The Response of Potato Late Blight to Potato varieties and Fungicide Spraying Frequencies at Meket, Ethiopia

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The Response of Potato Late Blight to Potato varieties and Fungicide Spraying Frequencies at Meket, Ethiopia

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Abstract: Potato late blight (Phytophthora infestans (Mont.) De Bary) is the major constraint of potato production in Ethiopia. The field experiment was done at Meket district during 2018 cropping season, to determine appropriate spraying frequency combined with different levels of resistance variety. The experiment had 15 treatments with a combination of three potato varieties (Belete, Gudene, and Jalene) and five spraying frequencies (zero, one, two, three, and four times spray). The experiment was arranged in a randomized complete block design in factorial combination with three replications. The combination of potato varieties and spraying frequencies of Ridomil applications showed statistically significant on the disease, yield, and yield component parameters. The highest disease severity (84.76%) was obtained from untreated Jalene variety. The maximum tuber yield (29.62 t ha\(^{-1}\)) was obtained from Belete variety sprayed with two-time spraying. Whereas the lowest tuber yield (12.93 t ha\(^{-1}\)) was recorded from untreated Jalene variety. Moreover, the highest (1774.65%) marginal rate of return was obtained from Belete variety treated with one spray. Finally, it is concluded that for moderately resistance one spray, moderately susceptible two sprays and four sprays for susceptible varieties were found better management options and get the highest cost-benefit as compared with other treatment combinations.

Subjects: Pest Management; Plant Pathology; Epidemiology

Keywords: Disease progress rate; severity; late blight; potato varieties; relative yield loss; ridomil

1. Introduction
Potato (Solanum tuberosum L.) is one of the major crops in the world and its center of origin is South America at the Andes highlands (Hawkes, 1978). It belongs to the Solanaceae family, genus Solanum. Its life cycle is an annual and spreads itself by vegetative propagation. Under the family Solanaceae, potato is the leading most important food and cash crop in the world. It is one of the main essential crops for guaranteeing food security (Knapp, 2008), as compared with other crops, it contains relatively more calories, vitamins, and nutrients (Sen et al., 2010).

Potato production area coverage of the World, Africa, and Ethiopia is 19.3 million, 1.89 million, and 67.6 thousand hectares, respectively. Potato production of the World, Africa, and Ethiopia are 388.2 million, 25.01 million, and 932.7 thousand tons, respectively (FAOSTAT, 2017). According to CSA (2018), potato production area coverage and production in Amhara Region are 19,199.47 hectares and 287,801.92 tons, respectively. In Ethiopia, the production of potato increases and become a source of cash income for producers, and retains its importance for daily household consumption.

The production of the crop is attrition by several biotic and abiotic factors. Among biotic constraints, fungal diseases are major factors affecting production and productivity as well as
the quality of the crop. Such as late blight, fusarium wilt, early blight, bacterial wilt, and root-knot nematodes (Ephrem, 2015). Among those diseases, late blight (Phytophthora infestans) is the most important and serious disease of potato and tomato in many countries of the world (Ermias, 2016). *Phytophthora infestans* is not a fungus, but it belongs to the class Oomycetes, order Peronosporales, family Pythiaceae and genus Phytophthora (Agrios, 2005). The disease was taken responsibility for the devastation of Irish potato farms and causes severe famine in the mid-nineteenth century (Bourke, 1993). It causes serious loss in yield and quality as well as reduces its marketability values (Bekele et al., 1996). The estimated potato yield losses reported in Ethiopia due to late blight is 22–46% (Fekede, 2011).

Accordingly, late blight management through host resistance, cultural practices, using late blight free tuber, and application of chemicals (fungicide) could be an important practice to control the infestation of the disease (Ephrem, 2015). Kirk et al. (2001) suggested that planting of resistant potato cultivars could minimize the application of fungicides rates and spraying frequencies.

Fungicides are the most important aspect of late blight management in temperate countries (Olayna et al., 2001). Ridomil Gold was the most effective management option of potato late blight by three consecutive sprays at 7 days interval as compared to 2 or 1 spray (Subhani et al., 2015).

An integrated disease management approach is effective to control potato late blight disease (Kirk, 2001). Integrated use of fungicides and resistance potato varieties are the most effective management options of late blight in Ethiopia (Olayna et al., 2001; Ermias, 2016). In tropical Africa, there is limited research on the application of fungicide intervals, spraying frequency, time, and rate of fungicide application (Kankwatsa et al., 2002).

In Ethiopia, the National Potato Research Program within the Ethiopian Institute of Agricultural Research releases potato cultivars with resistance to *Phytophthora infestans*, but they lost their resistance soon after dissemination. The profound ability of the disease to reach an epidemic level within short periods, inadequate efficiency of cultural practices to reduce the high level of disease severity, development of resistance to fungicides, and breaking of resistance potato varieties within a short period.

Moreover, in the study area, there is limited research on spraying frequency combine with different levels of resistance potato varieties. A combination of fungicides with susceptible and moderately resistant potato varieties, which could be treated against late blight of potato varieties could reduce the application of high fungicide, decrease the risk to human health, environmental contamination and increase the economic benefit of farmers (Shiferaw et al., 2011). In the study area, they have not known much more information about times of spraying frequency and different varieties responses to late blight disease reactions. Therefore, the present study was designed to evaluate the effect of fungicide spraying frequencies combined with potato varieties for the management of late blight and to select cost-effective management options of potato late blight disease.

2. Materials and methods

2.1. Description of the experimental site
The field experiment was conducted at Sirinka Agricultural Research Center (SARC) trial station in Meket district, Eastern Amhara, Ethiopia, during the main cropping season of 2018. The altitude of experimental field was 2898 m.a.s.l., located 11°47′05″ North latitude to 38°40′46″ East longitude. Substantial rainfall was observed from July to the last week of August and the average annual temperature and rainfall of the study area have ranged from 15°C to 17°C and from 934 to 1342 mm, respectively. Half of the annual rainfall occurred in July and August. Among each month, March and April are the hottest, and September is the coldest month (Samuale Tesfaye et al., 2014).
2.2. Experimental materials and agronomic practices
Three potato varieties, namely Belete (CIP-393,371.58), Gudene (CIP-386,423.13), and Jalene (CIP—384,321.19) were obtained from Adet Agricultural Research Center. Those varieties were released in 2009, 2006, and 2002, respectively. Those varieties have a different level of reaction to late blight disease. According to Shiferaw and Tesfaye (2018) report, Belete and Gudene have moderate resistance and moderately susceptible varieties, respectively, whereas Jalene has a susceptible level of reaction to late blight (Ashenafi et al., 2017). A fungicide Ridomil gold (Metalaxyl 40 g/kg + Mancozeb 640 g/kg), obtained from Sirinka Agricultural Research Center (SARC), at the rate of 2.5 kg/ha was used for the study. Uniform-sized potato tubers were used as planting material for all treatments. All agronomic practices such as earthing up, ridging, weeding, and cultivation were applied uniformly for all treatments in each plot.

2.3. Experimental treatment and design
The experiment had 15 treatments (Table 1); with a combination of three potato varieties (Belete, Gudene, and Jalene) and four fungicides (Ridomil) spraying frequencies (one, two, three and four times spray) and unsprayed treatment as a control check. The first spray of fungicides was started soon after the initial appearance of late blight symptoms and continue on the bases of treatment spraying frequency.

The field experiment was arranged in a randomized complete block design (RCBD) in factorial combination with three replications. The plot size of the experiment was 3 m x 3 m length and width, respectively. Each plot was contained four rows (with two harvestable central rows), with a plant spacing of 30 cm and 75 cm row spacing. Each plot and block was separated by a buffer zone of 1 m and 1.5 m, respectively, to prevent fungicide drift or cross-contamination for potato field trials. In addition to that, to avoid fungicide drift, plastic sheets were used during the application (Figure 1).

| Table 1. Treatment combination |
|--------------------------------|
| **Potato varieties** | **Spraying frequency** | **Treatment combination** | **Treatment code** |
| Belete | unsprayed | Belete + unsprayed, check | BS0 |
| | one time spray | Belete + one time spray | BS1 |
| | two times spray | Belete + two times spray | BS2 |
| | three times spray | Belete + three times spray | BS3 |
| | four times spray | Belete + four times spray | BS4 |
| Gudene | unsprayed | Gudene + unsprayed, check | GS0 |
| | one time spray | Gudene + one time spray | GS1 |
| | two times spray | Gudene + two times spray | GS2 |
| | three times spray | Gudene + three times spray | GS3 |
| | four times spray | Gudene + four times spray | GS4 |
| Jalene | unsprayed | Jalene + unsprayed, check | JS0 |
| | one time spray | Jalene + one-time spray | JS1 |
| | two times spray | Jalene + two times spray | JS2 |
| | three times spray | Jalene + three times spray | JS3 |
| | four times spray | Jalene + four times spray | JS4 |
2.4. Disease assessment

2.4.1. Disease incidence
Disease incidence was recorded by counting of plants that showing visible symptoms of late blight in the central rows and the data were expressed as a percentage of the total assessed plants. The disease incidence was calculated with the following formula.

\[
\text{Disease Incidence} = \frac{\text{Number of diseased plant}}{\text{Total number of plant inspected}} \times 100
\]

2.4.2. Disease severity
Disease severity was recorded by visually estimating the percentage of leaf area diseased from 10 randomly taken and pre-tagged plants in the middle two rows of each plot. The severity was recorded every 7 days interval starting from the onset of the disease until the un-spray treatment of the susceptible variety (Jalene) no longer increased in disease severity. The data on disease severity were recorded by using 1–9 rating scale of Shutong et al. (2007) (Table 2). Each severity scale was converted into the Percentage Severity Index (PSI) for analysis (Wheeler, 1969).

where \(Snr\) = the summation of numerical ratings, \(Npr\) = total number of plant rated, \(Msc\) = the maximum score of the scale.

2.4.3. Area under disease progress curve (AUDPC)
The area under the disease progress curve (AUDPC) was calculated for each treatment combination from the assessment of disease severity using the following formula (Campbell & Madden, 1990).

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

where \(n\) is the total number of assessments, \(t_i\) is the time of the \(i^{th}\) assessment in days from the first assessment date; \(x_i\) is the percentage of disease severity at \(i^{th}\) assessment.

2.4.4. Disease progress rate
Disease progress rate was calculated by using the following formulas.
Table 2. The rating scale for the assessment of late blight of potato leaves (Shutong et al., 2007)

| Severity scale | Rating grade in % | Level of resistance/susceptibility |
|----------------|-------------------|-----------------------------------|
| 0              | 0                 | No disease lesion                  |
| 1              | 10                | A small lesion on the leaves less than10% area coverage of the whole leaflet |
| 3              | 11–20             | Lesion area between 10–20 % of the whole leaflet |
| 5              | 21–30             | Lesion area between 20–30 % of the whole leaflet |
| 7              | 31–60             | Lesion area between 30–60 % of the whole leaflet |
| 9              | Over 60           | Lesion area over 60 % of the whole leaflet |

Linear Logistic model, \( r = \ln [(Y/1-Y)] \) (Van Der Plank, 1963) and Gompertz, \( r = -\ln [-\ln (Y)] \) (Berger, 1981) Where \( r \) is disease progress rate, \( Y \) is disease severity and \( \ln \) = Natural logarithm.

The two models for comparing the estimation of disease progression parameters from each treatment. The goodness of fit of the models was tested based on the magnitude of the coefficient of determination (\( R^2 \)) and residuals (SE) obtained from each model (Campbell & Madden, 1990). As a result, there was a higher coefficient of determination (\( R^2 \)) and lower standard error (SE) on logistic than the Gompertz model. Therefore, the rate of increase in late blight was estimated and compared using the Logistic model.

2.5. Yield and yield components

Yield and yield components such as; days to physiological maturity, plant height (cm), average tuber weight (g/tuber), marketable tuber yield (t/ha), marketable tubers weight, unmarketable tuber yield (t/ha) and total tuber yield (t/ha) were recorded based on their standard measures.

2.6. Relative yield loss and percentage yield increase

Relative Yield loss due to late blight was measured as percentage yield reduction of unsprayed plots compared with the most protected plot using the following formula of Robert and Janes (1991):

\[
RPYL = \frac{YP - YT}{YP} \times 100
\]

where \( RPYL \) = relative percent yield loss, \( YP \) = yield from the maximum protected plot and \( YT \) = Yield from plots of other treatments.

The percent yield increase (PYI) was calculated based on Lung’aho et al. (2003) suggested formula:

\[
PYI = \frac{\text{tuberyieldoffungicidetreatedplot} - \text{yieldofcontrolplot}}{\text{yieldofcontrolplot}} \times 100
\]

2.7. Cost-benefit assessment

The cost and benefit of each treatment were analyzed partially, and the marginal rate of return was computed by considering the variable cost available in the respective treatment. CIMMYT (1988) reported that marginal analysis is concerned with the process of making choice, between alternative factor-product combinations considering small changes. The formula is as follows:

\[
MRR = \frac{\text{DNI}}{\text{DIC}}
\]
Where; $MRR = \text{marginal rate of returns}$, $DNI = \text{difference in net income compared with control}$, and $DIC = \text{difference in input cost compared with control}$. The cost-benefit analysis included input variable costs like the cost for chemical and day labor for chemical spraying and fixed costs like cost of potato seed and costs of agronomic practices (land preparation, ridging earthing up, and harvesting). The price of Ridomil was Birr 1300 kg$^{-1}$; labor cost of Birr 35 man-days and Birr 80 sprayer knapsack rent was used. At the end of the production total gross benefit of the field was calculated from marketable potato tuber times with the local market price (Birr 7 kg$^{-1}$).

2.8. Data analysis

Data on disease parameters (incidence, PSI, disease progress rate, AUDPC), yield, and yield components were subjected to Analysis of variance (ANOVA) for each data by using GenStat version 18.0 Software (GenStat, 2015). By using Duncan’s multiple range test treatments mean separation was done. Correlation analysis was done to know the association of disease parameters with yield obtained from the interactions of different varieties and rates of fungicide applications. The linear regression model was used to predict the relationship of AUDPC and total tuber yield by using GenStat version 18.0 Software (GenStat, 2015).

3. Results and discussion

3.1. Disease incidence

The first symptoms of potato late blight disease were observed at 59 days after planting (DAP) on the susceptible variety (Jalene). The symptoms appear on lower leaves small, light-to-dark green, and circular-to irregularly shaped, water-soaked lesions were observed. The incidence of the disease was analyzed only from the first and second assessment dates because at the third assessment the incidence was 100% in all the plots.

Analysis of the 68DAP disease incidence showed significant differences ($p < 0.05$) among treatments (Table 3). The highest disease incidence of 90% was recorded on fungicide untreated plots of susceptible Jalene variety. Similarly, the lowest, 56.67% late blight incidence was recorded on plots of moderately resistant (Belete) and moderately susceptible (Gudene) varieties with three times spraying frequency of Ridomil fungicide (Table 3). The result inlined with Ashenafi et al. (2017) research result, the maximum (91.5%) disease incidence was showed from the unsprayed control of susceptible variety (Jalene). The same result from susceptible local cultivar showed maximum disease incidence (80%) in Awassa (Shiferaw et al., 2011).

3.2. Percent severity index (PSI)

The interaction effect of fungicides and varieties on late blight severity showed a significant difference ($p < 0.05$) among treatments. At the final disease assessment (96DAP), the highest 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 with four times spraying frequency of Ridomil (Table 3). Among spraying frequencies on Belete and Gudene varieties there was no statistically significant differences on treated plots from one time spray to four times spray. But there is significant difference among spraying frequencies on Jalene varieties. As compared with all treatment combinations the highest (84.76%) PSI was shown on Jalene variety. This variation might be due to the genetic difference among the varieties to resist the epidemics of late blight.

The finding of the result indicated foliar application of ridomil at seven days interval could be effective to reduce the severity of late blight as compared with untreated plot. Frequent foliar applications of ridomil on Jalene variety might be a reason for its high efficacy; even during the wet season, it has less chance to be washed off by rainfall that used to maintain its high efficacy. The present study was parallel to Ashenafi et al., (2017) research result on the management of late blight through varieties and different fungicides. His result indicated that the highest severity reduction was recorded on moderately resistant (Gera) variety treated with fungicides and the
highest severity was recorded in varieties of Jalene (83.5%) and Gudene (30%) combined with the unsprayed check. Susceptible cultivars require more fungicide spraying frequencies than resistant cultivars (Kirk et al., 2001). The result of our study agreed with Subhani et al. (2015) research result, Ridomil was most effective for the control of potato late blight by three consecutive sprays at seven days interval after disease appearance. Shiferaw and Tesfaye, (2018) also confirmed that the combination of host resistance variety and fungicide spraying played a significant role in reducing the severity of late blight on the potato crop. The present study result was in line with Kankwatsa et al. (2002), which suggested that the interaction of late blight resistant varieties and fungicide spraying minimized late blight disease severity by more than 50% as compared with unsprayed susceptible varieties.

### 3.3. Disease progress rate

Disease progress rate was calculated from initial disease assessment (61DAP) to each interval days of assessment by using a linear logistic model. Analysis of data of disease progress rate revealed significant (p < 0.05) differences among the treatment combinations of the three potato varieties and five spraying frequencies of Ridomil applications (Table 3). The highest disease progress rate of 0.0375 units per day was obtained on an unsprayed control plot of the variety Jalene in 2018 cropping season. Whereas the lowest disease progress rate of 0.0097 units per day was scored from the plots of Belete treated with ridomil four times at 7 days interval (Table 3). Hence, the result indicated that late blight disease progress was faster on unsprayed plots of Jalene variety than the sprayed plots of other varieties.

| Treatment combination | DI at 68DAP (%) | PSI at 96DAP (%) | AUDPC | Disease progress rate |
|------------------------|-----------------|-----------------|-------|-----------------------|
| BS0                    | 76.67           | 53.1            | 1004.47 | 0.0195                |
| BS1                    | 70              | 34.5            | 685.01  | 0.0136                |
| BS2                    | 60             | 30.96           | 682.46  | 0.0126                |
| BS3                    | 56.67           | 28.92           | 659.11  | 0.0122                |
| BS4                    | 60             | 26.03           | 661.73  | 0.0097                |
| GS0                    | 86.67           | 70.01           | 1395.33 | 0.0249                |
| GS1                    | 86.67           | 63.21           | 1228.16 | 0.0225                |
| GS2                    | 83.33           | 35.86           | 779.25  | 0.0118                |
| GS3                    | 56.67           | 43.70           | 799.2   | 0.0139                |
| GS4                    | 60             | 34.22           | 725.01  | 0.0125                |
| JS0                    | 90             | 84.76           | 1725.57 | 0.0375                |
| JS1                    | 86.67           | 75.43           | 1480.31 | 0.0312                |
| JS2                    | 86.67           | 65.79           | 1144.69 | 0.0211                |
| JS3                    | 76.67           | 35.18           | 807.08  | 0.0108                |
| JS4                    | 76.67           | 34.60           | 795.97  | 0.0111                |
| Mean                   | 74.22           | 47.74           | 971.56  | 0.0176                |
| Sig. level             | ***             | ***             | ***    | *                     |
| CV (%)                 | 9               | 15.9            | 9.4    | 27.7                  |

*Significant at p < 0.05, *** Significant at p < 0.001, CV = Coefficient of Variation, Means following by the same letter within the column or row are not significantly different at 0.05 probability level, DI = Disease Incidence, PSI = Percentage severity index, DAP = Days after planting, BS0 = Belete without spraying, BS1 = Belete with one spray, BS2 = Belete with two sprays, BS3 = Belete with three sprays, BS4 = Belete with four sprays, GS0 = Gudene without spraying, GS1 = Gudene with one spray, GS2 = Gudene with two sprays, GS3 = Gudene with three sprays, GS4 = Gudene with four sprays, JS0 = Jalene without spraying, JS1 = Jalene with one spray, JS2 = Jalene with two sprays, JS3 = Jalene with three sprays, JS4 = Jalene with four spray
Generally, treatment variation was observed in late blight infection rates due to the variable resistance levels of the varieties and the different fungicide spray frequencies. The present study indicated that application of fungicide in all potato varieties reduces the infection rate of potato late blight disease. These results inline with Shiferaw and Tesfaye, (2018) reported that the application of fungicides was minimized the infection of late blight than the control plots. Ermias (2016) 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 present study revealed that statistically significant (p < 0.001) differences had shown on the area under disease progress curve (AUDPC) at all treatment combinations with the highest AUDPC value of 1725.57%-days on the unsprayed plot of Jalene variety and the lowest AUDPC values of 661.73% days were obtained from the Belete variety treated with four times spraying frequency of Ridomil application (Table 3). The high degree of significance in the difference of AUDPC values among the evaluated varieties might be due to their genotypic resistance characteristics of late blight reaction. Among spraying frequencies on Belete variety AUDPC was not statistically significant differences for treated plots from one time spray to four times spray. Contrarily, on Gudene, it was statistically different among one and other spraying frequencies, but not on two, three and four times spray. Analysis of variance showed significant difference was observed on spraying frequencies on Jalene variety (Table 3).

This indicated that all evaluated ridomil foliar spray frequencies at 7-day interval had a significant reduction of late blight disease development on the three potato varieties as compared with their unsprayed check. The area under the disease progress curve is a very suitable summary of plant disease epidemics that incorporates initial disease severity, the rate parameter, and the duration of the epidemic, which determines final disease severity (Madden et al., 2008). The present study in line with Ashenafi Mulatu et al. (2017), the maximum AUDPC (2457.5% days) was recorded from untreated susceptible variety (Jalene).

3.5. Yield and yield component

3.5.1. Days to physiological maturity

Analysis of days to physiological maturity revealed significant (p < 0.001) differences among treatment combinations (Table 4). The longest days (104.33) to maturity was recorded on Belete variety treated with three times spraying frequency of Ridomil application at 7-day interval. While the shortest days (95.33) to reach maturity was recorded on Jalene variety treated with one-time ridomil spraying application. The highest days to physiological maturity (104.33, 103 and 102 days) was calculated from plots treated with three times spraying frequencies for Belete, Gudene and Jalene varieties, respectively. Whereas the lowest (102.33, 102 and 95.33 days) were obtained from plots treated with one time spray for all varieties, respectively (Table 4). From this result integrating resistant varieties with the application of Ridomil fungicide could increase the maturity period of potato varieties and correspondingly could increase tuber yield. The result of days to physiological maturity in-line with Anonymous (2011) findings, he stated that moderately resistant varieties have long maturity time than susceptible cultivars. Foliar application of fungicides extended days to physiological maturity of potato varieties by minimizing the disease pressure (Fekede, 2011). As the maturity period increased stored food in potato tuber also increased. Fungicide application in each treatment extended the time required by the potato cultivars studied to attain days to physiological maturity.

3.5.2. Plant height

The analysis of variance revealed that the combination of potato varieties and spraying frequencies showed a significant difference (p < 0.05) in their plant heights. The tallest (57 cm) was measured from the Belete variety treated with four times spraying frequency of Ridomil fungicides. While the shortest (38.33 cm) plant height was measured from untreated Jalene variety (Table 4).
Table 4. Interaction effect of potato varieties and different spraying frequencies on yield and yield components of potato against late blight at Meket 2018

| Treatment combination | DM (days) | PH (cm) | ATW (gm) | MKY (t ha⁻¹) | UMKY (t ha⁻¹) | TTY (t ha⁻¹) |
|-----------------------|----------|--------|----------|--------------|---------------|--------------|
| BS0                   | 102.67   | 47.67  | 55.12    | 17.59        | 2.61          | 20.2         |
| BS1                   | 102.33   | 52.33  | 78.36    | 28.57        | 0.52          | 29.08        |
| BS2                   | 104.33   | 50.33  | 65.76    | 27.04        | 2.58          | 29.62        |
| BS3                   | 104.33   | 54.67  | 76.28    | 25.61        | 1.23          | 26.84        |
| BS4                   | 103.67   | 57.33  | 77.94    | 28.01        | 1.34          | 29.36        |
| GS0                   | 99.67    | 39.33  | 40.37    | 14.75        | 2.88          | 17.63        |
| GS1                   | 102.33   | 39.33  | 38.78    | 15.69        | 3.22          | 18.91        |
| GS2                   | 102.33   | 40.33  | 58.47    | 26.77        | 2.02          | 28.79        |
| GS3                   | 103.67   | 47.67  | 54.49    | 26.51        | 2.06          | 28.57        |
| GS4                   | 101.33   | 38.67  | 60.66    | 25.85        | 1.52          | 27.37        |
| JS0                   | 96.67    | 38.33  | 25.09    | 9.88         | 3.04          | 12.93        |
| JS1                   | 95.33    | 39.67  | 32.78    | 12.56        | 3.65          | 16.15        |
| JS2                   | 97.33    | 43.53  | 45.26    | 18.11        | 3.13          | 21.23        |
| JS3                   | 102.33   | 48.67  | 47.98    | 21.67        | 1.88          | 23.48        |
| JS4                   | 102.67   | 47.67  | 59.27    | 25.97        | 3.0           | 28.6         |
| Mean                  | 101.25   | 45.71  | 54.44    | 21.61        | 2.31          | 23.92        |
| Sig. level            | ***      | *      | ***      | **           | **            | **           |
| CV (%)                | 1.4      | 6.7    | 14.4     | 12.6         | 28.5          | 11.4         |

* = Significant at p < 0.05, ** = Significant at p < 0.01, *** = Significant at p < 0.001; CV = Coefficient of Variation; Means following by the same letter within the column or row are not significantly different at 0.05 probability level, DM = Days to maturity, PH = Plant height, ATW = Average tuber weight, MKY = Marketable yield, UMKY = Unmarketable yield, TTY = Total tuber yield.

For Belete, Gudene and Jalene varieties the highest (57, 47.67 and 48.67 cm) plant height was measured from plots treated with four, three and three times spray, respectively. Whereas the lowest (47.67, 39 and 38.33 cm) were obtained from untreated plots of all varieties, respectively (Table 4).

Fungicide application might have enhanced plant height due to the encouraging ability of the fungicides that reduce foliage defoliation due to the disease and the plant continues in its physiological process. The present study is supported by Fekede’s (2011) research finding, among fungicides schedule the highest plant height was recorded from two times Ridomil and mancozeb sprayed plots, whereas the lowest plant height was recorded from unsprayed plot. It indicated that unsprayed plots had shown significantly lower plant height than sprayed plots.

3.5.3. Average tuber weight

The analysis of variance showed a significant difference between the combination of potato varieties and spraying frequencies of ridomil fungicide application at (p < 0.05) on average tuber weights (Table 4). From all combinations of these potato varieties and spraying frequencies of Ridomil applications, the highest (77.98 g) tuber weight was recorded on the potato variety Belete plots treated with four times spraying of Ridomil. On the other hand, the lowest (25.09 g) tuber weight was obtained from untreated Jalene variety. From Belet variety the highest (77.98 gm) and lowest (55.12 gm) average tuber weight was measured from plots treated with four times spray and treated with zero spray, respectively. But there was not statically significant difference average tuber weight observed on Belete variety among sprays from one up to four times spray. And also, from Gudene variety the highest (60.6 gm) and lowest (38.78 gm) average tuber weight was measured from Gudene variety treated with four and one times spray. Similarly, the highest
(59.27 gm) and lowest (25.09 gm) average tuber weight was measured from Jalene variety treated with four times spray and untreated plot, respectively (Table 4). Generally, the results of this study indicated that the integration of potato varieties and spraying frequencies of ridomil applications had a considerable effect on tuber weight. The highest tuber weight was recorded from moderate resistance (Belete) variety treated with fungicide than unsprayed susceptible variety. According to Ermias’s (2016) research finding, the highest and lowest tuber weights were obtained from Belete and local varieties, respectively.

3.5.4. Marketable tuber yield
The analysis of the data on marketable tuber yield from potato varieties treated with five spraying frequencies of Ridomil applications revealed highly significant (p < 0.01) differences among their combinations (Table 4). From Belete, Gudene and Jalene varieties the highest (28.57, 26.77 and 25.6 t ha⁻¹) marketable tuber yield were recorded from plots treated with one, two and four times spray, respectively. Whereas lowest (17.59, 14.75 and 9.89 t ha⁻¹) were obtained from untreated plots of all varieties, respectively. But there was no statistically significant difference on Belete variety among sprays from one upto four times spray. This study indicated that the increment in spraying frequencies improved the marketable tuber yield of the susceptible variety Jalene (Table 4).

The result of the present study in agreement with Ermias (2016) finding, integration of resistance host (Belete potato variety) with Ridomil gold 68% WG fungicide results in reduced late blight disease progress, with a correspondingly increased total and marketable tubers weight. Similar research was done by Ashenafi et al. (2017) on the control of late blight through different varieties and fungicides, weekly application of fungicides resulted in higher tuber yields from the susceptible variety as compared to the untreated plot. Shiferaw and Tesfaye (2018) also revealed that the highest marketable yield was obtained from moderately resistance variety (Belete) treated with two times spraying frequencies of Matco fungicide.

3.5.5. Unmarketable tuber yield
Analysis of unmarketable tuber yield showed significant (p < 0.01) differences among the combination of the three potato varieties and five spraying frequencies of Ridomil applications (Table 4). The highest unmarketable tuber yield was obtained from Jalene plots treated with all spraying frequencies except three times spray. Thus, highest (3.65 t ha⁻¹) unmarketable tuber yields were recorded on the variety of Jalene plots treated with one-time spraying frequencies of Ridomil application. The lowest (0.52 t ha⁻¹) unmarketable tuber yield was recorded from a moderately resistant variety Belete plot treated with one time sprayed.

3.5.6. Total tuber yield
Analysis of total tuber yield showed significant variation (p < 0.01) among the interaction effect of potato varieties and five spraying frequencies (Table 4). Analysis of variance indicated that there was significant difference among each potato varieties combined with spraying frequencies. For Belete variety the highest (29.62 t ha⁻¹) and lowest (20.2 t ha⁻¹) total tuber yield was obtained from plots treated with two times spray and zero spray, respectively. But there was no statistically significant difference among sprays from one upto four times spray. And also, the highest (28.79 t ha⁻¹) and lowest (17.63 t ha⁻¹) total tuber yield was obtained from Gudene variety treated with two times spray and untreated plot. Similarly, the highest (28.6 t ha⁻¹) and lowest (12.93 t ha⁻¹) tuber yields were obtained from Jalene variety treated with four times spray and untreated plot, respectively. This study indicated that when the spraying frequencies increase the total tuber yield of the susceptible variety Jalene increased (Table 4).

Similar research (Shiferaw et al., 2011) indicated that the interaction of all spraying frequencies of mancozeb fungicides with different potato varieties was significant on marketable and total tuber yield as compared with unsprayed potato varieties. In Uganda, combined fungicide
applications considerably increased potato tuber yield for different varieties of potato (Namada et al., 2004).

3.6. Relative yield loss

The yield loss assessment was calculated for all relative to the yield of maximum protected plot of Belete variety treated with four times spraying frequency of Ridomil applications. Tuber yield losses were varied among plots treated with different combinations of potato varieties and spraying frequencies of Ridomil applications (Table 5). The highest (55.96% and 44.99%) relative yield loss was recorded on unsprayed and one-time Jalene variety plots, respectively, and followed by 39.95% yield loss from Gudene variety treated with zero (untreated) spraying frequencies. Generally, the highest tuber yield losses were recorded on potato plots that were not treated any spraying frequency of fungicide (Ridomil) applications. This indicates that how much late blight disease is damaging potato plants during favorable conditions when effective management practices have not undertaken.

Moreover, the use of resistant cultivars would potentially reduce losses due to late blight and reduce the cost of crop protection in potato production. The results of this study are in line with a reported range of yield loss estimates due to late blight on susceptible varieties (Olanya et al., 2001).

\[ BS0 = \text{Belete without spraying}, \ BS1 = \text{Belete with one spray}, \ BS2 = \text{Belete with two sprays}, \ BS3 = \text{Belete with three sprays}, \ BS4 = \text{Belete with four sprays}, \ GS0 = \text{Gudene without spraying}, \ GS1 = \text{Gudene with one spray}, \ GS2 = \text{Gudene with two sprays}, \ GS3 = \text{Gudene with three sprays}, \ GS4 = \text{Gudene with four sprays}, \ JS0 = \text{Jalene without spraying}, \ JS1 = \text{Jalene with one spray}, \ JS2 = \text{Jalene with two sprays}, \ JS3 = \text{Jalene with three sprays}, \ JS4 = \text{Jalene with four spray} \]

3.7. Percentage yield increase

The percent yield increase study was calculated from all combinations of potato varieties and spraying frequencies of ridomil fungicide as compared to the untreated control, i.e., unsprayed

| Treatment Combination | Total yield (t ha\(^{-1}\)) | Relative Yield Loss (%) | Percentage yield Increase (%) |
|-----------------------|-----------------------------|--------------------------|------------------------------|
| BS0                   | 20.2                        | 31.20                    | 0.00                         |
| BS1                   | 29.08                       | 0.95                     | 43.96                        |
| BS2                   | 29.62                       | -0.89                    | 46.63                        |
| BS3                   | 26.84                       | 8.58                     | 32.87                        |
| BS4                   | 29.36                       | 0.00                     | 45.35                        |
| GS0                   | 17.63                       | 39.95                    | 0.00                         |
| GS1                   | 18.91                       | 35.59                    | 7.26                         |
| GS2                   | 28.79                       | 1.94                     | 63.30                        |
| GS3                   | 28.57                       | 2.69                     | 62.05                        |
| GS4                   | 27.37                       | 6.78                     | 55.25                        |
| JS0                   | 12.93                       | 55.96                    | 0.00                         |
| JS1                   | 16.15                       | 44.99                    | 24.90                        |
| JS2                   | 21.23                       | 27.69                    | 64.19                        |
| JS3                   | 23.48                       | 20.03                    | 81.59                        |
| JS4                   | 28.6                        | 2.59                     | 121.19                       |
plots of each variety. The highest (121.19%) yield increase was recorded from Jalene varieties treated with four times spray of Ridomil application (Table 5).

Moreover, the highest (46.63%) and the lowest (32.87%) tuber yield increase was obtained from Belete variety treated with two and three times spray Ridomil application, respectively (Table 5). The same is true in moderately susceptible (Gudene) variety the highest (63.3%) and the lowest (7.26%) yield increment was obtained from two and one times spraying frequency of ridomil application, respectively.

The result of the present study in agreement with Shiferaw and Tesfaye (2018), they reported that the yield advantage of fungicide-sprayed plots for both varieties (Belete and Gudene) was 62% as compared to the unsprayed plots. Ashenafi et al. (2017) indicated that the combination of host resistance varieties and fungicide applications increase the potato tuber yield more than 52.2%. Kankwatsa et al. (2002) research result indicated that the interaction of host resistance and fungicide application for the production of potato at a commercial level increased in yield by more than 30%.

3.8. Association of yield and disease parameters

The significance of associations between disease and yield parameters was examined using simple correlation analysis. The disease parameters, namely disease incidence, percentage severity index, AUDPC, and disease progress rates were significantly ($P < 0.01$) correlated with each other (Table 6). The correlation coefficients between disease parameters were positively correlated to each other.

Correlation coefficient of marketable yield with all disease parameters were significant ($P < 0.01$) and negatively correlated ($r = -0.680^{**}, -0.840^{**}, -0.881^{**}$ and $-0.772^{**}$) with disease incidence, final percentage severity index (96DAP), AUDPC and infection rate, respectively. Besides, total tuber yield and average tuber weight had highly ($r = 0.840^{**}$) significant and positive correlation. The results of the present study are consistent with the report of Kankwatsa et al. (2002), which indicated a highly significant and negative correlation existed between late blight and tuber yield. This result is in agreement with the finding of Fekede (2011) who reported that the associated disease parameters had shown negatively correlated with yield parameters.

$$DI = \text{Disease incidence}, \ PSI = \text{Percentage severity index at 96DAP}, \ AUDPC = \text{Area under disease progress curve}, \ r = \text{Disease progress rate}, \ MTY = \text{ Marketable tuber yield}, \ TTY = \text{Total tuber yield}, \ ATW = \text{Average tuber weight},$$

3.9. Linear regression between AUDPC and total tuber yield

The linear regression model was used to predict the relationship of AUDPC and total tuber yield. AUDPC was considered to be an independent variable and total tuber yield considered as a dependent

| Table 6. Correlation coefficients ($r$) of potato tuber yield, yield components and late blight of disease parameters |
|---|---|---|---|---|---|---|
| DI | PSI | AUDPC | r | MTY | TTY | ATW |
| DI | 1 | | | | | |
| PSI | 0.687^{**} | 1 | | | | |
| AUDPC | 0.738^{**} | 0.945^{**} | 1 | | | |
| r | 0.576^{**} | 0.925^{**} | 0.877^{**} | 1 | | |
| MTY | -0.680^{**} | -0.840^{**} | -0.881^{**} | -0.772^{**} | 1 | |
| TTY | -0.649^{**} | -0.819^{**} | -0.861^{**} | -0.764^{**} | 0.991^{**} | 1 |
| ATW | -0.672^{**} | -0.775^{**} | -0.809^{**} | -0.689^{**} | 0.865^{**} | 0.840^{**} | 1 |
variable was regressed to estimate the yield loss due to the disease. The equation of the model was, 
\[ Y = -0.0149X + 38.379 \]  
indicated that for every one unit increases in AUDPC (% days), there is a corresponding 0.0149 t ha\(^{-1}\) potato tuber yield loss was occurred at Meket, 2018 main cropping season (Figure 2). The relationship indicated by the regression linear model, 74.08% of loss in potato tuber yield was predicted due to potato late blight disease. In general, the linear regression graph indicates as the AUDPC increase there was a decreasing trend in potato tuber yield.

3.10. Cost-benefit analysis

The partial budget analysis was done for a combination of late blight disease management through different potato varieties and five spraying frequencies of ridomil fungicide application (Table 7). The maximum net benefit (155,065 ETB ha\(^{-1}\)) was obtained from a moderately resistant variety (Belete) treated with one-time spraying frequency of ridomil application. On the other hand, the lowest net benefit (41,071 t ha\(^{-1}\)) recorded from the un sprayed susceptible (Jalene) variety (Table 7). Similarly, the marginal rate of return was described as a method for comparing the costs that vary with the net benefits of all treatment combinations. The highest (1774.6%, 1294.6%, and 1010.8%) marginal rate of return had been obtained from Belete, Gudene, and Jalene varieties treated with one, two, and four times spraying frequencies of Ridomil application, respectively.

The result of the present study is supported by the result of Olanya et al. (2001); Optimum or appropriate fungicide applications and use of host-plant resistance based on favorable weather conditions have the most economical option for disease control method. Significant maximum marketable tuber yield and highest net benefit were obtained from moderately resistant variety Belete when fungicide Matco (2 kg/ha) sprayed in 10-day interval and two times spray frequency per season (Shiferaw and Tesfaye, 2018).

\[ MTY = \text{Marketable tuber yield}, \ AMTY = \text{Adjusted marketable tuber yield}, \ PP = \text{Price per kg}, \ GB = \text{Gross benefit}, \ TIC = \text{Total input cost}, \ MC = \text{Marginal cost}, \ NB = \text{Net benefit}, \ MNB = \text{Marginal net benefit}, \ MRR = \text{Marginal rate of return}. \]

4. Conclusions and recommendations

Interaction of moderately resistant (Belete), moderately susceptible (Gudene) and susceptible (Jalene) varieties with different spraying frequencies of Ridomil showed a significant difference in disease, yield and yield component parameters. The highest (28.57 t ha\(^{-1}\)) marketable tuber yield was obtained from Belete treated with one spray and the lowest (9.89 t ha\(^{-1}\)) were obtained from untreated Jalene variety. The highest marginal rate of return (1774.65%) was obtained from Belete variety treated with one-time spraying frequency, followed by 1294.6% and 1010.8% had been obtained from Gudene and Jalene varieties treated with two and four times spraying frequencies, respectively.
In general, it can be concluded that potato varieties with different levels of late blight disease reaction need different spraying frequencies of Ridomil application. Based on the finding of this study, for moderately resistant variety like Belete needs one-time spray, for moderately susceptible variety like Gudene needs two times spray and three times spraying frequencies of Ridomil fungicide applications for susceptible variety like Jalene are recommended. Because it gave relatively the highest protection from late blight disease and maximum economic advantage than other treatments and the control. Based on the result of this study, the cost-effective management of late blight was obtained by integrating potato varieties with spraying frequencies of Ridomil application.

Table 7. Partial budget analysis of Ridomil spraying frequencies on three potato cultivars at Meket during 2018 main cropping season

| Treatment | MTY (kg/ha) | AMTY (kg/ha) | PP (kg) | GB/ha | TIC (B/ha) | MC (B/ha) | NB (B/ha) | MNB (B/ha) | MRR |
|-----------|-------------|--------------|---------|-------|------------|-----------|----------|-----------|-----|
| BS0       | 17,590      | 15,831       | 7       | 110,817 | 21,236     | 0         | 89,581   | 0         | 0.0 |
| BS1       | 28,570      | 25,713       | 7       | 179,991 | 24,926     | 3690      | 155,065  | 65,484    | 177.4 |
| BS2       | 27,040      | 24,336       | 7       | 170,352 | 26,666     | 5430      | 143,686  | 54,105    | 996.4 |
| BS3       | 25,610      | 23,049       | 7       | 161,343 | 28,406     | 7170      | 132,937  | 43,356    | 604.7 |
| BS4       | 28,010      | 25,209       | 7       | 176,463 | 30,146     | 8910      | 146,317  | 56,736    | 636.8 |
| GS0       | 14,750      | 13,275       | 7       | 92,925  | 21,236     | 0         | 71,689   | 0         | 0.0 |
| GS1       | 15,690      | 14,121       | 7       | 98,847  | 24,926     | 3690      | 73,921   | 2232      | 60.5 |
| GS2       | 26,770      | 24,093       | 7       | 168,651 | 26,666     | 5430      | 141,985  | 70,296    | 129.4 |
| GS3       | 26,510      | 23,859       | 7       | 167,013 | 28,406     | 7170      | 138,607  | 66,918    | 933.3 |
| GS4       | 25,850      | 23,265       | 7       | 162,855 | 30,146     | 8910      | 132,709  | 61,020    | 684.8 |
| JS0       | 9890        | 8901         | 7       | 62,307  | 21,236     | 0         | 41,071   | 0         | 0.0 |
| JS1       | 12,500      | 11,250       | 7       | 78,750  | 24,926     | 3690      | 53,824   | 12,753    | 345.6 |
| JS2       | 18,100      | 16,290       | 7       | 111,030 | 26,666     | 5430      | 87,364   | 46,293    | 852.5 |
| JS3       | 21,600      | 19,440       | 7       | 136,080 | 28,406     | 7170      | 107,674  | 66,603    | 928.9 |
| JS4       | 25,600      | 23,049       | 7       | 161,280 | 30,146     | 8910      | 131,134  | 90,063    | 1010.8 |

In general, it can be concluded that potato varieties with different levels of late blight disease reaction need different spraying frequencies of Ridomil application. Based on the finding of this study, for moderately resistant variety like Belete needs one-time spray, for moderately susceptible variety like Gudene needs two times spray and three times spraying frequencies of Ridomil fungicide applications for susceptible variety like Jalene are recommended. Because it gave relatively the highest protection from late blight disease and maximum economic advantage than other treatments and the control. Based on the result of this study, the cost-effective management of late blight was obtained by integrating potato varieties with spraying frequencies of Ridomil application.

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Public interest statement
Potato is the most important root and tuber crop due to its high yielding per unit area and one of the most important food crops and consumed in the world. The production of the crop is faced different problems by several biotic and a biotic factor. Potato late blight disease, caused by Phytophthora infestans is the major constraint of potato production in Ethiopia. Due to these, integration of three potato varieties with different levels of resistance to Phytophthora infestans and five spraying frequencies of Ridomil fungicide were tested. Reducing fungicide use by growing resistant potato cultivars could decrease environmental contamination and increase the economic benefits of the farmers. In this study, moderately resistance variety needs one spray, for moderately susceptible variety needs two sprays and three times spraying frequencies of Ridomil fungicide applications for susceptible variety were enough for the management of late blight disease.

Conflicts of Interest
There is not any conflict of interest in related to the publication of this research manuscript.

Data Availability
The data used to support the findings of this study are available from the corresponding author upon request.

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