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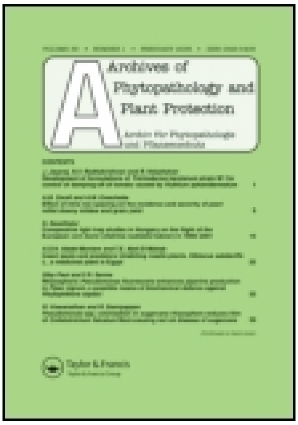

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Late blight caused by *Phytophthora infestans* is a major constraint to potato production. Inadequate control of the disease has often resulted in potato yield losses. We assessed the efficacy of fungicides, phosphoric acid and stinging nettle extract combinations for late blight control at two locations in Kenya. Disease severity, relative area under disease progress curves (RAUDPC), pathogen lesions and tuber yield were quantified during the 2008 and 2009 cropping cycles. The application of metalaxyl alternated with phosphate resulted in the greatest suppressive effects on late blight. The average late blight severity ranged from 3.5 to 34% in 2008 and 4.7 to 50% in 2009 at Tigoni location. RAUDPC for the same location ranged from 5 to 40% and 5 to 50% in 2008 and 2009, respectively. Similar levels of late blight severity were recorded at Marimba location in both years. Lesion growth and pathogen lesion numbers on potato plants differed significantly ($p < 0.05$) among treatments. Fungicides, phosphoric acid and stinging nettle extract varied in late blight control. Potato tuber yield varied among treatments. Phosphoric acid treatment had significantly ($p < 0.05$) greater tuber yield compared to metalaxyl at both locations. Field plots treated with plant extracts from stinging nettle resulted in the lowest tuber yield compared to other treatments with the exception of the untreated control. Fungicides, phosphoric acid, stinging nettle extract and their combinations can be readily effective in the suppression of late blight severity and pathogen lesions with moderate increases in tuber yield.

Keywords: plant extract; phosphoric acid; fungicide combinations; late blight; potato yield

Introduction

Management of potato late blight remains a major challenge worldwide, especially among small-scale farmers in the tropical highlands. In Kenya, attempts to control late blight are almost entirely accomplished by the use of fungicides and cultivars with low to moderate levels of resistance (Haverkort 1990). In most cases, there is an inadequate control of the disease resulting in high costs and complete crop loss.

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It has been estimated that $\sim$30–60% of the crop is lost due to late blight annually in Kenya (Nyankanga et al. 2004). Metalaxyl and mefenoxam have been effective in controlling late blight previously, but metalaxyl-resistant populations of *P. infestans* have been reported in many parts of the world (Dowley and O'Sullivan 1981; Derie and Inglis 2001).

The use of alternative products or combinations of products can reduce fungicide inputs and enhance integrated crop management (Cao and van Bruggen 2001). Some chemical compounds have been shown to increase natural plant defense mechanisms (Gozzo 2003). These chemical compounds can be used as components of integrated pest management. Amino butyric acid (BABA) and fosetyl–Al applied to foliage at early stages of crop growth can increase the resistance of potato foliage and tubers to late blight (Andreu et al. 2006). Phosphoric acid has been reported to inhibit sporulation of the pathogen and adversely impact pathogen infection (Schwinn and Margot 1991). Both phosphoric acids and fosetyl-Al have been reported as effective in controlling plant diseases caused by oomycetes (Coffey and Bower 1984; Ouimette and Coffey 1989b). The mode of action of phosphonate has been reported to be direct antifungal activity affecting mycelia growth (Fenn and Coffey 1989) and indirect stimulation of host defenses (Guest and Grant 1991). These compounds are also thought to have some systemic characteristics with basipetal and acropetal activity for control of foliar and tuber blight (Cooke and Little 2001). This chemical characteristic allows the compounds to be stable in plants for several weeks and offer long-term protection in potato leaves and tubers (Ouimette and Coffey 1989a; Smillie et al. 1989).

To the best of our knowledge, there is no published research detailing the effect of stinging nettle plant extract on potato late blight control. However, plant extract from stinging nettle has been reported to be effective against a different pathosystem, *Phomopsis thea* of tea (Onyiango et al. 2005). Plant extract from stinging nettle, phosphoric acid and fungicide combinations could offer a low-cost strategy for managing potato late blight in a region where disease occurrences are prevalent. Therefore, the objective of this study was to determine the efficacy of phosphoric acid, plant extract from stinging nettle, fungicides and their combinations for the management of potato late blight in comparison with fungicides such as premix of Ridomil (metalaxyl + mancozeb) and mancozeb currently used for late blight management in this region.

Materials and methods

Experimental design and layout

The study was carried out at the National Potato Research Centre (NPRC), Tigoni and Marimba location in Meru. The two sites have different climatic conditions of (temperature, relative humidity and rainfall) and late blight pressure (Ojiambo et al. 2001). Late blight is a perennial problem at these locations. Treatments were laid in a split plot, in a randomised complete block with three replicates. The main plot consisted of plant extract from stinging nettle and fungicide spray treatments, while the subplots had two potato cultivars grown in many potato cultivation areas of Kenya.

Desiree, a cultivar susceptible to late blight and grown in many potato cultivation areas of Kenya for fresh tuber consumption, and Tigoni, a late blight-resistant cultivar grown in many potato production regions for making chips, were used. The main plots were 4.5 × 3.0 m (length × width) while the subplots were 3.0 × 2.25 m (length × width). Potatoes were planted in furrow at a spacing of 0.75 m between rows and 0.3 m within rows. The distance between blocks was 2 m wide, while an alley of 1.5 m separated the subplots. Two outer rows were used as guard rows while disease severity was recorded in two middle rows and a border of 1 m width surrounded each potato plot.

Standard agronomic practices for this region were used for all trials. Sprouted certified potato seeds were planted on 23 October and 11 November 2008 at Tigoni and Marimba, respectively, during the short rainy season, and 13 March and 28 March 2009 at Tigoni and Marimba, respectively, during long rainy season. Diammonium phosphate (DAP) fertiliser was applied at the rate of 500 kg ha^{-1}. Field plots were hilled two times during crop growth at both locations. Supplemental irrigation was applied during dry periods as needed. Aphids were also controlled using deltamethrin as needed. Late blight development was initiated by natural inoculum present in the field sites during the cropping cycle.

Treatment applications

Seven treatments were applied for control of late blight as follows: (1) a premix of Ridomil (64% mancozeb + 4% metalaxyl) at the rate of 2.5 kg ha^{-1}, (2) Dithane M45 (80% mancozeb) at the rate of 2.5 kg ha^{-1}, (3) phosphite (mono dipotassium phosphoric acid) at the rate of 2.5 L ha^{-1}, (4) extract of stinging nettle at the rate of 50 g L^{-1}, (5) mancozeb alternated with phosphite, (6) Ridomil followed by application of phosphite in subsequent application and (7) control treatment. Mancozeb and the combination of mancozeb + metalaxyl (Ridomil) were used as the protective and curative fungicide treatments, respectively. Fungicides were applied at 7-day intervals except for mancozeb + metalaxyl which were applied two times during the cropping season. The sprayer was calibrated prior to commencement of applications so as to deliver spray volume of 400 L ha^{-1} at a pressure of 3 bars. The potato plants in the untreated plots were sprayed with water. Treatment applications were initiated at the onset of late blight symptoms initiated from natural inoculum. To prepare plant extract, stinging nettle plants were harvested from the University of Nairobi Farm located at Kanyariri during the flowering stage. Plant extract was prepared by crushing naturally dried whole plants except the roots into fine powder. The powder extract was filtered through a 5-mm mesh sieve to obtain a fine powder. Fifty grams of the fine powder was soaked in 1 litre of water for 24 hours and then added to 20 litres of water for application to foliage.

Late blight assessment

Late blight parameters assessed consisted of disease severity, disease incidence, lesion size, number of lesions and tuber blight incidence. Field plots were assessed for late blight severity by visual rating based on percent leaf area blighted using a scale of 0–100%, where 0% = no disease and 100% refers to total foliage damage (James 1971). Assessment for late blight was done in the two inner rows of a 4-row plot beginning from the time when symptoms were first observed. Subsequent disease assessments were made at 4-day intervals until the potato foliage in the untreated plots was completely destroyed. The size of lesions was determined from five lesions on each plant for a total sample size of five plants per subplot. Lesion measurements were repeated on the same plants on 4-day intervals until the end of the season. The number of lesions per plant was determined in five plants per subplot.

Tuber blight assessment

At physiological maturity, tubers from each of the 10 hills per subplot were harvested separately and diseased tubers were identified visually and tuber numbers counted. Tubers with external symptomatic lesions typical of blight were sliced to confirm the presence of brown discoloration backed up by pathogen isolation. Tuber blight incidence was calculated by counting the number of diseased tubers and expressing it as a percentage of the total number of tubers per plot.

Effect of fungicide on potato tuber yield and yield components

At physiological maturity, plants were dehaulmed 2 weeks prior to harvesting. At harvest, tubers from 10 hills in the middle of the two inner rows of each plot were harvested by carefully lifting out the tubers. The tubers were graded according to size as follows: chatt ($<$25 mm), seed (25–30 mm) and ware ($>$55 mm) in diameter. Tubers were also separated into marketable ($>$6.4 cm diameter) and unmarketable ($<$6.4 cm diameter) and subsequently weighed separately. The number of tubers per hill was also recorded and yield was converted to tonnes per hectare.

Statistical analyses

The area under disease progress curve (AUDPC) was computed from disease severity using the method previously described (Shaner and Finney 1977). Disease and yield data with the exception of lesion expansion rate were subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat (LAWES Agricultural Trust Rothamsted Experimental station 2006, version 9). The lesion expansion rate data were analysed using repeated measures analysis, and differences among the treatment means were compared using the Fisher's protected least significant difference (LSD) test at 5% significant level.

Results

Effect of fungicides, phosphate and plant extract on late blight severity

Late blight was observed at 55 and 48 days after planting in 2008 at Tigoni and Marimba locations, respectively (Figures 1 and 2). In 2009, the disease was observed at 52 and 56 days after planting at Tigoni and Marimba locations, respectively (Figures 1 and 2). The disease progress was rapid in the untreated (unsprayed) plots with disease severity values of 95% on Desiree and 38.33% on Tigoni cultivars within 30 days after appearance of the symptoms. At Marimba location, late blight severity levels of 83.3% were recorded on the cultivar Desiree and 28.8% on the cultivar Tigoni, within 36 days after initial detection of symptoms at the Tigoni location. The application of Ridomil (metalaxyl + mancozeb) followed by phosphite resulted in significantly ($p \leq 0.05$) lower late blight severity than the fungicidal application of metalaxyl + mancozeb by itself and mancozeb followed by phosphate; however, it did not differ significantly with plots where phosphite was applied by itself (Table 1).

Similarly, the results showed that phosphite application by itself did not differ significantly from metalaxyl + mancozeb and mancozeb followed by phosphite. The application of mancozeb and extract from stinging nettle resulted in significantly ($p \leq 0.05$) lower disease severity than the untreated plots. At Tigoni location, field

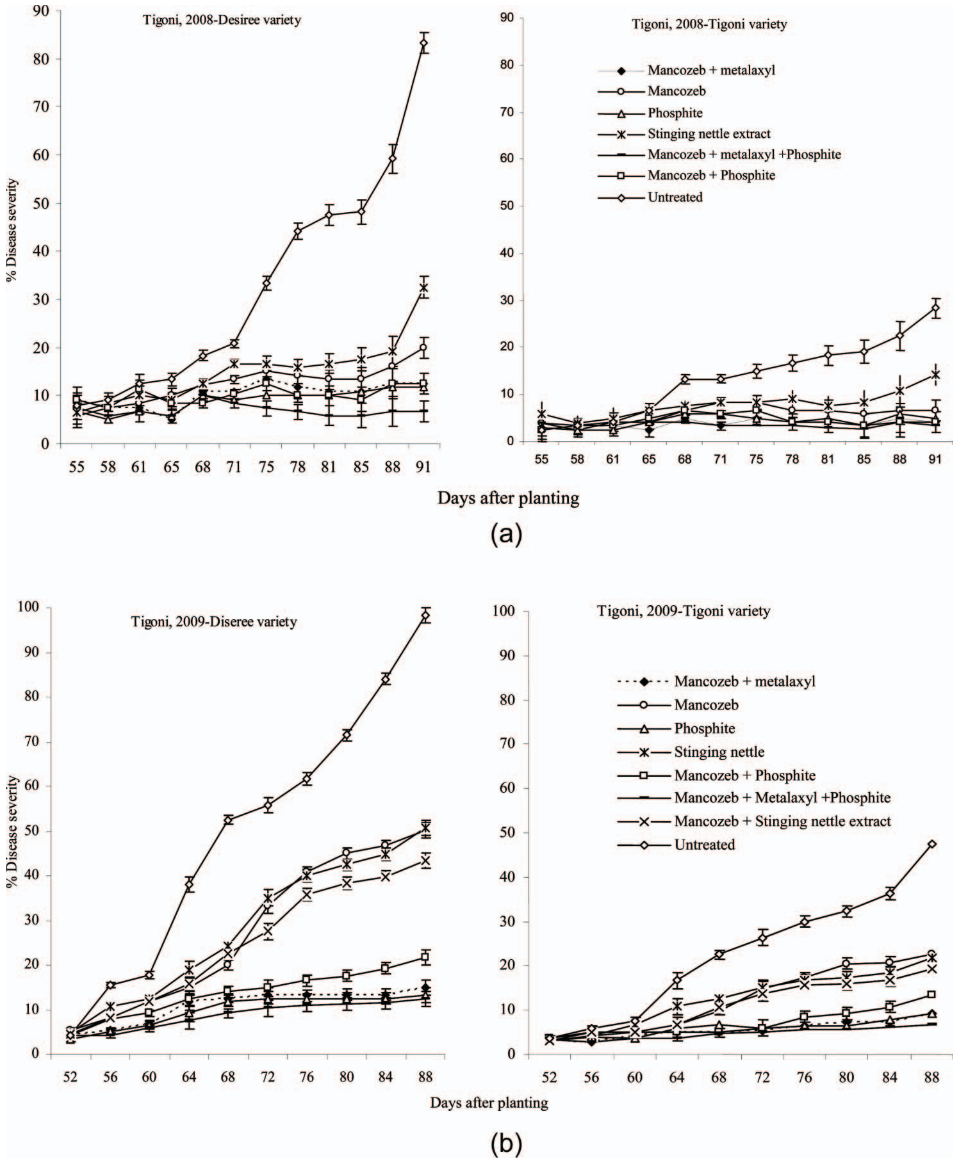

Figure 1. Progress of potato late blight (*Phytophthora infestans*) on two potato cultivars treated with fungicides, phosphate and plant extract (stinging nettle) at Tigoni location during 2008 (a) and 2009 (b) cropping years.

plots treated with mancozeb had a disease severity in the range of 12.8–27.6% compared to those plants treated with extract from stinging nettle, which had disease severity of 15.1–28.4% on Desiree, the susceptible cultivar (Table 1). However, there were no significant differences between the two treatments on the resistant cultivar. There were no significant differences between mancozeb + phosphate and mancozeb-treated plots for both potato cultivars at Tigoni site in 2008, but in 2009, the untreated plots had significantly ($p < 0.05$) higher late blight severity and RAUDC

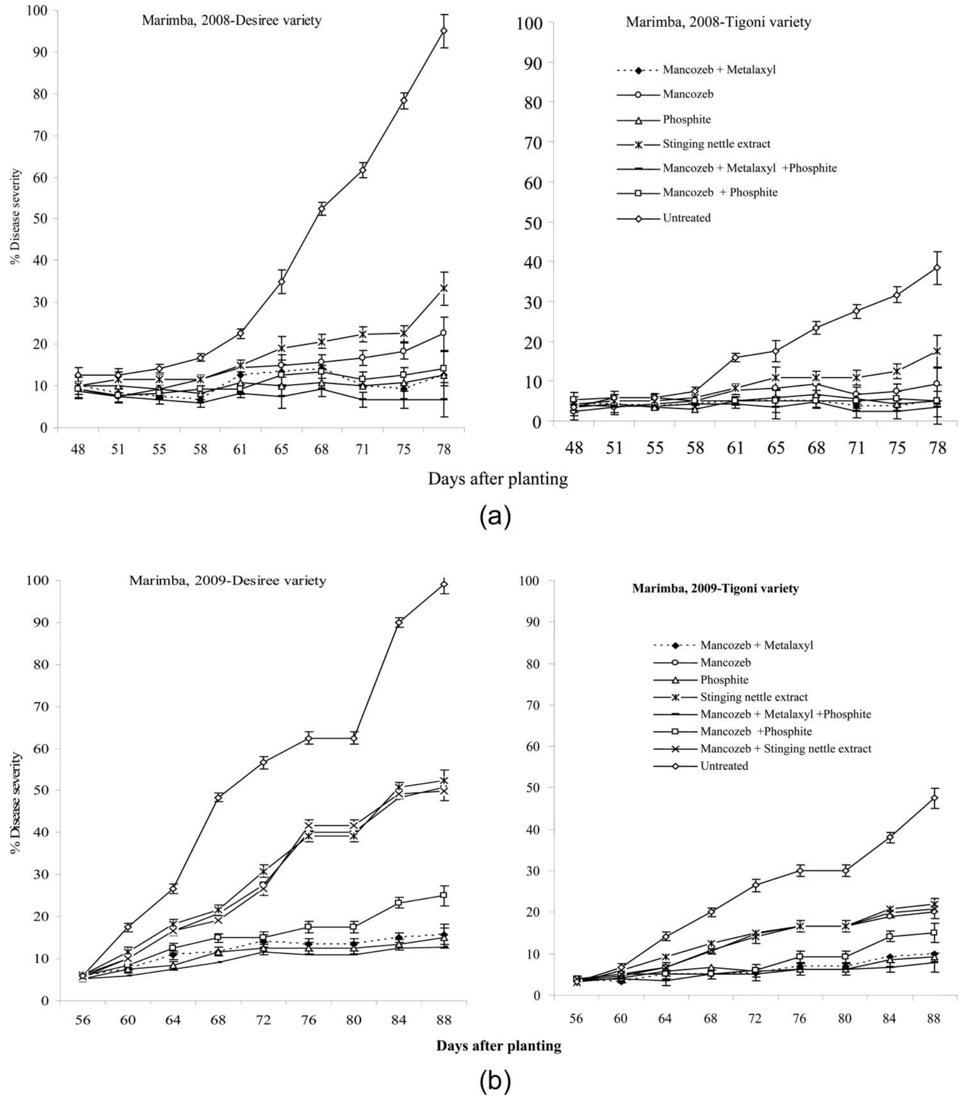

Figure 2. Progress of potato late blight (*Phytophthora infestans*) on two potato cultivars treated with fungicides, phosphate and plant extract (stinging nettle) at Marimba location during 2008 (a) and 2009 (b) cropping years.

than the rest of the treatments (Table 1). The application of metalaxyl + mancozeb followed by phosphite treatment had the least level of late blight disease at both locations (Tables 1 and 2). In 2008 cropping season, there was considerably lower disease levels at Tigoni than at Marimba. Late blight severity was significantly ($p < 0.05$) higher in 2009 compared to 2008 at the Tigoni location.

Effect of fungicides, phosphate and plant extract on lesion size and numbers

Mean lesion expansion increased on both cultivars and at both locations in all the plots during the 2 years of the experiment (Tables 3 and 4). There was a variation in

Table 1. Effects of fungicide and plant extract combinations on average disease severity (%) and relative area under disease progress curves (RAUDPC) on two potato cultivars at Tigoni location during 2008 and 2009 seasons.

	Tigoni 2008				Tigoni 2009			
	Disease severity		RAUDPC		Disease severity		RAUDPC	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	10.2	3.9	13.0	4.9	10.9	5.5	11.2	5.6
Mancozeb	12.8	5.87	15.5	7.5	27.6	12.5	27.1	12.6
Phosphite	9.0	4.4	11.3	5.6	10.0	5.9	10.3	5.8
Stinging nettle extract	15.1	8.0	18.4	9.8	28.4	12.7	28.2	13.1
Mancozeb + metalaxyl + phosphite	6.9	3.5	8.9	4.6	8.8	4.7	9.1	4.8
Mancozeb + phosphite	10.2	4.4	12.8	4.6	13.8.	7.1	14.1	7.1
Mancozeb + stinging nettle extract	–	–	–	–	24.8	11.1	25.2	11.4
Untreated	33.6	13.6	39.4	16.5	50	22.8	50.2	22.8
LSD ($p \leq 0.05$) treatment	2.7	1.7	6.6	3.2	2.4	2.1	2.6	2.2
LSD ($p \leq 0.05$) variety	0.7	0.4	2.7	2.2	1.3	1.1	1.6	1.3
% CV	9.0		7.1		2		3.1	

Table 2. Effects of fungicide and plant extract combinations on mean disease severity (%) and relative area under disease progress curve (RAUDPC) on two potato cultivars at Marimba location in 2008 and 2009 seasons.

	Marimba 2008				Marimba 2009			
	Disease severity		RAUDPC		Disease severity		RAUDPC	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	10.4	4.4	16.4	5.5	12.1	6.2	12.4	6.3
Mancozeb	14.0	6.3	17.1	11.1	29.1	13.3	24.7	12.9
Phosphite	10.2	4.6	16.2	5.8	11	6.2	11.4	6.4
Stinging nettle extract	17.8	9.1	21.5	14.3	30.5	13.7	30.4	13.9
Mancozeb + metalaxyl + phosphite	7.4	3.7	12.7	4.7	9.6	5.3	10	5.5
Mancozeb + phosphite	10.8	5.4	16.4	6.9	15.8	8.1	16.4	8.1
Mancozeb + stinging nettle extract	–	–	–	–	29	12.8	28.9	12.1
Untreated	40.1	18.0	49.1	24.3	53.2	24.5	52.5	24.1
LSD ($p \leq 0.05$) treatment	2.5	2.3	8.4	5.2	2.8	2.2	3.1	2.7
LSD ($p \leq 0.05$) variety	0.94	0.8	5.1	4.7	1.4	1.1	1.1	1.2
% CV	8.5		8.1		0.4		1.3	

lesion expansion rates in plots treated with fungicide combinations and plant extract. Potato foliage treated with metalaxyl + mancozeb (2.5 kg ha^{-1}) followed by phosphite (2.5 L ha^{-1}) had lower lesion sizes than the other treatments. At both

Table 3. Mean *Phytophthora infestans* lesion growth rate (mm/day) on two potato cultivars at Tigoni and Marimba locations.

	Tigoni 2008		Tigoni 2009		Marimba 2008		Marimba 2009	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	2.5	2.3	2.8	2.4	2.8	2.3	2.9	2.4
Mancozeb	3.4	2.3	5.7	2.9	3.7	2.7	4.3	3
Phosphite	2.7	2.1	2.8	2.5	2.8	2.4	2.8	2.4
Stinging nettle extract	4	2.9	4.3	3.2	4.3	3	4.4	3.1
Mancozeb + metalaxyl + phosphite	1.9	1.4	2.4	2.1	2.5	1.2	2.2	2.1
Mancozeb + phosphite	2.7	2.2	4.2	2.2	2.8	2.5	3.4	2.7
Mancozeb + stinging nettle extract	–	–	2.5	2.2	–	–	4.8	3..0
Untreated	6.8	3.8	8	4.4	9.2	6.2	8.4	4.5
LSD ($p \leq 0.05$) treatment	0.9	0.7	3	0.5	0.6	0.5	0.5	0.4
LSD ($p \leq 0.05$) variety	0.5	0.4	1.5	0.3	0.33	0.4	0.4	0.3
% CV	2.9		2.9		1.9		0.8	

Fungicide and plant extract combinations were applied during 2008 and 2009 cropping seasons.

Table 4. Effects of fungicides, phosphites and plant extract combinations on average number of lesions per plant quantified on two potato cultivars at Tigoni and Marimba locations in 2008 and 2009 cropping seasons.

	Tigoni 2008		Tigoni 2009		Marimba 2008		Marimba 2009	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	6.1	4.0	7.5	4.7	6.5	3.7	8	4.8
Mancozeb	9.2	5.0	15.5	8.3	10.4	5.3	16.1	8.6
Phosphite	5.6	4.0	7.2	4.6	6.8	3.3	7.8	4.9
Stinging nettle extract	11.1	8.0	16.7	8.8	13.4	8.0	17.4	9.1
Mancozeb + metalaxyl + phosphate	4.4	3.0	5.9	3.9	5.0	3.4	6.3	4.1
Mancozeb + phosphate	8.3	4.0	10.6	6.3	8.9	4.8	11.3	6.8
Mancozeb + stinging nettle extract	–	–	15.1	8.1	–	–	16.1	8.6
Untreated	21.8	12.0	29.1	16.2	23.8	12.1	30.0	16.9
LSD ($p \leq 0.05$) treatment	2.3	2.1	2.1	1.7	1.8	1.4	1.8	1.6
LSD ($p \leq 0.05$) variety	0.6	0.4	0.4	0.3	0.6	0.7	0.4	0.4
CV (%)	8.5		10.1		7		6.9	

locations, the size of lesions in treatments of metalaxyl + mancozeb by itself did not differ significantly from phosphite treatments. However, incorporating phosphite in plots treated with metalaxyl + mancozeb significantly reduced lesion expansion rate. Phosphite treatment resulted in reduced lesion expansion rate compared to mancozeb when applied on cultivar Desiree at both sites. The efficacy of mancozeb was increased when alternated with phosphoric acid (Table 3).

At both sites, the use of phosphite in combination with either metalaxyl + mancozeb (Ridomil) or mancozeb did not lead to any significant reductions in lesion size expansion on the cultivar Tigoni (Table 3). The extract from stinging nettle reduced pathogen lesion size significantly ($p < 0.05$) compared to the untreated plots. The plant extract from stinging nettle and mancozeb treatment resulted in similar lesion expansion rates at Tigoni location (Table 3). Lesion expansion rate on the cultivar Desiree was significantly greater than on Tigoni cultivar at both sites.

Pathogen lesion numbers quantified at both sites were generally low at 55–61 days after planting for all treatments but increased rapidly in plots treated with extract from stinging nettle and in the control (unsprayed) treatment. Mean lesion numbers in all treatments differed significantly ($p < 0.05$) with the control treatments on both cultivars at the two sites (Tables 3 and 4). Treatments of metalaxyl + mancozeb (Ridomil) followed by phosphite application resulted in the least number of pathogen lesions. Variation in lesion numbers was recorded in various treatment combinations of mancozeb (2.5 kg ha^{-1}), phosphite, and extract of stinging nettle extract on the cultivar Desiree. However, on the cultivar Tigoni, treatment sequence of metalaxyl + mancozeb followed by phosphite did not differ with other fungicides treatments with the exception of plant extract from stinging nettle (Table 4). At Marimba location, a similar trend was observed where treatments of metalaxyl + mancozeb followed by phosphite resulted in the lowest number of pathogen lesions on both cultivars. Lesion numbers were similar in field plots treated with either metalaxyl + mancozeb or phosphite by itself on both cultivars (Table 4). The lesion numbers were reduced in treatment of extract of stinging nettle compared to the untreated plot.

Table 5. Incidence of tuber blight (%) on two potato cultivars treated with different fungicides, phosphite, plant extract and treatment combinations during the 2008 and 2009 cropping seasons at Tigoni and Marimba locations.

	2008				2009			
	Tigoni		Marimba		Tigoni		Marimba	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	1.4	5.2	1.4	1.3	0.8	2.6	0.7	1.5
Mancozeb	3.2	7.4	1.8	3.1	1.4	3.8	1.7	2.9
Phosphite	1.4	4.3	1.1	1.1	0.7	1.4	0.7	1.1
Stinging nettle extract	4.0	7.3	2.1	4.8	1.2	2.4	1.3	2.9
Mancozeb + metalaxl + phosphite	0.5	3.3	0.8	0.8	0.5	1.3	0.3	1.0
Mancozeb + phosphite	0.7	2.8	1.5	2.5	0.9	2.6	1.1	1.9
Mancozeb + stinging nettle extract	–	–	–	–	0.4	1.2	0.8	2.0
Untreated	0.9	7.4	1.9	3.4	1.3	3.5	0.8	1.7
LSD ($p \leq 0.05$) treatment	2.5	2.1	2.1	0.3	1.4	1.2	0.9	0.7
LSD ($p \leq 0.05$) variety	1.0	0.7	0.5	0.3	0.2	0.32	0.3	0.16
CV (%)	24		36.4		11.6		8.7	

Effects of fungicides, phosphate and plant extract on tuber blight incidence

Tuber blight incidence was observed at harvest in all the treatments and at both locations (Table 5). The blight incidence on tubers was in the range of 0.7–7.4% on both cultivars during 2008. There were significant ($p \leq 0.05$) differences between the two potato cultivars in tuber blight incidence at harvest (Table 5). In 2008, tuber blight incidence on cultivar Desiree in the untreated plots differed significantly ($p < 0.05$) with the rest of the treatments (Table 5). On the cultivar Tigoni, tuber blight incidence were similar in plots treated with mancozeb, extract from stinging nettle and the untreated control. In 2009, the incidence of tuber blight ranged from 0.4 to 3.8% across cultivars at Tigoni location.

Effect of fungicides, phosphate and plant extract on tuber yield

Tuber yield varied between cultivars and years. At the Tigoni location, total tuber yield ranged from 4.8 to 19.2 and 6.6 to 21 t ha^{-1} on Desiree and Tigoni cultivars, respectively, during 2008 (Table 6). At Marimba location, the range in tuber yield was 5.3–20.1 on Desiree and 5.8–17.8 t ha^{-1} on the cultivar Tigoni (Table 6). In 2009, tuber yield at Tigoni ranged from 7.5 to 18.6 t ha^{-1} on Desiree and 9.9–26.7 t ha^{-1} on cultivar Tigoni (Table 6). Tuber yield was generally greater at Tigoni than the Marimba location. At both locations, the highest tuber yield was recorded on treatments where metalaxyl + mancozeb was followed by phosphite application. The untreated control plots had the lowest tuber yield recorded during both years. Stinging nettle extract did not result in any significant increases in tuber yield compared to the untreated control on the cultivar Tigoni but resulted in significantly higher yield on cultivar Desiree (Table 6).

All the treatments resulted in significantly ($p < 0.05$) greater marketable yield compared to the untreated plots where no fungicides or other treatments were applied (Table 7). The marketable yield generally ranged from 3.9 to 16.8 t ha^{-1}

Table 6. Effects of fungicides, phosphites, stinging nettle plant extract and treatment combinations on total yield of two potato cultivars during 2008 and 2009 cropping years.

	Total yield (t ha^{-1}) – 2008				Total yield (t ha^{-1}) – 2009			
	Tigoni		Marimba		Tigoni		Marimba	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	19.2	16.0	20.1	16.4	14.4	22.5	17.1	19.6
Mancozeb	9.1	13.5	8.8	9.7	9.0	15.3	8.6	9.9
Phosphite	15.6	17.0	14.2	18.0	15.6	24	13.7	16.2
Stinging nettle extract	7.7	12.0	7.6	8.9	11.0	15.3	8.1	9.7
Mancozeb + metalaxl + phosphite	18.3	21.0	20.1	17.8	18.6	26.47	22.7	21.9
Mancozeb + phosphite	11.8	16.0	8.8	11.1	15.7	21.5	8.9	10.7
Mancozeb + stinging nettle extract	–	–	–	–	10.2	13.4	8.8	10.1
Untreated	4.8	6.6	5.3	5.8	7.5	9.9	5.6	6.0
LSD ($p \leq 0.05$) treatment	6.8	5.8	5.9	4.8	6.7	5.2	4.5	3.6
LSD ($p \leq 0.05$) variety	0.7	0.6	1.17	1.3	2.5	1.9	1.1	0.8
CV (%)	17.1		26.3		16.5		10.7	

Table 7. Effects of fungicides, phosphites, stinging nettle plant extract and treatment combinations on marketable yield on two potato cultivars during 2008 and 2009 cropping years.

	Marketable Yield ($t\ ha^{-1}$) – 2008				Marketable Yield ($t\ ha^{-1}$) – 2009			
	Tigoni		Marimba		Tigoni		Marimba	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	16.9	13.4	18.4	15.5	13.5	20.8	16.1	18.3
Mancozeb	5.1	11.8	6.6	7.9	7.9	14	7.50	8.90
Phosphite	13.8	16.8	13.4	17	14.4	23.3	13.4	15.3
Stinging nettle extract	9.4	10.8	7.5	8.9	10.1	13.3	6.90	8.60
Mancozeb + metalaxl + phosphite	14.2	18.5	18.6	16.8	17.5	25.7	21.4	20.9
Mancozeb + phosphite	10.2	14.4	8.4	10.0	14.7	20.4	8.50	9.70
Mancozeb + stinging nettle extract	–	–	–	–	9.5	12.2	7.70	8.40
Untreated	3.9	4.8	3.8	4.3	6.9	8	3.90	4.40
LSD ($p \leq 0.05$) treatment	5.2	4.8	6.8	4.9	6.8	4.9	4.4	3.7
LSD ($p \leq 0.05$) variety	1.6	1.6	2.6	2.2	2.6	2.2	0.9	0.6
CV (%)	26.6		18.0		18.5		10	

Table 8. Effects of fungicides, phosphites, stinging nettle plant extract and treatment combinations on tuber numbers on two potato cultivars during 2008 and 2009 cropping years.

	Tuber numbers/hill – 2008				Tuber numbers/hill – 2009			
	Tigoni		Marimba		Tigoni		Marimba	
Treatments	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni	Desiree	Tigoni
Mancozeb + metalaxyl	7.5	11.0	6.3	9.3a	9.3	13	7.7	11.3
Mancozeb	4.9	8.0	4.7	6.8	6.7	8.3	6.0	8.3
Phosphite	7.7	10.0	8.33	8.7	9.7	14	8.3	10.7
Stinging nettle extract	5.8b	8.0	6.4	6.2	6.3	8	5.9	6.5
Mancozeb + metalaxl + phosphite	7.1	12.0	8.4	12.3	10.7	14.3	10.3	13.7
Mancozeb + phosphite	6.9	8.0	5.9	6.6	7.7	10.7	6.3	7.7
Mancozeb + stinging nettle extract	–	–	–	–	6.3	7.7	5.7	7.7
Untreated	4.6	6.0	3.3	4.0	5.3	6.3	4.0	4.3
LSD ($p \leq 0.05$) treatment	1.6	1.4	1.7	1.6	1.4	1.2	4.5	3.6
LSD ($p \leq 0.05$) variety	0.6	0.4	0.8	0.6	0.7	0.7	1.1	0.8
CV (%)	6.62		5.8		10.6		10.7	

across years and cultivars (Table 7). Potato crops in which metalaxyl + mancozeb and metalaxyl + mancozeb followed by phosphite application resulted in the highest marketable tuber yield of 16.93 and 18.53 in Desiree and Tigoni cultivars; respectively (Table 7). Alternating phosphite with mancozeb resulted in significantly higher marketable yield compared to plots where mancozeb alone was applied on

Desiree but not on Tigoni cultivar. Similarly, all treatments of mancozeb followed by phosphite; metalaxyl + mancozeb and metalaxyl + mancozeb followed by phosphite and phosphite alone resulted in significantly ($p < 0.05$) higher number of tubers per hill than the untreated control plants at Tigoni location (Table 8). Similar treatment effects produced significant marketable yield at Marimba location.

Discussion

The fungicide treatments reduced late blight severity and AUDPC as well as lesion size and numbers relative to the untreated control. Treatments of phosphite also resulted in reduction of late blight disease on potato relative to the untreated control. The extract from stinging nettle, however, had the least suppressive effects on late blight. Efficacy of fungicide control of late blight on potato has been previously documented in tropical environments due to their fungicidal properties (Olanya et al. 2001, 2006; Namanda et al. 2004; Nyankanga et al. 2004). Treatment combinations involving metalaxyl + mancozeb (Ridomil) and phosphite had much more effective late blight control as was evident by the lower late blight damage on treated plants compared to mancozeb or extract of stinging nettle. In general, better absorption of metalaxyl + mancozeb under various environmental conditions has been shown to be effective for control of most plant diseases incited by oomycetes (Easton and Nagle 2007).

The systemic nature of metalaxyl and its efficacy has been previously documented, particularly in populations of late blight with A1 mating type (Mukalazi et al. 2001). The relatively moderate late blight disease recorded in treatment of mancozeb suggests that protectant fungicides may have variable protectant effects on late blight under diverse conditions. In contrast to the above findings, research reports in other highland tropics showed that mancozeb can be effective in reducing the impacts of late blight (Namanda et al. 2004). The differences in disease levels between Tigoni and Marimba may be attributed to difference in weather conditions at these locations. Variation in late blight incidence and severity has been previously reported among the various locations of Kenya (Nyankanga et al. 2004; Olanya et al. 2006). The treatment of metalaxyl + mancozeb and the application of phosphoric acid had the highest suppressive effects on late blight epidemics. The enhanced disease control obtained suggests that this treatment combination (metalaxyl + mancozeb) can be most effective on late blight management. The incorporation of phosphite for late blight management subsequent to mancozeb fungicide also improved the suppressive effect of metalaxyl + mancozeb and mancozeb more than the use of mancozeb by itself on the susceptible potato cultivars.

The fungicides and phosphoric acid treatments had significant effects on pathogen lesion numbers and size compared to plant extract from stinging nettle or the untreated control. Although phosphoric acid was reported to be effective in controlling lesion development and sporulation on *P. infestans* in previous studies (Johnson et al. 2004), its effects did not differ with that of metalaxyl + mancozeb under the tropical conditions of our experiment conducted in Kenya. Lesion developments also differed between the locations of Tigoni and Marimba, perhaps due to the cooler environment at Marimba.

This study revealed that there was very little variance in the incidence of tuber blight recorded among treatments of fungicides, phosphite, and plant extract combinations at both locations and seasons. In previous research, it was observed that phosphoric acid and other protectant fungicides applied in the field prior to harvest and on harvested tubers can protect potato tubers from *P. infestans* upon subsequent inoculation (Cooke and Little 2001; Johnson et al. 2004). The same studies also demonstrated that foliar applications of phosphoric acid can reduce late blight infections occurring during the growing season (Cooke and Little 2001). Therefore, our findings are in agreement with the results of previous studies. The application of plant extract from stinging nettle did not have any significant suppressive effects on tuber blight incidence on both cultivars at harvest in our experiments and is not totally unexpected. This is similar to other previous findings in which plant extracts such as aerated compost tea and effective micro-organism mix were shown to have very little reduction in late blight disease on potato foliage (Cao and Van Bruggen 2001; Olanya and Larkin 2006; Al-Mughrabi 2007).

Variation in tuber blight incidences and disease control by fungicides in different treatments and locations has been reported in previous studies (Dorrance and Inglis 1998; Platt and Tai 1998; Nyankanga et al. 2007). It has been shown that potato tubers from field plots that are not protected by fungicides often have a lower incidence of tuber blight than do tubers from plots that have been protected due to the presence of suppressive soil conditions and other environmental factors that affect tuber blight development on potato (Andrivon 1995). This finding has been attributed to the fact that late blight epidemics on unprotected plants proceed more rapidly than disease development on fungicide-protected plants, leading to a limited sporangia from lesions which can be washed from the foliage onto tubers (shorter duration of epidemic) than for the unprotected plants. Similarly, the lack of differences in tuber blight incidence between Tigoni (resistant check) and Desiree (susceptible check) cultivars imply that foliar resistance may have limited effect on tuber blight incidence.

Potato tuber yield was significantly impacted by fungicide treatments and phosphite but to a lesser extent with the application of plant extract from stinging nettle in these experiments. Fungicides have shown grater efficacy compared to plant extracts due to their active ingredients which are often more potent for disease control compared to plant extracts. For example, successful fungicide controls for late blight and tuber yield have been documented in various studies (Fontem and Aighewi 1993; Ojiambo et al. 2001; Namanda et al. 2004). This has been attributed to fungicide protection of potato foliage, thereby increasing yield potential in treated plots compared to the untreated control plots. Alternating phosphite with mancozeb for late blight control on foliage resulted in significantly higher tuber yield than the application of mancozeb alone. This indicates that the treatment combinations can result in better blight control and tuber yield. On the contrary, the lack of significant difference in tuber yield between treatments of stinging nettle extract and the untreated control imply that the plant extract treatment had no effect on tuber yield.

We conclude that the applications of fungicides, phosphite and plant extract from stinging nettle resulted in effective management of late blight on potato. The combined use of metalaxyl + mancozeb with phosphate applications provided the best overall disease control. The stinging nettle extract, although did significantly reduce disease parameters relative to the untreated control, was overall the least effective of all treatments tested. Late blight severity, AUDPC, lesion development and pathogen lesion numbers varied between cultivars and were significantly greater on Desiree than on Tigoni cultivar at both locations. Low to moderate levels of late blight were recorded at both locations, and fungicides alone, alternating fungicides + phosphite and phosphite applications produced significantly greater late blight control compared to plant extract or the untreated control at both locations. Little variation in tuber blight incidence was detected among treatments and years; however, late blight incidence on tubers was greater on Tigoni than Desiree cultivar. Most treatments resulted in greater tuber and marketable yield compared to the untreated control.

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