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THE FUNGICIDE AND VARIETY INTEGRATION EFFECT ON LATE BLIGHT (*Phytophthora infestans*) DISEASE OF POTATO (*Solanum tuberosum L.*) IN WESTERN AMHARA REGION, ETHIOPIA

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ABSTRACT

Potato is suffered by many abiotic and biotic factors. Among biotic factors late blight disease (LBD) is the most important. The study was conducted during 2017 at Adet and Debre-Tabor to determine and evaluate the combination effect of varieties and fungicides, to reduce LBD intensities and increase yield. Four potato varieties and three fungicides with untreated check were used in factorial randomized complete block design with three replications. Lowest disease severity 11.11% was obtained from Belete and Gudene at Adet and Belete at Debre-Tabor. Similarly, the lowest AUDPC (9.33 and 89.83 %-days) were expressed from Gudene + Saboxyl 72% at Adet and Debre-Tabor, respectively, whereas, the maximum PSI and AUDPC were obtained from untreated plots. In average up to 359.81% yield increases were recorded from Abalo + Saboxyl 72% WP. The highest marginal rates of return (2,886.50 % and 3,786.35%) were obtained from Saboxyl 72% treated plots of Abalo & Guassa at Debre-Tabor and Adet, respectively. Therefore, an application of Saboxyl 72% with different varieties was effective at both locations to reduce the yield loss of potato and could be recommended to manage LBD. The combination of Saboxyl 72% with Gudene, Belete and Guassa were highly hinder LBD development at both locations. Even though, its yielding capacity was relatively lower Gudene could be recommended for production without fungicide. Variety Belete and Guassa could be recommended for production in combination with Saboxyl 72%, since they have best performance with relatively lower disease reaction at Adet and Debre-Tabor, respectively.

Contribution/Originality: This study contributes in the existing literature to fill the gap of the current state of knowledge of late blight disease management of potato. This study is one of very few studies which have investigated potato late blight disease management in Western Amhara Region Ethiopia.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) ranks 3rd after rice and wheat in terms of human consumption (Devaux *et al.*, 2014; FAOSTAT, 2015) and it is the primary non-grain food commodity in the world (Waga *et al.*, 2016). Among root and tuber crops, potato ranks first in volume of production and consumption, followed by cassava, sweet potato and yam (Egata *et al.*, 2016). It is a high potential contributor to national food security (Gildemacher *et al.*, 2009; Bitew and Abera, 2018). In Ethiopia, potatoes are a source of both food and cash income in the densely populated highlands, where 90% of the population resides (Gildemacher *et al.*, 2009; Abebe *et al.*, 2013). Its high yielding capacity, early maturing, and excellent food value give the potato great potential for improving food security, increasing household income, and reducing poverty (Devaux *et al.*, 2014). The productivity of potato in the World, Africa and Ethiopia is estimated to 19.63, 13.84 and 13.14 t/ha, respectively (FAOSTAT, 2017). The average potato yield in Eastern Africa has been reported to be about 8 t/ha (Schulte-Gelderman *et al.*, 2013), which is below the maximum yield of 25t/ha in the region.

Even though, potato plays a great role for the achievement of food security program due to its plasticity to environmental conditions and yielding capacity (Hailu *et al.*, 2017; Merkuz, 2017) the national average yield of the crop is estimated to only 13.14t/ha in Ethiopia (FAOSTAT, 2017), which is also far below the attainable yield of 45 t/ha (Abebe *et al.*, 2013). Many pathogens attack potato and causes significant losses to producers throughout the world' (Ephrem, 2015). Among these late blight disease caused by *Phytophthora infestans* is a major bottleneck that devastating of potato worldwide (Pérez and Forbes, 2010; Goss *et al.*, 2014) and Ethiopia (Bekele and Yaynu, 1996; Merkuz, 2017). It is the most serious disease constraint that makes wide gap between actual and attainable yield of potato (Fuglie, 2007; Gildemacher *et al.*, 2009; Forbes, 2012; Sparks *et al.*, 2014) and can cause a complete crop loss (Fry, 2008). The disease damage leaves, stems and tubers of potato and is found throughout the major potato producing areas (Forbes, 2012; Gebremedhin, 2013). Losses (yield and management cost) due to late blight disease are estimated to $6.7 billion and $365.1 million annually in Worldwide and USA, respectively (Manuela and Hermeziu, 2014).

However, in developing countries around $13.9 billion in yield losses and costs of management measures were estimated (Haverkort *et al.*, 2009). According to Baye and Gebremedhin (2013) the yield losses of potato due to this disease ranges from 30 to 100% in Ethiopia. It can cause 100% yield loss on susceptible local cultivar and 67.1% on a susceptible variety (Alemaya-624) (Bekele and Yaynu, 1996; Merkuz, 2017). Therefore, the pathogen is regarded as a threat to global food security (Goss *et al.*, 2014; Manuela and Hermeziu, 2014). Applying of different management methods separately does not provide sufficient management of late blight (Garrett *et al.*, 2001). According to Namanda *et al.* (2001) integrating fungicide applications with varieties by choosing the best fungicide-cultivar integration improves the durability or sustainability of the released potato varieties in potato production system. Even though, several varieties with different levels of resistance have been released at different times, the majority of grown varieties are becoming susceptible to late blight very soon (Ayda, 2015).

Even though, the disease problem is very serious at each rainy season its management studies are not as such enough. Generally, the ability of the disease to reach an epidemic level within short periods, the inadequate efficiency of cultural practices to reduce high level of disease severity, and rapid development of resistance to repeatedly application of fungicides and resistance breakage of released potato varieties within short period of time were made this study very essential in late blight management through the following objectives: to determine and evaluate the integration of resistance potato varieties and fungicides to reduce late blight disease intensities of potato, and to draw possible recommendations for further late blight disease management research and development activities.

2. MATERIALS AND METHODS

The experiment was conducted at Adet Agricultural Research Centre and Debre-Tabor Agricultural Research Sub-Center during 2017 main cropping season. Adet is found at 11°017' N, 37°043'E and 2,240 masl latitude, longitude and altitude, respectively. Soil type of the site is Nitosol, with pH 5.43 (Walleign, 2015). Debre-Tabor is found at 11°88'N latitude and 37°98' E longitude and at altitude of 2,591 m.a.s.l. with a soil type of Nitosol (Walleign, 2015).

Table-1. Climatic features of the study areas during 2017 main cropping season.

Locations	Climate data	Months						
		May	June	July	Aug	Sep	Oct	Average
Debre-Tabor	Max. Temperature (°C)	22.4	23.5	20.6	18.7	21.3	21.7	21.37
	Min. Temperature (°C)	10.9	11.4	10.8	11.0	10.6	9.9	10.77
	Rain fall (mm)	176.4	84.4	346	291	152	56.4	184.37
	RH (%)	68.1	68.5	80.7	85.3	74.1	68.0	74.12
Adet	Max. Temperature (°C)	27.0	27.7	24.3	23.8	25.2	25.3	25.55
	Min. Temperature (°C)	13.7	13.0	12.6	12.6	11.9	11.6	12.57
	Rain fall (mm)	115.5	77.8	392.6	168.3	143.4	78.5	162.68
	RH (%)	59	60	72	76	73	67	67.83

Source: Bahir Dar Meteorology Agency, 2017.
Remark: Max = Average maximum monthly temperature, Min = Average minimum monthly temperature, RH = Average relative humidity, na = not available.

2.1. Experimental Materials, Design and Treatments

The potato varieties used in this experiment were Belete, Gudene, Guassa and susceptible check (*Abalo*). These varieties do have different levels of late blight resistance (Belete resistant, Gudene moderately resistant and Guassa moderately susceptible (Hirut *et al.*, 2017). The first two varieties were released from Holeta Agricultural Research Center (HARC) in 2009, and 2006, respectively, whereas Guassa have released from AARC during 2002 (MoARD, 2010). Two types of fungicides [(Curzate R WP (Cymoxanil 4.2% + Copper oxychloride 68.95%) and Saboxyl 72% WP (Metalaxyl 8% + Mancozeb 64%)] were used in the experiment for foliar spray. Each fungicide was tested solely with each of four potato varieties and making the total treatment combinations of 12 including the untreated check. Both fungicides were applied based on the manufacturer recommendation *i.e.* 2.5 kg/ha Curzate R WP and 2kg/ha of Saboxyl 72% WP mixed with 400 liters of water per hectare. The products were applied at the frequency of four times in the 7th days interval starting from the first disease on set at the crop stage of 43 and 46 DAP at Adet and Debre-Tabor, respectively. During fungicide spraying, plastic sheets and two rows of triticale planted between each plot was used as a buffer zone to prevent the fungicide drift effect. The experiment was laid out in a factorial arrangement randomized complete block design (RCBD) with three replications at both locations. Each potato variety was integrated randomly with all fungicides and control check and resulting a total of 12 treatment combinations. Spacing between blocks and between adjacent plots measured 1.5 m, and 1.2m, respectively. Each plot had a size of 3.75m width and 3m length resulting 11.25m^2 and contained total five rows, spacing between rows and plants were 0.75m and 0.3m, respectively. Planting was done on 07 and 09 June 2017 at Debre-Tabor and Adet, respectively. All others agronomic practices like weeding, hoeing, earthing up, and fertilizer application both P_2O_5 (NPS) and nitrogen fertilizer (Urea) were done equally at the same time for all treatments. Therefore, it was fertilized with 108/69 and 81/69 kg/ha N/P_2O_5 based on the blanket recommendation rate for potato production in South Gondar and Gojjam areas, respectively (Tesfaye *et al.*, 2008). All NPS fertilizer was applied at planting but Urea (N) was applied three times, N which is found from NPS was applied at planting, half of N from Urea at 1st earthing up and the 2nd half N was applied at the starting of flowering. Four times of weeding, two times of hoeing and Earthing up was done starting from one week after emergence till flowering.

2.2. Data Collection

Days to first late blight disease symptom appearance (DTDSA) was taken by counting the number of days from planting to first disease symptoms observed on the leaves of the plant. The disease intensity assessment was done at every seven days interval after the first appearances of the disease symptom up to physiological maturity, starting at 43 and 46 DAP from Adet and Debre-Tabor, respectively and finally having nine (9) recordings. Disease incidence refers to the number of plant entities which are visually diseased out of the total number of plant units measured (Campbell and Madden, 1990). Disease incidence was assessed on whole plants at each plot those showing symptoms of the disease were counted and expressed in percent infection. Disease severity was also assessed as the proportion of leaf area affected by the disease from 10 randomly selected pre-tagged plants in the middle three rows. Disease severity was assessed by using 1 - 9-point scale suggested by Henfling (1987).

Area under the disease progress curve (AUDPC) was calculated for each plot by using present severity value by using the following formula suggested by Shaner and Finney (1977); Campbell and Madden (1990).

AUDPC= $\sum_{i=1}^{n-1} 0.5(xi + (xi + 1))(ti + (1 - ti))$; Where, x_i is the disease severity expressed in percentage at i^{th} observation, t_i, is time (days after planting) at the i^{th} observation, t' is the epidemic duration for each treatment and n is total number of disease assessments done. AUDPC values were expressed in %- days.

The disease progress rate (r): Was calculated by using linear logistic model (Van der Plank, 1963; Campbell and Madden, 1990) because this model was best fitted model with the majority of treatments obtained from both experimental sites than the Gompertz model as compared with coefficient of rate determination (R^2)and the calculated value were analyzed:

$$r = \frac{\left(Ln\frac{X}{1-X}\right)-\left(Ln\frac{Xo}{1-Xo}\right)}{t}$$ or [ln [(X/1-X)], Van der Plank (1963)]

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

2.3. Statistical Data Analyses

Analysis of variance (ANOVA) was done for disease parameters (incidence, PSI, disease progress rate, AUDPC) of each treatment to know the main effects of varieties and fungicides, and their interactions as described by Gomez and Gomez (1984) using SAS software (SAS, 2002). Least Significant Difference (LSD) values were used to separate differences among treatments means at 5% probability level. Analysis of variance (ANOVA) was performed using General Linear Model (GLM) of SAS procedure (SAS, 2002) version 9.0. Due to zero data recorded on the disease incidence it was transformed using log (n+1) base 10 transformation method before analysis. The severity data scored in 1-9 scale was converted into percent severity index (PSI) for analysis without transformations through the formula suggested by Wheeler (1969).

$$\text{PSI (\%)} = \frac{\text{Sum of numerical ratings}}{\text{No of plants scored x Maximum score on scale}} \text{x}100$$

Coefficient of correlation was also calculated to determine the relationship between disease parameters and yield and yield related parameters by using SPSS 16.0 statistical computer software (SPSS, 2007). Each data collected from Adet and Debre-Tabor experimental site were analyzed independently per site without combination, due to the variability of two sites (had different environmental conditions) Table 1 the disease reaction was different and the data were collected at different period of time.

3. RESULTS AND DISCUSSIONS

3.1. Days to First Disease Symptom Appearance

The days to first disease symptom appearance showed highly significant ($p<0.01$) differences among varieties, fungicides and their combinations at both locations Table 2. The disease symptom was first appeared on the susceptible variety *Abalo* within 41 days after planting (DAP) followed by Guassa and Gudene (50 DAP) on untreated plots. Whereas, the disease appeared 58 DAP on Belete untreated plot. The disease was appeared very late (67 DAP) on Belete followed by Gudene (65 DAP) both combined with Saboxyl 72% WP at Debre-Tabor. However, there was difference of 25 and 23 days between the first disease symptom appearance on susceptible variety and moderately resistant variety Belete and Gudene combined with fungicides and also around 9 days difference between sprayed and unsprayed plots of Belete Table 2. This result agreed with the results of Getachew *et al.* (2016) that 26 days difference was obtained between the first on set of disease on susceptible and relatively resistant potato genotypes.

Similarly, at Adet, the disease symptom was appeared very early (38.67 DAP) on the susceptible variety *Abalo*. Whereas, the disease appeared lately (65.67 and 61 DAP) on untreated moderately resistant varieties Belete and Gudene, respectively. However, the disease has seen very late (93.67 and 93.33 DAP) on the Saboxyl 72% WP fungicide treated plots of Belete and Gudene varieties, respectively Table 2. Binyam *et al.* (2014b) reported that the disease appeared lately on moderately resistant varieties than moderately susceptible and susceptible varieties. Similarly, Solano *et al.* (2014) reported that potato genotypes which developed late blight symptom early are susceptible and genotypes that developed late blight lately in the crop cycle are resistant.

3.2. Disease Incidence

The interaction effect of varieties and fungicides on disease incidence showed highly significant ($p<0.01$) difference at both locations Table 2. However, only the final incidence (at 99 and 102 DAP) have been taken to show the status on treated as well as untreated varieties. At the final date of assessment (102 and 99 DAP), all untreated varieties showed 100% incidence at both locations except Gudene (61.67%) at Debre-Tabor, and 100% incidence was also recorded on most varieties sprayed by Curzate R WP except Gudene at Debre-Tabor and Belete at Adet. However, except *Abalo* at Debre-Tabor all varieties combined with Saboxyl 72% showed lower incidence (<36%) at both sites Table 2. This result also supported by Bekele and Hailu (2001) that fungicide sprayed plots had lower disease incidence of late blight than unsprayed.

Table-2. Effect of fungicides and variety integrations on days to disease on set and incidence against late blight during 2017 *Meher* season.

Variety	Fungicide	DTDSA	Final disease incidence (%)	DTDSA	Final disease incidence (%)
		Debre-Tabor		Adet	
Belete	Curzate RWP	67^{a}	100^{a}	66^{b}	93.33^{a}
	Saboxyl 72%WP	66.67^{a}	26.67^{e}	93.67^{a}	10^{c}
	Untreated	58.00^{c}	100^{a}	65.67^{b}	100^{a}
Gudene	Curzate RWP	58.67^{c}	31.67^{c}	66.33^{b}	100^{a}
	Saboxyl 72%WP	65.33^{b}	5^{f}	93.33^{a}	8.33^{c}
	Untreated	50.00^{e}	61.67^{b}	61.00^{c}	100^{a}
Guassa	Curzate RWP	54.67^{d}	100^{a}	49.67^{d}	100^{a}
	Saboxyl 72%WP	55.33^{d}	28.33^{de}	49.67^{d}	35^{b}
	Untreated	50.00^{e}	100^{a}	42.67^{e}	100^{a}
Abalo	Curzate RWP	41^{g}	100^{a}	39.33^{f}	100^{a}
	Saboxyl 72%WP	42.67^{f}	30^{cd}	39.33^{f}	100^{a}
	Untreated	41^{g}	100^{a}	38.67^{f}	100^{a}
Significant difference		**	**	**	**
CV (%)		1.42	1.37	1.49	2.87

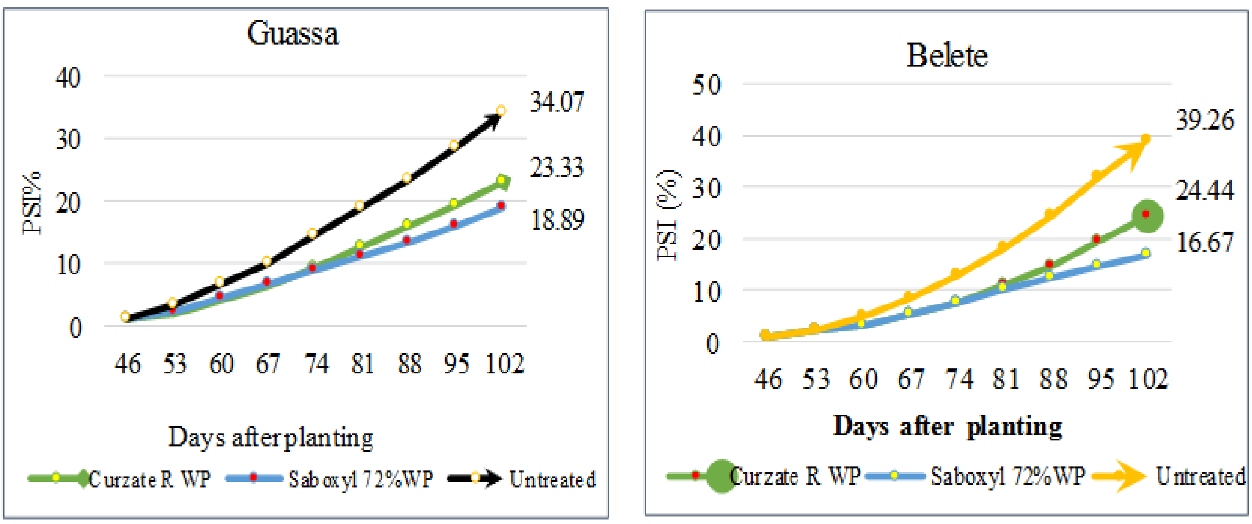
Note: CV = Coefficient of Variation, DTDSA = days to the first disease symptom appearance, values with the same letter does not have significant difference at 0.01 probability level. The (*) indicate the significances of the parameter.

Therefore, the combination of moderately resistant as well as moderately susceptible varieties and even susceptible varieties with the timely applications of Saboxyl 72% fungicide can significantly reduce late blight incidence at both study sites, especially, the fungicide highly inhibit the disease development on the moderately resistant varieties. This is supported by the result of Binyam *et al.* (2014b) that the integration of lower rate of Ridomil application with the moderately resistant potato varieties reduce the disease incidence of late blight.

3.3. Disease Severity

Analysis of percent severity index (PSI %) revealed highly significant ($p<0.01$) difference among the interaction of varieties and fungicides starting from 50 and 53 DAP at Adet and Debre-Tabor, respectively Figure 1 and Figure 2. While at the initial date of assessment (43 and 46 DAP) only the main effect of varieties showed significant difference but the fungicide and the interaction effects were non-significant (P>0.05) at both sites of the experiment, because the fungicides at this stage were not applied. The highest PSI obtained at 43 and 46 DAP of Adet and Debre-Tabor was 2.22% on *Abalo* and 1.85% on Guassa at Adet, whereas, the other varieties have only 1.11%. The maximum PSI (%) was recorded from untreated *Abalo* at each date of assessment from both sites followed by unsprayed Guassa at Adet and *Abalo* combined with Curzate R WP fungicide at Debre-Tabor Figure 1 and Figure 2. Even though, the disease was appeared lately on Belete the progress was nearly similar with variety Guassa and even faster after 88 DAP at Debre-Tabor Figure 1. The final PSI of the plots with different fungicide applications ranged from the least (16.67 and 11.11%) for the variety Belete and Gudene sprayed by Saboxyl 72% WP to the highest (62.59 and 53.7%) PSI % for the unsprayed *Abalo* from Debre-Tabor and Adet, respectively Figure 1 and Figure 2. However, the magnitude of disease severity was significantly different among varieties that was higher on *Abalo* than Guassa and moderately resistant varieties (Belete and Gudene) at both sites. This result coincides with the findings of Olanya *et al.* (2001) that late blight severity in fungicide treated plots was very low, however, it was highest in the untreated plots of susceptible variety, and also Bekele and Hailu (2001) reported that the highest disease severity has found on the unsprayed susceptible variety (Alemaya-624) as compared to on the tolerant variety (Tolcha).

As the result indicated, the magnitude of disease severity on fungicide treated moderately resistant varieties was below 25% especially Gudene (<20%). Therefore, the integration of Belete and Gudene varieties with timely applications of Saboxyl 72% WP and Curzate R WP fungicides have enabled to limit the fungus growth and development. The study of Ashenafi *et al.* (2017)showed supportive results that the interaction of host resistance and the application of fungicides was significantly reduced the progress of the disease as compared to unsprayed. Although, resistant varieties delay the occurrence of the disease or inhibit its rate of development, fewer sprays of fungicides may be needed to obtain a satisfactory level of disease management (Agrios, 2005; Ayda, 2015). Even though, fungicides were applied the final severity was relatively higher on all the varieties especially Curzate sprayed plots, as the disease development was supported by high humidity, and wet weather or frequent rainfall with moderate temperature Table 1. As Bekele and Eshetu (2008) stated that when the environmental conditions become conducive the disease can spread rapidly and might has the potential to destroy the potato fields completely not more than three weeks if no management measures are taken timely.



a. b.

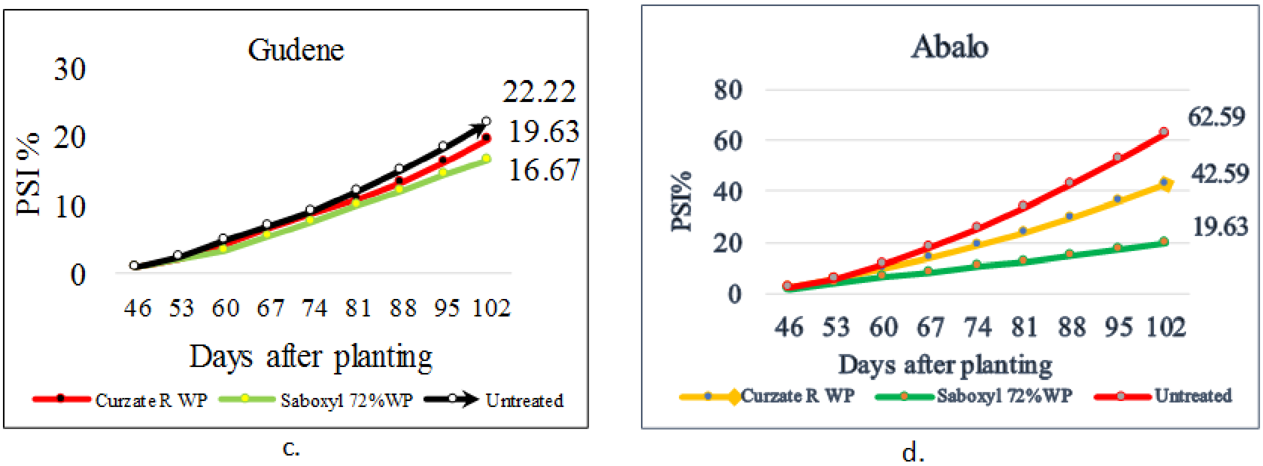


Figure-1. (a-d). The progress curve of late blight disease severity under fungicide spray on different potato varieties at Debre-Tabor, during 2017 *Meher* season.
Source: Field experiment.

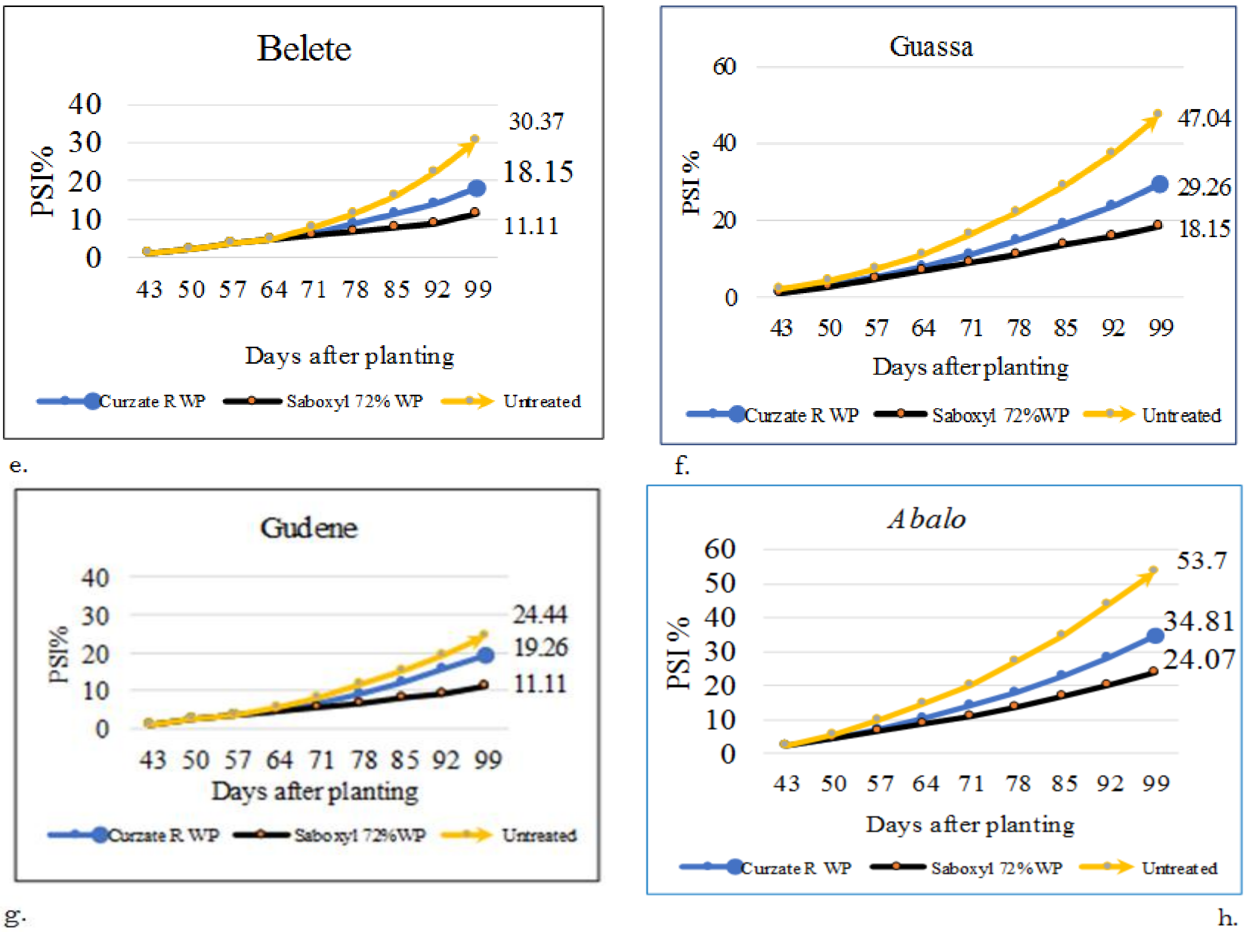


Figure-2. (e - h). The progress curve of late blight disease severity under fungicide spray on different potato varieties at Adet, during 2017 *Meher* season.
Source: Field experiment.

3.4. Disease Progress Rate (R)

The disease progress rate was calculated by using linear logistic model for both locations Debre-Tabor and Adet and the values were analyzed. The highly significant (P<0.01) differences was detected among the treatment combinations of varieties and fungicides application including unsprayed treatments Table 3.

The disease progress rate (slope) was varied among the varieties. The highest disease progress rates (r = 0.214182 and 0.132202-unit day^{-1}) were obtained at unsprayed plots of *Abalo* and Belete, respectively at Debre-

Tabor and the lowest progress rate (r = 0.006900) was obtained from Saboxyl 72% WP fungicide treated plots of *Abalo* followed by Gudene (r = 0.022426). Whereas, at Adet the highest rate (r = 0.186593unit day^{-1}) was obtained from unsprayed Guassa followed by *Abalo* (r = 0.170152-unit day-1). On the other hand, the lowest progress rates (r = 0.009467- and 0.015721-unit day^{-1}) were obtained on Saboxyl 72% WP sprayed Gudene and Belete, respectively Table 3.

Even though, the disease appeared lately on the moderately resistant varieties the progress rate was showed faster as the disease once appeared, this showed that the variety Belete is going to susceptibility because it showed high disease progress rate on unsprayed plots which also necessitates the supportive fungicide spraying Table 3. This result indicated that the ability of the variety to resist the disease development varied with the environment, since these two locations have relatively different environmental conditions rainfall, RH and temperature Table 1.

Table-3. Disease progress rate of potato late blight under the integrations of potato varieties and fungicides during 2017 *Meher* season at two locations.

Variety	Fungicide	Disease progress rate (r) (unit day $^{-1}$)	
		Debre-Tabor	Adet
Belete	Curzate R WP	0.079286^{c}	0.060511^{e}
	Saboxyl 72% WP	0.027173^{g}	0.015721^{g}
	Untreated	0.132202^{b}	0.129529^{c}
Gudene	Curzate R WP	0.038048^{f}	0.060613^{e}
	Saboxyl 72% WP	0.022426^{g}	0.009467^{g}
	Untreated	0.055276^{e}	0.079098^{d}
Guassa	Curzate R WP	0.055361^{e}	0.074284^{d}
	Saboxyl 72% WP	0.025016^{g}	0.027854^{f}
	Untreated	0.075716^{cd}	0.186593^{a}
Abalo	Curzate R WP	0.066967^{d}	0.078508^{d}
	Saboxyl 72% WP	0.006900^{h}	0.029183^{f}
	Untreated	0.214182^{a}	0.170152^{b}
Sig. difference		**	**
CV (%)		8.62	8.66

Note: Sig difference = Significant difference, CV = Coefficient of Variation, values followed by the same letter within the column or row are not significantly different at 0.01 probability level.

Generally, the disease progress rate increased rapidly on unsprayed plots than the sprayed once, regardless of the varieties. Among the varieties included in this study, moderately resistant variety Gudene was showed the least progress rate than the other three varieties both on the sprayed and unsprayed, even though the magnitude of 'r' varied, from both experimental sites Table 3. This coincides with the result of Binyam *et al.* (2014a) that late blight disease progress rate could be minimized through the integration of moderately resistant potato varieties with reduced rate of Ermias (2016) also suggested that the integration of resistance variety with fungicide Ridomil-gold WP 65% reduced the progress of late blight disease. Frequent application of fungicide could retard the rate of late blight progress in the field (Bekele and Hailu, 2001). The combinations of potato variety and fungicides reduced late blight progress rate (Habtamu *et al.*, 2012; Ashenafi *et al.*, 2017).

3.5. Area under Disease Progress Curve

Analysis of variance for area under disease progress curve (AUDPC) showed highly significant (p<0.01) difference among the interaction effects of varieties and fungicides Figure 3. Lower AUDPC values (361.67 and 484.17 %-days) were calculated from unsprayed plots of Gudene as compared with the other unsprayed three varieties at Debre-Tabor and Adet, respectively. On the other hand, the higher AUDPC values (3,937.5 and 3,080 %-days) were calculated from unsprayed plots of *Abalo* at Debre-Tabor and Adet, respectively followed by Belete (1,983.33%-days) at Debre-Tabor and Guassa (2,625%-days) at Adet Figure 3. The study on the effect of variety and fungicide combinations for the management of potato late blight in Southern Ethiopia (Shashemene and Hawassa) done by Habtamu *et al.* (2012) reported that the lowest AUDPC values were calculated from fungicide sprayed plots, while unsprayed plots had the highest values, and the authors also suggested that depending on the resistance level of the potato variety and types of fungicide application the values of AUDPC varied between locations. Area under disease progress curve had shown highly significant difference (p<0.01) both for Curzate R WP and Saboxyl 72% WP fungicide spray, however, Saboxyl 72% WP sprayed plots have lower AUDPC value as compared with Curzate R WP fungicide treated plots from all tested varieties at both locations Figure 3. This result argued with the result of Mesfin and Gebremedhin (2007) that when moderately resistant varieties had supplemented with fungicide sprays which resulted the lowest AUDPC values than unsprayed varieties.

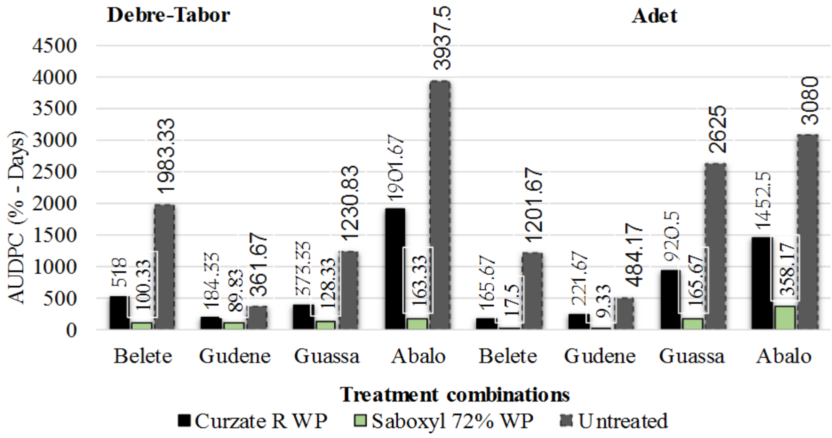


Figure-3. Area under disease progress curve of late blight disease as affected by fungicide spray on different varieties during 2017 main cropping season at two locations.
Note: AUDPC = area under disease progress curve.

3.6. Correlation among Late Blight Disease and Yield Parameters

The parameters AUDPC (%-days), disease progress rate and percent severity index (PSI%) (at 99 and 102 DAP) from Adet and Debre-Tabor were highly significantly correlated (p<0.01), except significantly correlated (p<0.05) AUDPC and progress rate correlation at Adet. A positive correlation between PSI and AUDPC (r = 0.992** and r = 0.979**) were observed at Debre-Tabor and Adet, respectively. Percent severity index (PSI) was positively highly correlated with disease progress rate (r= 0.913**) at Debre-Tabor and (r = 0.909**) at Adet. Similarly, the disease progress rate (r) and AUDPC were also highly correlated (r=0.932**) at Debre-Tabor, however, it was significantly correlated (r=0.912*) at Adet Table 4 which agreed with the study of Ayda (2015) that was reported as AUDPC and final severity of late blight had positive and highly significant correlation at (r =0.99**) and Binyam *et al.* (2014a) reported as the disease parameters PSI at 66 DAP and AUDPC were positively correlated (r =0.94***) and Wassu (2014) also suggested that highly significant positive correlations were observed among late blight parameters both at genotypic and phenotypic levels. Disease progress rate with PSI at 66 DAP and AUDPC was also highly significantly correlated (Binyam *et al.*, 2014a). Therefore, based on this result we can conclude as these disease parameters were interrelated to each other *i.e.* the presence of one have positive influence or effect on the other parameter. However, all disease parameters had negative correlation with the tuber yields of potato.

Table-4. Correlation coefficients (r) among different disease parameters of late blight during 2017 main cropping season at two study sites.

	Debre-Tabor				Adet			
	AUDPC	Rate(r)	PSI	TTY	AUDPC	Rate (r)	PSI	TTY
AUDPC	1			-0.779**	1			-0.742**
Rate (r)	0.932**	1		-0.625**	0.912*	1		-0.600**
PSI	0.992**	0.913**	1	-0.801**	0.979**	0.909**	1	-0.787**
TTY				1				1

Note: * Significant at P < 0.05, ** highly significant at P < 0.01, ns = non-significant P > 0.05, PSI at 102 (99) = percent severity index (%) at 102 & 99 days after planting, AUDPC = area under disease progress curve (%-days), Rate (r) = disease progress rate, TTY= total tuber yield.

3.7. Total Tuber Yields

The tuber yields at both sites was highly significantly ($p<0.01$) affected by the interactions effect of potato varieties and fungicides Table 5. The highest total tuber yields (31.49 and 30.78 t/ha) were obtained from Saboxyl 72% WP fungicide sprayed plots of Guassa and Belete, respectively at Debre-Tabor and (51.73 and 47.48 t/ha) from Belete and Guassa, respectively at Adet as compared with the other fungicide treated and untreated plots of the same variety Table 5. Based on this result the combinations of Belete and Guassa with Saboxyl 72% WP were performed best and resulted the highest yield than the other varieties combined with other fungicides and same fungicide at both sites. Whereas, the lowest total tuber yield was recorded on unsprayed plots of *Abalo* (4.55 t/ha) at Debre-Tabor and (5.21 t/ha) at Adet Table 5. Even though, the fungicide treatment enables the varieties to express their potential by inhibit the late blight disease development, the moderately resistant (Belete and Gudene) and moderately susceptible variety Guassa could result relatively high yield on unsprayed plots as compared with the susceptible *Abalo*. Generally, fungicide application considerably increased the tuber yield of susceptible and moderately resistant potato varieties, which argue with the result of Habtamu *et al.* (2012) and Ashenafi *et al.* (2017) that the yield of susceptible and resistant varieties could be increased through fungicide applications, however, the total tuber yield varied depending on the combinations of varieties and fungicides. The study of Habtamu *et al.* (2012) and Ayda (2015) also supports this result, *i.e.* the yields of potato are relatively higher on fungicide sprayed plots than untreated. The highest tuber yield could be found when Ridomil fungicide has been used in combinations with both resistant and susceptible varieties (Habtamu *et al.*, 2012). The weekly application of fungicide resulted in higher tuber yields in the susceptible varieties when compared to unsprayed treatments (Habtamu *et al.*, 2012; Ashenafi *et al.*, 2017). The integration of host resistance and fungicide application reduced late blight severity by >50% and resulted in yield gains of more than 30% (Kankwatsa *et al.*, 2002).

Table-5. The effect of varieties and fungicide integration on the yields (t/ha) of potato at two sites during 2017 main season.

Variety	Fungicide	Total tuber yield (t/ha)	
		Debre-Tabor	Adet
Belete	Curzate R WP	23.95^{c}	45.22^{c}
	Saboxyl 72% WP	30.78^{a}	51.73^{a}
	Untreated	23.41^{c}	35.02^{d}
	Mean	26.05	43.99
Gudene	Curzate R WP	21.07^{e}	31.28^{e}
	Saboxyl 72%	22.22^{d}	35.69^{d}
	Untreated	19.90^{f}	26.13^{f}
	Mean	21.06	31.03
Guassa	Curzate R WP	25.62^{b}	35.31^{d}
	Saboxyl 72% WP	31.49^{a}	47.48^{b}
	Untreated	21.72^{de}	25.55^{f}
	Mean	28.56	36.11
Abalo	Curzate R WP	8.74^{g}	14.12^{g}
	Saboxyl 72% WP	19.94^{f}	25.08^{f}
	Untreated	4.55^{h}	5.21^{h}
	Mean	11.08	14.80
Significant difference		**	**
CV (%)		2.67	2.26

Note: Sig. difference = Significant Difference, CV = Coefficient of Variation, values followed by the same letter within the column or row are not significantly different at 0.05 probability level.

3.8. Cost/Benefit Analysis

The partial budget analysis of this study indicated that the treatment sprayed by Curzate R WP fungicides had the highest total cost (fungicide price and spraying labor cost) (3,981.48 birr/ha) followed by Saboxyl 72% WP treated plots (2,181.48 birr/ha) as compared with unsprayed. As this result, indicated that all fungicide treatments on all potato varieties have resulted high net benefit and marginal rate of returns Table 6. The maximum net profits (196,853.52 and 131,668.52 birr/ha) were recorded from Belete (Adet) and Guassa (Debre-Tabor) both treated by Saboxyl 72% fungicide as compared with varieties sprayed by same fungicide and Curzate R WP and unsprayed plots. However, the lower net profits (18,350 and 19,890 birr/ha) were obtained from unsprayed plots of *Abalo* at Debre-Tabor and Adet, respectively. Even though, lower gross benefits were obtained from plots treated four times with Saboxyl 72% and Curzate R WP fungicide had higher net benefit as compared to unsprayed plots. The highest (62,968.52 birr/ha) marginal net benefit (MB) was obtained from *Abalo* at Debre-Tabor, however, at Adet, the highest (82,598.52 birr/ha) MB was calculated from Guassa followed by *Abalo* (74048.52 birr/ha) both treated by Saboxyl 72% WP fungicide as compared with the Curzate treated and unsprayed plots of each variety. The lowest marginal benefits (-1,881.48 and 15,593.52 birr/ha) were calculated from Curzate R WP treated plots of Belete at Debre-Tabor and Gudene at Adet, respectively. Generally, among four varieties the lower marginal benefit was recorded from Gudene combined with both fungicides from both sites Table 6.

Table-61. Result of partial budget analysis for fungicide applications used for controlling late blight of potato at Debre-Tabor and Adet during 2017 main season

No.	Cost benefit data	Treatments					
		Debre-Tabor			Adet		
	Belete	**Saboxyl**	**Curzate**	**Control**	**Saboxyl**	**Curzate**	**Control**
1	Adj. Y (t/ha) (Y*85)	26.07	20.15	19.73	44.23	38.50	29.89
2	Pr (birr ton-1)	5000	5000	5000	4500	4500	4500
3	Sale R (1*2)	130350	100750	98650	199035	173250	134491.5
4	TIC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
5	MC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
6	NP (3-4)	128168.52	96768.52	98650	196853.52	169268.52	134491.5
7	MB (birr/ha)	29518.52	-1881.48	0.00	62362.02	34777.02	0.00
8	MRR (**7/5**) (%)	1353.14	-47.26	0.00	2858.70	873.47	0.00
9	CBR (6/4)	58.75	24.31	---	90.24	42.51	---
	Gudene	Saboxyl	Curzate	Control	Saboxyl	Curzate	Control
1	Adj. Y (t/ha) (Y*85)	18.77	17.76	16.79	30.36	26.55	22.20
2	Pr (birr ton-1)	5000	5000	5000	4500	4500	4500
3	Sale R (1*2)	93850	88800	83950	136620	119475	99900
4	TIC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
5	MC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
6	NP (3-4)	91668.52	84818.52	83950	134438.52	115493.52	99900
7	MB (birr/ha)	7718.52	868.52	0.00	34538.52	15593.52	0.00
8	MRR (**7/5**) (%)	353.82	21.81	0.00	1583.26	391.65	0.00
9	CBR (6/4)	42.02	21.30	---	61.63	29.01	---
	Guassa	Debre-Tabor			Adet		
		Saboxyl	Curzate	Control	Saboxyl	Curzate	Control
1	Adj. Y (t/ha) (Y*85)	26.77	21.78	18.45	40.55	30.08	21.71
2	Pr (birr ton-1)	5000	5000	5000	4500	4500	4500
3	Sale R (1*2)	133850	108900	92250	182475	135360	97695
4	TIC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
5	MC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
6	NP (3-4)	131668.52	104918.52	92250	180293.52	131378.52	97695
7	MB (birr/ha)	39418.52	12668.52	0.00	82598.52	33683.52	0.00
8	MRR (7/5) (%)	1806.96	318.19	0.00	3786.35	846.01	0.00
9	CBR (6/4)	60.36	26.35	---	82.65	33.00	

Table-6. Continued.

No.	***Abalo***	Saboxyl	Curzate	Control	Saboxyl	Curzate	Control
1	Adj. Y (t/ha) (Y*85)	16.70	7.33	3.67	21.36	11.95	4.42
2	Pr (birr ton-1)	5000	5000	5000	4500	4500	4500
3	Sale R (1*2)	83500	36650	18350	96120	53775	19890
4	TIC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
5	MC (birr/ha)	2181.48	3981.48	0.00	2181.48	3981.48	0.00
6	NP (3-4)	81318.52	32668.52	18350	93938.52	49793.52	19890
7	MB (birr/ha)	62968.52	14318.52	0.00	74048.52	29903.52	0.00
8	MRR (7/5) (%)	2886.50	359.63	0.00	3394.42	751.07	0.00
9	CBR (6/4)	37.28	8.21	---	43.06	12.51	---

Note: Adj. Y = Adjusted marketable yield, Y*85 = yield *85%, Pr = price, sale R = sale revenue, TIC = total input cost, MC = marginal cost, NP = net profit, MB = marginal benefit, MRR = Marginal rate of return, CBR = cost benefit ratio, birr/ha = Ethiopian birr per hectare.

The highest marginal rate of return (MRR) (2,886.50% and 3,786.35%) were obtained from the combination of Saboxyl 72% and *Abalo* and Guassa at Debre-Tabor and Adet, respectively Table 6. On the other hand, the lowest MRR were obtained from Gudene variety combined with Saboxyl 72% and Curzate R WP fungicides as compared with the other three varieties. This showed that application of fungicides on the moderately resistant variety Gudene is not advisable (not profitable) than other varieties. The highest cost benefit ratio (CBR) *i.e.* total input cost: Net profits (1: 90.24 and 1: 60.36) were calculated from Belete and Guassa treated by Saboxyl 72% fungicide at Adet and Debre-Tabor, respectively. On the other hand, the lowest CBR (1: 8.21 and 1: 12.51) were obtained from *Abalo* and Curzate R WP combinations at Debre-Tabor and Adet, respectively Table 6. Therefore, as this result indicated, investing one Ethiopian birr on Belete and Guassa variety can produce 90.24 at Adet, and 60.36 birr at Debre-Tabor, respectively. However, investing on the susceptible variety *Abalo* and moderately resistant variety Gudene was not as such profitable as compared with the other varieties, especially investing on Curzate R WP fungicide application are not advisable as this result indicated.

4. CONCLUSIONS

All four potato varieties supplemented with fungicide foliar spray had pronounced effect in reducing late blight disease epidemics both at Adet and Debre-Tabor. However, the integration of potato varieties and four times spray of Saboxyl 72% at the rate of 2kg/ha significantly reduced the intensity of late blight disease of potato at both sites. Especially, the combination of Saboxyl 72% WP fungicide with moderately resistant varieties Gudene and Belete and moderately susceptible variety Guassa were highly inhibit late blight disease development. At the final date of assessment (102 and 99 DAP), except *Abalo* at Debre-Tabor all varieties combined with Saboxyl 72% showed lower incidence (<36%) at both sites. The lowest final disease severity was obtained from the moderately resistant varieties Gudene and Belete on both fungicides treated as well as untreated plots as compared with the other varieties at both sites. The lowest disease progress rates were obtained from Gudene and *Abalo*, and the lowest AUDPC values were obtained from moderately resistant varieties Gudene and Belete all treated by Saboxyl 72% WP at Adet and Debre-Tabor, respectively. Even though, its yield potential is not as such attractive Gudene variety has showed good disease resistant reactions *i.e.* the lowest disease severity, AUDPC and infection rates were recorded from it as compared with the other three varieties even on untreated plots at both study sites. However, on variety Belete the relatively higher disease progress rate was observed on unsprayed plots even though, the disease symptom occurred lately, this may have indicated that the variety Belete has going to susceptibility and needs the supplement of fungicide sprays. Based on this study, variety Gudene appears to have comparative resistance to late blight yet, and is still promising variety even though, its yielding capacity was relatively low as compared with Belete and Guassa varieties, and it might be recommended for production if the other management practices have not applicable or accessible. Variety Belete and Guassa could be recommended for production in combination with Saboxyl 72% fungicide, since they have best agronomic performance with relatively lower disease reaction at Adet and Debre-Tabor, respectively. Saboxyl 72% WP foliar spray was effective and best fitted with different varieties against late blight disease. Moreover, late blight disease resistant varieties need to be screened and developed frequently and should be addressed/distributed on the productive areas, since the high yielding and moderately resistant variety Belete has going to susceptibility as we have observed in the present study.

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