Integrated Management of Early Blight (*Alternaria solani*) in Tomato (*Solanum lycopersicum*) in Arbaminch Areas, Southwestern Ethiopia

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Abstract

Tomato early blight (*Alternaria solani*) is an important disease of tomato that reduces quantity and quality of fruit yield. Field experiments were conducted in 2016 and 2017 cropping seasons with the objective to evaluate the effect of varieties and fungicide application frequencies on early blight epidemics, total fruit yield and yield components. Treatments included four tomato varieties with different resistance levels and four foliar fungicide spray frequencies alone and in combination, including unsprayed plots as control. The treatments were arranged factorially in a randomized complete block design (RCBD) with three replications. The integrated use of tomato varieties with fungicide spray frequencies significantly reduced early blight epidemics and increased fruit yield parameters. A minimum mean disease severity was calculated for tomato varieties evaluated in the order of ART tomato d2, Roma VF, Bisholla and Melkasholla at 61 days after planting in four times fungicide sprayed plots compared to unsprayed plots in 2016 cropping season. A similar trend was observed in 2017 cropping season. The highest (12.54-17.79%-days) rAUDPC values were calculated for unsprayed plots in 2016 and 15.71-22.16%-days during 2017 cropping season. Roma VF produced the highest (49.15 t ha^{-1}) and Melkasholla gave the lowest (18.71 t ha^{-1}) mean marketable fruit yields, with three times fungicide spray frequencies in both cropping seasons. The study indicated that the inherent genetic potential of tomato varieties is complemented by foliar application of ridomil fungicide that contributed to low blight epidemics and high fruit yield, and provided higher net benefit with optimum marginal rate of return. It is commendable to screen additional tomato varieties and fungicides to come up with reliable recommendation against early blight for sustainable tomato production in the study area and other locations with similar agro-ecologies.

Keywords: *Alternaria solani*, AUDPCs, severity, fungicide spray frequency, tomato, fruit yield

Introduction

Tomato (*Solanum lycopersicum*) is an important vegetable crop grown worldwide. The crop ranks first with respect to world vegetable production and accounts for 14% (>100 metric tons per year) and $1.6 billion market income earnings (Bauchet & Causse 2010), which is expected to exceed this figure in recent years. Likewise, tomato is widely produced both during the rainy and dry periods under supplemental irrigation in Ethiopia (Lemma 2002; Tsedeke 2007; Derbew et al. 2012). The total area under tomato production reaches 6,298.63 ha and the production is estimated to be over 28,364.83 tons with an average productivity of 4.50 t ha^{-1} during the 2016/17 main cropping season in the country. Also, in the study areas, tomato covered 979.75 ha of land, with estimated productivity of about 1.07 t ha^{-1} (CSA 2017).

Tomato is a key food and cash crop for farmers wherever it is produced (FAOSTAT 2014). The crop is grown for its fruits, which are used in salads or cooked as a vegetable, in processed form as tomato paste, tomato sauce, ketchup and juice and the ripe fruits are rich in nutrients, minerals and vitamins (USDA 2005). Similarly, the crop is consumed in fresh and processed forms; and is a high value commodity crop, which has been given top priority in vegetable research in Ethiopia (Tsedeke 2007). However, the national average yield of tomato is very low as compared to the world average (32.80 t ha^{-1}) yield (Anonymous 2011). Low productivity of the crop is mainly attributed to numerous pests, which cause serious damage on yield in the world. And, diseases are major constraints of tomato productivity under production systems of Ethiopia.

Tomato early blight (*Alternaria solani*) is among the most common diseases that reduce yield and cause reduction in quality of tomato fruits. It is an economically important disease throughout Ethiopia (Tsedeke 2007) and in much of the hot and humid tomato-growing conditions of the world (Mizubuti et al. 2006). Tomato early blight epidemics are particularly severe in tropical countries during warm and wet seasons (Mizubuti et al. 2006). In severe cases, early blight can lead to complete defoliation and is most damaging in regions with heavy rainfall, high humidity and fairly high (24-29 °C) temperature (Prasad and Naik 2003). The pathogen causes infection on different parts of tomato, leading to defoliation, twig drying and premature fruit drop that ultimately reduce total fruit yield (Naveenkumar et al. 2003). The disease is reported to cause yield loses ranging from 14.22 to 52.94% under field conditions in Ethiopia (Mehari & Mohammed 2015). The disease is also a serious threat of tomato production in Arbaminch areas, southwestern Ethiopia (ACPC 2014).

As the disease is recurrently occurring and causing huge yield losses in tomato production, using effective management scheme is necessary in Ethiopia in general and Arbaminch areas in particular. In many literatures, cultural practices, host resistance and application of fungicides are recommended for field management of early blight. However, farmers indiscriminately use whatever fungicides are available alone or in combination two or more fungicides in Arabaminch areas. But inappropriate use and application of fungicides have adverse effects on human, animal and environmental health, reduce fresh market value and processing of tomato, and induce development of resistance to fungicides (WHO 2004). This calls for a biorational fungicides alternatively in the form of integration along with other management options, including host resistance, different fungicides and spray frequencies.

Under Ethiopian condition, there are different fungicides recommended for the management of early blight and different tomato varieties were also developed. However, the integrated application of host resistance and appropriate spray frequency for early blight management as an option is not well addressed. Therefore, the current study was carried out with the objectives to: (1) evaluate the effects of host plant resistance and fungicide spray frequency on early blight epidemics; (2) evaluate tomato varieties and fungicide spray frequency on tomato fruit yield and yield components; and (3) determine yield loss and the economics of fungicide spray feasibility for the management of tomato early blight in Arbaminch areas, southwestern Ethiopia.

Materials and Methods

Description of the study area

The field experiments were conducted under rainfall conditions with supplementary irrigation in Arbaminch areas, southwestern Ethiopia, during 2016 and 2017 cropping seasons. Arbaminch is geographically positioned at 06°06'841" N latitude and 037°35'122" E longitude with an altitude of 1216 meters above sea level. The area is characterized by a bimodal rainfall pattern where 33.3% rainfall occurs during short rainy season (March and April) and the remaining (66.7%) during the main rainy season (mid-August to mid-November). The detail descriptions of weather variables of the 2016 and 2017 cropping seasons are presented (Table 1). The experimental area is also characterized by alluvial, black sandy-loam and clay-loam soil (AMARC 2016).

Table 1. Monthly mean minimum and maximum temperatures, rainfall and relative humidity (RH) of Arbaminch areas, southwestern Ethiopia, during the 2016 and 2017 cropping seasons

Weather variable	2016 cropping season[1]						2017 cropping season[1]					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max. T (°C)	29.85	28.93	31.41	30.84	32.03	NA	32.85	35.05	34.00	32.11	29.45	NA
Min. 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	122.4	177.5	NA
RH(%)	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. The data were obtained from National Meteorological Agency, Hawassa Branch (2017).

Experimental materials

The experiments were conducted using four tomato varieties (ARP tomato d2, Roma VF, Bisholla and Melkasholla) and a systemic and residual fungicide (Ridomil MZ Gold 68.5% WG). Tomato varieties have different origin and level of resistance to early blight. Seeds of each variety were obtained from Melkassa Agricultural Research Center (MARC). Brief descriptions of the agronomic and morphological characteristics of the varieties are presented (Table 2) Ridomil MZ Gold 68.5% WG was used at the manufacturer's recommended ate (3 kg ha^{-1}) and five spray frequencies (no spray, one time, two times, three times and four times) were made at every 10-day interval and starting from the onset of visible disease symptoms (33 and 28 days after transplanting in 2016 and 2017, respectively).

Table 2. Agronomic and morphological characteristics, and early blight reactions of tomato varieties tested at Arbaminch areas, southwestern Ethiopia, during the 2016 and 2017 cropping seasons

Variety	Year of Release	Growing Altitude (m.a.s.l.)	Days to Maturity	Fruit Color	Fruit Shape and Size	Fruit Yield (t ha^{-1}) [1]	Reaction to EB [2]
ARP tomato d2	2012	700-2000	75-80	Brick Red	Circular and Large fruit size	43.50	R
Roma VF	1997/98	400-2000	75-80	Red	Plum/Pear and small to medium fruit size	42.50	MR
Bisholla	2005	700-2000	85-90	Light Red	Circular and Large fruit size	45.00	MS
Melkasholla	1997/98	700-2000	100-120	Light Red	Plum/Pear and small fruit size	35.00	S

[1] Reported fruit yield is on research stations; [2] EB = Early blight; R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; and S = Susceptible. Data were sourced and organized from MoARD (2005), Meseret *et al.* (2012), MoA (2012) and Jiregna (2014).

Nursery establishment, seedling transplanting and field management

Seeds of tomato genotypes were sown on standard seedbeds based on recommendations of MARC (Getachew et al. 2014). The size of the bed was 1 m width by 5 m length and 0.15 m height for each variety and each seedbed was separated by 0.60 m, which eased free access during nursery management. The seeds were sown at a depth of 0.05 m in 30 rows with the spacing of 0.15 m in each nursery bed. Seeds were drilled on rows and the beds were covered with grass mulch till seedling emergence.

Three weeks later, seedlings attained transplantable size and ready for transplanting. The plots of main experimental field were thoroughly plowed and leveled and ridges were then armed on sides of which transplanting was done. Healthy looking, vigorous and uniformly sized seedlings were transplanted to the main field. For this experiment, rows were spaced 1 m apart and 0.30 m spacing between plants was maintained during the layout. The seedlings were transplanted to plots with 4 m width by 6 m length (total gross plot size of 1440 m^2). Transplanting was done at 25 days after sowing (DAS) in 2016 and 20 DAS in 2017. Recommended inorganic fertilizers of DAP and Urea at a rate of 150 kg $ha^{-1}$and 100 kg ha^{-1}, respectively, were applied. DAP was applied in rows during transplanting and urea was added in split application as side-dressing during transplanting and early flowering stage both in 2016 and 2017. Diazinon 60% EC (2000 ml ha^{-1}) in 2016 and Ampligo 150 ZC (300 ml ha^{-1}) in 2017 were sprayed for the suppression of tomato bollworms and leaf miner, respectively. Weeding, supplementary irrigation and other agronomic practices were accomplished as deemed necessary.

Treatments and experimental design

The treatments were arranged in factorial combination in a randomized complete block design (RCBD) with three replications and each consisted of 20 treatments (four tomato varieties x five spray frequencies) (Table 3). Seedlings of each variety were raised on a standard seed bed size. The size of the experimental unit or plot was 4 m x 6 m (24 m^2). Each plot consisted of six rows. Ridomil fungicide spray was started soon after the initial appearance of visible early blight symptoms. For the spray frequencies such as one, two, three and four a total of 48, 36, 24 and 12 plots were sprayed with ridomil fungicide every 10 days, respectively. 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 interferences or drift. Fungicide unsprayed plots were left as controls. Plots were spaced from each other by 1.5 m and blocks were separated by a safeguard path of 2.5 m to prevent fungicide drifts or cross contamination.

Disease assessment

Disease severity was recorded every week starting from the first appearance of typical disease symptoms on the foliages (small black or brown spots that later enlarged to concentric ringed lesions). Severity data were recorded from 12 pre-tagged plants using systematically arranged pattern in the middle four rows per plot. Disease severity was rated using a 1-12 disease scoring scale (Horsfall & Barratt 1945); where, 1 = no infections; 2 = 1-3% leaf area infected; 3 = 4-6% leaf area infected; 4 = 7-12% leaf area infected; 5 = 13-25% leaf area infected; 6 = 26-50% leaf area infected; 7 = 51-75% leaf area infected; 8 = 76-87% leaf area infected; 9 = 88-94% leaf area infected; 10 = 95-97% leaf area infected; 11 = 98-99% leaf area infected and 12 = 100% leaf area infected. Disease severity scores were converted into percentage severity index (PSI) for analysis (Wheeler, 1969) as follows:

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

Table 3. Treatment and treatment combinations used for tomato early blight management at Arbaminch areas, southwestern Ethiopia, during 2016 and 2017 cropping seasons

S/N	Treatment	Treatment combination
1	ART + FUt_0	ART tomato d2 + Fungicide Untreated plot (control)
2	ART + FT_1	ART tomato d2 + Fungicide Treated plot (one time)
3	ART + FT_2	ART tomato d2 + Fungicide Treated plot (two times)
4	ART + FT_3	ART tomato d2 + Fungicide Treated plot (three times)
5	ART + FT_4	ART tomato d2 + Fungicide Treated plot (four times)
6	Bis + FUt_0	Bishola+ Fungicide Untreated plot (control)
7	Bis + FT_1	Bishola + Fungicide Treated plot (one time)
8	Bis + FT_2	Bishola + Fungicide Treated plot (two times)
9	Bis + FT_3	Bishola + Fungicide Treated plot (three times)
10	Bis + FT_4	Bishola + Fungicide Treated plot (four times)
11	Mel + FUt_0	Melkashola + Fungicide Untreated plot (control)
12	Mel + FT_1	Melkashola + Fungicide Treated plot (one time)
13	Mel + FT_2	Melkashola + Fungicide Treated plot (two times)
14	Mel + FT_3	Melkashola + Fungicide Treated plot (three times)
15	Mel + FT_4	Melkashola + Fungicide Treated plot (four times)
16	RVF + FUt_0	Roma VF + Fungicide Untreated plot (control)
17	RVF + FT_1	Roma VF + Fungicide Treated plot (one time)
18	RVF + FT_2	Roma VF + Fungicide Treated plot (two times)
19	RVF + FT_3	Roma VF + Fungicide Treated plot (three times)
20	RVF + FT_4	Roma VF + Fungicide Treated plot (four times)

From disease severity data, areas under disease progress curves (AUDPC) in %-days were calculated as used in Campbell and Madden (1990):

$$AUDPC = \sum_{i=1}^{n-1} 0.5(X_i + X_{i+1})(t_{i+1} - t_i)$$

Where, X_i = percentage of disease severity index at i^{th} assessment; t_i= time of the i^{th} assessment in days from the first assessment date; and n = total number of disease assessments.

AUDPC was calculated separately for each treatment. Since the epidemic periods of the two seasons were different, AUDPCs were standardized by dividing the values by the epidemic duration of the respective seasons (Campbell and Madden 1990). The epidemic periods were 42 days in 2016 and 35 days in 2017; and AUDPC was standardized (rAUDPC) accordingly.

Yield assessment

The following basic data on crop growth and yield parameters were determined from each plot. Number of fruit clusters per plant was recorded as the number of fruit clusters per plant from 12 plants in the middle four rows. Number of fruits per plant was recorded as the average number of fruits per plant from 12 plants in the middle four rows. Marketable, unmarketable and total fruit yields were recorded from the four middle rows for each treatment and converted into yield per hectare (t ha^{-1}). Linear relationships between growth and yield related and disease parameters per each treatment were examined using linear regression analysis. It was carried out to find out the association of disease parameters with yield obtained from the different spray frequencies of fungicide in relation to yield losses in every units of disease development.

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

$$\text{Relative yield loss (\%)} = \frac{\text{Ybt} - \text{Ylt}}{\text{Ybt}} \text{ X } 100$$

Where, Ybt is the yield of base treatment and Ylt is the yield of lower treatments.

Data analysis

Analysis of variance (ANOVA) was run for disease severity and rAUDPC values, and yield related parameters to determine treatment effects on each parameter in each year using SAS GLM Procedure (SAS 2009). Mean separations were made using Fisher's protected least significant deference (LSD) values at 0.05 probability level. The two seasons were considered separately because of heterogeneity of variances as tested using Bartlett's test (Gomez and Gomez 1984). Thus, the data were not combined for analysis.

Cost and benefit analysis

Use of additional input cost to earn marginal benefit in the experiment was analyzed using partial and marginal rate of return (MRR) as computed by considering the variable cost available for the respective treatments. Price of tomato fruits (\$ kg^{-1}) was assessed from the prevailing local market and total price of the goods obtained was computed on hectare basis. Input costs per hectare like fungicides, knapsack sprayer, labor, irrigation, plant support and insecticides were considered. Accordingly, the price of fungicide was \$10.11 kg^{-1} (2016) and \$13.19 kg^{-1} in 2017. Cost of labor for field managements and fungicide spraying was done with \$2.20 man^{-1} day^{-1}. During cost and benefit analysis, costs of agronomic practices were uniform for all treatments and costs of labor and spraying equipment were taken based on the prevailing wage rates in the locality. Before doing partial budget economic analysis, statistical analysis was done on the collected data to compare the average yields between treatments. Since there were differences between treatment means, the obtained economic data were subjected to analysis using the partial budget analysis method and MRR was calculated based on CIMMYT (1988) procedure:

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

Where, MRR = marginal rate of return, DNI = difference in net income compared with control, and DIC = difference in input cost compared with control.

Results and Discussion

Early blight severity and relative AUDPC (rAUDPC)

The severity indices and rAUDPC values showed a highly significant ($p < 0.01$) difference between fungicides sprayed and unsprayed plots. Among fungicide spray frequencies and tomato varieties evaluated throughout the assessment periods beginning from 19 days after transplanting (DAT) in 2016 and 14 DAT in 2017 (Table 4). Significant variety x fungicide spray frequency interaction effect was also calculated on level of severity indices consistently starting from 33 DAT in 2016 and 35 DAT in 2017. Mean disease severity index at final date of recording (61 DAT) ranged from 13.89-17.90% on ART tomato d2; 15.74-23.46% on Bisholla; 16.67-24.69% on Melkasholla and 15.12-22.22% Roma VF varieties in fungicide sprayed plots in comparison with 19.44, 28.09, 28.09 and 25.62% in unsprayed plots on the varieties, in same order, in 2016. A similar trend was indicated in the 2017 main cropping season.

The highest rAUDPC (12.54-17.79%-days) values occurred in unsprayed tomato variety plots in 2016 and 15.71-22.16%-days in 2017. The integrated application of varieties and fungicide spray frequencies showed strong synergetic effect against early blight epidemics by reducing disease severity from 7.92-28.55% (ART tomato d2), 16.48-43.97% (Bisholla), 12.10-40.66% (Melkasholla) and 13.27-40.98% (Roma VF) as compared to the unsprayed control plots of each variety at the 61 DAT in 2016. Similarly, a disease severity reduction percentage of 17.16-32.86% (ART tomato d2), 20.57-38.33% (Bisholla), 25.00-38.55% (Melkasholla) and 18.01-53.00% (Roma VF) at 49 DAT were recorded in 2017. It appears that the genetic resistance potential of the varieties was further boosted by fungicide application as susceptible varieties had high level of disease severity reductions.

There are several studies with regard to the effects of variety by fungicide application against epidemics of several foliar pathogens, including different foliar diseases of tomato (Keinath & DuBose 1996; Zitter 2006; Sahile et al. 2010; Shifa et al. 2010; Abdussamee et al. 2014; Chohan et al. 2015). Results of this study revealed that variety by fungicide application consistently reduced early blight severity and rAUDPC. Frequent application of fungicide highly reduced disease severity and enhanced the early blight resistance of the varieties evaluated. A study by Tewari & Vishunavat (2012) indicated that application of fungicides reduced seedling infections but enhanced germination of tomatoes. A study by Abdussamee et al. (2014) revealed that tomato genotypes with different levels of resistance responded differently to fungicide applications.

Genetic variation of varieties' reaction to early blight was recorded in which lower mean severity was obtained from the genotype ART tomato d2 compared to other varieties evaluated. This result is in agreement with the findings of Pandey et al. (2003) and Abdussamee et al. (2014) who noted that different tomato varieties had different resistance reactions to early blight disease. Fungicide spray frequencies also showed strong differences in reducing early blight epidemics where four times sprayed plots comparably had the lowest level of disease severity and rAUDPC for each variety in both cropping seasons. Comparable results were obtained by Keinath & DuBose (1996) and Arunakumara (2006). Mehari & Mohammed (2015), Abdussamee et al. (2014) also found that maximum disease control with reduced early blight disease severity and disease progress rate was obtained from more spray frequencies in all varieties evaluated than in the control plots.

Season-wise comparisons indicated that the overall disease severity in the 2017 cropping season was higher than disease severity in 2016, which could be explained by the prevailing relatively warm temperature, many rainy days and extended leaf wetness late in the epidemic period that induced high level of severity (Table 1). It is fact that heavy rainfall and warm temperature (Markham & Julie 1999; Batista et al. 2006; Li 2012), and long period of dew and wet leaf (Keinath & DuBose 1996; Prasad & Naik 2003) aggravate early blight disease epidemic in tomato.

Effect of early blight on tomato yield and yield related parameters

Analysis of variance indicated that the interaction effect of tomato varieties x ridomil spray frequencies on yield attributes (marketable fruits, total fruits, number of fruit clusters per plant and number of fruits per plant) showed highly significant ($p \leq 0.001$) influence in both years (Table 5). But, the interaction effect of tomato varieties x ridomil spray frequencies did not show significant ($p > 0.05$) difference among the treatment means rather the main effect of varieties by spray frequencies only for unmarketable yield revealed highly significant ($p \leq 0.001$) difference in both cropping seasons. It appears that each variety performance was affected by level of spray frequencies, except for unmarketable yield.

Marketable, unmarketable and total fruit yield were very highly and significantly ($p < 0.0001$) varied among tomato varieties and spray frequencies both in 2016 and 2017. Tomato fruits picked out as diseased, insect attacked and small sized (< 20 g) from harvested fruits were recorded as unmarketable fruits for those damages not controlled by ridomil fungicide spraying. 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, respectively. Similarly, the highest 46.59 t ha^{-1} (2016) and 46.54 t ha^{-1} (2017) total fruit yields were obtained from Roma VF. Number of fruit clusters per plant and number of fruits per plant were highly significantly ($p \leq 0.001$) varied among tomato varieties and spray treatments in both cropping seasons. Roma VF variety had the highest (21.64 and 19.99) number of fruit clusters per plant and fruits per plant (61.28 and 56.48) as compared to the other varieties tested in the 2016 and 2017, respectively. This difference might have resulted from the variation in inherent genetic potential of the tomato varieties

Table 4. Effects of integrated application of variety resistance and fungicides spray frequencies on early blight (*Alternaria solani*) severity (%) of tomato and area under disease progress curve (%-days) at Arbaminch areas, southwestern Ethiopia, during the 2016 and 2017 cropping seasons.

Treatments		2016 cropping season						2017 cropping season				
		Disease severity index (%) at different DAT [2]						Disease severity index (%) at different DAT [2]				
Variety	Fungicide SF [1]	33	40	47	54	61	rAUDPC[3]	28	35	42	49	rAUDPC[3]
ART tomato d2	No spray	13.58^{fgh}	13.58efg	14.81de	18.82ef	19.44f	12.54gh	14.81c	22.59hi	24.81g	25.93ef	15.71fg
	One SF	13.58^{fgh}	14.81cde	15.43cd	17.59gh	17.90gh	12.63fgh	12.96e	19.26kl	20.74hi	21.48hi	13.70jk
	Two SF	12.96^{ghi}	14.20def	15.12d	17.59gh	17.59hi	12.24hi	12.96e	18.15lm	19.63ij	19.63ij	13.15kl
	Three SF	12.35^{i}	13.27fg	14.81de	16.05ij	16.05jk	11.66j	12.59e	17.41m	19.26ij	19.26jk	12.81lm
	Four SF	12.04^{i}	12.65g	13.58fg	13.89k	13.89^{l}	10.82k	12.59e	17.41m	17.41k	17.41k	12.38m
Bisholla	No spray	16.36^{bc}	19.75a	21.30a	27.16a	28.09a	17.00b	18.15a	36.30a	38.52a	39.63a	22.16a
	One SF	14.20^{ef}	16.05bc	16.36c	23.15c	23.46c	14.13d	14.44cd	29.26d	30.37d	31.48c	18.09d
	Two SF	14.20^{ef}	14.81cde	15.12d	19.75e	20.68e	13.12ef	13.33de	25.93e	27.78ef	28.89d	16.64e
	Three SF	12.96^{ghi}	13.89defg	15.12d	18.52fg	18.83fg	12.50gh	12.96e	24.81efg	24.44g	25.19ef	15.56gh
	Four SF	12.65^{hi}	13.89defg	13.89efg	15.43j	15.74jk	11.62j	12.96e	22.59hi	23.33g	24.44fg	14.88hi
Melkasholla	No spray	18.83^{a}	19.45a	22.22a	27.47a	28.09a	17.79a	16.29b	31.48c	34.07c	35.56b	19.69c
	One SF	15.74^{cd}	16.98b	17.90b	24.07c	24.69b	15.41c	13.70cde	25.19ef	27.41f	26.67e	16.36ef
	Two SF	14.81^{de}	15.12cd	15.12d	18.83ef	19.64f	12.96efg	13.33de	23.33gh	24.44g	25.56ef	15.37gh

	Three SF	13.89[efg]	14.81cde	15.12d	17.90fg	18.21gh	12.90efg	12.96e	21.48ij	21.48h	22.59gh	14.26ij
	Four SF	13.58[fgh]	14.50def	14.50def	16.67hi	16.67ij	12.28h	12.59e	20.74jk	20.74hi	21.85h	13.86jk
Roma VF	No spray	16.98[b]	17.28b	18.21b	25.31b	25.62b	15.87c	16.67b	33.70b	35.93b	37.04b	20.77b
	One SF	15.12[de]	16.05bc	16.36c	21.91d	22.22d	14.26d	14.44cd	28.15d	29.26de	30.37cd	17.62d
	Two SF	14.81[de]	14.81cde	15.12d	21.30d	21.61de	13.45e	13.70cde	24.07fgh	24.81g	24.81ef	15.59gh
	Three SF	13.27[fghi]	13.27fg	13.27g	16.05ij	16.05jk	11.68ij	12.59e	18.15lm	18.15jk	18.15jk	12.75lm
	Four SF	12.96[ghi]	13.58efg	13.89efg	15.12j	15.12k	11.62j	12.59e	17.41m	17.41k	17.41k	12.35m
Variety x SF		**	***	***	***	***	***	ns	***	***	***	***
CV (%)		5.24	6.01	4.26	3.17	3.65	2.59	5.39	3.94	4.14	4.74	2.83

Means in each column followed by different letter (s) represent significant variation at 5% probability level; [1] SF = spray frequency(s); [2] DAT = Days after transplanting; [3]rAUDPC = Standardized area under disease progress curve of early blight of tomato; CV (%) = Coefficient of variation.

Reports of MoARD (2005) showed that the tomato varieties Melkasholla and Bisholla yielded up to 35 and 45 t ha^{-1}, respectively, in Ethiopia. However, this study indicated that both varieties yielded less than that of their reported potentials (30.95 t $ha^{-1}$for Melkasholla) and (29.88 t ha^{-1} for Bisholla) in 2016. The same scenario was also observed (28.29 t ha^{-1} for Melkasholla and 29.27 t ha^{-1} for Bisholla) during the 2017 cropping season. This might be due to high disease pressure during the experiment that leads to very low yield. But compared to the findings of the present study, several investigations reported fruit yields ranging from 31.4 (Roma VF) to 43.5 t ha^{-1} (ARP Tomato d2) (MoARD 2005; Belay 2009; MoA 2012), implying that fruit yields of the varieties ARP Tomato d2 and Roma VF were relatively higher than the yields of the varieties Bisholla and Melkasholla even under high early blight disease pressure in both cropping seasons. This also showed that the variety ARP tomato d2 and Roma VF were fruitful and brought about significantly better and healthy fruit yields than Bisholla and Melkasholla varieties evaluated.

With regard to fungicide spray frequency, ridomil application at 10 days interval had significant effect on the tomato varieties rather than the unsprayed ones. 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 found from unsprayed plots in 2016 and 2017, respectively, whereas the highest (44.16 t ha^{-1} in 2016 and 38.25 t ha^{-1} in 2017) marketable yield and total fruit yield (52.00 t ha^{-1} in 2016 and 50.47 t ha^{-1} in 2017) were obtained from plots treated three times with ridomil at 10 days interval (Table 5). Similar to the differences observed in marketable fruits, the varieties also exhibited difference in unmarketable fruits. Unmarketability of tomato fruits was reduced when plots sprayed four times were compared with unsprayed or once sprayed plots of each variety.

Comparably, the lowest (4.85 t ha^{-1} in 2016 and 3.92 t ha^{-1} in 2017) unmarketable fruit yield was found from those plots treated four times with ridomil at 10 days interval. Similar research results by Abhinandan et al. (2004), Kaushik et al. (2011) and Mehari & Mohammed (2015) suggested that fungicides significantly reduced disease severity and gave higher yield than unsprayed counterparts. Plots treated triple times with ridomil recorded the highest (27.74 in 2016 and 23.71 in 2017) number of fruit clusters per plant and number of fruits per plant (80.06 in 2016 and 68.81 in 2017). However, the lowest number of fruit clusters per plant and number of fruits per plant were obtained from unsprayed plots in both cropping seasons. Other studies also confirmed that wide range of differences in yield parameters related to number of fruit clusters and fruits per plant in tomato genotypes (Chernet et al. 2013; Emani et al. 2013).

Table 5.Mean yield and yield components as influenced by integration of tomato varieties and fungicide spray frequencies in Arbaminch areas, southwestern Ethiopia, during 2016 and 2017 main cropping seasons.

Treatment		2016 Cropping season[2]					2017 Cropping season[2]				
Variety	Fungicide SF [1]	MFY (t ha^{-1})	UMFY (t ha^{-1})	TFY (t ha^{-1})	NFCPP	NFPP	MFY (t ha^{-1})	UMFY (t ha^{-1})	TFY (t ha^{-1})	NFCPP	NFPP
ART tomato d2	No spray	28.58^{efg}	7.31^{jk}	35.90^{ef}	9.28^{k}	21.81j	27.49^{fgh}	8.01^{h}	35.50^{gh}	7.96^{j}	26.38^{hi}
	One SF	33.15^{de}	5.84^{kl}	38.98^{e}	11.25^{jk}	26.36^{ij}	31.53^{efg}	6.07^{i}	37.60^{fgh}	9.39^{ij}	32.38^{fghi}
	Two SF	45.50^{ab}	5.54^{l}	51.04^{bcd}	17.78^{defg}	48.28^{efg}	43.60^{abc}	6.01^{i}	49.60^{bcd}	15.37^{efgh}	40.10^{efg}
	Three SF	48.73^{a}	5.06^{l}	53.79^{abc}	21.17^{cd}	52.53^{de}	44.39^{ab}	5.26^{ij}	49.65^{bc}	18.24^{de}	45.48^{de}
	Four SF	42.29^{bc}	4.85^{l}	47.15^{d}	18.92^{def}	45.47^{efg}	39.10^{bcd}	3.92^{j}	43.02^{def}	15.29^{efgh}	38.77^{efgh}
Bisholla	No spray	21.71^{hi}	13.36^{a}	35.06^{ef}	10.64^{jk}	25.45^{ij}	21.57^{hi}	14.88^{a}	36.46^{fgh}	8.97^{ij}	21.50^{i}
	One SF	23.04^{ghi}	11.81^{ab}	34.86^{ef}	11.95^{ijk}	27.45^{ij}	24.84^{hi}	12.25^{bcd}	37.09^{fgh}	10.16^{ij}	35.28^{efgh}
	Two SF	26.15^{fgh}	9.62^{defg}	35.77^{ef}	12.61^{hijk}	29.14^{hij}	27.03^{gh}	11.36^{cde}	38.39^{fgh}	15.79^{efg}	42.50^{ef}
	Three SF	40.41^{bc}	8.88^{fghi}	46.96^{d}	23.81^{c}	66.00^{cd}	37.76^{cde}	10.90^{def}	46.07^{cde}	20.36^{cd}	56.19^{cd}
	Four SF	38.09^{cd}	7.75^{ij}	48.17^{cd}	20.75^{cde}	55.11^{de}	35.16^{de}	9.74^{fg}	47.50^{bcde}	17.67^{def}	46.92^{de}
Melkasholla	No spray	18.54^{i}	12.98^{ab}	31.52^{f}	12.81^{hijk}	34.00^{ghij}	18.88^{i}	14.92^{a}	33.80^{h}	10.86^{hij}	28.66^{ghi}
	One SF	27.23^{fgh}	10.65^{cde}	37.88^{e}	14.44^{ghij}	38.00^{fghi}	23.10^{hi}	12.91^{bc}	36.01^{gh}	12.26^{ghij}	32.16^{fghi}
	Two SF	29.36^{ef}	9.29^{efgh}	38.65^{e}	15.72^{fghi}	48.53^{ef}	27.95^{fgh}	10.99^{def}	38.94^{fgh}	13.41^{fghi}	41.14^{efg}
	Three SF	40.67^{bc}	8.60^{ghij}	49.27^{cd}	32.31^{ab}	102.83^{a}	37.77^{cde}	11.58^{bcde}	49.35^{bcd}	27.74^{a}	88.29[illegible]

	Four SF	38.94c	7.94^{hij}	46.88^{d}	28.44^{b}	72.14^{bc}	33.74^{def}	8.08^{h}	41.82^{efg}	24.53^{abc}	61.55^{bc}
	No spray	22.85^{ghi}	11.00^{cd}	33.85^{ef}	12.97^{hijk}	30.83^{hij}	23.44^{hi}	12.97^{b}	36.40^{gh}	11.06^{hij}	26.42^{hi}
	One SF	26.96^{fgh}	10.11^{def}	37.06^{ef}	15.67^{fghi}	42.64^{efgh}	26.63^{gh}	11.31^{efg}	37.94^{fgh}	13.32^{fghi}	35.69^{efgh}
Roma VF	Two SF	39.11^{c}	9.25^{efgh}	48.36^{cd}	16.42^{efgh}	49.97^{ef}	45.25^{ab}	10.45^{ef}	47.72^{bcde}	21.93^{bcd}	64.21^{bc}
	Three SF	49.15^{a}	8.83^{fghi}	57.98^{a}	33.69^{a}	98.89^{a}	46.06^{a}	10.73^{ef}	56.79^{a}	28.51^{a}	84.47^{a}
	Four SF	48.73^{a}	7.52^{ij}	55.69^{ab}	29.47^{ab}	84.08^{b}	37.27^{cde}	8.59^{gh}	53.84^{ab}	25.16^{ab}	71.62^{b}
Varietyx SF		**	ns	**	**	***	*	ns	*	*	***
CV (%)		10.18	10.21	8.22	14.25	16.56	11.97	9.62	9.38	16.79	16.75

Means in each column followed by different letter(s) represent significant variation at 5% probability level; [1]SF = Spray frequency(s); [2]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; CV = Coefficient of variation (%).

Relationship of early blight of tomato with tomato total fruit yield

A linear regression analysis was made to see the association of disease parameter (rAUDPC) with level of total fruit yield loss per each treatment. The mean values of rAUDPC were used to predict the total yield loss in all tomato varieties in each cropping season (Figure 1). It was indicated that as the effect of rAUDPC getting higher, the yield obtained from tomato varieties has become lower; implying that the higher the rAUDPC values on the varieties its effect on yield would be more. For every one unit increase in rAUDPC values there was 3.20and 1.72 unit of total fruit yield loss in tomato varieties evaluated in 2016 and 2017, respectively. The value of coefficient of determination (R^2) indicated that 55 and 50% of the variation in yield loss was explained by rAUDPC in2016 (Figure 1A) and 2017 (Figure 1B), respectively.

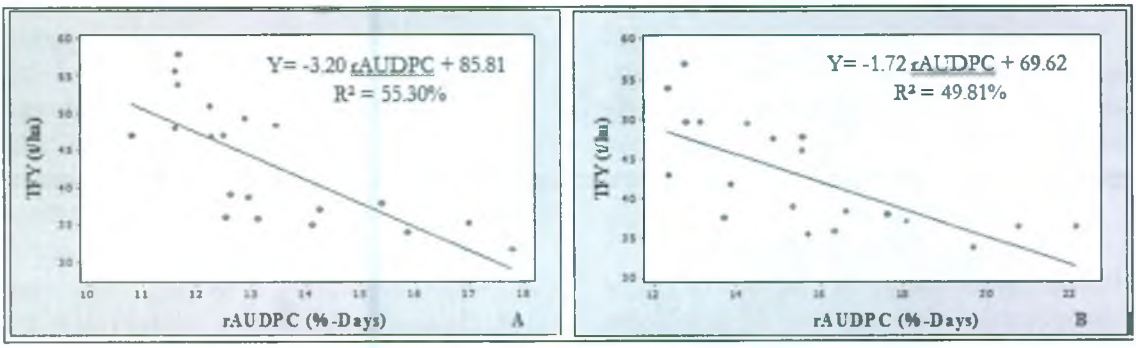

Figure 1. Mean linear regression of tomato total fruit yield (TFY) and rAUDPC values of early blight of tomato in Arbaminch areas, southwestern Ethiopia, during 2016 (A) and 2017 (B) cropping seasons.

Relative yield loss and cost and benefit analysis

Estimation of relative yield loss was made on the basis of best fungicide spray frequency and associated yield gains or losses in tomato varieties (Table 6). The relative yield loss that was incurred by using different ridomil foliar spray frequencies was calculated relative to the plots having maximum yields (computed based on mean values of two season experiments). Accordingly, unsprayed plots had the highest relative yield loss as compared to losses recorded from those plots sprayed with one or two or three or four spray frequencies. Due to combined treatment of tomato genotypes and foliar spray frequencies of ridomil, the lowest relative yield losses were computed from plots sprayed three times at 10 day intervals in all tomato varieties. However, the highest relative fruit yield losses were obtained on unsprayed plots of Melkasholla, Roma VF, Bisholla and ARPT tomato d2 with corresponding values of 52.29, 51.39, 43.11 and 39.80%, in that order, as compared to plots sprayed three times.

This could have been associated with defoliation of leaves and drop out of fruits due to fruit rots and weakening of the plant parts (loss of strengthen of stems during fruit setting). It was also reported in many researches that less or none protected tomato plants failed to set fruits that directly constitute to total fruit yield. This finding is in conformation with the studies of Gwary & Nahunnaro (1998) who reported yield losses within the range of 30-50% of the harvest due to fruit drops of infected fruits. The present observation also agrees with the findings of Deahl et al. (1993) who reported that yield reduction is observed when plants defoliate their leaves, which hampered the plants to set fruits. But it has to be noted that fruit yield losses found in the current study could not be only attributed to early blight severity as some damages were recorded due to other pests.

The integrated effect of tomato variety x ridomil spray frequency on early blight management with the use of additional costs, net benefit and MRR were computed per variety versus different ridomil spray frequencies. Differences in net benefit were obtained among the treatment combinations (analysis was done with pooled two season's data) (Table 6). The net benefit obtained from sale of the produce for each spray frequency ranged from 16,271.50 to $42,188.09. Partial budget analysis indicated that three time spray frequencies of ridomil had the highest net benefits from Roma VF ($42,188.09) and ARP tomato d2 ($41,232.20). Even though different levels of low net benefits were recorded from different genotypes versus spray frequencies, the least net benefit was obtained from unsprayed plot of the genotype Melkasholla (16,271.50 USD). The overall results with regard to two seasons mean values of the goods marginal analysis indicated that the highest MRR was obtained when ridomil sprayed twice for ARP tomato d2 (40.79%) and three times spray frequencies for Roma VF (47.18%), Bisholla (26.36%) and Melkasholla (33.46%) varieties. However, the least MRR was calculated from unsprayed plots of each variety evaluated.

Table 6.Mean relative fruit yield losses (%) due to tomato early blight and cost and benefit of fruit yieldsfromintegrated use of tomato varieties by ridomil spray frequencies in Arbaminch areas, southwestern Ethiopia, during 2016 and 2017 main cropping seasons.

Variety	Spray Frequency	Yield (t ha^{-1})	RYL (%)[1]	NP (\$ ha^{-1})[2]	MRR (%)[3]
ARP tomato d2	No spray	28.03	39.80	24,809.18	0.00
	One SF	32.34	30.54	28,547.4	18.03
	Two SF	44.55	4.32	39,572.31	40.79
	Three SF	46.56	0.00	41,232.20	30.13
	Four SF	40.69	12.61	35,544.18	12.45
Bisholla	No spray	21.64	43.11	18,955.83	0.00
	One SF	23.94	37.02	20,853.15	9.15
	Two SF	26.59	30.01	23,124.02	11.52
	Three SF	37.93	0.00	33,323.97	26.36
	Four SF	37.79	0.37	32,885.17	16.16
Melkasholla	No spray	18.71	52.29	16,271.50	0.00
	One SF	25.16	35.85	21,974.07	27.50
	Two SF	28.65	26.95	25,016.71	24.16
	Three SF	39.22	0.00	34,510.14	33.46
	Four SF	36.41	7.16	31,621.93	17.81
Roma VF	No spray	23.14	51.39	20,330.8	0.00
	One SF	26.79	43.72	23,468.83	15.13
	Two SF	42.18	11.39	37,407.99	47.18
	Three SF	47.60	0.00	42,188.09	40.09
	Four SF	42.72	10.25	37,400.32	19.80

[1]RYL = Relative yield loss;[2]NP = Net price; and [3]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.

Conclusion

Substantial level of early blight reduction in tomato could be achieved through integration of varietal resistance and foliar fungicide applications. Integration of tomato varieties and ridomil spray frequencies had promising effect in reducing early blight epidemics and increasing yield parameters. Thus, yields obtained from two times (ARP tomato d2 both in 2017) and three times (Roma VF, Bisholla and Melkasholla in 2016) ridomil spray frequencies at 10 days interval were generally higher than those yields obtained from other treatments. The study indicated that ARP tomato d2 variety appears to have better resistance to early blight than other evaluated varieties and was a promising tomato variety in both test years. The overall results of the study also confirmed that better performance of combination of tomato variety and two and three times ridomil spray frequencies can attribute to better yield and higher monetary benefit than other treatments, including unsprayed plots although the highest disease suppression was recorded from four times sprayed plots. Therefore, instead of using several fungicides indiscriminately, it is recommended to use resistant tomato variety by two times, and moderately resistant and susceptible genotypes by three times ridomil spray frequencies to manage early blight and sustain productivity of tomato. Such combinations of varieties by fungicide spray frequencies could give maximum net benefit and minimize cost of production. Further studies should be carried out in other agro-ecologies to counter-confirm whether the results obtained in the study areas would be replicated and sustained in different seasons.

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References

Abdussamee H, Hussain M, Ali M, Siddique MS, Jatoi SUK, Sahi ST, Hannan A. 2014. Genetic response of tomato germplasm against early blight and its management through fungicides. Applied Science Reports 6(3):119-127.

Abhinandan D, Randhawa HS, Sharma RC. 2004. Incidence of Alternaria leaf blight in tomato and efficacy of commercial fungicides for its control. Annual Biological Science 20: 211-218.

Anonymous. 2011. Indian horticulture database: Major tomato producing countries in the World. New Delhi, India. 15 pp.

Arunakumara KT. 2006. Studies on *Alternaria solani* (Ellis and Martin) Jones and Grout, causing early blight of tomato. MSc Thesis. University of Agriculture and Science, Dharwad, India. pp. 1-70.

Batista DC, Lima MA, Haddad F, Maffia LA, Mizubuti ESG. 2006. Validation of decision support systems for tomato early blight and potato late blight, under Brazilian conditions. Crop Protection 25:664-670.

Bauchet G, Causse M. 2010. Genetic diversity in tomato (*Solanum lycopersicum*) and its wild relatives. pp. 133-162. *In:* Caliskan, M (ed.),Genetic Diversity in Plants. InTech Publisher, Croatia, ISBN: 978-953-51-0185-7.

Belay Habtegebriel. 2009. Early blight (*Alternaria solani*) of tomato in East Shoa Zone: importance and management through host resistance and fungicides in central rift valley, Ethiopia. MSc Thesis. Haramaya University, Haramaya, Ethiopia.

CIMMYT (International Maize and Wheat Improvement Center). 1988. From agronomic data to farmer recommendations: an economics training manual. Completely revised edition. Mexico, ISBN 968-6127-18-6. 79 pp.

Chernet Shushay, Belew Derbew, Abay Fetien. 2013. Genetic variability and association of characters in tomato (*Solanum lycopersicon* L.) genotype in Northern Ethiopia. International Journal of Agricultural Research 8:67-76.

Chohan S, Perveen R, Mehmood MB, Naz S, Akram N. 2015. Morpho-physiological studies, management and screening of tomato germplasm against *Alternaria solani,* the causal agent of tomato early blight. International Journal of Agriculture and Biology 17:111-118.

CSA (Central Statistics Agency). 2016. Statistics agency agricultural sample survey 2015/2016. Statistical Bulletin. Volume No. 578. Addis Ababa, Ethiopia. 131 pp.

CSA (Central Statistical Agency). 2017. Agricultural sample survey, 2016/2017. Report on area and production of crops (Private peasant holdings, main season). Central Statistical Agency, Volume, No. 584. Addis Ababa, Ethiopia.

Deahl K, Inglis D, DeMuth S. 1993. Testing for resistance to metalaxyl in *Phytophthora infestans* isolates from northwestern Washington. American Journal of Potato Research 70:779-795.

Derbew Belew, Ali Mohammed, Amina, JG. 2012. Yield and quality of indeterminate tomato (*Lycopersicon esculentum* Mill.) varieties with staking methods in Jimma. Singapore Journal of Scientific Research 2(2):33-46.

Emani A, Homayouni-Far M, Razavi R, Eivazi AR. 2013. Introduction of superior tomato cultivars (*Solanum lycopersicon* Mill.). Journal of Food Science and Technology 1:19-26.

FAOSTAT (Food and Agriculture Organization/Statistics Division). 2014. FAO Statistical Databases. Food and Agriculture Organization of the United Nations, Statistics Division.

FekedeGirma. 2011. Management of late blight (*Phytophthora infestans*) of potato (*Solanum tuberosum* L.) through potato cultivars and fungicides in Hararghe highlands, Ethiopia. MSc Thesis. Haramaya University, Haramaya, Ethiopia.

Getachew Tabor, Selamawit Ketama, Yosef Alemu, Mohammed Yusuf and Gashawbeza Ayalew. 2014. Guide to major vegetable crops production and protection. Amharic Version. Addis Ababa, Ethiopia.

Gomez KA, Gomez AA. 1984. Statistical Procedures for Agricultural Research.2nd ed. John Wiley and Sons, Inc., New York, USA.680 pp.

Gwary DM, Nahunnaro H. 1998. Epiphytotics of early blight of tomatoes in northeastern Nigeria. Crop Protection 17:619-624.

Haverkort AJ, Boonekamp-Hutten PM, Jacobsen E, Lotz LAP, Kessel GJT, Visser GFE, Van der Vossen AG.

2008. Societal costs of late blight in potato and prospects of durable resistance through cisgenic modification. Potato Research 51(11):47-57.

Horsefall JG, Barratt RW. 1945. An improved grading system for measuring plant disease. Phytopathology 35:655.

Jiregna Tasisa. 2014. Field, greenhouse and detached leaf evaluation of tomato (*Lycopersicon esculentum* Mill.) genotypes for late blight resistance. World Journal of Agricultural Sciences 10(2):76-80.

Kaushik SK, Tomar DS, Dixit AK. 2011. Genetics of fruit yield and its contributing characters in tomato (*Solanum lycopersicum*). Journal of Agricultural Biotechnology and Sustainable Development 310:209-213.

Keinath AP, DuBose VB, Rathwell PJ. 1996. Efficiency and economics of three fungicidal application schedules for early blight control and yield of fresh market tomato. Plant Disease 80:1277-1282.

Lemma Desalegn. 2002. Tomatoes; research experiences and production prospects. EARO Report. No. 43. Addis Ababa, Ethiopia, pp. 1-15.

Li Y. 2012. Early blight of tomato. Department of Plant Pathology and Ecology, The Connecticut Agricultural Experiment Station, 123 Huntington Street, New Haven. pp.1-2.

Macleod B, Sweetingham M. 1999.Plant research and development service. Northam and South Perth. Available at htmihttp://www.agric.wa.gov.au.

Mehari Desta and Mohammed Yesuf. 2015. Efficacy and economics of fungicides and their application schedule for early blight (*Alternaria solani*) management and yield of tomato at South Tigray, Ethiopia. Journal of Plant Pathology and Microbiology 6:268, Doi:10.4172/2157-7471.1000268.

Meseret Degefa Regassa, Ali Mohammed, Kassahun Bantte. 2012. Evaluation of tomato (*Lycopersicon esculentum* L.) genotypes for yield and yield components. The African Journal of Plant Science and Biotechnology 6:45-49.

Mizubuti ESG, Batista DC, Lima MA, Haddad F, Maffia LA. 2006. Validation of decision support systems for tomato early blight and potato late blight, under Brazilian conditions. Crop Protection 25(7):664-670.

MoA (Ministry of Agriculture). 2012. Animal and Plant Health Regulatory Directorate Crop Variety Register. Issue No. 15. Addis Ababa, Ethiopia. 180 pp.

MoARD (Ministry of Agriculture and Rural Development). 2005. Crop development department crop variety register. Issue No. 8. Addis Ababa, Ethiopia. 143 pp.

Naveenkumar S, Saxena RP, Pathak SP, Chauhan SKS. 2001. Management of alternaria leaf disease of tomato. Indian Phytopathology 54:508.

Prasad Y, Naik MK. 2003. Evaluation of genotypes, fungicides and plant extracts against early blight of tomato caused by *Alternaria solani*. Indian Journal of Plant Protection 31:49-53.

Reching NA, Reching JE. 1997. Environmental safe approaches to crop disease control. Chemical Rubber Company. Lewis Publisher. New York.

Robert GD, James HT. 1991. A Biomerical Approach. Principles of statistics. 2nd ed. New York, USA.

Sahile S, Fininsa C, Sakhuja PK, Ahmed S. 2010. Yield loss of faba bean (*Vicia faba*) due to chocolate spot (*Botrytis fabae*) in sole and mixed cropping systems in Ethiopia. Archives of Phytopathology and Plant Protection 43(12):1144-1159.

SAS Institute Inc. 2009. SAS/ Stat Guide for Personal Computers, Version 9.1 edition.SAS Institute Inc., Cary, North Carolina. USA.

Shifa H, Hussien T, Sakhuja PK. 2011. Association of faba bean rust (*Uromyces viciae-fabae*) with environmental factors and cultural practices in the Hararghe highlands, eastern Ethiopia. East African Journal of Sciences 5:58-68.

Tewari R, Vishunavat K. 2012. Management of early blight (*Alternaria solani*) in tomato by integration of fungicides and cultural practices. International Journal of Plant Protection 5(2): 201-206.

Tsedeke Abate. 2007. Focusing on agricultural research to address development needs: Direction for agricultural Research in Ethiopia. Addis Ababa, Ethiopia.

USDA (United States Department of Agriculture). 2005. Agricultural research service, nutrient database for standard reference, Release 18. Available at http: //usda.res.

Vander Plank JE. 1963. Plant Diseases: Epidemics and Control. Academic Press, London, UK.349 pp.

Wheeler BJ. 1969. An Introduction to Plant Diseases. John Wiley and Sons, Ltd. 374 pp.

WHO (World Health Organization). 2004. The WHO recommended classification of pesticides by hazard and guidelines to classification: 2004. ISSN: 1684-1042; ISBN: 9241546638. Geneva, Switzerland. 60 pp.

Zitter TA. 2006. Improved and integrated management strategies for controlling diseases of potato and tomato. Project Proposal.National Institute of Food and Agriculture, Cornell University, USA.