

Research Article

Integrated Management of Late Blight Potato (*Phytophthora infestans*, (Mont) de Bary) Disease through Potato Varieties and Fungicides in Lay-Armachiho District, Ethiopia

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Potato (*Solanum tuberosum* L.) is an important source of livelihood for smallholder farmers of north-western Ethiopia. However, its productivity is markedly low due to late blight disease caused by *Phytophthora infestans*. The objective of this study was to evaluate the integrated use of potato varieties and fungicides for the management of late blight disease. Field experiment was conducted in Lay-Armachiho district during the main potato cropping season of 2018. The experiment consisted of twelve treatments as factorial combinations of two synthetic fungicides (Ridomil and Mancozeb) and untreated check with four potato varieties (three improved varieties, namely, Jalene, Gudene, Belete, and Local variety) was laid out in RCBD design with three replications. Disease incidence, severity, AUDPC, yield, and yield components were analyzed using SAS software (version 9.1) at $P < 0.05$ to separate treatment means. Fungicide sprayed treatments significantly reduced late blight epidemics and increased potato tuber yield on the Belete variety. The lowest disease severity (38.50%) and AUDPC values (761.02% unit-days) were recorded on Belete variety when sprayed with Ridomil fungicide. Late blight disease severity, incidence, AUDPC, and disease progress rate were reduced more in Belete variety than in the other three varieties. The highest disease severity (91.40%) and lowest yield (10.63 ton-ha⁻¹) were recorded from the local control plot with a clear significance difference as compared to other treated plots. This study revealed that the application of Ridomil fungicide with the combination of Belete variety was effective in controlling late blight potato disease with the highest cost-benefit advantage.

1. Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in many countries of the world in terms of quantities produced [1] and it is the third most important crop in terms of consumption after wheat and rice [2]. Potato has a significant impact on providing nutrition to families, increasing household income and employment opportunities [3]. Potato is an excellent smallholder farmer's crop in the highlands, with about 3-4 months cropping cycle and used to attain food security during the "hungry months" before the grain crops being harvested in Ethiopia [3, 4].

Ethiopia is among the top potato producers in Africa, with 70% of its arable land in the high altitude areas above 1500 m.a.s.l being suitable for potato production [5]. However, currently, only 2% of the potential area in Ethiopia is under potato production and the average productivity of potatoes is less than 10 tons per hectare [6]. The same is true for the Amhara Region where most of the agricultural land suitable for potato is located in the range from 1800 to 2500 m.a.s.l altitude and receive annual rainfall of more than 600–1,200 mm [7].

In Ethiopia, the total area coverage of potato is nearly 0.18 million hectares from which 1.62 million ton is harvested and the national average productivity of potato in

Ethiopia is 8 tons·ha⁻¹, which is below the African continent average (10.8 tons·ha⁻¹) [8, 9]. About 600,000 rural households in the Amhara region are involved in potato production and the area covered by potatoes is as high as 70,000 ha and the average productivity of 4.8 tons·ha⁻¹ which is very low compared to the national average productivity (8·tons ha⁻¹) [8].

A number of production problems account for the low yield of potato production in Ethiopia: namely, the absence of well-adapted varieties, shortage of high-quality seed potatoes, inadequate storage and marketing facilities and problems of disease are economically important [10]. Among the diseases, late blight is the most devastating and destructive disease of potatoes in areas where potatoes are grown [11]. Late blight potato disease (*Phytophthora infestans*) is the most devastating and causes 50–70% potato yield loss under favorable environmental conditions [12].

At a global level, the major approach to preventing late blight disease development has been through the application of fungicides and the use of resistance varieties [13]. The use of contact and systemic fungicides for managing late blight has perhaps been the most studied aspect in temperate countries [14]. In tropical Africa, however, the use of fungicide application and relatively resistance variety response relationships have not been well investigated. Excellent control of the late blight disease was achieved through the use of phenyl amide fungicides, like Ridomil and Mancozeb across the Sub-Saharan Region [15, 16]. Use of fungicides like Metalaxy in controlling the disease was found to boost potato yield in various East African countries [15]. Different varieties of potatoes treated with different fungicide frequencies showed a significant difference in disease, yield, and yield components [17]. Much remains to be done on the management of potato late blight in Ethiopian conditions. Hence, the objective of this work was to identify effective management options for late blight (*Phytophthora infestans*) disease on different potato varieties together with effective fungicide sprays in the Lay-Armachiho District of Northwest Ethiopia.

2. Materials and Methods

2.1. Description of the Study Site. The study was conducted in the North Gondar zone, Lay-Armachiho district, Kerker Balegizabeher Kebele during main cropping rainy season (June-October) of 2018. The experimental site is located at 12°49'N latitude, 37°28'E longitudes, and situated at an average altitude of 2,057 m.a.s.l. The area receives an average annual rainfall of 1,785 mm and the mean annual minimum and maximum temperatures are 10°C and 31.5°C respectively [18]. In the study area, potato is the major crop and the soil is sandy loam, well-drained with different stratification of sub-soil and the areas are suitable for potato production and late blight pressure is generally high during the rainy season.

2.2. Treatments and Experimental Design. The field experiment was carried out in twelve treatments with the combinations of four potato varieties (Jalene, Gudene,

Belete, and local) and two foliar-applied fungicides (Ridomil MZ 68% and Mancozeb 80% WP) and untreated treatments were used. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications in a factorial arrangement of thirty-six plots. Gross plot size was 7.2 m² (2.4 m × 3 m). The total area of the experimental site was 317.1 m² (10.5 m × 30.2 m). The varieties (Jalene, Gudene, and Belete) were obtained from Adet Agricultural Research Center (AARC) and one local potato variety was purchased from the local market. Spacing between plants and rows were 30 and 75 cm, respectively. Eight plants were planted per row and four rows per plot were arranged for evaluating varieties' resistance and fungicide efficacy. Each plot and block were separated by 1 and 1.5 m, respectively in order to minimize fungicidal drifts between treatments during the spraying of fungicides. The first disease symptoms appeared in all varieties on 45 days after planting (DAP). The data recording started at 52 DAP as after seven days of the first spray of fungicides and then continued for every 7 days intervals with each fungicide applied at five times spray frequencies until the varieties attained physiological maturity. The fungicides (Mancozeb80% WP and Ridomil68%MZ) were applied at 3 kg·ha⁻¹ [19] according to manufacturer recommendations using a manual knapsack sprayer at 7 days interval. DAP and Urea were applied at the planting and vegetative stage at the rate of 195 kg/ha and 165 kg/ha, respectively [20]. Agronomic practices were carried out as necessary and as per the recommendation of Adet Agricultural Research Center (AARC).

2.3. Data Collection

2.3.1. Disease Assessment. Disease assessments of potato late blight were made at 7-day intervals from the center of two middle rows of each plot; with the initial data being collected at 52 DAP following the first fungicide application and continued until the variety reached physiological maturity (80DAP).

2.3.2. Disease Incidence. Disease incidence was assessed on each experimental plot by randomly selecting five plants in the middle of two rows. The percent of disease incidence was calculated by the following formula:

$$\text{disease incidence} = \frac{\text{number of diseased plant}}{\text{total number of plant assessed}} \times 100. \quad (1)$$

2.3.3. Disease Severity. Disease severity was recorded by estimating the percentage of leaf area affected by randomly selecting five plant leaves from the central two middle rows of each plot and scoring them using a one-to-nine point scale according to Shutong et al. [21]:

$$\text{disease severity (\%)} = \frac{\text{sum of individual numerical ratings}}{\text{no. of plants scored} \times \text{maximum score on scale}} \times 100. \quad (2)$$

2.3.4. *Area under the Disease Progress Curve (AUDPC)*. AUDPC values were calculated for each plot using the formula described by Campbell and Madden [22].

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5 (x_i + 1 + x_{i+1}) (t_{i+1} - t_i), \quad (3)$$

where X_i is the cumulative disease severity expressed as a proportion at the i^{th} observation, t_i is the time (days after planting) at the i^{th} observation, and n is total number of observations. AUDPC values were expressed in percent-days.

2.3.5. *Disease Progress Rate*. The disease progress rates (r) were calculated for each plot by using the procedures of Campbell and Madden [22].

2.3.6. *Assessments of Yield and Yield Components*. Potato tubers were harvested at maturity level from each plot's two central rows and then sorted out into marketable and unmarketable tubers depending on the presence or absence of blighted tubers. In addition, the weights of marketable, unmarketable, and total potato tuber per plot were measured and translated to tons per hectare ($\text{ton} \cdot \text{ha}^{-1}$).

2.3.7. *Relative Yield Loss (%)*. This is the crop value lost due to late blight potato disease damage, and it was calculated by comparing the yields of protected and unprotected plots and converting the value to a percentage base using Robert and James [23] formula as follows:

$$\text{RYL (\%)} = \frac{\text{YP} - \text{YUP} \times 100}{\text{YP}}, \quad (4)$$

RYL is the relative yield loss (reduction of the parameters yield and yield component), YP is the mean of the corresponding parameter on protected plots (plots with maximum protection), and YUP is the mean of the respective parameter in unprotected plots (unsprayed plots).

2.3.8. *Cost-Benefit Analysis*. The cost-benefit analysis of each treatment was conducted in part, and the marginal rate of return (MRR) was calculated by taking into account the variable costs associated with each treatment. To compare the benefits of different potato varieties and types of fungicides used in the treatment combinations, yield, and economic data were computed. The economic data were calculated from the crop's tuber yield, which was converted to a hectare basis using the local market price of potato ($6 \text{ birr} \cdot \text{kg}^{-1}$) at harvest in 2018. Based on the collected data, cost-benefit analysis was performed using the partial budget analysis [24] formula as follows:

$$\text{MRR} = \frac{\text{DIC}}{\text{DNI}}, \quad (5)$$

where MRR is the marginal rate of returns, DNI is the difference in net income compared with control, and DIC is the difference in input cost compared with control.

2.4. *Statistical Data Analysis*. Data on potato late blight incidence, percentage severity index, yield, and yield components were calculated separately. ANOVA was performed using the general linear model (GLM) procedure of SAS software [25]. The least significant difference (LSD at 5%) was used to separate treatment means. Correlation analysis was performed to determine the association of disease parameters of different varieties and types of fungicide applications.

3. Results and Discussion

3.1. *Disease Incidence*. Potato late blight disease symptoms were first appeared 45 days after planting (DAP) in almost all treatments after flowering and the fungicides spray was started at this time. This result agreed with the findings of Gebremariyam et al. [26] that the first symptom appeared on susceptible variety *Abalo* within 41 days after planting. The first disease incidence data were recorded after 7 days of the spray of the fungicide (52 DAP) and continued until the end of the final disease incidence data of 80DAP. The interaction effects of varieties and fungicide applications showed significant differences among treatments ($P < 0.05$) in the initial and final disease incidence. During the onset of the disease, the highest (29.20%) incidence was recorded on the local control variety which was significantly different from other treatments. On the first appearance of the disease, lower initial disease incidence of 10.40%, 6.30%, and 2.10% were recorded on treatments of Jalene with Ridomil, Belete with Mancozeb and Belete with Ridomil treatments respectively, and they were significantly different from the other treatments (Table 1). Similar findings were observed with Fekede [27] who reported that late blight potato disease incidence was higher in susceptible local potato variety at initial and final disease assessment.

ANOVA results indicated that the final disease incidence was significantly different ($P < 0.05$) among treatments. The maximum final percentage of disease incidence of 81.20, 79.20, and 77.10% were recorded by the local control variety, local variety treated with Mancozeb, and untreated Gudene variety, respectively. The minimum final disease incidence of 31.30% was recorded from the Belete variety treated with Ridomil followed by the Belete variety treated with Mancozeb (47.90%) (Table 1). Application of Ridomil and Mancozeb fungicides on all varieties except the local potato variety significantly ($P < 0.05$) reduced the progress of the foliage infection of late blight on final disease incidence development (Table 1). However, Ridomil significantly ($P < 0.05$) reduced the progress of the disease as compared to Mancozeb fungicide on Jalene and Belete varieties. Similarly, Gebremariam

TABLE 1: Interaction effects of fungicides and potato varieties on late blight disease incidence.

Variety	Fug.	52DAP	59DAP	66DAP	73DAP	80DAP
Local	NO	29.20 ^a	47.93 ^a	62.50 ^a	72.93 ^a	81.20 ^a
	MM	22.93 ^b	35.46 ^{cb}	54.20 ^b	68.80 ^{ba}	79.20 ^{ba}
	RR	20.86 ^b	37.53 ^b	47.96 ^{cb}	62.50 ^{bc}	72.93 ^{bdc}
Jalene	NO	18.80 ^{cb}	35.46 ^{cb}	43.76 ^{cde}	60.43 ^{dc}	70.86 ^{edc}
	MM	14.60 ^{cd}	27.17 ^{ced}	39.60 ^{de}	52.10 ^{fe}	58.36 ^g
	RR	10.43 ^{ef}	25.03 ^{ed}	37.53 ^{fe}	43.70 ^g	50.03 ^h
Gudene	NO	20.86 ^b	35.40 ^{cb}	45.86 ^{cd}	62.50 ^{bc}	77.10 ^{bac}
	MM	14.60 ^{cd}	33.33 ^{cbd}	43.76 ^{cde}	54.20 ^{dfe}	62.53 ^{gf}
	RR	12.50 ^d	33.33 ^{cbd}	41.70 ^{cde}	47.93 ^{gf}	64.60 ^{egf}
Belete	NO	18.80 ^{cb}	35.40 ^{cb}	43.76 ^{cde}	56.26 ^{dce}	66.70 ^{dfe}
	MM	6.26 ^{ef}	18.76 ^{fe}	31.30 ^f	41.70 ^g	47.93 ^h
	RR	2.10 ^f	10.43 ^f	18.80 ^g	27.10 ^h	31.26 ⁱ
Significancee (0.05%)		ns	ns	*	*	**
LSD (0.05) 7.7 (0.05)		8.06	10.08	7.85	6.33	7.85
CV (%)		21.5	19.1	10.9	6.9	7.3

Ns = non significant at $P < 0.05$ (%) or $P < 0.01$ (%); * and ** means within the same column followed by the same letter(s) are not significantly different at $P < 0.05$ (%) and $P < 0.01$ (%) respectively. LSD = least significant difference, CV (%) = coefficient of variation, Var. = variety, Fug = fungicide, DAP = days after planting, NO = control, MM = mancozeb and RR = ridomil fungicide.

et al. [26] also reported that late blight incidence was higher in susceptible local potato varieties than in resistance varieties, and fungicides application significantly reduced late blight incidence as compared to local control plots. Our results are in line with Shiferaw and Tesfaye [28] who reported that the application of fungicides minimized the infection of late blight than the control plots. On the other hand, our findings disagree with Ashenafi et al. [29] who reported that late blight disease incidence reached a maximum of 91.5% on unsprayed control susceptible Jalene variety.

3.2. Disease Severity. The interaction effect of fungicides and varieties on late blight severity showed a significant difference ($P < 0.05$) among treatments. The maximum initial potato late blight disease severity was observed on the local variety with a mean value of 31.13% followed by the local variety treated by Mancozeb and Ridomil fungicide of 23.90 and 23.30%, respectively. While the local untreated and treated, Gudene and Jalene varieties with untreated plots were significantly different from the Belete variety treated with Ridomil and Mancozeb fungicides (Table 2). The minimum initial potato late blight disease severity of 8.60% was observed on the variety of Belete treated with Ridomil and followed by 9.80% disease severity on Belete treated with Mancozeb fungicide. Admasie et al. [17] reported the final disease assessment the highest percent severity index (PSI) (84.76%) was recorded on the unsprayed plots of Jalene, and also the lowest (26.03%) PSI was recorded on plots treated with combinations of the variety Belete treated with Ridomil. Shiferaw and Tesfaye [28] also confirmed that the combination of host resistance variety and fungicide spraying played a significant role to reduce the severity of late blight on the potato crop. Our finding was in agreement with Subhani et al. [14] who reported that Ridomil was most effective for the control of potato late blight after disease appearance.

3.3. Disease Progress Rate. The highest disease progress rate (0.1 units per day) was recorded on untreated plots of the local variety. Whereas all the other treatments except the Belete variety treated with Ridomil fungicide recorded 0.08 units per day (Table 3). The lowest (0.01 unit per day) infection rate was recorded on the Belete variety treated with Ridomil fungicide. Similar finding has been reported by Admasie et al. [17]. The disease developed faster on untreated and treated varieties differently with both fungicides except the Belete variety treated with Ridomil fungicide. This finding was similar to that of Tsedaley [16] who reported that the highest disease progress rates were recorded on untreated plots of varieties and the disease was developed faster on susceptible potato varieties than on moderately resistant varieties. Generally, it was found that the development of late blight or disease progress rate and tuber yield losses of potato varieties could be minimized by integrating Belete potato variety with Ridomil fungicide applications. Similarly, Ermias [30] suggested that the integration of resistance host (Belete potato variety) with Ridomil fungicide reduces the late blight disease progress rate.

3.4. Area under Disease Progress Curve (AUDPC). The highest AUDPC value (1702.17% days) was recorded on control plot treatment whereas the lowest AUDPC values (761.02 and 928.78% days) were recorded on Belete variety treated with Ridomil and Mancozeb fungicides respectively (Table 4). Similarly, Admasie et al. [17] reported lowest AUDPC values of 661.73% days were obtained from the Belete variety treated with Ridomil application. The results of the present study were also similar to Binyam et al. [31] who reported that the highest value of AUDPC indicated the highest disease development on plots that were not treated with any combinations of variety and fungicide applications. Values of AUDPCs varied depending on the variety and the types of fungicide application and plots treated with fungicide had the lowest AUDPC values while

TABLE 2: Interaction effects of fungicides and potato varieties on late blight disease severity.

Variety	Fun.	52DAP	59DAP	66DAP	73DAP	80DAP
Local	NO	31.13 ^a	46.83 ^a	60.33 ^a	74.33 ^a	91.40 ^a
	MM	23.90 ^b	40.23 ^{bac}	55.13 ^{b^a}	65.36 ^{bc}	78.73 ^b
	RR	23.30 ^b	42.40 ^{ba}	55.73 ^{ba}	69.73 ^{ba}	75.23 ^{cb}
Jalene	NO	16.90 ^c	42.40 ^{ba}	54.30 ^{bac}	62.60 ^{bcd}	71.30 ^{cd}
	MM	13.16 ^{de}	38.50 ^{bdc}	48.33 ^{edc}	58.66 ^{ecd}	68.66 ^d
	RR	12.66 ^{de}	31.40 ^d	43.06 ^e	53.43 ^e	62.33 ^e
Gudene	NO	22.60 ^b	40.23 ^{bac}	55.63 ^{ba}	65.70 ^{bc}	78.06 ^b
	MM	14.33 ^{dc}	37.73 ^{bdc}	47.53 ^{ed}	56.80 ^{ed}	68.16 ^{ed}
	RR	12.93 ^{de}	35.01 ^{dc}	45.96 ^{ed}	55.50 ^{ed}	67.70 ^{ed}
Belete	NO	15.00 ^{dc}	37.83 ^{bdc}	50.73 ^{bdc}	59.96 ^{cd}	70.43 ^{cd}
	MM	9.80 ^{fe}	22.23 ^e	35.96 ^f	44.00 ^f	51.16 ^f
	RR	8.60 ^f	19.76 ^e	29.33 ^g	36.06 ^g	38.50 ^g
	Significance	ns	*	*	*	**
	LSD (0.05)	3.44	7.13	6.10	7.41	6.00
CV (%)	12	11.6	7.4	7.5	5.2	

Ns, *, ** non-significant or significant at $P < 0.05$ (%) or $P < 0.01$ (%) respectively, means within the same column followed by the same letter(s) are not significantly different at $P < 0.05$ (%); LSD = least significant difference, CV (%) = coefficient of variation, Var. = variety, Fug = fungicide, DAP = days after planting NO = control, MM = mancozeb and RR = ridomil fungicide.

TABLE 3: Linear regression statistics' used evaluation of linear logistic growth model.

Treatment	R^2	MSE	St. dev. int.	Rate parameter	St. dev slope
Local untreated	94.4	0.28	-6.56	0.10	0.48
Local + mancozeb	96.7	0.16	-5.60	0.08	0.29
Local + ridomil	96.6	0.16	-5.21	0.08	0.28
Jalene untreated	87.6	0.33	-5.60	0.08	0.58
Jalene + mancozeb	89.2	0.32	-6.07	0.08	0.56
Jalene + ridomil	90.3	0.27	-5.78	0.08	0.48
Belete untreated	90.2	0.30	-5.96	0.08	0.53
Belete + mancozeb	91.4	0.25	-6.09	0.08	0.45
Belete + ridomil	91.7	0.05	-5.51	0.01	0.50
Gudene untreated	96.5	0.17	-5.63	0.08	0.30
Gudene + mancozeb	88	0.3	-5.82	0.08	0.57
Gudene + ridomil	90.1	0.30	-6.14	0.08	0.53

R^2 = coefficient of determination, MSE = mean square error, st. dev of int = standard deviation of intercept, st. dev of slope = standard deviation of slope.

untreated (control) plots had the highest values. ANOVA results showed that AUDPC values were significantly different (0.05%) among the interaction of variety and fungicide application (Table 4). The results of the present study were consistent with the report of Mesfin and Gebremedhin [32] who reported that moderately resistant varieties had the lowest AUDPC when supplemented with a fungicide treatment.

3.5. Effects of Fungicide on Yield and Yield Components.

The highest overall mean percent tuber infection was observed on control plots of local variety whereas the least tuber blight infection was shown on Belete variety sprayed with Ridomil and Mancozeb fungicides (Table 5). Significant variations ($P < 0.05$) were observed among the yields obtained from plots that received different treatments (Table 5). The highest potato yield of 37.48 and 34.71 t/ha was obtained from Belete variety plots treated with Ridomil and Mancozeb fungicides respectively. These yields were significantly different from the yields of other treatments. This finding was in agreement with Ermias [30] finding indicating Belete variety treated with Ridomil resulted in reduced disease progress with a corresponding

increase of total and marketable tubers' weight. Shiferaw and Tesfaye [28] also revealed that the highest marketable yield was obtained from moderately resistant variety (Belete) treated with Matco fungicide. On the other hand, the lowest yield (10.63 t/ha) was recorded by untreated local variety, which was significantly different from the plots of Jalene, Gudene and Belete varieties treated with Mancozeb and Ridomil fungicides. Similarly, Admasie et al. [17] reported that the lowest tuber yield was obtained from untreated plots of all varieties.

3.6. Relative Yield Loss. The highest levels of yield loss of 24.60, 19.46, 44.20, and 54.34 ton ha⁻¹ occurred on the untreated plots of local, Gudene, Jalene, and Belete varieties respectively as compared to the best-protected plots sprayed with Ridomil fungicide. The least relative yield losses of 11.41, 9.70, 0.04, and 7.39 ton·ha⁻¹ were obtained on varieties of local, Gudene, Jalene, and Belete respectively sprayed with Mancozeb fungicides (Table 6). Generally, higher yield loss was recorded on plots that were not treated with any fungicide. Similar results have been reported by Gudero [33] whereby the late blight of potato causes tuber yield losses of 21.71–45.8% and 29–57% for local and

TABLE 4: Interaction effects of fungicides and potato varieties on late blight AUDPC.

Variety	Fungicide	AUDPC
Local	NO	1702.17 ^a
	MM	1482.25 ^b
	RR	1522.03 ^b
Jalene	NO	1423.80 ^{cd}
	MM	1304.92 ^{cd}
	RR	1161.77 ^e
Gudene	NO	1481.90 ^b
	MM	1283.18 ^{ed}
	RR	1238.18 ^{ed}
Belete	NO	1338.75 ^{cd}
	MM	928.78 ^f
	RR	761.02 ^g
	Significance	*
	LSD (0.05)	135.72
	CV (%)	6.18

* significant at $P < 0.05$ (%), means within the same column followed by the same letter(s) are not significantly different, LSD = least significant difference at (0.05%), CV (%) = coefficient of variation, NO = control, MM = mancozeb and RR = ridomil.

TABLE 5: Interaction effect of different fungicides application and potato varieties on yield and yield components.

Variety	Fungicide	MY (t/ha)	UMY (t/ha)	TY (t/ha)
Local	NO	2.30 ^h	8.33 ^a	10.63 ^f
	MM	5.78 ^g	6.71 ^{ba}	12.49 ^{fe}
	RR	7.63 ^{gf}	6.47 ^{bac}	14.10 ^{dfe}
Jalene	NO	9.48 ^{ef}	6.01 ^{bc}	15.49 ^{dcf}
	MM	22.22 ^c	5.55 ^{bc}	27.75 ^b
	RR	23.14 ^c	4.62 ^{dc}	27.76 ^b
Gudene	NO	8.33 ^{gf}	6.94 ^{ba}	15.27 ^{dce}
	MM	11.57 ^{ed}	5.55 ^{bc}	17.12 ^{dc}
	RR	14.34 ^d	4.62 ^{dc}	18.96 ^c
Belete	NO	12.03 ^{ed}	5.08 ^{bdc}	17.11 ^{dc}
	MM	31.25 ^b	3.46 ^{ed}	34.71 ^a
	RR	35.647 ^a	1.843 ^c	37.48 ^a
Significance	***	ns	***	
LSD (0.05%)	2.84	2.00	3.98	
CV (%)	11.01	21.93	11.32	

ns, *** non significant or significant at $P < 0.05$ (%) or $P < 0.01$ (%) respectively, means within the same column followed by the same letter(s) are not significantly different at $P < 0.05$ (%) LSD = least significant difference, CV (%) = coefficient of variation, MY = marketable yield, UMY = unmarketable yield, TY = total yield, t/ha = ton per hectare, NO = control, MM = mancozeb and RR = ridomil fungicide.

susceptible varieties in Ethiopia. The results of this study are consistent with the reported range of yield loss estimates due to late blight on susceptible varieties [34]. In Ethiopia, tuber yield losses due to late blight ranged from 31 to 100%, depending on the variety used [35]. The disease can absolutely destroy a crop, producing a 100% crop loss for unimproved local cultivars [36].

3.7. Association of Yield and Disease Parameters. Correlation among final severity, incidence, AUDPC, and total yield was important since the change of either of the parameters influenced the response of the other during the

TABLE 6: Interaction effects of fungicide and potato variety on relative yield loss of late blight potato disease.

Variety	Fungicide	MY (t/ha)	UMY (t/ha)	TY (t/ha)	RYL (%)
Local	NO	2.30 ^h	8.33 ^a	10.63 ^f	24.60 ^{bc}
	MM	5.78 ^g	6.71 ^{ba}	12.49 ^{fe}	11.41 ^{dc}
	RR	7.63 ^{gf}	6.47 ^{bac}	14.10 ^{dfe}	0.00 ^d
Jalene	NO	9.48 ^{ef}	6.01 ^{bc}	15.49 ^{dcf}	44.20 ^{ba}
	MM	22.2 ^c	5.55 ^{bc}	27.75 ^b	0.04 ^d
	RR	23.14 ^c	4.62 ^{dc}	27.76 ^b	0.00 ^d
Gudene	NO	8.33 ^{gf}	6.94 ^{ba}	15.27 ^{dce}	19.46 ^c
	MM	11.57 ^{ed}	5.55 ^{bc}	17.12 ^{dc}	9.70 ^{dc}
	RR	14.34 ^d	4.62 ^{dc}	18.96 ^c	0.00 ^d
Belete	NO	12.03 ^{ed}	5.08 ^{bdc}	17.11 ^{dc}	54.34 ^a
	MM	31.25 ^b	3.46 ^{ed}	34.71 ^a	7.39 ^{dc}
	RR	35.64 ^a	1.84 ^e	37.48 ^a	0.00 ^d
Significance	***	ns	***	ns	
LSD (0.05%)	2.84	2.00	3.98	17.04	
CV (%)	11.01	21.93	11.32	21.74	

ns, *** non significant or significant at $P < 0.05$ (%) or $P < 0.01$ (%) respectively, means within the same column followed by the same letter(s) are not significantly different at $P < 0.05$ (%); LSD = least significant difference, CV (%) = coefficient of variation, MY = marketable yield, UMY = unmarketable yield, TY = total yield, t/ha = ton per hectare, NO = control, MM = mancozeb and RR = ridomil fungicide.

experiment. The correlation analysis indicated that disease incidence had a positive and highly significant correlation with disease severity and AUDPC; whereas it had a negative and highly significant correlation with yield as indicated in (Table 7). In general, total yield (ha^{-1}) had a negative and highly significant correlation to both disease severity and incidence (Table 7). Similar results have been reported by Admasie et al. [17] and Fekede [27].

There was a negative effect of potato late blight on the total yield and a decline in yield was correlated with an increase in foliar late blight disease (Table 7). AUDPC and final severity were positively and highly significantly correlated ($P < 0.01$, $r = 0.96^{**}$). Similar findings have been reported by Gebremariam et al. [26] and Ayda [37]. In most cases, the negative correlation of total yield with late blight development was found to be stronger with the final severity than with AUDPC. Yield and final severity were negatively and highly significantly correlated ($P < 0.01$, $r = -0.89^{**}$) indicating the negative effects of late blight on the total yield of potato varieties. Gebremariam et al. [26] also reported that all disease parameters had a negative correlation with tuber yields of potatoes. Applying Mancozeb and Ridomil fungicides gave the highest yield, lowest late blight incidence, severity, progress rate, and AUDPC values for the respective potato varieties. Untreated treatments of the respective variety gave the least yield and highest late blight severity incidence and AUDPC values (Table 7). Similar results were reported by Getachew et al. [38].

3.8. Cost-Benefit Analysis. Ridomil sprayed fungicides had the highest total cost, while the unsprayed plots had the lowest cost (Table 8). On the other hand, partial budget analysis indicated that all fungicide sprayed varieties gave

TABLE 7: Association analysis between disease parameters and yield on potato varieties.

Parameters	Severity	Incidence	Total yield	AUDPC
Severity	—	—	—	—
Incidence	0.900**	—	—	—
Total yield	-0.895**	-0.893**	—	—
AUDPC	0.960**	0.891**	-0.892**	—

AUDPC = area under disease progress curve, ** = highly significant ($P < 0.01$).

TABLE 8: Partial budget analysis for fungicide treated and untreated plots in controlling late blight of potato main cropping season.

Variety	Fung.	MY (tha ⁻¹)	P (Br·t ⁻¹)	SR (Brha ⁻¹)	TIC (Brha ⁻¹)	MC (Brha ⁻¹)	NP (Brha ⁻¹)	MNB (Brha ⁻¹)	MRR (%)
Local	NO	2.07	6,000	12,420	0	0	12,420	0	0
	MM	5.2	6,000	31,200	900	900	30,300	17,880	1,986.7
	RR	6.86	6,000	41,160	1,200	1,200	39,960	27,540	2,295
Jalene	NO	8.5	6,000	51,228	0	0	51,228	0	0
	MM	19.99	6,000	119,988	900	900	119,088	67,860	7,540
	RR	20.83	6,000	124,992	1,200	1,200	123,792	72,564	6,047
Gudene	NO	7.50	6,000	45,000	0	0	45,000	0	0
	MM	10.42	6,000	62,520	900	900	61,620	16,620	1,846.7
	RR	12.91	6,000	77,460	1,200	1,200	76,260	31,260	2,605.2
Belete	NO	10.83	6,000	64,980	0	0	0	0	0
	MM	28.12	6,000	168,720	900	900	167,820	102,840	11,426
	RR	32.08	6,000	192,480	1,200	1,200	191,280	126,300	10,525

MY = marketable yield, P = price, SR = sale revenue, TIC = total input cost, MC = marginal cost, NP = net profit, MNB = marginal net benefit, MRR = marginal rate of return, NO = control, MM = mancozeb and RR = ridomil fungicide, Brha⁻¹ = (birr per hectare), tha⁻¹ = (ton per hectare).

high gross field benefit and marginal rate of return. Belete variety showed the maximum total gross yield benefit from plots treated with Ridomil fungicide followed by the same variety treated with Mancozeb (Table 8). Significant maximum marketable tuber yield and highest net benefit were reported from the Belete variety when Matco fungicide was used [28].

Lower gross yield benefit was obtained from the local variety treated with Ridomil and Mancozeb fungicides which were highly susceptible to late blight disease. Variation in net benefit had been observed among the varieties. Belete variety treated with Ridomil fungicide showed the highest net profit with a marginal rate of return (MRR) 10525%. In general, the highest net benefit and MRR were recorded on the Belete variety followed by Jalene and Gudanie varieties treated with Ridomil and Mancozeb fungicides. All Untreated varieties and local varieties treated with both fungicides showed the lowest MRR record (Table 8).

4. Conclusion and Recommendation

Late blight is an important disease that calls for better attention to achieve economic management with fungicides and varieties. The variety Belete appears to have outstanding resistance to potato late blight disease and is a promising variety against late blight. The present study suggested that the application of variety Belete with Ridomil fungicide spray resulted in reduced late blight disease progress, with a correspondingly increased total and marketable yield. Generally, the integration of Belete variety and application of Ridomil fungicide was effective, instead of using single

management options, can substantially suppress potato late blight, thereby minimizing the cost of production, giving maximum net benefit, and avoiding the risk of fungicide resistance development.

Data Availability

All the data are included in the manuscript itself.

Conflicts of Interest

The authors declare that they do not have any conflicts of interest.

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