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Influence of Potato Varieties and Alternate Application of Fungicides with Different Modes of Action on Potato *(Solanumtuberosum L.)* Late Blight [*Phytophthorainfestans (Mont.) de Bary*] Tuber Yield in Central Ethiopia

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Abstract

The experiment was conducted at Holetta Agricultural Research Center and on-farm at TikurEnchini during 2017 crop season to test the influence of potato varieties and alternate application of fungicides on potato late blight severity and tuber yield in three potato varieties, namely Belete, Gudene and Jalene were used as factor A, fungicide application sequences (Mancozeb, Ridomiland Trust-Cymocop) as factor B fungicide application sequences included fungicide sprays, which were applied as sole and alternate application sequences. Each plot ($9m^2$ with 40 plants per plot) consisted of six rows with 10 plants per row and with spacing of 75 cm between rows and 30 cm between plants. The spacing between plots and adjacent replications was 1 m and 2 m, respectively. The treatments were arranged in a randomized complete block design in factorial experiment with three replications. Disease severity, yield and yield-related data were collected from the four central rows of each experimental plot. The result indicated that variety, fungicide, locations and their interactions significantly reduced late blight severity and increased tuber yield and yield components. The final percent disease severity reached a maximum value of 89.17%, 83.33% and 71.67% on the unsprayed variety Belete, Jalene and Gudene, respectively. All fungicide application sequences reduced the progress of the disease as compared to unsprayed control, but TRM and RRR spray sequence highly reduced the progress of the disease as compared to other application sequences. Higher tuber yield was recorded on the variety Belete (56.84 tons ha^{-1}), followed by Gudene and Jalene. In this study, TRM and RRR spray sequence retarded late blight development consistently when combined with all varieties and the highest yields were obtained from plots sprayed with TRM and RRR spray sequences. The mean relative yield loss calculated for the control plots due to late blight ranged from 30.35 to 52.16%. The highest (298,231 ETB/ha) net benefit was maintained from Belete sprayed with TRM spray sequence. The least (73,446 ETB/ha) net benefit next to the absolute control (52,887 ETB/ha) was Jalene sprayed with TTT spray sequence. The highest (3341.7%) Marginal rate of return was maintained from Belete sprayed with TRM spray sequence. On the other hand,the lowest marginal rate of return was obtained from variety Gudene and Jalene sprayed three times with Trust-Cymocop. Therefore, application of these fungicides alone is not recommended in controlling potato late blight, especially for the tested varieties and locations. The overall results indicated that alternate application of fungicide significantly reduced late blight epidemics, improved potato productivity and profitability, thus, the fungicide application sequence is recommended for the study areas and for areas with similar agro-ecologies.

Keywords: Tuber; Cost benefit; Disease severity; Relative yield loss

Introduction

Late blight *[Phytophthorainfestans (Mont.) de Bary]* of potato *(Solanumtuberosum L.)* is by far the most destructive disease of potato and causes tremendous yield losses. The disease caused yield losses ranging from 31%-100% in Ethiopia, depending on the variety used [2]. The disease occurs throughout potato producing areas and is difficult to produce the crop during the main rainy season (June to October) without chemical protection. The disease is polycyclic, the pathogen having several cycles of infection and inoculum production during one growing season. The polycyclic nature of the pathogen forces the potato growers to apply fungicides several times in one growing season. Spray of fungicides up to 15–20 times per growing season was reported, depending on the climatic conditions and intensity of the potato cultivation, to protect the crop from late blight [1]. However, repeated application of fungicides slows down the disease suppression potential due to adaptation and gradual loss of sensitivity of the targeted pathogen population to the fungicide in addition to increase in production costs and environmental risk. Many fungicides, including contact and systemic chemicals, are available to manage potato late blight and farmers are using them many times to protect their crops. Currently there is a tendency of development of resistant fungal physiological races due to use of systemic fungicides]. The use of fungicides with different modes of action along with host resistance is the best strategy to delay buildup of resistance by the pathogen to applied fungicides. Theoretical arguments, practical experiences and experimental evidences all indicate that the build-up of fungal resistance to fungicides is greatly favored by the sustained, sole use of fungicides with specific mechanisms of action. It is therefore important that only the most effective fungicides within the most efficient programs are recommended and used [2].Therefore, the objective of this study was to determine the influence of potato varieties and alternate application of fungicides with different modes of action on potato late blight severity and tuber yield in central Ethiopia.

Materials and Methods

Description of the experimental site

The experiment was conducted under rain fed conditions at Holetta Agricultural Research Center and at TikurEnchini on-farm in central Ethiopia during the 2017 main cropping season. Holetta Agricultural Research Center is located at 9º00'N, 38º30'E at an altitude of 2400 Meters Above Sea Level (m.a.s.l.). TikurEnchini is located at 8.84º00'N, 39.67º30'E at an altitude of 2477 (m.a.s.l.).

Experimental materials and procedures

Three potato varieties, namely Belete, Gudane and Jalene that have been recommended for central highland production of Ethiopia, were employed in the study. Two fungicides, Ridomil Gold (Metalaxyl +Mancozeb) andTrust-Cymocop(Cymoxanil+CopperOxychloride), both of which are systemic, and the contact fungicide Mancozeb, along with the three potato varieties were used as treatments. Fungicide spray application was started as soon as the potato late blight symptom was observed on the foliage in the field (Table 1).

Name of	Accession	Year of release	Altitude	Tuber yield	
Variety	Code		(m.a.s.l.)	Research	Farmer's
				Field	Field
Belete	CIP-393371.58	2009	1600-2800	47.2	28.0-33.8
Gudene	CIP-386423.13	2006	1600-2800	29	21
Jalene	CIP-37792-5	2002	1600-2800	40.3	29.1

Table 1: Description of potato varieties used for the experiment at Holetta and TikurInchiniin 2017 crop season.

Treatments and experimental design

The treatments included two factors: the first factor was potato varieties with three levels [(Belete (resistant), Gudene (Moderately susceptible) and Jalene (Susceptible)]; and the second factor included exchangeable sequence of three fungicides (Ridomil Gold, Mancozeb 85% WP and Trust Cymocop). A total of 21 treatment combinations were arranged in a factorial experiment in a Randomized Complete Block Design (RCBD) with three replications using the abovementioned three potato varieties in combination with three fungicide sprays alternating with one another at each spray sequence and three sole fungicide application sequences (six fungicides alternate and sole fungicide application sequences and a control) [3]. Therefore, there were two factors, viz. potato varieties and fungicide sprays alternating with one another at each spray sequence and also spraying individually each fungicide at all intervals for each variety, which was compared with three unsprayed control plots of each variety [4].

Experimental field management

The gross plot size was 3 × 3 m=9 m, which accommodated four rows with 10 plants per row and thus 40 plants per plot. Medium-sized and well-sprouted potato tubers of the three selected potato varieties were planted on prepared ridges of four rows per plot at spacing of 75 cm between rows and 30 cm between plants [5]. The spacing between plots and adjacent replications was 1 m and 2 m, respectively. Fungicide application was started when disease symptom was visiblein the field. Subsequent spray was made at 7 and 14 days' interval for the contact (Mancozeb) and systemic (Ridomil Gold, and Trust-Cymocop) fungicides, respectively. The plots were managed properly as per the recommendation for potato production.

Data collection

Disease severity: It was assessed based on percent leaf area infected by using key for assessing severity of late blight under field conditions.

Area under disease progressive curve and disease progress rates: The effect of variety and fungicide combinations on disease severity data was integrated into Area Under Disease Progress Curve (AUDPC)

$$\mathrm{AUDPC} = \sum_{ni=1}^{n-1}([0.5(x_{i+1} + x_i)(t_{i+1} - t_i)]$$

Where n is the total number of assessments, ti is the time of the ith assessment in days from the first assessment date, xi is percentage of disease severity at ith assessment. AUDPC was expressed in percent-days because the severity (x) was expressed in percent and time (t) in days.

The rates of disease progress in time was determined by recording the severity of late blight at 7 days interval from the appearance of the first disease symptoms (35DAP) till the maturity of the crop in the different treatments. During harvest, Marketable tuber yield was determined by weighting tubers free from diseases, insect pests, and greater than or equal to 20 g in weight harvested from the net plot area [6]. Unmarketable tuber yield was determined by weighting tubers as diseased, insect attacked and small-sized (<20 g) harvested from the net plot area. Total tuber yield was determined by sum of the weights of marketable and unmarketable tubers from the net plot area.

Relative yield loss (LYL): The percent tuber yield loss was computed using the formula

% RYL=[(YP-YT)/YP] × 100

Where RYL=Relative percent tuber yield loss

YP=Yield from the maximum protected plot

YT=Yield from other treated plots (Robert and James, 1981).

Cost benefit analysis

Cost benefit analysis was done using the current price of potato and fungicides in the local market. The current price of Mancozeb was

ETB 180 kg^{-1} (ETB 540 ha^{-1}), Ridomil Gold MZ 68 WG was ETB 650 kg^{-1}(ETB 1950 ha^{-1}) and Trust Cymocop 439.5 WP was ETB 500 kg^{-1} (ETB 750 ha-1) and the price of potato was ETB 6000/ton. Costs that varied (price of each chemical, labor spent to spray and time taken to fetch water) were used to calculate the partial budget] (CIMMYT 1988).

Gross average marketable tuber yield (AvY): It is an average yield of each treatment.

Adjusted yield (AjY): It is the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers.

AjY=AvY- (AvY*0.15)

Gross Field Benefit (GFB): It was computed by multiplying field/ farm gate price that farmers received for the crop when they sold it as adjusted yield.

GFB=AjY*field/farm gate price for the crop

Total cost: It is the cost of fungicide treatment for the experiment. The costs of other inputs and production practices, such as labor cost for land preparation, planting, weeding, and harvesting were considered remained the same or considered as insignificant among treatments.

Net Benefit (NB): It was calculated by subtracting the total costs from gross field benefits for each treatment.

NB=GFB – total cost

Marginal Rate of Return (MRR%): It was calculated by dividing change in net benefit by change in cost as follows.

$$MRR = \frac{\Delta NB}{\Delta TC} X100$$

Where, MRR is marginal rate of returns, ΔNB is difference in net benefit compared with the control, ΔTC, difference in total input cost compared with the control.

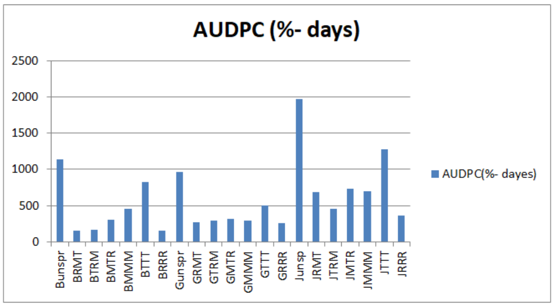
Data analysis

Data were subjected to analysis of variance (ANOVA) to determine the treatment effects. Combined analysis was performed for the two locations due to homogeneous error variances. All the data analyses were done using the Statistical Analysis System (SAS) Version 9. Least Significant Difference (LSD) at 5% probability level was used for mean separation [7].

Results and Discussion

Effects of fungicide and variety on disease severity and audpc

The combined analysis of disease severity and AUDPC showed highly significant (p ≤ 00200.001) differences among interactions of potato varieties and fungicide application sequences (data not shown). The final disease severity was reached at the maximum of 89.17, 83.3 and 71.67% on the unsprayed variety Belete, Jalene and Gudene, respectively. All fungicide application sequences reduced the progress of the disease as compared to unsprayed control, but TRM and RRR spray sequence highly reduced the progress of the disease compared to other application sequences. The highest AUDPC value showed on susceptible variety, Jalene followed by Belete and Gudene [8]. The lowest AUDPC values (150.4, 151.3 and 168-% unit-days) observed on variety Belete sprayed with RRR, RMT and TRM spray sequence, respectively, while the highest AUDPC value (1965.83%unit-days) showed from unsprayed variety Jalene. TRM, RMT and RRR spray sequence did not significantly differ from each other with respect to mean AUDPC value reduction on this variety; however, all the three fungicide spray sequences significantly reduced mean AUDPC value as compared to unsprayed plots. Thus alternate fungicide application with TRM spray sequence combined with variety Belete effectively reduced mean AUDPC values [9]. The current findings confirmed that using the systemic fungicide Ridomil alone and Ridomil and Mancozeb applied sequentially was more effective in lowering severity of late blight than the sole use of the protecting fungicide Mancozeb (Figure 1).



B = Belete; G = Gudene; J = Jalene; M = Mancozeb; R = Ridomil Gold ; T = Trust-Cymocop applied with the indicated sequence in the three successive sprays.

Figure 1: Area Under Disease Progress Curve (AUDPC) of late blight in relation to varieties of potato and fungicides.

Effects of late blight on average tuber weight

The combined analysis of average tuber weight showed highly significant (p≤0.01) differences among interactions of potato varieties and fungicide application sequences(data not shown). Highest (91.6g) average tuber weight was obtained on the variety Belete followed by Gudene and Jalene. Application of TRM spray sequence gave highest average tuber weight as compared to other treatments (Table 2).

Treatment		AUDPC	ATW	MY	TY
Variety	Belete	455.35	91.6	47.02	56.84
	Gudene	414.64	57.23	26.54	35.57
	Jalene	883.01	57.22	21.35	29.37
LSD		66.3	5.4	0.65	2.4
Fungicide	RRR	258.28	71.48	38.2	47.4
	MMM	482.1	73	33.9	43.5
	TTT	867.2	57	23.2	31.9
	RMT	370	73.5	33	41.4

	TRM	305.28	81.1	38.6	47.5
	MTR	452.5	70.9	33.6	43.7
	Control	1354.8	53.6	20.7	28.6
LSD	LSD	101.3	8.3	3.2	3.7
CV%		26.1	18.4	15	13.8

(AUDPC), Average Tuber Weight (ATW), Marketable Yield (MY) and Total Yield (TY).

LSD (0.05)=Least/*significant difference at P ≤ 0.05, M=Mancozeb 80 WP, R=Ridomil Gold MZ 68 WG, T=Trust-Cymocop 439.5 WP applied with the indicated sequences in the three successive sprays.

Table 2: Effect of fungicides and varieties on area under disease progress curve.

The results were suggested that superiority of TRM spray sequences in controlling late blight and improving average tuber weight as compared to the other treatments. Variety Belete combined with TRM fungicide application sequence gave highest (108.98 g) average tuber weight as compared to varieties Gudene and Jalene [10]. On the other hand, the lowest average tuber weights was obtained on variety Jalene unsprayed plot(Table 3) (Figures 2 and 3).

Varieties	Fungicide	DS	AUDPC	ATW	MY	TY	RYL (%)
Belete	RMT	17.50gh	151.25i	105.79a	49.18b	58.67b	11.8
	TRM	14.17ghi	168i	108.97a	59.26a	66.52a	0
	MTR	20.00fg	306.58ghi	96.22ab	51.11b	63.26ab	4.9
	MMM	40.83d	455fg	98.24ab	49.48b	60.15ab	9.58
	TTT	81.67ab	820.67de	71.68cde	35.26c	46.37c	30.29
	RRR	8.33i	150.42i	85.43cb	52.59b	62.37ab	6.24
	Control	89.17a	1135.5bc	74.58cd	32.30cd	40.59cde	38.98
Gudene	RMT	12.50ghi	273.58hi	55.93e-h	26.22efg	35.11d-g	18.14
	TRM	10.83hi	291.17ghi	64.04def	31.11cde	41.48cd	0
	MTR	15.83ghi	316.42ghi	57.14e-h	27.56d-g	37.48def	9.64
	MMM	10.00hi	291.75ghi	61.70d-g	29.34def	37.93def	8.56
	TTT	29.17e	503.08f	47.91fgh	19.41hi	26.67hi	23.65
	RRR	11.67hi	263.17hi	68.28de	32.44cd	41.48cd	0
Gudene	Control	71.67c	963.33cd	45.64gh	19.70hi	28.89ghi	30.35
Jalene	RMT	26.67ef	685.33e	58.78d-g	23.70gh	30.67gh	10.78
	TRM	15.00ghi	456.67fg	70.30cde	25.48fg	34.37efg	0
	MTR	34.17de	734.5e	59.35d-g	22.37gh	30.37gh	11.64
	MMM	34.17de	699.58e	59.17d-g	22.96gh	32.45fgh	5.59
	TTT	75.00bc	1277.92b	51.51fgh	14.96ij	22.82ij	33.62
	RRR	10.00hi	361.25fgh	60.74d-g	29.63def	38.52def	-12.06
Jalene	Control	83.33a	1965.83a	40.76h	10.37j	16.45j	52.16
LSD (0.05)	---	7.76	174.4	16.45	5.6	6.43	---

AUDPC, Average Tuber Weight (ATW), Marketable Yield (MY), Total Yield (TY) and Relative Yield Loss (RYL) .

Means within the same column followed by the same letter(s) are not significantly different, LSD (0.05)=Least Significant Difference at P≤0.05, M=Mancozeb 80 WP, R=Ridomil Gold MZ 68 WG, T=Trust-Cymocop 439.5 WP applied with the indicated sequence in the three successive sprays.

Table 3: Interaction effect of alternate fungicide application sequences and potato varieties.

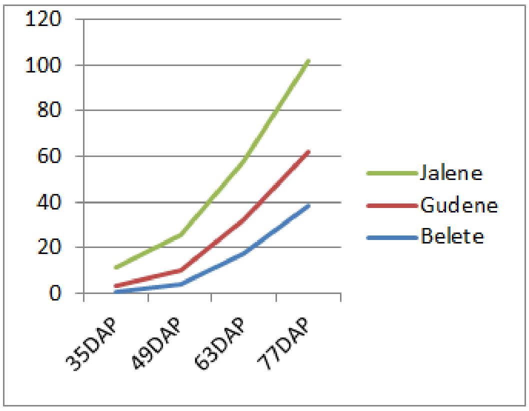
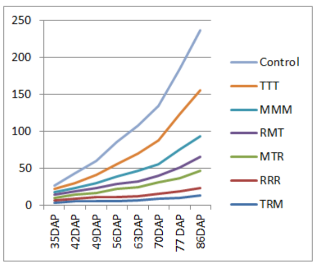


Figure 2: Disease progress curves of potato late blight severity on potato varieties; DAP=Days After planting.



DAP= Days After Planting; M = Mancozeb; R=Ridomil Gold ; T=Trust-Cymocop applied with the indicated sequence in the three successive sprays

Figure 3: Effect of fungicides on disease progress curves of potato late blight percentage. Severity.

Effects of late blight on marketable tuber yields

The combined analysis of marketable yield showed that significant (p<0.01) differences among interactions of varieties and fungicide application sequences(data not shown). Highest marketable tuber yield of 47.02 (t ha^{-1}) was recorded on the variety Belete, followed by Gudene and Jalene. Application of RRR and TRM fungicide spray sequences increased marketable yield of potato and gave highest tuber yields as compared to other treatments. On the combination of varieties and fungicides application sequences ,the mean marketable tuber yields ranged from 32.3 t ha^{-1}in unsprayed plots of variety Jalene to 59.26 t ha^{-1}in variety Belete sprayed with TRM spray sequence. Thus combination of alternate fungicide application with TRM spray sequence and variety Belete effectively suppressed the disease and increased marketable tuber yield per hectare as compared to the other spray sequences and varieties [11]. The current findings confirmed that alteration of fungicide applications, instead of single fungicide, proved more effective in reducing late blight infection and increasing yield than untreated control plots.

Effects of late blight on total tuber yield

The combined analysis of total tuber yield data showed highly significant (p 0.001) dif ferences among interactions of potato varieties and fungicide application sequences(data not shown). Higher tuber yield of 56.84 t ha^{-1} was recorded on the variety Belete, followed by Gudene and Jalene. Application of TRM and RRR spray sequences gave the highest total tuber yields as compared to other treatments [12]. On the combination of varieties and fungicides application sequences, the mean total tuber yields ranged from 16.45 ha^{-1} to 66.52 t ha^{-1}on unsprayed plot of variety Jalene and variety Belete sprayed with TRM spray sequence. The highest (66.52 t ha-1) mean marketable tuber yield was obtained from the variety sprayed with TRM spray sequence as compared to other treatments. Thus combination of resistance potato variety Belete and alternate fungicide application with TRM spray sequence effectively protect the disease and increased tuber yield [13].

Relative yield losses

The potato tuber yield loss that was incurred due to late blight severity following each fungicide spray sequence was calculated relative to the tuber yield of the maximum protected plots, i.e. TRM spray sequence with 66.52, 41.48 and 34.37 t ha^{-1} for the varieties Belete, Gudene and Jalene, respectively. The highest (52.16%) level of yield losses occurred in the unsprayed plots of susceptible variety Jalene followed by BeleteGudene as compared to the best protected plots sprayed with TRM spray sequence. The result is in agreement with previous report that the average estimated losses due to late blight ranged from 30 to 75% on susceptible cultivars. Thus use of alternate fungicide application sequence combined with resistance variety potentially reduces losses due to late blight.

Cost-benefit analysis

The data analysis indicated that TRM spray sequence gave the highest 3544.6, 1942.40 and 1440.93% marginal rate of return on the varieties Belete, Jalene and Gudene, respectively. The data analysis indicated that the highest (298,231 ETB/ha) net benefit was maintained from Belete sprayed with TRM spray sequence. Moreover, Belete sprayed with RRR, MTR, MMM, and RMT spray sequence also gave promising net benefit with mean value of 261,759; 256,666; 248,178 and 246,823 ETB/ha, respectively. The least (73,446 ETB/ha) net benefit next to the absolute control (52,887 ETB/ha) was obtained from variety Jalene sprayed with TTT spray sequence with mean. The highest (3341.7%) Marginal rate of return was maintained from Belete sprayed with TRM spray sequence. In other words, investing one Ethiopian Birr (ETB) to apply TRM spray sequence on the variety Belete provided 33.41 extra net benefits in ETB. On the other hand,the lowest marginal rate of return was obtained from variety Gudene and Jalene sprayed three times with Trust-Cymocop. Therefore, application of these fungicides alone is not recommended in controlling potato late blight, especially for the tested varieties and locations. Moreover, other fungicide spray sequences gave promising Marginal rate of return. The present investigation does not agree with the previous study result mentioned since the cost-benefit ratios were higher for susceptible than for resistant varieties, suggesting that fungicide applications were more profitable in susceptible varieties than in resistant ones. This might be due to the genetic yield potential difference of the tested improved variety. On the other hand,the lowest 460.84, -156.84 and 769.68%) marginal rates of return were obtained from plots sprayed three times with Trust-Cymocopon the varieties Belete, Gudene and Jalene, respectively. Therefore, application of this fungicide alone is not recommended for managing potato late blight, especially for the tested varieties in the specific study locations.

Conclusion

The present field data provided empirical evidences that the combination of varieties and fungicide spray sequence influenced potato late blight severity and the amount of tuber yield losses attributed to potato late blight. Alternate fungicide application sequence had retarded late blight development consistently when combined with all varieties and the highest yields were obtained from plots sprayed with TRM spray sequence. Higher tuber yield was recorded on the variety Belete followed by Gudene and Jalene. Economic analysis revealed that the highest net benefit was obtained from Belete when sprayed with TRM spray sequence and the least were obtained from Jalene unsprayed plot. The present study has determined that an application of TRM spray sequence combined with resistance variety Belete was more economical and feasible for the management of potato late blight and increases tuber yields markedly. The present findings can benefit farmers through increased potato production and productivity and can increase farmers' income in the study areas and other locations with similar agro-ecologies. Further research is appealing with more number of potato varieties and several contact and systemic fungicides application sequences in multi-locations to come up with reliable and realistic recommendation for integrated late blight management and sustainable potato production in Ethiopia and elsewhere.

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