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ORIGINAL RESEARCH ARTICLE

Evaluation of interaction effect of Fungicides and Potato (*Solanum tuberosum* L) Varieties against Late Blight (*Phytophthora infestans*), Disease in Chilga District, Central Gondar, Ethiopia

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ABSTRACT

Potato is the fourth most important food crop in the world. Late blight potato disease is the major bottleneck problem in the Chilga district. **This study was designed** to find out the integrated use of potato varieties and fungicides for the management of late blight disease. Three improved varieties (Belete, Jalenie, Gudenie) and one local variety combined with two fungicides (Agro-Laxyle MZ 63.5WP, Cozaxyle 72% WP) were used as a treatment combination. The experiment was laid out in Randomized Complete Block Design (RCBD) in factorial arrangement with three replications. Data on first disease symptom appearance date, disease incidence, percentage severity index, and disease progress rate were recorded according to standard procedures. The highest (98.15%) percentage severity index and the lowest (4.53 t ha^{-1}) marketable tuber yield were obtained from the highly susceptible local varieties untreated plots, while the lowest (22.59%) percentage severity index and the highest (41.63 t ha^{-1}) marketable tuber yield were obtained from the relatively resistant Belete variety treated with Cozaxyle72% WP fungicide. **This study showed** the relatively resistant Belete variety treated with Cozaxyle 72% WP fungicide was more economical and feasible for the management of late blight potato disease and increased yield markedly.

Keywords: Fungicide, Incidence, Late blight, Management, Potato, Resistance

INTRODUCTION

Interims of human consumption Potato (Solanum tuberosum L) is the fourth most important food crop in the world next to rice, maize, and wheat in terms of human consumption (FAO, 2019). It is the world's third most important food crop in production after rice and wheat and it is also a food security crop (Devaux et al., 2014). Hundreds of millions of people in developing countries depend on potatoes for their survival. Potato is essential for the survival of hundreds of millions of people in developing countries. Potato farming is booming in developing countries, where the potato's low cost of production and high nutritional value have made it valuable food security and cash crop for millions of farmers. The world's largest producers and importers of are currently developing countries (FAO, 2019).

Potato is one of the most important foods and cash crops and also become an important garden crop for low-income farm households (FAO, 2019). Potato is produced mainly in the northwestern, central, and eastern highlands of Ethiopia. The northwestern part of the country which mainly includes the highlands of the west Amhara sub-region is the major production area. The sub-region makes up over one-third of the total area allotted to potato production nationally. According to CACC (2003), the area covered by potatoes in the region may be as high as 70,000 ha. Potato is the most important food and cash vegetable crop in and around the Chilga districts. The crop is a staple food and cash crop that mitigate seasonal food shortage. Moreover, since the area is close to the Metema Ethio-Sudan border, it has a high market opportunity through border trade (Tesfaye Abebe, 2007).

However, many factors limit potato yield in Ethiopia. These factors include lack of improved varieties, excessively high temperatures, insect pests, diseases of which fungal, viral and bacterial wilt diseases appear to be significant constraints (Adane et al., 2010; Bekele et al., 2011). Among these diseases, late blight is one of the most important, notorious, and widespread phytopathogenic fungal diseases caused by Phytophthora infestans mainly during the main cropping seasons. Late blight is a destructive disease in vegetable crops including potatoes in Ethiopia (Hijmans et al., 2000; Mesfin 2009) with yield losses ranging from 31 to 100% depending on the variety used (HARC, 2007). Late blight is a major limitation to potato production in high humid elevations; with estimated average yield losses of about 30 to 75% on susceptible varieties (Olanya et al., 2001). Research centers have made estimates of losses ranging from 6.5 to 61.7%, depending on the level of susceptibility of the varieties. Ecological factors that can lead to poor yield also include technical limitations such as poor land preparation, lack of high-yielding varieties that can adapt to different climate conditions, poor harvest management, and bad post-harvest management (Belehu, 2003).

Integrated pest management (IPM) is a broad-based approach that integrates practices for the economic control of pests. Improved crop protection strategies to prevent such damage and loss can increase production and make a substantial contribution to food security (Yitagesu, 2019). In addition to the benefits of reducing yield losses due to epidemics of late blight pathogen, the combined use of fungicide with resistance varieties can also contribute to reducing the health risks associated with high fungicide applications, environmental contamination, and increasing the economic benefit to farmers. Metalaxyl belongs to phenylamides, a group of systemic fungicides with a preventive and curative activity that is limited to Oomycetes (Abdelhak et al., 2016).

Therefore, this study was undertaken to evaluate the resistance of potato varieties against late blight disease, determine the interaction effect of fungicides and potato varieties on late blight disease, and assess the relative yield loss of potato varieties due to late blight disease and its cost-benefit analysis.

MATERIAL AND METHODS

Experimental site description

The experiment was conducted in the Chilga district, Central Gondar administrative zone, Northwestern Ethiopia; at *Serako* kebele administration during June – October 2018 main cropping season. Chilga district is located about 45km southwest of Gondar town. Chilga district is located at latitude 12° 44'59.99" N and longitude 36°39' 59.99" E. The average annual minimum and maximum temperature of the district ranges from 13.33ºC to 23.04ºC. The dominant soil in the district is clay loamy soil. The land under cultivation in Chilga is 47,188 hectares, of which 3,400 hectares are used for potato production (Chilga District Agricultural Office, 2018). The location represents the major potato production area of the district. The experiment was conducted on farmer fields with an altitude of 2261masl and unimodal rainfall. According to Chilga meteorological data annual rainfall of the study area ranges from about 800mm to 1175 mm.

Experimental treatments and design

The experiment was laid out in Randomized Complete Block Design (RCBD) in factorial arrangement with three replications. The treatments consisted of three potato varieties (Belete, Gudenie, Jalenie) and local check in combination with two types of fungicides ((Cozaxyle 72% WP (Metalaxyle 8%+ Mankozeb 64%) and Agro-laxyle MZ 63.5% WP (Metalaxyle 75g/kg + Mancozeb 560g/ kg)) and untreated plots.

Experimental plot size 9m^2 (3× 3m) with plant spacing of 0.75 × 0.3m between row and plants respectively (Mohammad *et al*., 2013). The total number of experimental plots was 36 plots. The spacing between plots and blocks was 1m and 1.5 m respectively. The fungicide application was started 43 days after planting (DAP) during the first appearance of late blight disease symptoms. The fungicides were applied as per the recommendation of the manufacturers using the knapsack sprayer. The fungicides (Agro-laxyle MZ 63.5WP and Cozaxyle72 % WP) were applied at the rate of 3 and 2.5 kg ha^{-1} respectively using 600 liters of water based on the recommendation level. Two consecutive sprays were done at 14 days intervals and the last spray was done 57 days after planting (DAP). Land preparation was done in late May 2018 four times by using ox plows and human labor. Seed tubers were medium-sized (35–55 mm) sprouting seed tubers that are free of disease infection and were planted manually on June 7, 2018. Fertilizer NPS was used as a phosphorus source and Urea was used as a nitrogen source, at rates of 180 and 117kg ha-1, respectively. The NPS was applied once at planting time, while the Urea was applied in three splits, at planting time, at first weeding June 28, 2018, i.e 21 Days After Planting (DAP), and at second weeding July 13, 2018 (36 DAP) as a side dressing as recommended by researchers (Adet Agricultural Research Center, 2017). All agronomic practices such as weeding and cultivation were kept uniform for all treatments in each plot (Gebremedhin *et al*., 2008; Amin *et al*., 2013).

Disease assessment

Disease incidence was assessed on each experimental plot with 10 randomly selected and pre-tagged plants in the middle two rows and plants showing symptoms of the disease were counted and expressed in percentage (%). The percent of disease incidence was calculated as the following formula (Habtu and Abiye, 1997).

$$\text{Disease Incidence (\%)} = \frac{\text{Number of Infected Plants}}{\text{Total number of assessed Plants}} \text{X } 100$$

Disease severity was recorded by estimating the percent of leaf area affected by pre-tag 10 plant leaves from the central two middle rows of each plot and by using a 1-9 point scale as suggested by Henfling (1987). The first disease severity data were recorded at 43 DAP before the first sprays of fungicides and continued until the variety attained physiological maturity (85 DAP). Severity grades were converted into percentage severity index (PSI) for analysis using the formula suggested by Wheeler (1969):

$$\text{PSI (\%)} = \frac{snr}{Npr \times Mss} \times 100$$

Where, PSI = percentage severity index, Snr = the sum of numerical ratings, Npr = number of plants rated, and Mss = maximum score of scale

Table 1. Henfling modified disease estimation scale for late blight of potato (Henfling, 1979)

Grade	Varietal response	% incidence	Nature of Infection (Level of Resistance / Suscepti-bility)
0	HR	0.0	No disease
1	R	10%	Small lesions on the inoculated point with the lesion area less than 10% of the whole leaflet
3	MR	10% - 20%	Lesions area between 10% and 20% of the whole leaflet
5	MS	20% - 30%	Lesion area between 20% and 30% of the whole leaf-let
7	S	30% -60%	Lesion area between 30% and 60%
9	HS	Over 60%	Lesion area over 60% of the whole leaflet

The disease progress rates (r) were calculated based on the linearized logistic model and the calculated value was analyzed (Vander Plank, 1963; Campbell and Madden, 1990).

$$r = \frac{\left(\mathrm{Ln}\frac{X}{1-X}\right)-\left(\mathrm{Ln}\frac{Xo}{1-Xo}\right)}{t}$$

Where, r = infection rate, Xo = initial disease severity, X = final disease severity, t is the duration of the epidemic, and Ln = Natural logarithm.

Area under Disease Progress Curve (AUDPC)

The AUDPC value was measured for the level of late blight disease attack (Andrivon *et al.,* 2006). To obtain the AUDPC, disease readings were taken based on the percentage of leaf area affected by late blight and it was frequently calculated using the midpoint formula (Campbell and Madden, 1990):

Where t is the time of i^{th} assessment, y is the

$$\mathrm{AUDPC}(\%/\mathrm{day}) = \sum_{i=1}^{n-1}\left(\frac{yi + yi + 1}{2}\right)(ti + 1 - ti)$$

percentage of affected foliage at i^{th} assessment and n is the total number of disease assessments. The variable “t” can represent days after planting.

Potato yield

Marketable yield (t ha^{-1}) of potato tubers was calculated from all harvested tubers which were free from disease and with a size of greater than 25mm (Tekalign and Hammes, 2005). **Unmarketable yield** (t ha^{-1}) of potato tubers was calculated as the tubers which were diseased and those having tuber size less than 25mm.

Data analysis

Data on first disease symptom appearance date, disease incidence disease percentage severity index, disease progress rate, AUDPC, marketable yield, and unmarketable yield of potato tuber were calculated separately. Analysis of variance (ANOVA) was performed using the general linear model (GLM) procedure of SAS software (SAS, 2018). The least significant difference (LSD at 5%) was used to separate treatment means.

RESULTS

Disease Incidence

Results of data on potato Late blight potato disease incidence showed a very highly significant ($P < 0.001$) difference among the interaction effects of potato varieties treated with two types of fungicides and including untreated plots starting from 50 up to 85 DAP. At 50 days after planting the highest (66.67%) disease incidence was recorded on the local variety of untreated plots. Whereas, the lowest (0.00%) disease incidence was recorded on the variety Belete untreated and treated with fungicides. On the final recording day (85 DAP), the lowest (36.67%) late blight potato disease incidence was recorded on the variety Belete treated with Cozaxyle 72% WP fungicide, and significantly different from other treatments, and followed by (73.33%) disease incidence was recorded on the variety Belete treated with Agro-laxyle and Jalenie treated with Cozaxyle fungicide. Fekede (2011) also reported that late blight incidence was higher in susceptible local potato varieties than in resistance varieties and the fungicide application significantly reduced late blight disease incidence as compared to local control. Mukalazi *et al.* (2001) also reported that late blight incidence on susceptible potato varieties could be high. Hence, fungicides must be used to ensure disease control in moderately resistant varieties (Table 2).

Table 2. Interaction effects of fungicides and potato varieties on late blight disease incidence.

Disease incidence (%)							
Treatments		50 DAP	57 DAP	64 DAP	71 DAP	78 DAP	85 DAP
Belete	Control	0.00^{e}	0.00^{g}	0.00f	43.33^{de}	73.33^{b}	100.00^{a}
	Agro-laxyle	0.00^{e}	0.00^{g}	0.00^{f}	0.00^{f}	46.67^{d}	73.33^{b}
	Cozaxyle	0.00^{e}	0.00^{g}	0.00^{f}	0.00^{f}	20.00^{e}	36.67^{c}
Gude-nie	Control	50.00^{b}	73.33^{b}	96.67^{a}	100.00^{a}	100.00^{a}	100.00^{a}
	Agro-laxyle	33.33^{c}	53.33^{c}	73.33^{b}	93.33^{a}	100.00^{a}	100.00^{a}
	Cozaxyle	20.0^{d}	26.67^{ef}	36.67^{de}	50.00^{cd}	73.33^{b}	96.67^{a}
Jalenie	Control	33.33^{c}	53.33^{c}	70.00^{b}	93.33^{a}	100.00^{a}	100.00^{a}
	Agro-laxyle	20.00^{d}	33.33^{de}	43.33^{cd}	56.67^{bc}	73.33^{b}	96.67^{a}
	Cozaxyle	20.00^{d}	20.00^{f}	30.00^{e}	40.00^{e}	56.67^{c}	73.33^{b}
Local	Control	66.67^{a}	96.67^{a}	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}
	Agro-laxyle	50.00^{b}	66.67^{b}	76.67^{b}	100.00^{a}	100.00^{a}	100.00^{a}
	Cozaxyle	30.00^{c}	40.00^{d}	50.00^{c}	60.00^{b}	70.00^{b}	100.00^{a}
	Mean	26.94	38.6	48.06	61.39	76.11	89.72
	LSD	8.55***	9.05***	8.03***	7.75***	6.54***	6.54***
	CV	18.74	13.84	9.87	7.46	5.07	4.30

LSD = Least Significance Difference; CV = Coefficient of Variation, DAP = days after planting. Means following by the same letter within the column are not significantly different at 0.05 probability level. *** = very highly significant difference.

Disease Severity

At 50 Days after Planting (DAP), the maximum Percentage Severity Index (PSI) (30.74%) was recorded on the local untreated plot variety, which was significantly different from other treatments. Whereas, the minimum PSI (11.11%) was recorded on Belete variety from treated and untreated plots (Table 3). At 85 DAP, the highest PSI (98.15%) was recorded on untreated plots of the local variety and 87.41% PSI was recorded on unsprayed plots of Gudenie variety. The lowest (22.59%) PSI was recorded on Belete variety treated with Cozaxyle (Table 3).

Table 3. Interaction effects of fungicides and potato varieties on percentage severity index (PSI).

Treatments		PSI (%)					
		50 DAP	**57 DAP**	**64 DAP**	**71 DAP**	**78 DAP**	**85 DAP**
Belete	Control	11.11^{e}	11.11^{f}	11.11^{g}	25.18^{g}	37.04^{f}	55.92^{f}
	Agro-laxyle	11.11^{e}	11.11^{f}	11.11^{g}	11.11^{i}	20.74^{g}	32.59^{g}
	Cozaxyle	11.11^{e}	11.11^{f}	11.11^{g}	11.11^{i}	16.67^{g}	22.59^{h}
Gudenie	Control	23.33^{b}	38.52^{b}	50.00^{b}	65.18^{b}	74.81^{b}	87.41^{b}
	Agro-laxyle	16.67^{cd}	28.52^{d}	39.26^{c}	48.89^{d}	60.37^{c}	72.59^{c}
	Cozaxyle	13.33^{de}	13.33^{f}	15.55f	21.11^{h}	44.44^{e}	57.04^{ef}
Jalenie	Control	17.03^{c}	30.37^{cd}	41.85^{c}	51.15^{cd}	58.15^{c}	71.85^{c}
	Agro-laxyle	13.33^{de}	21.85^{e}	28.89^{d}	37.78^{e}	50.74^{d}	60.37^{de}
	Cozaxyle	12.22^{e}	12.22^{f}	12.22^{fg}	13.33^{i}	38.52^{f}	56.30^{ef}
Local	Control	30.74^{a}	47.04^{a}	64.81^{a}	74.81^{a}	94.81^{a}	98.15^{a}
	Agro-laxyle	23.33^{b}	34.44^{bc}	42.22^{c}	52.59^{c}	61.11^{c}	72.59^{c}
	Cozaxyle	13.33^{de}	14.44^{f}	21.11^{e}	31.11^{f}	50.37^{d}	64.44^{d}
	Mean	16.39	22.84	29.1	36.95	50.64	62.65
	LSD	3.60***	4.18***	4.37***	3.57***	4.67***	4.27***
	CV	12.98	10.80	8.86	5.70	5.45	4.02

DAP = Days after Planting, LSD = Least Significance Difference; CV = Coefficient of Variation. Means following by the same letter within the column are not significantly different at 0.05 probability level. *** = very highly significant difference.

Table 4. Summary of ANOVA for different potato varieties and fungicides treatments on potato late blight disease parameters at Chilga district during 2018 main cropping season

		Mean squares					
Source of variation	df	50DAP	64DAP	78DAP	85DAP	DPR	AUDPC
Replication	2	5.34	9.50	12.46	12.40	0.00000222	13299.77
Variety	3	214.7***	1635.5***	3249***	2994.1***	0.00216***	2248750.1***
Fungicide	2	195.4***	2192.6***	2523.8***	2480***	0.0004***	2549451.4***
Varity * Fung.	6	43.5***	278.1***	141.7***	70.85***	0.0001**	157068.8***
Error	22	4.52	6.65	7.62	6.36	0.000025	6986.6
CV (%)		13	8.86	5.45	4.02	6.47	6.18
R^2		0.93	0.99	0.99	0.99	0.94	0.99

DAP = Days After Planting, df = degree of freedom, DPR = disease progress rate,AUDPC= Area Under Disease Progress Curve, CV = Coefficient of Variation, ** = Highly significant different,*** = Very highly significant difference, R^2 = Coefficient of determination.

Analysis of percentage severity index (PSI) data at 50 days after planting (DAP) up to 85days after planting (DAP) revealed very highly significant differences ($P < 0.001$) among interactions of the four potato varieties, two types of fungicides and untreated plots (Table 4).

Disease Progress Rate (r)

The analysis of data on disease progress rate revealed highly significant ($P < 0.01$) differences among the treatment combinations of four potato varieties with two types of fungicides and untreated plots (Table 4 and Table 5). The highest ($r = 0.104$) unit per day disease progress rate was recorded on the untreated Local variety plots followed by ($r = 0.099$ and 0.093) units per day for local variety treated with Agro-laxyle and cozaxyle fungicides, respectively. On the other hand, Belete variety treated with Cozaxyle fungicide had the lowest disease progression rate. This experimental result showed that the late blight potato disease progress rate was faster on local untreated than other untreated improved varieties (Table 5).

Table 5. Interaction effects of potato varieties and fungicide on late blight potato disease progress rate

	Potato Varieties				
Fungicides	Belete	Gudenie	Jalenie	Local	Mean
Control	0.076^{c}	0.074^{cd}	0.077^{c}	0.104^{a}	0.083
Agro-laxyle	0.063^{e}	0.071^{cde}	0.074^{cd}	0.099^{ab}	0.076
Cozaxyle	0.049^{f}	0.070^{cde}	0.067^{de}	0.093^{b}	0.072
Mean	0.063	0.072	0.073	0.099	
LSD	0.0084**				
CV	6.47				

LSD = Least Significant Difference, CV = Coefficient of Variation. Means followed by the same letter within the column or row are not significantly different at 0.05 probability level, ** = highly significant difference.

Area under Disease Progress Curve (AUDPC)

Analysis of the area under the disease progress curve (AUDPC) revealed very highly significant differences ($P < 0.001$) among treatment combinations of the four potato varieties with two types of fungicides and untreated plots (Fig.1 and Table 4). The highest (2571.8%-days) AUDPC value was recorded on the untreated local variety, and the second highest (2111.6%-days) AUDPC value was recorded on untreated plots of the Gudenie variety. Whereas, the lowest (609.2 and 545.7 %-days) AUDPC values were recorded on the Belete variety treated with Agro-laxyle 63.5% WP and Cozaxyle 72% WP fungicides respectively (Fig. 1)

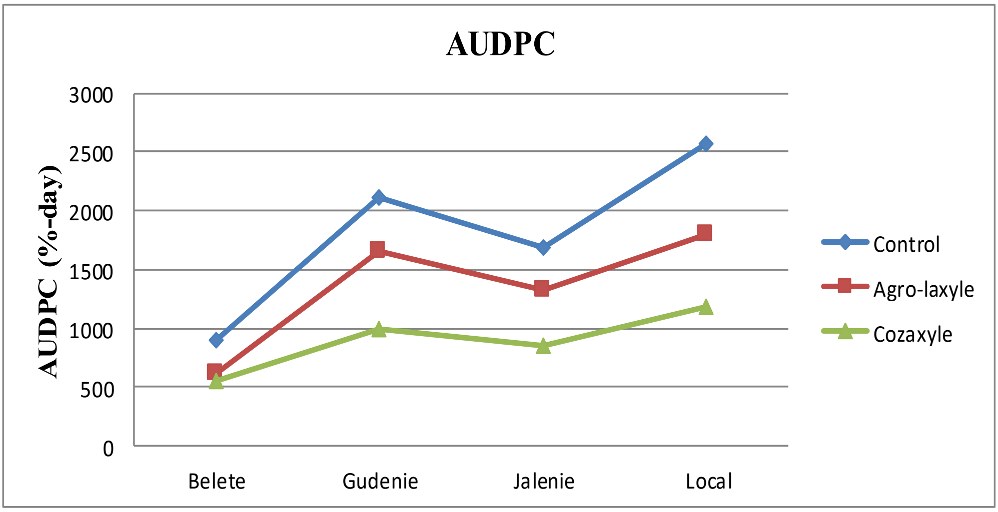

Figure 1. Interaction effects of fungicide and varieties on Area under Disease Progress Curve (AUDPC) value.

The highest (2571.8%-days) AUDPC value was recorded on the untreated local variety, and the second highest (2111.6%-days) AUDPC value was recorded on untreated plots of the Gudenie variety. Whereas, the lowest (609.2 and 545.7 %-days) AUDPC values were recorded on the Belete variety treated with Agro-laxyle 63.5% WP and Cozaxyle 72% WP fungicides respectively (Fig. 1).

Marketable tuber yield

Analysis of marketable tuber yield data revealed highly significant ($P < 0.01$) differences among the interaction of four potato varieties with two types of fungicides and the untreated plots (Table 6 and Table 7).

Table 6. ANOVA on different potato varieties and fungicides treatments on late blight disease yield and yield components

		Mean squares				
Source of variation	df	Physiological maturity date	Plant height	MY	UMY	TY
Replication	2	0.00	12.54	6.07	0.41	3.49
Variety	3	147.0***	386.0***	1151***	4.29***	1022.9***
Fungicide	2	306.25***	252.8***	305.6***	5.28***	230.9***
Variety*Fungicide	6	12.25***	42.5**	12.24**	0.15^{ns}	10.9**
Error	22	0.0	6.5	3.04	0.24	2.86
CV (%)		0.00	5.33	9.6	14.56	7.85
R^2		1	0.93	0.98	0.83	0.98

df = degree of freedom, MY = Marketable Yield, UMY = Unmarketable Yield, TY = Total Yield, CV = Coefficient of Variation, ns = none significant, ** = Highly significant different, *** = Very highly significant different, R2 = Coefficient of determination.

The highest (41.63 t ha^{-1} and 34.27 t ha^{-1}) marketable tuber yield was obtained from Belete variety treated with Cozaxyle 72% WP and Agro-laxyle 63.5% WP fungicides respectively, and both were significantly different from other treatments. The lowest (4.53 t ha^{-1}) marketable tuber yield was obtained from the untreated local variety plots as shown in Table 7.

Unmarketable tuber yield

The analysis of variance showed that the two main effects of fungicides and varieties were highly significant ($P < 0.001$) on unmarketable tuber yield. However, the interaction effects between treatments were not significant (Table 7 and Table 8).

Table 7. Interaction effects of fungicides and potato varieties on marketable yield (MY)

Fungicides	**Marketable yield (t ha^{-1})**				
	Belete	Gudenie	Jalenie	Local	Mean
Control	25.63^{c}	7.93^{g}	14.00ef	4.53^{h}	13.0
Agro-laxyle	34.27^{b}	12.60^{f}	19.07^{d}	7.90^{g}	18.45
Cozaxyle	41.63^{a}	16.00^{e}	22.93^{c}	11.83^{f}	23.1
Mean	33.84	12.18	18.66	8.08	
LSD	2.95**				
CV	9.59				

MY = Marketable Yield, LSD = Least Significant Difference; CV = Coefficient of Variation, Means followed by the same letter within the column or row are not significantly different at 5% probability level, ** = highly significant difference.

Table 8. The main effects of potato varieties and fungicides on late blight disease of unmarketable yield

Varieties	**Unmarketable yield(t/ha)**	**Fungicides**	**Unmarketable yield(t/ha)**
Belete	2.48^{c}	Control	3.99^{a}
Gudenie	3.38^{b}	Agro-laxyle	3.38^{b}
Jalenie	3.37^{b}	Cozaxyle	2.67^{c}
Local	4.17^{a}		
LSD	0.48**		0.41**
CV	14.56		

LSD = Least Significant Difference; CV = Coefficient of Variation, Means followed by the same letter within the column are not significantly different at 0.05 probability level. ** = highly significant difference.

Correlation of disease parameters with yield and yield components

The correlation Analysis was done between the epidemiological parameters disease incidence (Inc) and percentage severity index (PSI) at the last recording day, disease progress rate (DPR), and AUDPC with plant height, marketable yield, and unmarketable yield. Correlation analysis showed that late blight of potato disease incidence at 85 days after planting (DAP) and marketable tuber yield of different potato varieties had a very highly significant negative correlation (r = -0.85) (Table 9). This indicates that the observed value of the disease incidence had a considerable adverse effect on the marketable tuber yield of potatoes. On the other hand, late blight potato disease incidence at 85 days after planting (DAP) and unmarketable tuber yield of different potato varieties had a highly significant and positive correlation (r = 0.83).

Percentage severity index at 85 days after planting (DAP) and marketable tuber yield of different potato varieties had a very highly significant and negative correlation (r = -0.95***).On the other hand, the percent severity index at 85 days after planting (DAP) and unmarketable tuber yield of different potato varieties had a very highly significant and positive correlation (r = 0.92). Disease progress rate (DPR) and marketable tuber yield of different potato varieties had highly significant and negative correlation (-0.83), whereas, disease progress rate and unmarketable tuber yield had very highly significant and positive correlations (0.9).

Table 9. Correlation coefficients (r) of treatments on late blight potato disease by different parameters

	Inci	PSI	DPR	AUDPC	Ph	MY	UMY	TTY
Inci	1							
PSI	0.79**	1						
DPR	0.74**	0.80**	1					
AUDPC	0.64*	0.95***	0.75**	1				
ph	-0.54^{ns}	-0.82**	-0.82**	-0.91***	1			
MY	-0.85***	-0.95***	-0.83**	-0.87***	0.8**	1		
UMY	0.83***	0.92***	0.9***	0.9***	- 0.85***	-0.89***	1	
TTY	-0.84***	-0.94***	-0.82**	-0.86***	0.79**	0.99***	-0.88***	1

Ns = non-significant difference,* = significant difference, ** = highly significant difference, *** = very highly significant difference. Inci = Incidence at 85DAP, PSI = Percentage Severity Index at 85DAP, DPR = disease progress rate, AUDPC = Area under Disease Progress Curve, ph = Plant height, MY = Marketable Yield, UMY = Unmarketable Yield and TY = Total Yield

The AUDPC and marketable tuber yield of different potato varieties had a highly significant and negative correlation (r = -0.87). Whereas, AUDPC and unmarketable tuber yield of different potato varieties had a very highly significant and positive correlation (r = 0.9). The potato plant height was highly significantly and negatively correlated with disease parameters and unmarketable yield, while highly significantly and positively correlated with marketable yield.

Regression between Area under Disease Progress Curve (AUDPC) and Total Tuber Yield

Linear regression of the area under disease progress curve (AUDPC) was used for predicting the tuber yield loss in potatoes (Figure 2). Because, AUDPC linear regression was better indicated that the relationship of yield loss and disease than severity linear regression. On the other hand, disease progress curves are highly sensitive to fluctuations in epidemiological factors during disease development.

The relationship indicated by the model accounted for 70.8% of the variance (Figure 2).The estimated slope of the regression line for late blight of potato observed at this study on the combination of potato varieties and different types of fungicides were b1 = -0.014 t ha^{-1} yield loss were predicted on these treatment combinations for every %-day increase of AUDPC.

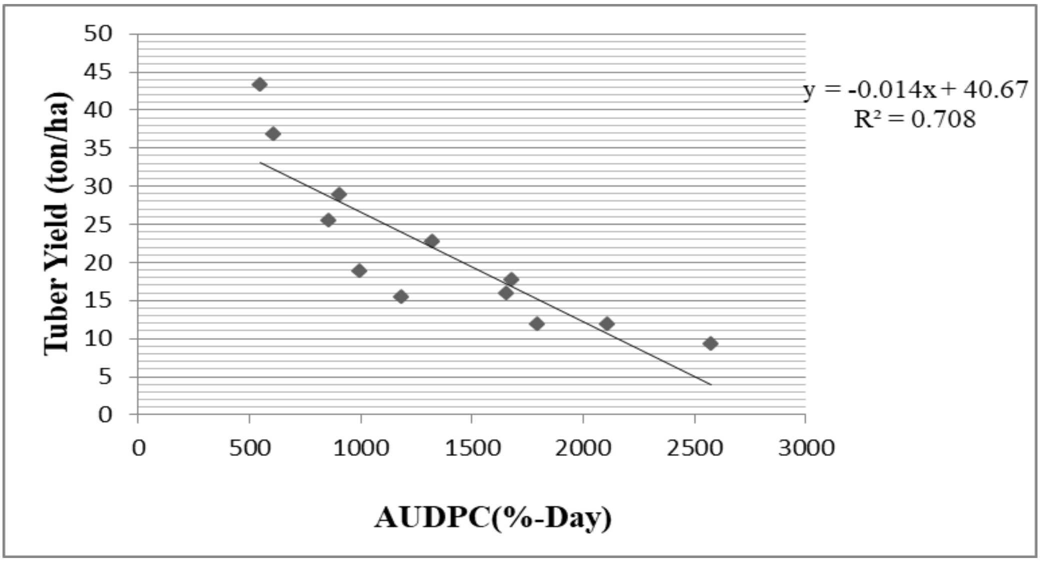

Figure 2. Regression between area under disease progress curve (AUDPC) and total tuber yield

DISCUSSION

Late blight potato disease first appeared within 43 days after planting (DAP) in the improved (Gudenie and Jalenie) and the local varieties. In Belete variety untreated and treated with fungicide, the first disease symptom appeared within 71 and 78 days after planting respectively, and they were significantly different from the other varieties. In Belete variety treated with fungicides, the first disease symptom appearance was delayed by 35 days due to their different degree of resistance compared to other varieties combinations. In general, the disease appeared early on in the varieties (Local, Gudenie, and Jalenie) than in the Belete variety. This result was similar to that of Tsedaley *et al*., (2014) who reported that late blight disease appeared early on moderately susceptible and susceptible varieties than moderately resistant ones. On the final recording day (85 DAP), the lowest (36.67%) late blight potato disease incidence was recorded on Belete variety treated with Cozaxyle 72% WP fungicide, and this was significantly different from other treatments.

Similar findings were observed with Fekede (2011) who reported that late blight potato disease incidence was higher in susceptible local potato varieties at initial and final disease assessment. Fekede (2011) also reported that late blight incidence was higher in susceptible local potato varieties than in resistance varieties and the fungicide application significantly reduced late blight disease incidence as compared to local control. Mukalazi *et al.,* (2001) also reported that late blight incidence on susceptible potato varieties could be high. Hence, fungicides have the possibility to reduce and ensure disease control in moderately resistant varieties.

The potato varieties (Gudenie and Local) were highly susceptible to late blight disease than other varieties. The result of this finding disagrees with Ashenafi Mulatu *et al*., (2017) who have reported that late blight disease incidence reached a maximum of 91.5% on unsprayed control susceptible Jalene variety. On the other hand, the result of this finding was similar to the findings of Namanda *et al.,* (2004) and Kankwatsa *et al.,* (2002) who reported that the management of potato late blight disease by using a combination of host plant resistance and fungicide applications in the tropical highlands of East Africa is important. Additionally, Simons (1972) and Vander Plank (1963) also reported that the use of cultivars with durable resistance combined with scheduled applications of protective fungicides has been found useful method for managing the late blight of potatoes.

The present finding showed that the development of late blight disease progress rate and tuber yield losses of potato varieties could be minimized by integrating Belete variety with Cozaxyle fungicide. This finding was similar to that of Tsedaley *et al*., (2014) 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.

Combinations of Belete variety treated with fungicide showed the lowest AUDPC value and had a significant difference as compared to other treatments. The highest AUDPC value indicated the highest disease development on treatments, whereas the lowest AUDPC value indicates the use of resistant varieties and fungicides had reduced the development of the disease. Similarly Binyam *et al*., (2004), the highest value of AUDPC showed the highest disease development on plots that were not treated with any combinations of variety and fungicide application; and also consistent with the report of Mesfin and Gebremedhin (2007) in which moderately resistant varieties had the lowest AUDPC when supplemented with a fungicide treatment. The AUDPC accounts for all these factors (Chaube and Pundhir, 2005) as the crop yield loss depends upon severity as well as on the duration of the disease. Similarly, Samuel *et al*., (2008) have shown the relationship between yield loss and faba bean chocolate spot in sole and mixed cropping systems under Ethiopian conditions.

All potato varieties treated with Cozaxyle and Agro-laxyle fungicides were significantly higher marketable tuber yields than untreated plots. This result was in agreement with Asamenew and Bahru's (2000) finding which reported increased marketable and total tuber yield in resistant varieties under Ethiopian conditions.

For commercial production of potatoes, Kankwatsa *et al*., (2002) suggested the use of resistant varieties reduced late blight severity by more than 50% and resulted in yield gains of more than 30%, which clearly supports the present study.

Among the main effects of varieties, the highest (4.17 t ha^{-1}) unmarketable tuber yield was obtained from the local variety. While, the lowest (2.48 t ha^{-1}) unmarketable tuber yield was obtained from Belete variety. On the main effect fungicide, the maximum (3.99 t ha^{-1}) unmarketable tuber yield was obtained from untreated plots, whereas the minimum (2.67 t ha^{-1}) unmarketable tuber yield was obtained from the plots treated with Cozaxyle 72% WP fungicide.

CONCLUSION AND RECOMMENDATIONS

Based on the result of this experiment, the variety Belete was resistant to late blight potato disease compared to other varieties; and the application of Cozaxyle 72% WP fungicide effectively reduced disease development and increased yield in all varieties as compared to Agro-laxyle MZ 63.5WP fungicide. Generally, the result of this study showed that Belete variety was not susceptible to late blight potato disease and Cozaxyle fungicide can protect against the disease compared to Agro-laxyle MZ 63.5 WP fungicide. According to this experiment result with the highest marketable yield and lowest disease severity as compared to other treatments the best management method for late blight potato disease was recommended the integration of resistance variety Belete treated with Cozaxyle fungicide.

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