000). Yield losses due to the disease are attributed to both premature death of foliage and diseased tubers. In Ethiopia, the disease occurs throughout the major potato production areas and it is difficult to produce the crop during the main rainy season without chemical protection measures (Borgal *et al*., 1980; Bekele and Gebere Medhin, 2000).

To effectively manage late blight, farmers have increasingly adopted fungicide application as a main control strategy. Nonetheless, losses due to the disease were estimated to be 65-70% and complete crop failures are frequently reported (Bekele & Yaynu, 1996). The National Potato Program within the Ethiopian Institute of Agricultural Research (EIAR), together within the International Potato Center (CIP) and several Ethiopian Universities have worked over the last two decades to introduce potato cultivars with resistance to *P. infestans*. But, some of them have lost their resistance soon after dissemination.

The profound ability of the disease to reach an epidemic level within short periods, the inadequate efficiency of cultural practices to reduce high level of disease severity, and rapid development of resistance to fungicides and breakage of plant resistance in potato cultivars within short period of time have made integrated use of different disease management strategies very essential in late blight management. Thus, the combined uses of fungicide and resistance varieties have evolved as one of the most important options in the management of the disease (Namanda *et al*., 2001). Integrating fungicide applications with varieties by choosing the best fungicide-cultivar combinations improves the durability/sustainability of the released potato varieties in the potato production system. This is particularly important in developing countries such as Ethiopia, where the set-up of efficient and sustainable breeding programs for potatoes are inadequate. Integration of fungicides with cultivars has been commonly practiced for sustainable production of potatoes in most developed world (Namanda *et al*., 2001).

In addition to the benefits of reducing yield losses due to epidemics of late blight, the combined uses of fungicide with resistance varieties can also contribute to reduce the health risks associated with high fungicide applications. Integration of fungicide with potato cultivars could reduce the need of application of high fungicide and able to decrease the risk to human health, environmental contamination, and increase the economic benefit of farmers. The objective of this study therefore was to evaluate the combined effects of fungicides with some Ethiopian potato varieties on epidemics of late blight and yields of potato varieties.

MATERIAL AND METHODS

Description of the sites

The study was conducted in Hawassa, South Nations and Nationalities Regional State (SNNPRS), and around Shashemene (Oromiya region), Ethiopia, from June to October, 2010. Hawassa is located, at $7^{0}4^{o}$ N and $38^{0}31$‘ E with an elevation of about 1,700 meters above sea level (masl) and an annual rain fall of 1100 mm. It has an annual minimum and maximum temperature in the range of 13.5^{0}C - 27.6^{0}C, respectively. On the other hand, Shashemene is located at 7° 12' North latitude and 38° 36' east longitude and having an elevation of 1700-2600 meters above sea level (masl) with an annual rain fall of 1200 mm. It has an annual minimum and maximum temperature in the range of $12\text{-}27^{0}$C, respectively. Both sites are suitable for potato production, and late blight pressure is generally high in both locations during the rainy season.

Treatments and Experimental Design

Four potato varieties and three fungicides were used in the experiment. The two relatively resistant varieties namely Jallene (CIP-384321.19) and Guidene (CIP-386423.13) were obtained from Ethiopian Agricultural Research Institute (EIAR), Holleta Agricultural Research Center. Both have wide-range environmental adaptation in Ethiopia. Jallene was released in 2002, while Guidene was released in 2006 (Woldegiorgis *et al.,* 2008). The other two highly susceptible varieties (White flower and Agazar) were purchased from tuber seed producing farmers' organization around Shashemene. All the four potato varieties have different levels of resistance to late blight and commonly grown in the areas. The test fungicides used in the study was Ridomil (Ridomil MZ 63.5% WP), Pencozeb (Pencozeb 80% WP) and Chlorothalonil (Odeon 82.5% WG). The fungicides were applied as per the recommendation of the manufacturers (at the rate of 3kg/ha) using a manually-pumped knapsack sprayer of 15 liter capacity. Spraying started soon after the first late blight lesions were observed on the foliage and continued depending on the needs of the variety-fungicide combinations at seven days interval for up to three consecutive weeks.

A randomized complete block design with four replications was employed in a factorial arrangement at each location. Each potato variety was randomly combined with one of the three fungicide sprays (Ridomil, Pencozeb and Chlorothalonil) and a non-spray treatment. Plots consisted of 5 rows with spacing of 0.3 m between plants and 0.75 m between rows, giving an overall dimension of 4m X 4m. In order to minimize fungicidal drifts between treatments during spraying, two rows of maize were planted between each plot. Di-ammonium phosphate (DAP) and Urea were applied at planting and during weeding at the rate of 195 kg/ha and 165 kg/ha, respectively (Rotem and Sari, 1983). In all field plots, normal agronomic practices were carried out as necessary.

DATA COLLECTIONS AND ANALYSIS

Disease development

Starting with the appearance of the first late blight symptoms, each plant within each plot was visually evaluated for percent foliar infection (severity) at seven days interval. Evaluations continued until late blight ceased to progress on untreated plots of the most susceptible variety. The effect of variety and fungicide combinations on disease severity data was integrated in to area under disease progress cure (AUDPC), as described by Campbell and Madden

(1990). Further, disease severity of variety susceptibility to *P. infestans* was recorded following the CIP (International Potato Center) procedure on a 0-100%, scale where; 0% represented no apparent disease and 100% equivalent to total leaves and stems destruction (Yuen and Forbes, 2009).

On the other hand, disease incidence on each experimental plot was recorded by counting number of diseased plants and calculating as the proportion of the diseased plant over the total number of stand count on the plot.

Yield and yield components

At maturity, potato tubers were harvested from the three inner rows of each plot and then sorted out into marketable and unmarketable tubers based on the presence or absence of blighted tuber, tuber color, and size and shape deformation. Additionally, the weights of marketable, unmarketable, and total yield of potato tuber per hectare were recorded.

Statistical analysis

The data on disease severity were converted to area under disease progress curves (AUDPC), mean value of disease incidence, disease severity and yield components were subjected to repeated measures of analysis of variance (ANOVA) to evaluate treatments effect. The analysis was done using the general linear model of statistical analysis using SAS computer package version 9.11 (SAS Institute Inc, 2003 version). Means for different fungicides and varieties combinations were compared using Least Significant Difference test at the 5% significance level ($LSD_{5\%}$).

RESULTS

Effects of fungicide application and late blight occurrence in relation to potato varieties

Late blight was recorded at both sites and cropping seasons during the period which the experiment was conducted. Late blight incidence was high in Shashemene and moderate in Hawassa during the cropping season. The disease incidence, at Shashemene reached at the maximum of 82.5% and 76.25% on the unsprayed (control) local susceptible varieties, Agazar and White flower, respectively and 50% and 58% was recorded on the resistant varieties Jallene and Guidene, respectively (Table 2). At Hawassa, late blight incidence reached at 70.3% and 77.5% on the unsprayed (control) local susceptible varieties, White flower and Agazar, respectively and 36.3 and 47.5 % was recorded on Jallene and Guidene, respectively (Table 2). On the whole, the of application fungicides Ridomil, Pencozeb and Chlorothanoil arrested disease development more effectively compared to no fungicide application. In all varieties the application of fungicide reduced the progress of the disease as compared to unsprayed (controls), but Ridomil highly reduced the progress of the disease compared to the other two fungicides in all varieties (Table 2). In general in both site, the results of the combined analysis showed that the interaction of varieties (host resistance) and fungicides was significant (Table 1). The result from both locations showes that, significant variations in late blight incidence among the variety and fungicides combinations, but variations between Pencozeb and Chlorothanoil were insignificant at $p<0.05$ when they are applied in combinations with improved varieties (Table 2). Nonetheless, significant variations in late blight incidence were obtained when the fungicides were applied on susceptible varieties.

Throughout the cropping season the combined effect of varieties and fungicides on disease development was significant based on AUDPC values for both sites (Table 2).Values of AUDPCs varied between locations depending on the resistance level of the variety and the types of fungicide application, and plots sprayed by fungicide had the lowest AUDPC values while non sprayed (control) plots had the highest values. This indicates that different fungicide-variety combinations reduced late blight development. On the local varieties, White flower and Agazar, the AUDPC without fungicide spray was 2335 and 3304, respectively, while it was 1535 and 1801 on the resistant varieties Jallene and Guidene, respectively in Shashemene. In Hawassa, White flower and Agazar had AUDPC of 2179 and 2447, respectively, and AUDPC on Jallene and Guidene at the same location was ca. 1304 and 1435, respectively (Table 2).

Table 1. Analysis of variance on the effects of variety and fungicide combinations on late blight severity, incidence, area under disease progress curve (AUDPC) and yield on four potato varieties during 2010 cropping season at Shashemene and Hawassa , Southern Ethiopia.

Source	Df	Shashemene Severity	Incidence	AUDPC	Yield(t/ha)	Hawassa Severity	Incidence	AUDPC	Yield(t/ha)
Replication	3	25.9_{ns}	118.8^{*}	123051^{*}	23.8^{*}	40.8^{*}	59.11^{*}	63376.5^{*}	22^{*}
Varieties	3	4115.3^{**}	2900.4^{**}	7216308.7^{**}	29.8^{*}	1854^{**}	1765.4^{**}	3065379.5^{**}	53^{*}
Chemicals	3	3266^{**}	2942^{**}	5877145.6^{**}	30.2^{*}	3398^{**}	4159.6^{**}	5876677.6^{**}	27^{*}
Varieties*chemicals	9	60^{*}	174.4^{*}	148799.4^{*}	3.8^{*}	77^{*}	277.7^{*}	123729.3^{*}	5^{*}
Error	45	22	77.0	46334.8	5.6	12	41.5	24145.3	5.5

*^{Ns}-Statistically not significant *Significant at $P< 0.05$ and **significant at $P<0.01$.*

Table 2. Effects of different fungicides and variety combinations on disease incidence, disease severity and area under disease progress curve (AUDPC) of potato late blight infection at Shashemene and Hawassa, Southern Ethiopia

		Shashemene			Hawassa		
Variety	Fungicide	Incidence (%)	Severity (%)	AUDPC	Incidence (%)	Severity (%)	AUDPC
Agazar	Control	$82.5.0^{a}$	88.0^{a}	3304.4^{a}	77.8^{a}	71.8^{a}	2447^{a}
	Chlorothanoil	56.9^{cd}	51.0^{c}	1749^{cd}	44.3^{bc}	42.8^{d}	1365^{d}
	Pencozeb	53.8^{cd}	53.8^{c}	1837^{c}	38.3^{bcd}	51.3^{c}	1793^{c}
	Ridomil	50.6^{de}	50.0^{c}	1680.0^{cd}	33.1^{def}	39.3^{d}	1137.5^{d}
Guidene	Control	58.8^{cd}	52.5^{c}	1802.5^{c}	47.5^{b}	48.3^{c}	1435^{cd}
	Chlorothanoil	27.5^{fgh}	24.5^{g}	616.9^{f}	26.4^{efgh}	25.3^{ef}	650^{ef}
	Pencozeb	27.5^{fgh}	35.8^{f}	700.6^{f}	28.1^{efg}	29.3^{e}	845.3^{e}
	Ridomil	23.8^{h}	19.8^{gh}	415^{fg}	25.6^{fgh}	18.3^{gh}	315.6^{gh}
Jallene	Control	50^{de}	43.3^{de}	1593^{cd}	36.3^{cde}	40.5^{d}	1303.8^{d}
	Chlorothanoil	40^{ef}	19.8^{gh}	455^{fg}	18.8^{gh}	21.5^{fg}	332.5^{fg}
	Pencozeb	33.8^{fgh}	19.8^{gh}	634^{f}	21.3^{gh}	25.5^{ef}	424^{fg}
	Ridomil	26.9^{gh}	16.0^{h}	217^{g}	17.1^{h}	15.0^{h}	198^{h}
White Flower	Control	76.3^{ab}	65.3^{b}	2335^{b}	70.3^{ab}	62.5^{b}	2178^{b}
	Chlorothanoil	48.2^{de}	40.8^{def}	1343^{e}	25.6^{fgh}	42.8^{d}	780.5^{e}
	Pencozeb	66.3^{cd}	47.0^{cd}	1509^{cde}	26.9^{efgh}	41.3^{d}	1373.8^{d}
	Ridomil	39.4^{efg}	36.8^{def}	1181^{e}	22.5^{gh}	21.4^{fg}	506.8^{fg}
CV		18.4	11.5	16.1	18.2	10.8	14.0
LSD (5%)		12.5	6.8	306	9.1	5.00	221.3

Means in a column followed by the same letters are not significantly different according to LSD at 5% probability level.

EFFECTS OF FUNGICIDE APPLICATION AND VARIETY RESISTANCE IN POTATO TUBER YIELD AND YIELD COMPONENTS

Weekly application of fungicide (7 day schedule) resulted in higher tuber yields in the susceptible variety when compared to the control treatments (no sprays). Higher tuber yield was 31.8(ton/ha) was recorded on the variety Jallene. The control treatments (no sprays) had the lowest tuber yield. Potato tuber yield was higher in the resistant than the susceptible varieties (Table 3). Fungicide application considerably increased the yield of susceptible varieties and also resistant varieties. The total tuber yield varied depending on the combination of varieties and fungicide application (Table 3).The resistant variety Jallene and Guidene gave highest total yield as compared to the local susceptible varieties (White flower and Agazar) at both sites (Table 3).

Application of Ridomil fungicide increased the total yield of potato and gave highest yield as compared to other treatments (Table 3). A more or less similar result was obtained at Hawassa suggesting the superiority of Ridomil in controlling late blight and ensuring higher yield compared to the other fungicides tested in this experiment. The improved variety Jallene and Guidene combined with fungicide application had significantly ($p<0.05$) higher marketable yields as compared to the local varieties White flower and Agazar. But there is also significant difference between the yields of the local varieties when combined with fungicide application.

DISCUSSION

Occurrence of *P. infestans* in sub-Saharan Africa has been closely linked to the introduction of susceptible potato varieties (Hakiza *et al*., 2001; Olanya *et al*., 2001). In Ethiopia, potato late blight has been a serious problem since the introduction of the crop into the country. Between 1987 and 2006, eighteen potato cultivars were released in Ethiopia (Woldegiorgis *et al*., 2008). All of these cultivars came from potato germplasm introduced by the CIP as varieties with resistance to *P. infestans.* Since then attempts have been made to identify resistant varieties. However, resistance to late blight in these cultivars has since been overcome and significant yield losses experienced (Woldegiorgis *et al*., 2008). Significant variations also existed between the resistant and susceptible varieties in terms of marketable and unmarketable yield (Table 3). This was in agreement with Asamenew and Bahru (2000) also reported that increased marketable and total tuber yield in resistant varieties under Ethiopian conditions. White flower and Agazar were highly susceptible to late blight and early season infection, contributing significantly to the lower yields observed. Fry and Shtienberg (1990) reported that complete suppression of yield in susceptible varieties is possible if the disease occurs early in the season. Mukalazi *et al*. (2001) also reported that susceptible varieties could be preferred by farmers due to their good agronomic characteristics, and hence fungicides must be used to ensure disease control. It was, therefore, necessary to establish the type of fungicide needed and it was also important to establish the response of different cultivars to fungicidal application and variety combined. For commercial production of potato, Kankwatsa *et al.* (2002) suggested that integration of host resistance and fungicide application reduced the late blight severity by more than 50% and resulted in yield gains of more than 30%, which clearly supports the present investigation. Fontem and Aighew (1993) also reported that fungicides applied for late blight management increased tuber yield by as much as 60%. According to Bradshaw (1992) and Thind *et al.* (1989), potato yield loss attributed primarily to late blight is dependent on variety susceptibility or tolerance / resistant and disease management practices. In both resistant and susceptible varieties, our data shows that highest yield occurred when Ridomil fungicide was used in combinations with both resistant and susceptible varieties. Nyankanga *et al*. (2003) suggests that if susceptible potato varieties are used with rigorous spray regimes of Ridomil fungicide, then effective late blight control and high yield can be attained. Hakiza *et al.* (2001) and Olanya *et al*. (2001) reported that even if occurrence of *P. infestans* in sub-Saharan Africa has been closely linked to the introduction of susceptible potato varieties, successful management of late blight through the foliar fungicides application is dependent on several factors such as proper timing of initial fungicide application, use of effective dosage, timely scheduling of fungicide intervals and adequate coverage of foliage. In this study, Ridomil consistently retarded late blight development when combined with all varieties and the highest yields were obtained from plots treated with Ridomil. The present study has determined that an application of Ridomil controls late blight and increases yields markedly.

Table 3. Effects of different fungicides and variety combinations on marketable yield (MY), unmarketable yield (UNMY) and total yield (TY) of potato at Shashemene and Hawassa, Southern Ethiopia

		Shashemene			Hawassa		
Variety	Fungicide	MY (t/ha)	UNMY (t/ha)	TY (t/ha)	MY (t/ha)	UNMY (t/ha)	TY (t/ha)
Agazar	Control	13.0^{ef}	3.6^{a}	16.6^{d}	16.7^{f}	2.5^{a}	18.2^{de}
	Chlorothanoil	19.0^{bcd}	2.95^{ab}	21.8^{c}	19.6^{cdfe}	2.1^{bc}	21.7^{bcde}
	Pencozeb	17.9^{de}	2.9^{b}	20.8^{c}	18.8^{def}	2.0^{b}	20.8^{cde}
	Ridomil	20.8^{cde}	2.5^{abc}	23.3^{bc}	$20.^{bcdef}$	1.8^{cd}	21.7^{bcde}
Guidene	Control	18.0^{de}	2.2^{cd}	20.3^{c}	19.8^{cdef}	1.2^{e}	21.0^{bcde}
	Chlorothanoil	23.6^{abc}	1.9^{de}	24.8^{bc}	23.5^{abc}	0.55^{f}	24.0^{ab}
	Pencozeb	21.4^{cde}	2.2^{cd}	23.4^{bc}	21.0^{bcde}	0.99^{e}	22.0^{bcde}
	Ridomil	25.9^{ab}	1.8^{e}	27.7^{a}	24.0^{ab}	0.53^{f}	24.5^{ab}
Jallene	Control	19.6^{de}	2.2^{cd}	21.8^{c}	19.4^{def}	1.75^{cd}	21.1^{bcde}
	Chlorothanoil	24.3^{abcd}	1.8^{e}	26.0^{ab}	22.6^{abcd}	1.2^{e}	23.8^{abcd}
	Pencozeb	22.8^{cde}	1.9^{de}	24.5^{bc}	22.1^{abcde}	1.0^{e}	23.0^{abcd}
	Ridomil	30.1^{a}	1.7^{e}	31.8^{a}	25.1^{a}	0.95^{e}	26.1^{a}
Whiteflower	Control	16.0^{e}	2.9^{ab}	18.9^{cd}	16.8^{f}	2.4^{a}	19.2^{de}
	Chlorothanoil	21.4^{cde}	2.3^{c}	22.6^{bc}	$22.2.^{abcde}$	2.0^{bc}	24.2^{ab}
	Pencozeb	19.5^{de}	2.3^{c}	21.8^{c}	20.2^{bcdef}	2.1^{b}	22.1^{bcde}
	Ridomil	22.0^{cde}	2.2^{cd}	24.3^{bc}	22.1^{abcde}	1.6^{d}	23.7^{abcd}
CV		10.5	10.3	10.2	11.3	14.5	10.8
LSD (5%)		3.00	0.38	3.38	3.35	0.29	3.4

Means in a column followed by the same letters are not significantly different according to LSD at 5% probability level.

Reduction in number of applications of the systemic fungicide (Ridomil) would also reduce the risk of development of pathogen resistance to metalaxyl (Deahl *et al*., 1995). Namanda *et al*. (2001); Kankwatsa *et al*. (2003) showed that management of potato late blight by using a combination of host resistance and fungicide applications in the tropical highlands of East Africa are important. Among the used contact fungicides Chlorothanoil showed better performance reducing disease parameters and increasing yield compared to Pencozeb and the control treatments. This was in agreement with Khanna (1989); Singh *et al.* (1994); and Singh and Shekhawat (1999). Islam *et al.* (2002) and Tsakiris *et al.* (2002) found out that the mode of action of fungicides like Pencozeb involves protection of the foliage by inhibiting germination and/or penetration of the spores. The efficacy of these fungicides can be enhanced by increasing the dosage and frequency of application (Islam *et al.,* 2002; Tsakiris *et al.,* 2002). Results of this study were consistent with previous studies and indicate that a combination of resistance varieties and managed application of protective and contact fungicides can reduce foliar late blight to acceptable levels in most situations (Clayton and Shattock, 1995; Fry, 1975, 1977; Kirk *et al*., 2001; Van der Plank, 1968). The use of protectant and systemic fungicides for managing late blight has perhaps been the most studied aspect of late blights management in temperate countries (Olanya *et al.*, 2001). Olanya *et al.* (2001) also reported that, with the exception of optimum or scheduled fungicide applications based on favorable weather conditions, the most economical option for disease management is the use of host-plant resistance. The use of cultivars with durable resistance combined with scheduled applications of Protective fungicides has been reported as useful for managing late blight (Simons, 1972), as well as other diseases (Van der Plank, 1963). The performance of Ridomil MZ in controlling late blight under present investigation has been supported by many researchers throughout the world (Singh and Shekhawat, 1999; Singh *et al.*, 2001; Islam *et al.*, 2002; Tsakiris *et al.*, 2002). In tropical Africa, the contact fungicide Dithane M 45 (Mancozeb 80% WP) and the systemic fungicide Ridomil MZ are widely used to control late blight (Olanya *et al*., 2001; Fontem, 2001).

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REFERENCES

Asamenew, T., and Bahru, Z. 2000. Transfer of improved potato varieties and production technologies in the southeastern highlands of Ethiopia. African Potato Association Conference Proceedings Uganda. 5: 153-156.

Bekele Kassa and G/medihin W/giorgis. 2000. Effect of planting date on late blight severity and tuber yield on different potato varieties. Pest Management Journal of Ethiopia 4: 51-63.

Bekele Kassa and Yaynu Hiskias. 1996. Tuber yield loss assessment of potato cultivars with different level of resistance to late blight.pp. 149-152. In: Eshetu, Bekele, Abdurrahman Abdullah and Aynekulu Yemane (Eds). Proceedings of the 3rd annual conference of crop protection Society of Ethiopia 18-19 May, Addis Ababa Ethiopia, CPSE, and Addis Ababa.

Borgal, H.B., Arend, C., Jacobi, Kanyarukis, S., Kulazia, A., Lemaga, B.L., Mogaeka, and prante,W.1980. Production, marketing and consumption of potato in the Ethiopia highlands' (Holleta, Awassa, and Alemaya) Center of Advanced training in agricultural development technology. University of Berlin.

Bradshaw, N.J. 1992. The use of fungicides for control of potato late blight (*Phytophthora infestans*). Aspects of Applied Biology 33: 101-106.

Campell, C.L., and Madden, L.V. 1990. Introduction to plant disease Epidemology. John Wiley and Sons, New York. p. 532.

Clayton, R.C., Shattock, R.C. 1995. Reduced fungicide inputs to control *Phytophthora infestans* in potato cultivars with high levels of polygenic resistance. Potato Research 38: 399–405.

Deahl, K.L., Demuth, S.P., Rivera-Pena, A. 1995. Identification of mating types and metalaxyl resistance in North American populations of *Phytophthora infestans*. Am. Potato Journal 72: 35–49.

Fontem, D.A., and Aighew, B. 1993. Effect of fungicides on late blight control and yield loss of potato in the western highlands of Cameroon. International Journal of Pest Manage 39: 152–155.

Fontem, D.A. 2001. Influence of rate and frequency of Ridomil Plus applications on late blight severity and potato yields. Africa Crop Science Journal 9: 235-243.

Fry, W.E. 1975. Integrated effects of polygenic resistance and a protective fungicide on development of potato late blight. Phytopathology 65: 908–911.

Fry, W.E. 1977. Integrated control of potato late blight and effects of polygenic resistance and techniques of time of fungicide application. Phytopathology 67: 415–420.

Fry, W.E., and Shtienberg, D. 1990. Integration of host resistance and fungicide to manage diseases. Canadian Journal of Plant Pathology 12: 111–116.

Hakiza, J.J., Turyamureeba, G., Kakuhenzire, R.M., Odongo, B., Mwanga, R.M., Kanzikwera, R., Adipala, E. 2001. Potato and sweet potato improvement in Uganda: a historica Perspective. In: Adipala, E., Nampala, P., Osiru, M., (Eds.), Proceedings of the Fifth Triennial Conference of the African Potato Association, 29 May–2 June 2000, Kampala, Uganda, pp. 47–58.

Hijmans, R.J., Forbes, G.A., and Walker, T.S. 2000. Estimating the global severity of potato late blight with GIS linked disease forecast models. Plant Pathology 49: 697–705.

Horton, D., and Sawyer, RL. 1985. The potato as a world food crop, with special reference to developing areas. In: Li PH, ed. potato physiology. London, Academic Press 1-34.

Islam, M.R., Dey, T.K., Rahman, M.M., Hossain, M.A., and Ali, M.S. 2002. Efficacy of some fungicides in controlling late blight of potato. Bangladesh Journal of Agriculture Research 27(2): 257-261.

Kankwatsa, P., Adipala, E., Hakiza, J.J., Olanya, M., Kidanemariam, H.M. 2002. Effect of integrating planting time, fungicide application and host resistance on potato late blight development in South-western Uganda. Journal of Phytopathology 150: 248–257.

Kankwatsa, P., Hakiza, J.J., Olanya, M., Kidanemariam, H.M., Adipala, E. 2003. Efficacy of different fungicide spray schedules for control of potato late blight in southwestern Uganda. Crop Protection 22: 545–552.

Khanna, R.N. 1989. Disease management through cultural and chemical methods. In: SAARC Training Course on Late Blight of Potato, held at CPRI, Shimla, H.P., India from 17-31 July, 1989. pp 96-106.

Kirk, W.W., Niemira, B.A., and Stein, J.M. 2001. Influence of storage temperature on rate of potato tuber tissue infection caused by *Phytophthora infestans* (Mont.) de Bary estimated by digital image analysis. Potato Research 44: 87-96.

Mukalazi, J., Adipala, E., Sengooba, T., Hakiza, J.J., Olanya, M., Kidanemariam ,H.M. 2001. Variability in potato late severity and its effect on tuber yield in Uganda. Africa Crop Science Journal 9: 195–201.

Namanda, S., Adipala, E., Olanya, O.M., Hakiza, J.J., El-Bedewy, R., Bhagsari, A.S. 2001. Integration of host resistance and minimum fungicide application for management of Potato late blight in Uganda. Fifth Biennial Conference of the African Crop Science Society (Abstract), October 19–26, Lagos, Nigeria.

Nyankanga, O.R., Wein, H.C., Olanya, O.M., Ojiambo, P.S. 2003. Farmers' cultural practices and management of potato late blight in Kenya Highlands: implications for development of integrated disease management. International Pest Management Journal in press.

Olanya, O.M., Adipala, E., Hakiza, J.J., Kedera, J.C., Ojiambo, P., Mukalazi, J.M., Forbes, G., Nelson, R. 2001. Epidemiology and population dynamics of Phytophthora infestans in sub-Saharan Africa: progress and constraints. Africa Crop Science Journal 9: 181–193.

Rotem, J., and Sari. A. 1983. Fertilization and age-conditioned predisposition of potatoes to sporulation of and infection by *Phytophthora infestans.* Journal of Plant Diseases and Protection 90(1): 83–88.

SAS Institute Inc. 2003. SAS/STATA Guide for personal computer version 9.1 SAS Institute Inc. carry, NC, USA.

Simons, M.D. 1972. Polygenic resistance to plant disease and its use in breeding resistant cultivars. Journal of Environmental Quality 1: 232–240.

Singh, B.P., Roy, S., Bhattacharyya, S.k., and G.S. Shekhawat. 1994. Scheduling of Metalaxyl based fungicides and development of fungicide resistant strains in *Phytophthora infestans*. In: Potato: Present and Future (Eds. G.S. Shekhawat *et al.,)* Indian Potato Association, CPRI, Shimla, India.

Singh, B.P. and G.S. Shekhawat. 1999. Potato late blight in India. Tech. Bull. No. 27 (revised), CPRI, Shimla, H.P., and India. pp 85.

Singh, B.P.,Singh, P.H., Jhililmil-Gupta; Lokendra-Singh, Gupta, J. and Singh, L. 2001. Integrated management of late blight under Shimla hills. National Symposium on Sustainability of Potato Revolution in India, Shimla. Journal of the Indian Potato Association 28(1): 84-85.

Thind, T.S., Chander-Mohan, J.S., Bedi, R.K., Grewal and Sokhi, S.S. 1989. Role of application time of fungicides in the control of late blight of potato. Plant Disease Research 4(2): 113- 117.

Tsakiris, E., Karafyllidis, D.I., Mansfield, J., Paraussi, G., Voyiatazis, D., and Paronssis, E. 2002. Management of potato late blight by fungicides. Proceedings of the Second Balkan Symposium on Vegetables and Potatoes, Thessaloniki, Greece. Acta Horticulture 579: 567-570.

Van der Plank, J.E. 1963. Plant diseases epidemics and control. Academic Press, NewYork,349pp.

Van der Plank, J.E. 1968. Disease resistance in plants. Academic Press, New York, USA.

Woldegiorgis, G., Gebre, E., Lemaga, B. 2008. Potato breeding. In: Woldegiorgis, G., Gebre, E., Lemaga, B. (Eds.) Root and Tuber Crops, the Untapped Resources. Addis Ababa. Ethiopian Institute of Agricultural Research. pp. 15-32.

Yuen, J.E., Forbes, G.A. 2009. Estimating the level of susceptibility to *Phytophthora infestans* in potato genotypes. Phytopathology 99: 783-786.