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Integrated Management of Tomato Late Blight [Phytophthora infestans (Mont.) de Bary] Through Host Plant Resistance and Reduced Frequency of Fungicide in Arbaminch Areas, Southern Ethiopia

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Abstract
A field experiment was conducted at Arbaminch Agricultural Research Center's of Sub-center (Chano Mille) during 2016 and 2017 cropping seasons, with the specific objectives to: 1) evaluate the effect of varieties by fungicide application frequencies on *Phytophthora infestans* epidemics in different cropping seasons; 2) determine the effects of host plant resistance and fungicide on fruit yield and yield components of tomato; and 3) determine the economics of fungicide spray for the management of tomato late blight. The treatments consisted of four tomato varieties with different level of resistance to late blight and five foliar spray frequencies (ridomil), including unsprayed plots as a control and the treatments were laid out in a factorial arrangement in a randomized complete block design with three replications. Integration of varieties and fungicide spray frequencies at 10 day interval significantly reduced late blight epidemics and increased fruit yield in both cropping season. In both cropping season, severity was highest on the susceptible variety (Melkasholla with 56.17% in 2016 and 27.41% in 2017 cropping seasons). Disease severities as low as 25.92, 31.78, 38.71 and 44.51% were recorded on ARP tomato d2, Bisholla, Roma VF and Melkasholla varieties in 2016, respectively. Whereas disease severities of 30.21, 33.35, 34.28 and 43.23% were recorded on ARP tomato d2, Roma VF, Bisholla and Melkasholla varieties, respectively, in 2017 when ridomil was sprayed four times during the growing seasons. The highest mean AUDPC values of 826.43, 1011.12, 1134.25 and 1245.52%-days were recorded from unsprayed plots of ARP tomato d2, Roma VF, Bisholla and Melkasholla varieties, respectively, in 2016, while the lowest mean AUDPC values were recorded from plots treated with four time sprays for all varieties in both cropping seasons. In 2016 and 2017 cropping seasons, three times foliar applications with ridomil proved to be an effective treatment against late blight and gave the highest (44.16 and 38.25 t ha^{-1}) marketable fruit yields over the control yields of 22.92 and 19.59 t ha^{-1-}, respectively. Nevertheless, marginal analysis indicated that the highest 40.00 and 41.30% marginal rates of return in comparison with unsprayed plots were obtained where ridomil was sprayed two times for ARPT tomato d2 variety for both cropping seasons as compared to other spray frequencies. In conclusion, integration of varieties and two times for resistant and moderately reistant varieties and three times for susceptible varieties with ridomil foliar sprays were found to be effective treatments in reducing tomato late blight epidemics and increasing fruit yields. Thus, it is recommended to use this spray frequency as it gave the highest protection against late blight and the highest monetary benefit as compared to the other treatments and the control. However, further extensive studies have to be undertaken for developing concrete recommendation for stabilizing tomato production in the country.
Keywords: AUDPC, cropping seasons, disease severity, marginal analysis, *Phytophthora infestans*, ridomil sprays, tomato varieties, yield.

1. INTRODUCTION

Tomato, *Solanum lycopersicum* Mill., is an important vegetable crop grown around the world and is second to potato (Mutschler *et al.,* 2006). Tomato is the most widely cultivated and lucrative vegetable and ranking 8th in annual national production in Ethiopia (Derbew *et al.,* 2012). It is produced both during the rainy and dry seasons under supplemental irrigation (Lemma, 2002; Tsedeke, 2007). Under this circumstance, the total area under tomato production reaches 9767.78 ha and in main cropping season production is estimated to be over 913,013.42 t with the average productivity of 93.47 t ha^{-1} (CSA, 2016).

In Gamo Gofa areas, tomato is widely grown on about 3,520 ha of land and its production is increasing from time to time. However, the yield of this crop is very low (estimated at 4.85 t ha^{-1}) as compared to the national average yield of 97.47 t ha^{-1} (CSA, 2016). This low productivity is attributed to several factors among which diseases, like late blight, are the main ones according to Arbaminch Crop Protection Clinic and Gamo Gofa Zone Agriculture Office. The diseases affect the crop at different growth stages in the field. Tomato late blight occurs year after year in this area and causes considerable yield losses, ranging from 63.7 to 100% in tomato fields in the study areas, i.e. Gamo Gofa in southern Ethiopia (Working paper, 2014). To reduce such disease severities and crop losses that accrue from the diseases, management options, including up to date information, must be generated to decide on the management measures.

To prevent tomato crop yield loss incited by late blight, farmers use indiscriminately whatever fungicide available alone or in combination. Frequent sprays of single fungicide up to harvesting for all tomato varieties irrespective of the cropping season are also very common in response to disease symptoms on the foliage. However, the indiscriminate use of fungicides has adverse effects on human and animal health, pollute the environment and also lead to development of resistance by the pathogen (WHO, 2004). This necessitates the use of integrated disease management options that include host plant resistance and alternate sprays, like frequency of either protectant or systemic fungicides, in different years with different cropping seasons. In addition, reports on combination of varieties and fungicide sprays indicate that performance of varieties may vary with frequency of sprays. A variety may perform well with one spray; another with two sprays and yet another may require more sprays. This has economic as well as ecological implications. A variety that will perform well with one or two sprays will definitely be preferred to a variety that requires more spray frequencies and also the need for frequent application of fungicide may vary with cropping season, which may favor or delay the development of the target pathogen during the growing period, either in the same cropping season in different location or in different year with different cropping seasons. These alternative management options and host plant disease resistance, including different years and cropping seasons, have not been evaluated in the study area.

Therefore, the current research was carried out with the following specific objectives to: 1) evaluate the effect of host plant resistance and fungicide spray frequencies on *Phytophthora infestans* epidemics in different cropping seasons; 2) determine the effects of host plant resistance and fungicide on fruit yield and yield components of tomato; and 3) determine the economics of fungicide spray for the management of tomato late blight.

2. MATERIALS AND METHODS

2.1. Description of the Experimental Site

The field study was conducted at Arba-Minch Agricultural Research Sub-Center (AMARC), Arbaminch areas, Southwestern Ethiopia. AMARC is geographically located at 06°06'841"' N-latitude and 037°35'122"' E-longitude. The site is laid at an altitude of 1216 m.a.s.l. The area is characterized by a bimodal rainfall pattern where short rainy season occurs during the months of March and April and the main rainy season starts in mid August and extends to mid November. Very high amount of rainfall is obtained in the months of late August, September and up to mid October. The average annual rainfall and temperature of the areas are 750 mm and 27.5 °C, respectively. The detail descriptions of weather variables of the 2016 and 2017 cropping seasons are presented in Table 1. In addition, the soil is characterized by alluvial, black sandy-loam and clay-loam. The soil is characterized by alluvial, black sandy-loam and clay-loam (ATA, 2016).

Table 1. Mean annual minimum and maximum temperature, rainfall and relative humidity of the study areas in the 2016 and 2017 cropping seasons

Weather variable	**Average monthly temperature, rainfall and relative humidity for AMARC in 2016 and 2017 cropping season**											
	2016 cropping season[1]						**2017 cropping season[1]**					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Maximum T (°C)	29.85	28.93	31.41	30.84	32.03	NA	32.85	35.05	34.00	32.11	29.45	NA
Minimum T (°C)	18.05	18.29	17.09	16.54	17.85	NA	15.96	16.09	19.10	18.24	18.88	NA
Rainfall (mm)	45.8	41.9	65.7	143.1	103.2	NA	1.50	2.70	57.10	122.40	177.50	NA
Relative humidity (%)	NA	56.83	49.00	53.73	43.23	NA	40.76	36.29	42.73	59.07	69.07	NA

[1] NA= Data not available from meteorological station at the research center during the study periods.
Source: National Meteorological Agency, Hawassa Branch (2017)

2.2. Experimental Materials

The tomato late blight management experiment was carried out during the main and short rain season in 2016 and 2017, respectively, with supplementary of irrigation. The treatments were four tomato varieties (ARP tomato d2, Roma VF, Bisholla and Melkasholla), which were currently under production and differed in their resistance levels to late blight. Brief description of the agronomic and morphological characteristics of the tomato varieties are tabulated hereunder (Table 2). Ridomil MZ Gold 68.5% WG as a foliar spray was used at the manufacturer's label dose of 3 kg ha^{-1} and spray frequency at 10 day interval (Anonymous, 2011) with five spray frequencies (no spray, one time, two times, three times and four times) in the tomato growth period. Thus, there were 20 treatment combinations of four tomato varieties along with five fungicide spray frequencies.

Table 2. Descriptions of agronomic and morphological characteristics of tomato varieties employed in the experiment at Arbaminch Agricultural Research f Sub-Center during the 2016 and 2017 cropping seasons

Tomato Variety	**Agronomic and morphological characteristics of tomato varieties used**[1]						
	Year of release	**Breeder/ maintainer**	**DM**	**Fruit color**	**Fruit shape**	**Fruit yield (t/ha)***	**Reaction to LB**
ARP tomato d2	2012	MARC/ EIAR	80	Brick Red	Circular	43.5	R
Roma VF	1997/98	ROME/ ITALY	80	Red	Plum/Pear	42.5	MR
Bisholla	2005	MARC/ EIAR	75	Light Red	Circular	45	MS
Melkasholla	1997/98	MARC/ EIAR	90	Light Red	Plum/Pear	35	S

[1] MARC = Melkassa Agricultural Research Center; EIAR = Ethiopian Institute of Agricultural Research; DM = Days to maturity; LB = Late Blight; R = Resistance; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; *Yield on research station; Growing altitudinal ranges between 400 and2000 m.a.s.l.

Source: MoARD, 2005; MoA, 2012; Jiregna, 2014.

2.3. Raising Seedling and Transplanting

The standard method of raising seedlings recommended by Melkassa Agricultural Research Center (Getachew *et al.,* 2014) was used. Seedlings for the field experiment were raised on four seedbeds with 1 m width and 5 m length and 15 cm height for each variety. Seedbeds were separated by 60 cm. The seeds were sown at a depth of 0.5 cm in 30 rows with intra-row spacing of 15 cm in each nursery bed. Grass mulch was applied on each nursery bed and removed after the seedlings emerged. The nursery beds were weeded and irrigated as deemed necessary. Seedlings were transplanted at 25 and 20 days after sowing in 2016 and 2017 cropping season, respectively.

2.4. Treatments, Experimental Design and Trial Management

In both cropping seasons, the treatments consisting of four levels of tomato varieties and fungicide (ridomil) five spray frequencies, 20 treatment combinations, were randomly arranged in factorial experiment in a randomized complete block design (RCBD) with three replications. The complete randomization and layout of the experimental field was done by using random numbers obtained from a scientific calculator. Each treatment combination was assigned randomly to the experimental units within a block. The size of the experimental unit plot was 4 m x 6 m (24 m^2). There were six rows per plot and the middle four rows with a net plot area of 16 m^2 (excluding the two border rows) were used for data collection. A spacing of 1.5 and 2.5 m was left to separate each plot and block, respectively.

Transplanting was done with spacing of 100 and 30 cm inter- and intra rows, respectively, and the total gross plot size was 1440 m^2. A recommended fertilizer rate of 150 kg DAP ha^{-1} was applied in rows at transplanting and 100 kg urea ha^{-1} was used by split application as side-dressing at transplanting and early flowering stage , 21 and 14 days after transplanting in 2016 and 2017 cropping seasons, respectively. Supplementary irrigation, weeding and cultivation were performed manually whenever they were necessary in both cropping seasons. Fungicide spraying was started with the first appearance of typical disease symptom and continued according to spray schedule designated for each treatment in every 10 days interval. Fungicide unsprayed plots were left as controls for all varieties. During fungicide sprays, the plants were sprayed to run-off and each plot was shielded with polyethylene sheets, which was 2 m high on all sides of the plot to reduce inter-plot interference or spray drift. The entire experimental plots, including the control plots, were sprayed with diazinon 60% EC (2 Lha^{-1}) in 2016 and ampligo 150 ZC (300 ml ha^{-1}) in 2017 cropping seasons for the suppression of tomato bollworms and leaf miner, respectively. The experiment was relied entirely on natural infection.

2.5. Disease Assessment

Disease Severity: Tomato late blight severity was recorded from 12 pre-tagged plants using systematically arranged pattern in the middle four rows of each plot starting from the first appearance of the disease symptoms. It was ratted using a 0 to 9 disease scoring scale; where, 1 = no infections; 2 = 1-10% leaf area infected; 3 = 11-20% leaf area infected; 4 = 21-30% leaf area infected; 5 = 31-40% leaf area infected; 6 = 41-50% leaf area infected; 7 = 51-60% leaf area infected; 8 = 61-70% leaf area infected; and 9 = 71-100% leaf area infected as described by Horneburg and Becker (2011). Disease severity scores were converted into percentage severity as follows.

$$\text{Disease Severity}(\%) = \frac{\text{Area of Diseased Tissue}}{\text{Total Tissue Area}} \times 100$$

The severity grades were converted into percentage severity index (PSI) for analyses as indicated by

Wheeler (1969):

$$\text{PSI} = \frac{\text{Sum of numerical ratings}}{\text{No. of plants scored x maximum disease score on scale}} \text{x } 100$$

The relative disease severity reduction on untreated and treated plots of the treatment combination was calculated as follows.

$$\text{Relative disease severity reduction (\%)} = \frac{\text{Untreated} - \text{Treated}}{\text{Untreated}} \text{ X } 100$$

Area under disease progress curve (AUDPC): It was also computed from PSI values for each plot as described by Campbell and Madden (1990).

$$\textbf{AUDPC} = \sum_{i=1}^{n-1} \mathbf{0.5\ (Xi + Xi + 1)(ti + 1 - ti)}$$

Where, n is the total number of disease assessments, t_i is the time of the i^{th} assessment in days from the first assessment date and x_i is the PSI of disease at the i^{th} assessment. AUDPC was expressed in %-days because severity (x) is expressed in percent and time (t) in days.

Disease progress rate: Logistic, ln [(Y/1-Y)] (van der Plank, 1963), and Gompertz, -ln[-ln(Y)] (Berger, 1981) models were compared for estimation of disease progression rate from each treatment, and the Logistic model was found fit to the data. The goodness of fit of the models was tested based on the magnitude of the coefficient of determination (R^2). The transformed data of disease severity were regressed over time (DAT) to determine the model. The model was then used to determine the apparent rate of disease increase (r) and the intercept of the curve.

$$Y_t = \frac{1}{1 + \exp^{-\ln[Yo/(1-Yo)] + rLt}}$$

Percentage fruit infection (PFI): It was recorded as percentage of tomato fruits infected per plant in the middle four rows as the average of 12 plants. Then the score was expressed as a percentage as follows:

$$\text{PFI} = \frac{\text{No. of fruits infected}}{\text{Total no. of fruits assessed}} \text{x } 100$$

2.6. Assessment of Growth, Yield and Yield Related Traits

Important parameters like days to 50% flowering, days to 50% fruit setting, days to first and last picking, number of branches per plant, number of fruit clusters per plant, plant stand count, yield (t/ha) (marketable, unmarketable and total fruit yields) and single fruit weight (g) were collected.

2.7. Data Analysis

Data were analyzed following a procedure appropriate to the design of the experiment as described by Gomez and Gomez (1984) and logistic model and, general linear model (GLM) of SAS version 9.2 (SAS, 2009). The treatment means were separated using the least significant difference (LSD) test at 5% probability level. Correlation and regression analysis was used to determine the relationships between growth, yield and yield related traits, and disease severity and AUDPC across the treatments. It was performed to determine the association of disease parameters with yield obtained from the different fungicide schedules.

2.8. Relative yield loss and Yield increase in fruit yield

In addition to the above, relative yield loss from each plot was calculated using the formula suggested by Robert and James (1991):

$$\text{Relative \% yield loss} = \frac{Y_{bt} - Y_{lt}}{Y_{bt}} \text{X}100$$

Where, Ybt is the yield of best treatment and Ylt is the yield of lower treatments. At the same time, yield increase, and change in yield increase, over the untreated plots were obtained with the formula:

$$\text{Yield increase over the untreated check} = \frac{\text{Treated} - \text{Untreated}}{\text{Treated}} \text{ X } 100$$

2.9. Cost and Benefit Analysis

Cost and benefit of each treatment was analyzed using partially and marginal rate of return (MRR) as computed by considering the variable cost (fungicides and knapsack sprayer costs and cost of labor for fungicide applications) available for the respective treatment. Price of fruits, in $, of each tomato variety per kilogram was obtained from the contemporary local market at harvest and total sale from one hectare were computed. Cost-benefit analysis of each fungicide schedule was made to evaluate the economic benefits expected using the farm gate price of tomato at the time of harvest. Before applying the partial budget analysis (economic analysis) statistical analysis was done on the collected data to compare the average yields between each treatment to determine the economics of the disease management. With this, there were significance differences among the treatments. MRR was calculated using (CIMMYT, 1988):

$$\text{MRR } (\%) = \frac{\text{DNI}}{\text{DIC}} \text{ X } 100$$

Where, DNI = difference in net income compared with control, and DIC = difference in input cost compared with control.

During cost benefit analysis using partial budget important points were considered; costs for all agronomic practices were uniform for all treatments; cost of labor and spraying equipment were taken based on the prevailing rates of payment in the locality; costs, return and benefit were calculated on hectare basis; and it is assumed that farmers produce this variety under integrated management of tomato late blight when the variety provided 100% marginal rate of returns.

3. RESULTS AND DISCUSSION

3.1. Effect of Variety and Fungicide Applications on Tomato Late Blight Development

3.1.1. Late Blight Severity

The interaction effects were significant in both 2016 and 2017 cropping seasons. The mean disease severity of late blight was highly and significantly ($p \leq 0.001$) varied among the tomato varieties at all dates of assessments in both cropping seasons (Table 3). In both cropping seasons, the highest mean severity was recorded on the susceptible (Melkasholla) variety (56.17% in 2016 and 27.41% in 2017) (Table 3). However, the lowest was recorded on the resistant and moderately resistance varieties, namely Roma VF with 29.32% in 2016 and ARP tomato d2 with 13.07% in 2017, respectively. When the two cropping seasons were compared, the higher disease severity was recorded in 2016 than in 2017 cropping season. This variation in varietal responses to late blight might be due to genetic differences and epidemic differences between cropping seasons could be attributed to variability in weather variables during the experimental period since there was higher rainfall and relative humidity and lower aerial temperature in the growing period of 2016 than in 2017 cropping season. Cloudiness or heavy wetness following lower temperature favours disease development (Majid *et al.,* 2008). The result of the current study coincides with the findings of Phillips *et al.* (2005) who stated that if varietal diversity is available for plant resistance against late blight, the disease severity would be reduced if any given mixture or variety is grown.

All ridomil foliar spray frequencies significantly ($p \leq 0.05$) differed from the unsprayed control plots in reducing disease severity index both in 2016 and 2017 cropping seasons. The mean disease severity, due to four times redomil sprays compared to the control, was reduced by 25.92, 31.78, 38.71 and 44.51% on ARP tomato d2, Bisholla, Roma VF and Melkasholla varieties, respectively in 2016. Similarly, the reduction was in the order of 30.21, 33.35, 34.28 and 43.23% on ARP tomato d2, Roma VF, Bisholla and Melkasholla varieties, respectively in 2017 (Table 3). This lower amount of disease severity reduction in 2017 than 2016 cropping season might be due to spray frequency of ridomil and less occurrence of the disease during the growing period; also there was unfavorable environmental conditions for the development of *Phytophthora infestans* epidemic in 2017 cropping season. Binyam *et al*. (2014) reported that application of the fungicides significantly reduced disease severity. The mean disease severity of the plots treated with ridomil four times ranged from the least 38.52% for Roma VF and 16.22% for ARP tomato d2 varieties to the highest 44.38% for Bisholla and 22.22% for Melkasholla varieties, used as control plots in 2016 and 2017 cropping season, respectively. From the results, it would be possible to deduce that different foliar spray frequencies, like four times foliar spray frequencies of ridomil could effectively reduce the magnitude of late blight severity on each variety. Frequent foliar applications (4 times) of ridomil might be a reason for its high efficacy; even during the wet season it had less chance to be washed off by rainfall that used to maintain its high efficacy. Therefore, it is advisable to use this fungicide accordingly. This present result coincides with the investigation of Abhinandan *et al.* (2004) who reported that frequently applied fungicides by far reduced disease severity as compared to the less frequently sprayed fungicides and unsprayed plots.

3.1.2. Area Under disease Progress Curve (AUDPC)

Very highly significant ($p \leq 0.001$) difference was observed in the magnitude of the AUDPC among the varieties as well as different foliar spray frequencies in both cropping seasons. AUDPC was calculated in the range of 661.11-1245.52%-days in 2016 from the moderately resistant variety, Roma VF, to the susceptible variety, Melkasholla, respectively. At the same time, it was ranged in 449.81-693.52%-days from the resistant variety ARP tomato d2 to the susceptible variety Melkasholla, respectively, in 2017 cropping season. On the resistant ARP tomato d2 (in 2017) and moderately resistant Roma VF (in 2016) varieties, the AUDPC values were significantly less than the other varieties at both cropping seasons. Generally, the high degree of significant difference in AUDPC values among the evaluated varieties might be due to their genotypic resistant reaction to late blight and, in addition, the difference in the cropping seasons, which favored or delayed the development of *P. infestans* (Table 3).

However, as compared to the two cropping seasons the highest mean AUDPC values were recorded from unsprayed control plots of ARP tomato d2, Roma VF, Bisholla and Melkasholla varieties with the corresponding values of 826.43, 1011.12, 1134.25 and 1245.52%-days in 2016 than 2017 cropping seasons. Similarly, the lowest mean AUDPC values were recorded from plots treated with four time spray frequencies of ridomil on ARP tomato d2, Roma VF, Bisholla and Melkasholla varieties with the corresponding values of 449.81, 471.85, 484.81 and 488.70 %-days, respectively, in 2017 cropping season. This indicated that all evaluated four times spray frequencies had significant impact on late blight development on tomato genotypes, especially when combined with ARP tomato d2 and Roma VF varieties as it showed the lowest AUDPC values of the other two varieties in both cropping seasons (Table 3). Previous researchers reported that the highest value of AUDPC resulted from the highest disease development on plots that were not treated with any combinations of crop varieties and fungicide applications with favorable environmental conditions for the development of the pathogen (Campbell and Madden, 1990; Binyam *et al*., 2014; **Desta and Yesuf, 2015)**. The findings of the current study, especially the 2016 cropping season, is consistent with the report of Mesfin and Gebremedhin (2007) and Ayda (2015) who found that the moderately resistant varieties , of the major host (Irish potato) had the lowest AUDPC values when supplemented with fungicide treatments in wet season.

3.1.3. Disease Progress Rate (DPR)

The rates of late blight progress highly and significantly ($p \leq 0.001$) differed among the tomato varieties in both cropping seasons. In 2016 cropping season, the highest mean DPRs on ARP tomato d2, Roma VF, Melkasholla and Bisholla varieties were 0.0352, 0.0379, 0.0421 and 0.0431 units per day, respectively. Similarly in 2017 cropping season, the highest mean DPRs calculated for ARP tomato d2, Roma VF, Melkasholla and Bisholla varieties were 0.0191, 0.0236, 0.0285 and 0.0294 units per day, respectively. However, as compared in the two seasons, the lowest mean DPR on ARP tomato d2, Roma VF, Bisholla and Melkasholla varieties with corresponding value of 0.0112, 0.0148, 0.0176 and 0.0219 units per day, respectively, were recorded in 2017 cropping season. Variation in DPRs of late blight among the varieties might be due to the genetic background of the varieties and the importance of environmental conditions, which might have favor or delayed the development of the target pathogen during the growing periods both in 2016 and 2017 cropping seasons. At the same time, the highest mean DPRs on different spray frequencies, i.e. zero, one time, two times, three times and four times were 0.0489, 0.0444, 0.0389, 0.0344 and 0.0311 units per day, respectively, in 2016 cropping season, whereas the lowest mean DPRs were recorded in 2017 cropping season with corresponding values of 0.0252, 0.0210, 0.0154 and 0.0088 units per day, respectively (Table 3). The reduction of disease progress rates occurred as a result of the frequent application of ridomil, and the more and less chance for the disease to occur in 2016 and 2017 cropping seasons, respectively.

Disease progress rates in plots of individual treatment varied very highly and significantly ($p \leq 0.001$) among treatments both in 2016 and 2017 cropping seasons. The highest DPR of 0.0547 unit per day was obtained in unsprayed control plot of the variety Melkasholla in 2016 cropping season, whereas the lowest DPRs of 0.0048 unit per day was recorded from the plots of ARP tomato d2 variety treated with ridomil four times in 2017 cropping season (Table 3). Hence, the rate of late blight progress was faster on unsprayed control plots of Melkasholla variety than on the unsprayed plots of the other varieties in both cropping seasons (Table 3). On unsprayed plots, late blight increased at a rate of 0.477 and 0.832 units per day in 2016 and 2017 cropping seasons, respectively. However, all the sprayed plots reduced the DPR significantly. Moreover, among the different foliar spray frequencies, the lower infection rates were recorded from the plots treated with ridomil four times on each variety in both 2016 and 2017 cropping seasons than plots that received less spray frequencies. This might be due to its high spray frequencies (four times spray). Generally, variation was clearly observed in late blight infection rates due to the variable resistance levels of the genotypes and the different fungicide spray frequencies and inclusion of the importance of environmental conditions during the growing periods in both cropping seasons. Late blight increased more rapidly on unsprayed plots than on the sprayed plots in both 2016 and 2017 cropping seasons. The lower values observed on plots sprayed with four times indicate the impacts of frequent application of ridomil on late blight development and epidemic condition. Bekele and Hailu (2001) reported that frequent application of fungicides could retard the rate of late blight progress on potato (alternate host for the pathogen) in the field.

Table 3. Effect of varieties and fungicide spray frequencies on mean disease severity of tomato late blight at Arbaminch during 2016 and 2017 cropping season

Treatment		2016 Cropping season				2017 Cropping season			
		Severity (%)		AUDPC	DPR	Severity (%)		AUDPC	DPR
Variety	**Spray Frequency**	PSI_i	PSI_f	(%-days)	(Units/day)	PSI_i	PSI_f	(%-days)	(Unit/day)
ART tomato d2:	One time	11.11^{b}	38.27^{h}	745.41^{ij}	0.0381^{g}	11.11^{c}	17.41^{ef}	496.48^{fgh}	0.0149^{ef}
	Two times	11.11^{b}	34.26^{j}	712.98^{jk}	0.0347^{h}	11.85^{ab}	15.56^{g}	469.26^{ij}	0.0089^{hi}
	Three times	11.11^{b}	32.41^{kl}	681.64^{kl}	0.0313^{ijk}	11.48^{bc}	14.07hi	449.81^{j}	0.0067^{ji}
	Four times	11.42^{ab}	30.87^{m}	663.26^{l}	0.0303^{kl}	11.85^{ab}	13.70^{i}	449.81^{j}	0.0048^{j}
	Control	11.11^{b}	41.67^{g}	826.43^{gh}	0.0415^{f}	11.11^{c}	19.63^{d}	535.37^{d}	0.0191^{cd}
Bisholla:	One time	11.73^{ab}	46.91^{d}	1005.69^{c}	0.0451^{e}	11.48^{bc}	22.22^{c}	569.07^{c}	0.0226^{b}
	Two times	11.73^{a}	43.52^{f}	945.18^{d}	0.0419^{f}	11.85^{ab}	18.52^{de}	521.11^{de}	0.0149^{ef}
	Three times	11.11^{b}	41.67^{f}	863.15^{ef}	0.0415^{f}	12.22^{a}	17.78^{ef}	517.22^{def}	0.0126^{fg}
	Four times	11.73^{b}	36.42^{i}	801.55^{h}	0.0348^{h}	11.11^{c}	18.15^{ef}	484.81^{ghi}	0.0111^{gh}
	Control	11.42^{a}	53.39^{b}	1134.25^{b}	0.0520^{b}	11.11^{c}	25.93^{b}	642.96^{b}	0.0294^{a}
Melkasholla:	One time	11.11^{ab}	50.00^{b}	1040.30^{c}	0.0495^{c}	11.85^{ab}	26.67^{ab}	632.59^{b}	0.0284^{a}
	Two times	11.11^{b}	43.52^{f}	887.97^{e}	0.0433^{ef}	11.48^{bc}	21.85^{c}	560.00^{c}	0.0219^{bc}
	Three times	11.42^{ab}	33.33^{jk}	698.92^{k}	0.0323^{ij}	12.22^{a}	17.04^{f}	506.85^{efg}	0.0163^{de}
	Four times	11.11^{ab}	31.17^{lm}	680.57^{kl}	0.0307^{jk}	11.11^{c}	15.56^{g}	488.70^{ghi}	0.0111^{gh}
	Control	11.42^{b}	56.17^{a}	1245.52^{a}	0.0547^{a}	12.22^{a}	27.41^{a}	693.52^{a}	0.0285^{a}
Roma VF:	One time	11.11^{b}	45.06^{e}	838.33^{fg}	0.0448^{e}	11.48^{bc}	19.63^{d}	523.70^{de}	0.0181^{d}
	Two times	11.11^{b}	36.73^{i}	752.96^{i}	0.0358^{h}	11.48^{bc}	15.56^{g}	479.62^{hi}	0.0111^{gh}
	Three times	11.42^{ab}	33.64^{jk}	734.56^{ij}	0.0326^{i}	11.11^{c}	15.19^{gh}	471.85^{ij}	0.0092^{hi}
	Four times	11.11^{b}	29.32^{n}	661.11^{l}	0.0286^{l}	11.11^{c}	14.81^{ghi}	471.85^{ij}	0.0094^{hi}
	Control	11.11^{b}	47.84^{d}	1011.12^{c}	0.0475^{d}	11.11^{c}	22.22^{c}	570.37^{c}	0.0236^{b}
Mean		11.30	40.31	846.54	0.0396	11.52	18.94	527.00	0.0161
LSD (5%)		0.59	1.37	35.12	0.0019	0.71	1.38	23.29	0.0030
CV (%)		3.18	2.05	2.51	2.87	3.74	4.42	2.2.68	11.08

Mean values in the same column with different letters represent significant variation at 5% probability level; PSI_i = Percent severity index at initial state date; PSI_f = Percent severity index at final state date; AUDPC = Area under disease progress curve; DPR = Disease progress rate; CV = Coefficient of variation (%); and LSD = Least significant difference at 5% probability level

3.1.4. Percent Fruit Infection per Plant (PFI)

Varieties and fungicide spray frequencies did not exhibit significant ($p > 0.05$) difference on PFI interaction in both 2016 and 2017 cropping seasons; only their independent effects are presented in the table, which exhibit highly significant ($p \leq 0.001$) difference. In 2016 and 2017 cropping seasons, the lowest (3.10% and 7.26%) and highest (5.64% and 12.83%) infections were recorded from ARP tomato d2 and Melkasholla varieties, respectively, as compared to the other varieties (Table 4). When 2016 and 2017 cropping seasons were compared, the higher PFI was recorded in 2017 than in 2016 cropping season; this variation might have happened due to the increase in the pathogen infection ability with the crop growth.

In the current study, symptoms of late blight appeared prior to flowering stage and became more severe after flowering and fruiting setting stage for this particular pathogen. This showed that tomato plants were more susceptible at fruiting stage of the plant than at early vegetative stage. This observation is in line with findings of Jones *et al.* (1997) who stated that plants are more susceptible to infection by the pathogen during fruiting stage than earlier stage. Hence, infection of tomato fruits by the pathogen might be initiated by zoospores, sporangia or oospores washed in precipitation from tomato foliage and deposited in the fruits, and/or diffusion of the pathogen through xylem and phloem of tomato plant into the fruit.

The present study revealed the relationship between foliage damage and diffusion of the pathogen into tomato fruits, causing late blight infection on the fruit. This difference in tomato varieties might have resulted from the variation in genetic background of the tomato varieties. Among the different sprayed treatments, unsprayed control plots of the four varieties had significantly higher, 7.44% and 13.86%, PFI than sprayed plots in 2016 and 2017 cropping seasons, respectively. Similarly, the lowest, 2.12% and 8.67%, PFI was recorded from the plots treated four times with ridomil at 10 days interval in 2016 and 2017 cropping seasons, respectively (Table 4). This might be due to the high number of spray times (four times sprays) that suppressed the development of the disease under natural environment.

Table 4. Effect of integration of variety and fungicide spray frequencies on late blight on fruit infection of tomato varieties at Arbaminch during 2016 and 2017 cropping season

Treatments	Late Blight Fruit infection (%)	
	2016 Cropping season	2017 Cropping season
Tomato Variety		
ARP tomato d2	3.10^{b}	7.62^{c}
Bisholla	4.98^{a}	13.28^{a}
Melkasholla	5.64^{a}	12.83^{a}
Roma VF	3.73^{b}	11.48^{b}
LSD (0.05)	0.73	0.72
P-value	<0.001	<0.001
Spray Frequency		
Control	7.44^{a}	13.86^{a}
One time	5.74^{b}	12.30^{b}
Two times	4.25^{c}	11.13^{c}
Three times	2.27^{d}	10.54^{c}
Four times	2.12^{d}	8.67^{d}
LSD (0.05)	0.81	0.80
P-value	<0.001	<0.001
Var * SF	ns	ns
Mean	4.36	11.30
CV (%)	22.64	8.58
R^2 (%)	0.89	0.93

Values within the column with the different letters represent significant variation; Var = variety; SF = spray frequencies; CV = Coefficient of variation (%) and LSD = Least significant difference at 5% probability level; Var * SF = Interaction effect of variety x spray frequency; and ns = not significant (p>0.05)

3.2. Effect of Integrated Management of Tomato Late Blight on Crop Growth, Yield and Yield Related Parameters

3.2.1. Crop Growth Parameters

In 2016 and 2017 cropping seasons, the interaction effects of varieties x spray frequencies did not reveal significant difference on days to 50% flowering, number of branches per plant and plant stands per plot and first and last picking date in 2016; to this effect, only their independent effects are presented (Table 5). This implies that each variety responded differently to the different foliar spray frequencies. However, interaction effect of varieties x spray frequencies showed significant difference on days to 50% fruit setting and first harvesting date in 2017; to this effect, only their interaction mean value of the two parameters are presented in the table. The table consisted of their mean values of both main and interaction effects of crop growth parameters.

3.2.1.1. Days to 50% Flowering and Fruit Setting

In 2016 and 2017 cropping seasons, very highly significant ($p \leq 0.001$) difference was observed among the varieties and fungicide spray frequencies with regard to days to 50% flowering and fruit setting. Melkasholla had longer duration reach 50% flowering and fruit setting than the other varieties in both cropping seasons (Table 5). This difference might have resulted from the variation in genetic background of the tomato varieties. Kaushik *et al.* (2011) also found significant variability in yield produced by six tomato varieties evaluated for pest and disease reaction and productivity in Botswana. Similarly, this result is in agreement with the finding of Shushay and Haile (2014) who found that days to 50% flowering ranged from 29 to 38. However, it was found that among the different varieties, 'ARP tomato d2 and Roma VF' showed earliest flowering, whereas 'Bisholla' and 'Melkasholla' had delayed flowering, and this current observation coincides with the finding of Shushay and Haile (2014). In contrast to this study, Ajal and Ajani (2014) reported that days to 50% flowering ranged from 46.75 to 64.

With regard to ridomil spray frequencies in 2016 and 2017 cropping seasons, the unsprayed control plots of the four varieties had also significantly shorter days to 50% flowering and fruit setting than the sprayed plots (Table 5). Three times ridomil spray frequencies showed early to days to 50% flowering and fruit setting as compared to the other spray frequencies in both cropping seasons. This indicates that fungicide application might have extended the period to 50% flowering and fruit setting due to the encouraging ability of the fungicides in reducing disease stress; as a result the plant continues in its normal physiological processes.

3.2.1.2. Number of Branches per Plant and Plant Stand Count at Picking

Varieties and fungicide spray frequencies exhibited very highly significant ($p \leq 0.001$) difference on the number of branches per plant and plant stand count at harvest both in 2016 and 2017 cropping seasons. In 2016 and 2017 cropping seasons, the maximum number of branches per plant was recorded in the varieties Melkasholla (14.79) and Roma VF (13.43), respectively. Similarly, in both cropping seasons, minimum number of branches per plant was recorded in the variety ARP tomato d2 (12.58 and 11.48), respectively (Table 5). This present result is in close conformity with the findings of Meseret *et al*. (2012) who reported that the significant variations among the varieties of tomato for the number of branches per plant. ARP tomato d2 had relatively higher plant stand count at harvest, while Melkasholla and Roma VF in 2016 and Roma VF in 2017 cropping seasons had more number of branches per plant than other tomato varieties (Table 5). This difference might have resulted from the variation in genetic background of the tomato varieties.

Similarly, unsprayed plots of the four tomato varieties had very highly and significantly ($p \le 0.001$) less number of branches per plant (12.04 and 10.77) and plant stand count (29.50 and 28.33) at harvest than the sprayed plots regardless of the spray frequencies of ridomil in 2016 and 2017 cropping seasons, respectively (Table 6). At the same time, the highest plant stand count and numbers of branches of 40.25 and 15.19 were recorded from the sprayed plots of three times spray frequencies and unsprayed plot**,** respectively in 2016 cropping season (Table 6). Nevertheless, in 2017 cropping season the highest plant stand count and numbers of branches were recorded in plots treated with three and four times with corresponding value of 39.50 and 37.60 and two and three times spray frequencies at 10 days intervals with corresponding values of 13.36 and 13.96 (Table 5). This indicates that wise application of fungicides would reduce the magnitude of disease severity on the number of branches per plant and plant stand count and would enhance the plants to perform their normal physiological processes.

3.2.1.3. First and Last Picking Date

Very highly significant ($p \le 0.001$) difference was observed among the tomato varieties on first and last harvesting date in both 2016 and 2017 cropping seasons. Roma VF had relatively shorter first and last harvesting dates than the other varieties on both cropping seasons (Table 5). The number of days to first harvesting ranged from 63.40 – 76.60 days in 2016 and 52.00 - 68.27 days in 2017 cropping season for the varieties Roma VF and Melkasholla, respectively. Similarly, the number of days to last harvesting ranged from 89.60 – 98.53 days in 2016 and 81.47 – 93.93 days in 2017 for Roma VF and Melkasholla varieties, respectively. Roma VF took the shortest (89.60 and 81.47 days) period and Melkasholla the longest (98.53 and 93.93 days) period to cease fruit bearing in 2016 and 2017 cropping season, respectively. This difference might have resulted from the variation in genetic background of the varieties and likely to be due the favorable agro-ecology of the growing areas for the varieties to bear and cease fruiting earlier in the growing period in both cropping seasons. Moraru *et al.* (2004) and Ketema *et al.* (2016) also recognized the presence of a wider range of variability in days to first harvest amongst ten and nine tomato varieties tested, respectively. Moreover, Bohner and Bangerth (1988) also reported that time from transplant to first harvest of plum types and large fruited-type tomatoes ranged between 70 to 90 days, where the earlier maturity occurred for plum types and the late harvesting for large fruited types of tomatoes, which is in agreement with the present findings. This was true for the varieties ARP tomato d2, Bisholla and Melkasholla but for Roma VF it was in contrast since first harvesting date for this variety was less than predetermined date range found by Bohner and Bangerth (1988) (Table 5).

Spray treatments had no significant ($p>0.05$) difference in the duration for first harvesting date in 2016 but there was very highly significant ($p \le 0.001$) difference in 2017 cropping season, where the last harvesting date significantly varied in both cropping seasons. In 2017 cropping season, the shortest first harvesting date was recorded from unsprayed and one time sprayed plots of all varieties, and the longest was recorded from three and four times sprayed plots of all varieties. Unsprayed plots of the four varieties had significantly shorter last harvesting days of 82.25 and 80.58 than the sprayed plots in both 2016 and 2017 cropping seasons, respectively. At the same time, the longest first and last harvesting duration, i.e. 74.00 and 101.25 days in 2016, and 67.00 and 90.00 days in 2017 cropping seasons, respectively, took three and four times ridomil spray frequencies (Table 5). This indicates that wise application of fungicides would reduce the magnitude of disease severity and enhance the plants to perform their normal physiological processes. Similar results were reported by Ayda (2015) and opined that fungicide application in integration with resistant genotypes and fungicide treatment lengthened the time required by the potato genotypes, alternate host for *P. infestans,* to reach physiological maturity.

3.2.2. Yield and Yield Related Parameters

The main effects of varieties x spray frequencies did not exhibit significant difference ($p>0.05$) on all components of yield attributes, except unmarketable yield, which exhibited very highly significant ($p \le 0.001$) for its main effects in the experiment both in 2016 and 2017 cropping seasons (Table 6). With this, only their interaction effect of mean value of variety and spray frequencies of all parameters were considered in the table, including unmarketable yield. This implied that each variety was affected by the level of the different foliar spray frequencies except for unmarketable yield.

3.2.2.1. Marketable, Unmarketable and Total Fruit Yield

Marketable, unmarketable and total fruit yields were very highly and significantly ($p \le 0.001$) varied among tomato varieties and spray frequencies in both 2016 and 2017 cropping seasons. ARP tomato d2 (39.63 and 37.22 t ha^{-1}) and Roma VF (37.25 and 35.73 t ha^{-1}) varieties had the highest marketable and lowest unmarketable fruit yield (5.72 and 5.85 t ha^{-1} for ARP tomato d2) as compared to the other tomato varieties in 2016 and 2017 cropping seasons, respectively. Similarly, in the two cropping seasons (i.e. 2016 and 2017), the highest, such as 46.59 and 46.54 t ha^{-1}, total fruit yields were obtained from Roma VF, respectively (Table 6). This difference might have resulted from the variation in genetic background of the varieties.

Table 5. Effect of integration of varieties and fungicide spray frequencies for late blight management on growth traits of tomato at Arbaminch during 2016 and 2017 cropping season

Treatments	2016 Cropping season						2017 Cropping season					
	50%DF DAT	50%FS DAT	FPD DAT	LPD DAT	PSC	NBPP	50%DF DAT	50%FS DAT	FPD DAT	LPD DAT	PSC	NBPP
Tomato Variety:												
ARP tomato d2	28.87^{c}	46.27^{c}	71.00^{b}	90.33^{b}	39.47^{a}	12.58^{c}	24.00^{b}	33.07^{c}	62.93^{c}	84.00^{b}	39.20^{a}	11.48^{c}
Bisholla	30.33^{b}	48.07^{b}	74.60^{ab}	89.87^{b}	33.60^{c}	13.63^{b}	25.47^{b}	36.00^{b}	64.27^{b}	83.00^{bc}	30.67^{c}	12.36^{b}
Melkasholla	36.00^{a}	55.53^{a}	76.60^{a}	98.53^{a}	32.67^{c}	14.79^{a}	30.67^{a}	40.80^{a}	68.27^{a}	93.93^{a}	29.73^{c}	13.22^{ab}
Roma VF	18.93^{d}	38.93^{d}	63.40^{c}	89.60^{b}	35.53^{b}	14.68^{a}	16.40^{c}	28.60^{d}	52.00^{d}	81.47^{b}	36.53^{b}	13.43^{a}
LSD (0.05)	1.36	0.63	4.79	4.89	1.78	0.68	1.68	0.81	0.85	2.17	1.96	0.87
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01
Spray Frequency:												
Control	27.41^{c}	45.17^{c}	70.75^{a}	82.25^{c}	29.50^{d}	12.04^{d}	23.33^{a}	33.50^{c}	60.33^{c}	80.58^{c}	28.33^{c}	10.77^{c}
One time	29.00^{ab}	46.42^{b}	70.75^{a}	85.00^{c}	31.67^{c}	13.00^{c}	24.67^{a}	34.25^{bc}	61.00^{c}	81.83^{c}	30.50^{c}	12.05^{b}
Two times	28.42^{abc}	46.17^{b}	71.75^{a}	92.92^{b}	35.00^{b}	14.40^{b}	24.33^{a}	34.58^{b}	64.33^{b}	85.75^{b}	34.17^{b}	13.36^{a}
Three times	29.67^{a}	49.17^{a}	74.00^{a}	101.25^{a}	40.25^{a}	15.19^{a}	24.33^{a}	35.75^{a}	66.67^{a}	89.83^{a}	39.50^{a}	13.93^{a}
Four times	28.17^{bc}	49.08^{a}	69.75^{a}	99.00^{a}	40.17^{a}	14.96^{ab}	24.33^{a}	35.00^{ab}	67.00^{a}	90.00^{a}	37.67^{a}	13.00^{ab}
LSD (0.05)	1.52	0.71	5.47	3.81	1.99	0.76	1.88	0.90	0.95	2.43	2.19	0.98
P-value	≤0.05	<0.001	>0.05	<0.001	<0.001	<0.001	>0.05	<0.01	<0.001	<0.001	<0.001	<0.001
Var *SF	ns	HS	ns	ns	ns	ns	ns	S	VHS	ns	ns	ns
Mean	28.53	47.20	71.40	92.08	35.32	13.92	24.13	34.62	63.87	85.60	34.03	12.62
CV (%)	6.48	1.81	9.28	5.02	6.85	6.00	9.46	3.16	1.81	3.44	7.81	9.36
R^2 (%)	0.95	0.99	0.54	0.84	0.87	0.81	0.88	0.96	0.95	0.88	0.88	0.68

Values within the column with the different letter represent significant variation; Var = Variety; SF = Spray frequencies; DF = Date of flowering; DS = Date of fruit setting; FPD = First picking date; LPD = Last picking date; PSC = Plant stand count; NBPP = Number of branch per plant; DAT = Date after transplanting; CV = Coefficient of variation; LSD = Least significant difference; R^2 = Coefficient of determination; Var * SF = Interaction effect of variety x spray frequency; S = Significant at p≤ 0.05; HS = Highly significant at p≤ 0.01; VHS = Very highly significant at p≤ 0.0001; and ns = not significant (p>0.05)

The report of MoARD (2005) showed that the varieties Melkasholla and Bisholla yielded up to 35 and 45 t ha^{-1}, respectively, in Ethiopia. However, in this experiment the yield was less than that of the potential yields of the varieties Melkasholla and Bisholla that gave 30.95 and 29.88 t ha^{-1} in 2016 and 28.29 and 29.27 t ha$^{-1,}$ in 2017 cropping seasons, respectively. This might indicate that the disease pressure was high during the experiment leading to very low yield (Table 6). But compared to this present study report, MoARD (2005), Belay **(2009) and MoA (2012)** reported that yields of the varieties ranged from 31.4 (Roma VF) to 43.5 t ha^{-1} (ARP tomato d2). It can be seen that in general the fruit yields of the varieties ARP tomato d2 and Roma VF were relatively higher than the yields of the varieties Bisholla and Melkasholla even while being under high disease pressure in this study in both cropping seasons (Table 6).

With regard to the spray treatments in 2016 and 2017 cropping seasons, the lowest (22.92 and 19.59 t ha^{-1}) marketable and total fruit yield (34.08 and 35.54 t ha^{-1}) and highest (11.16 and 12.69 t ha^{-1}) unmarketable fruit yield were obtained from unsprayed control plots, respectively (Table 7). At the same time, both in 2016 and 2017 cropping seasons, the highest marketable (44.16 and 38.25 t ha^{-1}) and total fruit yield (52.00 and 50.47 t ha^{-1}) were obtained from plots treated three times with ridomil, respectively. Similarly, in both 2016 and 2017 cropping seasons, the lowest such as 7.02 and 7.58 t ha^{-1} unmarketable fruit yields were obtained from plots treated four times with ridomil, respectively (Table 6). This is in agreement with results of Desta and Yesuf (2015) who reported three times sprays of metalaxyl (ridomil) can give optimum fruit yield. According to Dillard *et al.* (1997), fungicide applications were found to have a variable effect on tomato yields. Jiregna (2014) reported that fungicides significantly reduced disease severity and gave increased yield over the control. Kaushik *et al.* (2011) also found significant variability in yield produced by six tomato varieties evaluated for pest and disease and productivity in Botswana.

3.2.2.2. Yield Related Fruit Parameters

Number of fruit clusters per plant, number of fruits per plant and single fruit weight were very highly and significantly (p≤0.001) varied among tomato varieties and spray treatments both in 2016 and 2017 cropping seasons. Roma VF variety had the highest, such as 21.64 and 19.99 number of fruit clusters per plant and fruits per plant, such as 61.28 and 56.48 as compared to the other varieties in both cropping seasons, respectively (Table 6). Many authors reported a wide range of differences in number of fruits per plant in tomato genotypes (Chernet *et al.*, 2013; Emani *et al.*, 2013). In both 2016 and 2017 cropping seasons, the highest, such as 111.47 and 119.83 g single fruit weight, was obtained from Bisholla (Table 6). This difference might have resulted from the variation in genetic background of the varieties.

Concerning spray frequencies, the least (11.42 and 9.71) number of fruit clusters per plant, number of fruits per plant (28.02 and 25.74) and single fruit weight (59.33 and 63.68 g) were obtained from unsprayed control plots in both cropping seasons, respectively. Similarly, in both 2016 and 2017 cropping seasons, the highest (27.74 and 23.71) number of fruit clusters per plant and number of fruits per plant (80.06 and 68.81) were obtained from plots treated three times with ridomil (Table 6), while the highest single fruit weight was obtained from plots treated four and three times with ridomil with corresponding values of 103.64 g in 2016 and 111.53 g in 2017 cropping seasons, respectively (Table 6). Abhinandan *eat al.* (2004) and Kaushik *et al.* (2011) reported that fungicides significantly reduced disease severity and gave increased yield over the control.

3.3. Association of Late Blight Epidemics with Tomato Fruit Yields

Associations between tomato late blight and yield parameters were examined using simple correlation analyses. Pearson correlation coefficients (r) were used as indices for strength of the associations (Table 7). The negative correlation of late blight development with yield was found to be stronger with the final severity than AUDPC values both in 2016 and 2017 cropping seasons. Total fruit yield and final PSI and percent fruit infection showed very highly significant ($p \leq 0.001$) and negative correlations r = -0.81 and r = -0.67 in 2016 and r = -0.67 and r = -0.44 in 2017 cropping seasons, respectively. Similarly, AUDPC values and disease progress rates also revealed very highly significant ($p \leq 0.001$) and negative association with fruit yield with correlation coefficient values of r = -0.74 and -0.81 in 2016 and -0.63 and -0.67 in 2017 cropping seasons, respectively (Table 7). This indicates that the observed values of late blight had considerable adverse effects on fruit yield of the tomato. This result is in agreement with the finding of Fekede (2011) who reported that the associated disease parameters had a negative impact on yield parameters.

In general, both in 2016 and 2017 cropping seasons, final PSI, percent fruit infection, disease progress rate and AUDPC had high and significant negative correlations with yield and yield related parameters, including marketable fruit yield, number of fruit clusters per plant, number of fruits per plant and single fruit, with the exception of unmarketable fruit yields for they had positive correlation (Table 7). This indicates that the observed levels of late blight epidemics had a considerable adverse effect on yield related parameters of tomato varieties. Previously, researchers found that early infection due to *P. infestans* causing late blight of potato and tomato resulted in severe disease and highest correlations between yield and disease indices under natural field conditions (Olanya *et al.,* 2001). Similar findings were reported by Bekele and Gebremedhin (2000) who indicated that late blight severity, AUDPC and infection rates were strongly correlated with final yields of potato, alternate host of *P. infestans*.

Table 6. Effect of integration of varieties and fungicide spray frequencies for management of late blight on marketable, unmarketable and total fruit yield of tomato at Arbaminch during 2016 and 2017 cropping seasons

Treatments	2016 Cropping season						2017 Cropping season					
	MFY ($t\ ha^{-1}$)	UMFY ($t\ ha^{-1}$)	TFY ($t\ ha^{-1}$)	NFCPP	NFPP	SFW (g)	MFY ($t\ ha^{-1}$)	UMFY ($t\ ha^{-1}$)	TFY ($t\ ha^{-1}$)	NFCPP	NFPP	SFW (g)
Tomato Variety												
ARP tomato d2	39.65^{a}	5.72^{c}	45.37^{a}	15.68^{b}	38.69^{b}	83.75^{b}	37.22^{a}	5.85^{c}	43.07^{b}	13.2^{c}	36.62^{c}	89.89^{a}
Bisholla	29.88^{b}	10.28^{a}	40.17^{a}	15.95^{b}	40.63^{b}	111.47^{a}	29.27^{b}	11.83^{a}	41.09^{b}	14.59^{c}	40.48^{c}	119.83^{a}
Melkasholla	30.95^{b}	9.89^{ab}	40.84^{a}	20.74^{a}	59.10^{a}	63.95^{c}	28.29^{b}	11.69^{a}	39.98^{c}	17.76^{b}	50.36^{b}	68.58^{c}
Roma VF	37.25^{a}	9.34^{b}	46.59^{b}	21.64^{a}	61.28^{a}	68.43^{c}	35.73^{a}	10.81^{b}	46.54^{a}	19.99^{a}	56.48^{a}	73.08^{c}
LSD (0.05)	2.59	0.66	2.62	1.95	6.10	7.24	2.88	0.71	3.30	2.03	5.68	9.36
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001
Spray Frequency												
Control	22.92^{d}	11.16^{a}	34.08^{c}	11.42^{d}	28.02^{d}	59.33^{c}	19.59^{d}	12.69^{a}	35.54^{c}	9.71^{d}	25.74^{e}	63.68^{c}
One time	27.59^{c}	9.60^{b}	37.19^{c}	13.33^{cd}	33.61^{d}	67.08^{c}	23.28^{c}	10.64^{b}	37.16^{c}	11.28^{d}	33.88^{d}	71.94^{c}
Two times	35.03^{b}	8.43^{c}	43.46^{c}	15.63^{c}	43.73^{c}	83.16^{b}	32.71^{b}	9.70^{c}	43.66^{b}	16.62^{c}	46.99^{c}	92.51^{b}
Three times	44.16^{a}	7.84^{c}	52.00^{a}	27.74^{a}	80.06^{a}	96.30^{a}	38.25^{a}	9.62^{c}	50.47^{a}	23.71^{a}	68.81^{a}	111.53^{a}
Four times	42.45^{a}	7.02^{d}	49.47^{b}	24.40^{b}	64.20^{b}	103.64^{a}	33.07^{b}	7.58^{d}	46.54^{b}	20.67^{b}	54.71^{b}	99.56^{b}
LSD (0.05)	2.89	0.74	2.93	2.18	6.82	8.10	3.22	0.78	3.12	2.27	6.35	10.46
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
VAr *SF	HS	ns	HS	HS	VHS	VHS	S	ns	S	S	VHS	VHS
Mean	34.43	8.81	43.24	18.50	49.52	81.90	32.63	10.05	42.67	16.39	45.98	87.84
CV (%)	10.18	15.72	11.64	14.25	16.56	17.99	11.97	9.62	9.38	16.79	16.75	14.43
R^2 (%)	0.92	0.91	0.88	0.92	0.92	0.92	0.87	0.94	0.81	0.89	0.90	0.89

Values within the column with the different letters represent significant variation; Var = variety; SF = spray frequencies; MFY = Marketable fruit yield; UMFY = Unmarketable fruit yield; TFY = Total fruit yield; NFCPP = Number of fruit clusters per plant; NFPP = Number of fruits per plant; SFW (g) = Single fruit weight in gram; CV = Coefficient of variation (%); LSD = Least significant difference; Var *SF = Interaction effect of variety x spray frequency; S = Significant at $p \leq 0.05$; HS = Highly significant at $p \leq 0.01$; VHS = Very highly significant at $p \leq 0.001$; and ns = not significant ()p>0.05)

Table 7. Correlation coefficients between late blight epidemics of tomato varieties and fungicide spray frequencies and fruit yields at Arbaminch during 2016 and 2017 cropping seasons

Year	Variables	FPSI	AUDPC	DPR	PFI	NFCPP	NFPP	SFW	MFY	UMFY	TFY
2016	FPSI	1									
	AUDPC	0.97***	1								
	DPR	0.99***	0.95***	1							
	PFI	0.64***	0.59***	0.65***	1						
	NFCPP	-0.66***	-0.59***	-0.68***	-0.83***	1					
	NFPP	-0.62***	-0.55***	-0.62***	-0.81***	0.96***	1				
	SFW	-0.32**	-0.26**	-0.34***	-0.35***	0.20*	0.15*	1			
	MFY	-0.87***	-0.83***	-0.86***	-0.65***	0.71***	0.70***	0.34***	1		
	UMFY	0.80***	0.84***	0.78***	0.33**	-0.30**	-0.25*	-0.33***	-0.71***	1	
	TFY	-0.81***	-0.74***	-0.81***	-0.67***	0.75***	0.75***	0.36***	0.94***	-0.55***	1
2017											
	FPSI	1									
	AUDPC	0.97***	1								
	DPR	0.98***	0.93***	1							
	PFI	0.81***	0.82***	0.80***	1						
	NFCPP	-0.58***	-0.53***	-0.57***	-0.26***	1					
	NFPP	-0.22*	-0.51***	-0.51***	-0.22*	0.94***	1				
	SFW	-0.39***	-0.39***	-0.45***	-0.23*	0.20*	0.13*	1			
	MFY	-0.81***	-0.78***	-0.82***	-0.63***	0.65***	0.67***	0.34***	1		
	UMFY	0.77***	0.76***	0.77***	0.92***	-0.15*	-0.11*	-0.24*	-0.58***	1	
	TFY	-0.66***	-0.63***	-0.67***	-0.44***	0.74***	0.77***	0.27**	0.086***	-0.0.32**	1

*** Correlation is significant at p≤0.001; ** Correlation is significant at p≤ 0.01; * Correlation is significant at P≤0.05; ns correlation is not significant (p>0.05); FPSI = Final percent severity index; AUDPC = Area under disease progress curve; DPR = Disease progress rate; PFI = Percent fruit infection; NFCPP = Number of fruit clusters per plant; NFPP = Number of fruits per plant; SFW (g) = Single fruit weight in gram; MFY = Marketable fruit yield; UMFY = Unmarketable fruit yield; and TFY= Total fruit yield

In the linear regression analysis, the AUDPC was used for predicting the yield loss in tomato for both 2016 and 2017 cropping seasons (Figure 1). This is because AUDPC linear regression is a better analytical model to indicate the relationship of yield loss with the disease effects than other models. The higher the AUDPC values in disease epidemics, the more susceptible are the varieties. Thus as AUDPC increases, the yield decreases and goes towards zero asymptote, which indicates the inverse relation between AUDPC values and fruit yields of tomato. At the same time, the typical distance between the line and all the points along it on either side indicates whether the regression analysis has captured a relationship that is strong or weak. Overall, the closer a line is to the points, the stronger the relationship. The coefficient of determination (R^2) value indicated that 63.7 and 52.7% of the variation of yield were explained by AUDPC values in 2016 and 2017 cropping seasons, respectively. This regression graph showed that for every one unit increase in AUDPC value, there was 0.0408 and 0.0743 unit loss in yield of tomato varieties in 2016 and 2017 cropping seasons, respectively.

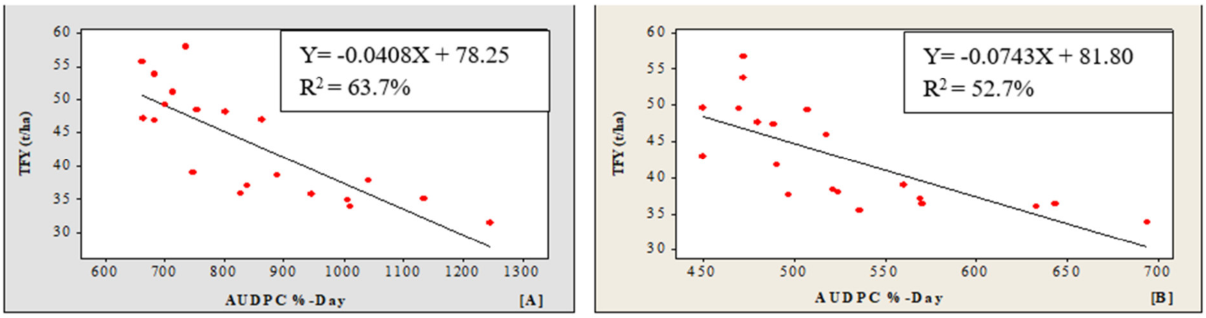

Figure 1. Linear regression of tomato fruit yield and AUDPC values at Arbaminch during 2016 (A) and 2017 (B) cropping season

3.4. Relative Yield Loss and Yield Increase in Fruit Yields

The losses inflicted on tomato fruit yields at different foliar spray frequencies were calculated relative to the yield of maximally protected plots, i.e. treated three times with ridomil at 10 days interval. The highest fruit yield losses of 54.41, 53.51, 46.29 and 41.35 t ha^{-1} in 2016 and 41.75, 49.12, 57.92 and 62.55 t ha^{-1} in 2017 cropping seasons were calculated for the varieties Melkasholla, Roma VF, Bisholla and ARPT tomato d2 in 2016 cropping season, respectively, as compared to the best protected plots sprayed three times with ridomil (Table 8). This was because plants on the less protected plots failed to set fruits due to defoliation and dropped their fruits due to fruit rots caused by *P. infestans*. When the two cropping seasons were compared, relatively the lower (48.83%) relative yield lose was computed from 2016 than from 2017 cropping season. This finding is in conformation with the investigation of Gwary and Nahunnaro (1998) who reported yield losses within the range of 30-50% of the harvest due to fruit-drops of infected fruits. This observation also agrees with the findings of Deahl *et al.* (1993) who reported that yield reduction is observed when plants lose their leaves because the plants fail to set fruits. It should be acknowledged that the fruit yield losses calculated in the current study could not be solely attributed to late blight considering the medium levels of severity of early blight, septoria leaf spot and insect pests damaged. On the other hand, in 2016 and 2017 cropping seasons, the fruit yield increased because the different foliar spray frequencies were obtained as relative to the yield of individual treated with untreated plots, i.e. treated three times with ridomil at 10 days intervals showed 54.41, 53.51, 43.00 and 41.35 t ha^{-1} in 2016 and 50.01, 49.12, 42.87 and 38.08 t ha^{-1} in 2017 cropping seasons for the varieties Melkasholla, Roma VF, Bisholla and ARP tomato d2, respectively (Table 8).

In general, it can be concluded that foliar spraying with ridomil three times at 10 days interval would better protect tomato from fruit yield losses than other foliar spraying frequencies of the same fungicide at the same interval in both cropping seasons, with the exceptions in 2017 cropping season in which two times spray frequencies also gave reseanable yields. In addition to use of fungicides, use of resistant varieties would ultimately reduce cost of crop protection. According to some researchers, crop yield losses attributed primarily to late blight were dependent on variety tolerance/resistance or susceptibility and disease management practices (Thind *et al.*, 1989; Bradshaw, 1992). Mukalazi *et al.* (2001) also reported that susceptible tomato varieties could be preferred by farmers due to their good agronomic characteristics, and hence fungicides should be used to ensure successful disease management and sustainable tomato production.

3.5. Cost and Benefit Analysis

Partial budget analysis showed that all ridomil foliar spray frequencies used on the four tomato varieties gave high gross field benefit and marginal rate of return (MRR) (Table 8). Marginal analysis indicated that the highest marginal rate of return in comparison with unsprayed plots was obtained where ridomil was applied two times for ARP tomato d2 (40.00%) and three times spray frequencies for Roma VF (41.30%), Bisholla (29.09%) and Melkasholla (34.59%) varieties in 2016 cropping season. Similarly, in 2017 cropping season the highest MRR was obtained where ridomil was applied two times for ARP tomato d2 (41.25%) and Roma VF (56.21%), and three times for Bisholla (27.20%) and Melkasholla (31.90%) varieties spray frequencies were used. However, the least marginal rate of return was recorded from the untreated control plots.

On the variety Roma VF, the maximum total gross marketable yield benefit of 40,043.20 and 47,238.36 \$ ha^{-1} were obtained from plots treated three times with ridomil at 10 days interval, followed by plots treated with three times spray frequencies on ARP tomato d2 variety with a gross yield benefit of 39,688.57 and 45,474.96 \$ ha^{-1} in 2016 and 2017 cropping seasons, respectively (Table 8). Although lower gross yield benefits were obtained from unsprayed plots of Melkasholla, and Bisholla with corresponding values of 32,883.00 and 38,474.47 in 2016, and 32,671.91 and 38,463.47 \$ ha^{-1} in 2017 cropping seasons, plots treated three times with ridomil (Table 8) had higher gross fruit yield benefits than from the unsprayed plots (i.e. 14,722.21 and 17,398.85 in 2016 and 19,104.74 and 21,951.66 \$ ha^{-1} in 2017 cropping seasons). Thus, variations in net benefits and MRR were manifested among the four varieties due to the inherent behavior of the genotypes and additional use of fungicide applications.

Table 8. Relative fruit yield losses due to tomato late blight and yield increase in fruit yields under integration of varieties with ridomil different spray frequencies at Arbaminch during 2016 and 2017 cropping seasons

Tomato Variety	Spray Frequency	2016					2017				
		Yield (t/ha)	RYL (%)[1]	CYI (%)[2]	NP ($ ha-1)[3]	MRR (%)[4]	Yield (t/ha)	RYL (%)[1]	CYI (%)[2]	NP ($ ha-1)[3]	MRR (%)[4]
ARP tomato d2:	One time	33.15	31.97	13.79	26,856.76	18.14	31.53	28.97	12.83	32,254.50	17.69
	Two times	45.50	6.63	36.86	37,137.82	40.00	43.60	2.03	36.95	44,838.17	41.25
	Three times	48.73	0.00	41.35	39,688.57	31.41	44.39	0.00	38.08	45,474.96	28.45
	Four times	42.29	13.22	32.42	33,935.66	12.78	39.10	21.30	29.71	39,538.26	11.93
	Control	28.58	41.35	0.00	23,199.62	-	27.49	62.55	0.00	28,204.38	0.00
Bisholla:	One time	23.04	42.99	5.77	18,320.25	4.57	24.84	34.22	13.15	25,176.71	14.08
	Two times	26.15	35.30	16.98	20,799.39	9.76	27.03	30.53	20.18	27,315.05	13.30
	Three times	40.42	0.00	46.29	32,671.91	29.09	37.76	0.00	42.87	38,463.47	27.20
	Four times	38.09	5.76	43.00	30,389.33	15.35	35.16	11.24	38.65	35,375.06	14.13
	Control	21.71	46.29	0.00	17,398.85	-	21.57	57.92	0.00	21,951.66	0.00
Melkasholla:	One time	27.23	33.05	31.91	21,858.13	35.40	23.10	38.85	18.25	23,334.42	18.47
	Two times	29.36	27.81	36.85	23,509.80	25.22	27.95	29.12	32.45	28,291.45	22.78
	Three times	40.67	0.00	54.41	32,883.00	34.59	37.77	0.00	50.01	38,474.47	31.90
	Four times	38.94	4.25	52.39	31,233.70	19.65	33.74	15.15	44.03	33,864.20	15.54
	Control	18.54	54.41	0.00	14,722.21	-	18.88	41.75	0.00	19,104.74	0.00
Roma VF:	One time	26.96	45.15	15.24	21,630.15	16.21	26.63	42.18	12.00	27,071.97	13.76
	Two times	39.11	20.43	41.58	31,750.78	38.43	45.25	2.17	48.21	46,586.76	56.21
	Three times	49.15	0.00	53.51	40,043.20	41.30	46.06	0.00	49.12	47,238.36	38.41
	Four times	48.17	1.99	52.56	38,900.52	24.45	37.27	19.26	37.13	37,606.72	14.41
	Control	22.85	53.51	0.00	18,361.42	-	23.44	49.12	0.00	23,921.48	0

[1]RYL = Relative yield loss; [2]CYI = Change in yield increase; [3]NP = Net income; and [4]MRR = Marginal rate of return. Mean unit of mean price of fruit per kilogram was 0.92 **\$** (at the exchange rate of 1\$ = 22.75 ETB) at the time of fruit selling in 2016 and 2017 cropping seasons.

4. CONCLUSIONS AND RECOMMENDATIONS

Tomato late blight (*Phytophthora infestans*) is known as one of production-limiting biotic agent in the world and in Ethiopia. The current research was carried out at Chamo Mille Sub-Station of Arbaminch Agricultural Research Center, Gamo Gofa Zone (SNNPR), Southern Ethiopia, during 2016 and 2017 cropping seasons. This

2016 and 2017 cropping seasons study on tomato late blight management with varieties in integration with ridomil foliar spray fungicide indicated that ARP tomato d2 variety appeared to possess comparative resistance to late blight and is a promising tomato variety. Further investigation should be carried out to verify whether it has a real genetic resistance; until that moment comes, this variety can be used in combination with other management measures, wherever the disease is a pressing problem. Also, instead of using several fungicides indiscriminately, two times ridomil foliar applications at 10 days can substantially manage the disease if used in combination with resistant/moderately resistant varieties, like ARP tomato d2 variety, even with three times for susceptible varieties, like Melkasholla, giving maximum net benefit and avoiding risk of development of fungicide resistance by the pathogens and minimizing cost of production.

In general, complete management of late blight is difficult to achieve, especially during heavy rainy seasons. However, substantial levels of disease suppression could be achieved through integration of tomato varieties with foliar fungicide applications. Thus, the use of ridomil with spray frequencies of two times for resistant and moderately resistant varieties, like ARP tomato d2 Roma VF varieties, and three times for moderately resistant/moderately susceptible and susceptible varieties, like the susceptible Bisholla and Melkasholla varieties, are recommended as they gave relatively the highest protection against late blight and the highest monetary benefit as compared to the other treatments and the control.

Therefore, integrated management practices must be adopted by all tomato growers, including small household farmers, private investors, and state enterprises, for curbing the development of late blight and for sustainable tomato production in the study area and in other areas with similar agro-ecologies that favour tomato late blight epidemics. Also, further extensive studies are recommended for evaluation of additional tomato varieties and management options under different agro-ecological conditions to come up with suitable conclusive management options and to enhance high quality tomato production in the study areas and elsewhere in Ethiopia, having similar agro-ecologies.

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