Journal of Plant Pathology & Microbiology
ISSN: 2157-7471
OPEN ACCESS Freely available online
Research Article

Effect of Varieties and Fungicide Application Frequencies on Late Blight (*Phytophthora infestans*) Disease Development and Fruit Yield of Tomato in North Western Tigray, Ethiopia

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ABSTRACT

Diseases like late blight are among the major constraints that limit tomato production in most tomato growing regions. Field experiment was conducted in North Western Tigray in 2018 main season with objectives: to investigate the effect of varieties and fungicide application frequencies on late blight disease development and tomato fruit yield. The treatments consisted of four tomato varieties (Melkashola, Melkasalsa, Sirinka-1 and Gelilema) and five application frequencies of the fungicide Matco 72% WP including the control. The experiment was laid out in a split plot design with three replications. Results indicated that integration of varieties and fungicide spray frequencies significantly reduced late blight disease development and maximizes tomato fruit yield. Melkasalsa variety is found better with lowest disease incidence (36.87%), disease severity (26.83%), AUDPC (587.5% days), DPR (0.0604unit per days) and highest marketable (50.05 tha-^{1}) and highest total fruit yield (54.63 t ha^{-1}) when sprayed four times. The highest percent disease incidence (81.50%), disease severity (74.60%), AUDPC (1558.3% days) and Disease Progress Rate (DPR) (0.1074 units per day) were obtained from untreated Gelilema variety. The lowest fruit yield (35.02 tha-1) was harvested from none sprayed Gelilema variety. Highest MRR of 3058% was obtained on Melkasalsa variety treated thrice. Thus it is recommended to use 3 sprayings of the fungicide Matco 72% WP at 10 days interval where the variety Melkasalsa is to be used in the study area. However, other management practices should be employed to this variety to confirm its resistance ability and to maximize its fruit yield in the presence of the disease in main season.

Keywords: AUDPC; PSI; Late blight; Matco 72% WP spray; Tomato varieties

INTRODUCTION

Tomato (*Solanum lycopersicum L.*) is an important vegetable crop grown around the world and is the second next to potato [1]. Economically, it is the fourth most important crop in the world after rice, wheat, and soybean [2] and ranking 8th in annual national production in Ethiopia [3]. It is a source of minerals, vitamins, lycopene and health benefits in reduce cancer and heart disease [4] and most commonly produced under off season but rare in main season when its demand and price sharply rises [5]. Its production in Ethiopia is 27,774.54 tons from area of 5235.19 ha and productivity of 5.31 t ha^{-1} [6]. Production and area coverage is reduced by 590.29 tones and 1063.44ha as compared to the past cropping season and is far below the average of major producers in Africa [7]. Tigray region shares area of 769.42 ha and particularly North western Tigray more than 495.55 ha area with total yield of 3,367 tons were reported [6]. Growers opt to shift their irrigated tomato field with other field crops in the main season. Despite of its importance as income generating for small scale farmers especially in main season, its production and productivity is affected by different biotic and abiotic factors, such as pests and disease, weeds, lack of improved and adapted varieties, harsh environmental conditions, inadequate knowledge of production and management, and poor marketing system are the major ones [8]. More than 200 known diseases and pests are affecting tomatoes worldwide among which late blight is the most devastating foliar and fruit diseases in the highlands of sub-Saharan Africa, and in Ethiopia [9-12]. It can cause up to 90% of crop losses in cool and wet weather conditions, most prevalent during the rainy season and cause yield losses of up to 100% [2] and fruit losses up to 30-60% [13]. Fungicides (protectant and systemic) application integrated with resistant crop genotypes has perhaps been reported as the most effective for management of this

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Received: November 06, 2020; **Accepted:** December 19, 2020; **Published:** December 26, 2020

Citation: Hagos G, Meles K, Tsehay H (2020) Effect of Varieties and Fungicide Application Frequencies on Late Blight (*Phytophthora infestans*) Disease Development and Fruit Yield of Tomato in North Western Tigray, Ethiopia. J Plant Pathol Microbiol 11:531.

disease in temperate countries [14]. However, growers including in the study area use whatever fungicide available alone frequently up to harvesting and some only once in the crop growing period with unknown dose, application time and application frequencies for all tomato varieties irrespective of their resistance ability to the disease. Consequently, the promiscuous use of fungicides might bring adverse effects on human, animal health, environment and lead to development of resistance by the pathogen. Hence, it is needed to integrate fungicide with varying application frequencies and crop genotypes of unlike resistance level to the disease to minimize the negative impact of the chemical and prevent resistance by the pathogen. Therefore, the current research was carried out with the following objective: 1) To evaluate the effect of host plant resistance and fungicide spray frequencies on tomato late blight disease development in main seasons; 2) To investigate the effects of host plant resistance and fungicide application frequencies on fruit yield and yield components of tomato; and 3) To elucidate the economic profitability of the management practices for tomato late blight disease.

MATERIALS AND METHODS

Description of the study area

Experiment was conducted at Shire Maytsebri Agricultural Research Center, in Adigdad experimental site, Tahtay-Koraro Wereda, North Western Tigray, during the 2018 rainy season. It is located at 14^0 10' 30 " N latitude and 38^o 10' 30" E longitude. The site is laid at an altitude of 1800 m.a.s.l. Climatic zone of the study areas belong to Weyna-Dega agro-climatic zone and uni-modal pattern rainfall with main rainy season extended from June to September with mean annual temperature of 24^oc and mean annual rainfall of 1000mm.

Experimental materials

Four tomato varieties ((Melkasalsa, Gelillema, Sirinka-1 and Melkashola), which currently under production and differed in their resistance levels to late blight disease were used as experimental test crop. Matco 72% WP (Metalaxyl 8% WP + Mancozeb 64%) as a foliar spray was used at the manufacturer's label dose of 2.5 kg ha-1 and spray frequency at 10 day interval with five spray frequencies. Brief description of the agronomic and morphological characteristics of the tomato varieties are tabulated here under (Table 1).

Experimental design and treatment combinations

Seed was obtained from Shire Maytsebri Agricultural Research Center and the standard method of seedling raising method recommended by the Melkassa Agricultural Research Center [15-17] was used and transplanted in to the experimental field 28 days after sowing with a spacing of 70 cm and 30 cm between rows and plants. Treatments are arranged in Split plot design and replicated thrice with plot size of 9.45 m^2. Recommended standard fertilizer rate of 150 kg DAP ha^{-1} was applied in rows at transplanting and 100 kg urea per ha^{-1}. Fungicide application was started immediately during the onset of the first disease symptom in 31 days after transplanting and Disease assessments 7 days later (38 DAT) and continued according to the spray schedule for each treatment at 10 days interval. The experiment relied entirely on natural infection because the site was hot spot area for late blight disease during the rainy season.

Data collection

1. **Disease Severity (DS):** Disease severity was recorded from the five pre-tagged plants (five leaves from each plant) in the middle three rows of each plot starting from 7 days after the first appearance of the disease symptoms to determine the disease severity over a time [18] for every seven days for a period of six weeks. 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 and converted in to PSI as described by Horneburg et al. [19].

PSI = (Sum of numerical ratings/(Number of plants scored × maximum disease score on scale)) × 100

2. **Area under disease progress curve (AUDPC):** AUDPC was computed from PSI value for each plot as described [20,21] and used for comparisons of susceptibility groups of the tested varieties.

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

Where, n= is the total number of disease assessments, ti is the time of the i^{th} assessment in days from the first assessment date and xi 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.

3. **Disease progress rate (DPR):** Logistic, ln [(Y/1-Y)] and Gompertz, -ln [-ln(Y)] [22] models were compared for the estimation of disease progression parameters from each treatments 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 to determine the model. The model was then used to determine the apparent rate of disease increase.

4. **Days to 50% flowering and fruit setting:** This was recorded

Table 1: Description of the agronomic characteristics of tomato varieties employed in the experiment.

Varieties Name	Year of release	Breeder/ Maintainer	Growing altitude	Maturity date	yield (t /ha)		Fruit color	Fruit shape	Reaction to LB
					RY	FY			
Melkashola	1997/8	EARO/NZARC	700-2000	100-120	43	14-18	Light red	pear	S
Melkasalsa	1997/8	EARO/NZARC	700-2000	100-110	45	13-17	-	pear	MR
Sirinka-1	2006	SRARC/ARARI	800-2000	95-100	38.2	14.4	Light red	round	Unknown
Gelilema	2015	MARC/ EIAR	500-2000	80-92	50	-	Cherry	Oval	Unknown

RY: Research Field; FY: Farmer Yield; S: Susceptible; MR: Moderately Resistant; LB: Late Blight Source: [15,16]

as the number of days from transplanting until 50% of plants have at least one open flower and least one fruit per plant respectively. Fruits number, number of fruit cluster and number of branches per plant was counted and recorded from five plants sampled in the three middle rows of each plots. Marketable, Unmarketable and Total fruit yield (t/ha) was measured at each harvesting and converted in to hectare.

Statistical analysis

Data on late blight disease severity, AUDPC, DPR and various agronomic data collected were subjected to analysis of variance (ANOVA) using Gen Stat-16 statistical software programs and least significance difference (LSD) was used for the mean comparison at 5% probability level. Correlation analysis was used to examine the relationship between disease development and fruit yield and related parameters of the crop.

Relative yield loss (%) and yield increase in fruit yield

The relative percent yield loss and yield increase over the untreated plot were obtained using the formula suggested by Robert et al. [23].

Relative yield loss (%) = ((Yield of best treated –Yield of untreated plot)/Yield of best treated plot) × 100

Yield increase over control (%) = ((Yield of Treated plot –Yield of Untreated plot)/Yield of Treated plot) × 100

Cost and benefit analysis

A simple cost-benefit analysis was computed for each treatment using the formula of partial budget analysis [24] to determine the profitability of tomato late blight management through combination of varieties and fungicide sprays at different frequencies. It was analyzed by considering the variable cost for the respective treatments. Price of fruits per kilogram was obtained from the local market (18.5 Birr/kg). Cost-benefit analysis of each fungicide schedule was done to evaluate the economic benefits expected using the farm gate price of tomato at the time of harvest. MRR was calculated using:

Marginal rate of return (MRR) = Difference in net income compared with control/Difference in input cost compared with control

RESULTS AND DISCUSSION

Disease development: Late blight disease severity

The interaction effect of tomato varieties and spray frequency showed highly significant ($p < 0.001$) difference on the percent severity index at all assessment dates except at the intial date when only the main effects were significant but their interaction did not (38 DAT). Melkasalsa variety had scored lowest disease record in all spray frequencies including in the untreated plots. In the final date of assessment (73 DAT), The highest percent severity index was recorded on the untreated Gelilema, and the least on moderately resistant variety Melkasalsa than the variety X spray frequency treatment combinations (Table 2). In line with Abhinandan and Binyam [25,26] who found that frequently applied fungicides by far reduced disease severity as compared to the less frequently sprayed fungicides and unsprayed plots of tomato. The study of Namanda et al. [27] also noted that the combined uses of fungicide and resistance varieties have evolved as one of the most important options in the management of the disease.

Area under disease progress curve (AUDPC) (% days)

The interaction effect of varieties and fungicide spray frequencies revealed significant ($P \leq 0.001$) variation in the magnitude of the AUDPC. AUDPC value was maximum on none sprayed Gelilema and smallest on Melkasalsa tomato variety when treated four times (Table 2). All unsprayed varieties scored maximum disease development, however, lowest in Melkasalsa variety. In agreement with the report of Mesfin and Ayda [28,29] who found lowest AUDPC values of late blight disease on moderately resistant potato varieties when supplemented with fungicide treatments in the wet season. Previous studies also reported that the highest value of AUDPC resulted from the highest disease development on untreated with any combinations of crop varieties and fungicide applications [20,26,30].

Disease progress rate (unit per days)

Comparisons among the growth models on disease progress rate of late blight for four tomato varieties with five fungicide spray frequencies were made and the logistic model was found appropriate to determine the final rate of disease severity for this study as the coefficient of determination (R^2) was higher for logistic model in all the varieties than the Gompertz model while the error mean square for logistic model was lower than that of Gompertz model. Therefore, comparisons of the rate among treatments were made based on logistic model. The interaction effect of treatments revealed significant ($p \leq 0.05$) variation in late blight disease progress rate. Disease progress rate was highest on unsprayed Gelilema and Sirinka-1 variety than the other treatments. Whereas, development rate of the disease was significantly reduced on Melkasalsa variety times treated with Matco WP 72% at 10 days interval (Table 2). All tomato varieties remained statically similar when treated thrice and four times with Matco 72WP fungicide. However, all the fungicides sprayed at weekly interval was reduced the progress rate significantly. As reported by Bekele [31] the frequent application of fungicide retards rate of potato late blight progress in the field.

Growth, fruit yield and related components

Days to 50% flowering and fruit setting

Main treatment effect (varieties and spray frequencies) exhibited a very highly significant ($p \leq 0.001$) difference among varieties and fungicide spray frequencies with regard to days to 50% flowering. Gelilema variety took extended time to reach 50% flowering, whereas, Melkashola variety attained early (Table 3). None sprayed plots were delayed more than one week compared to Four times sprayed plots. The result is in line with [32] who reported variations in days to flowering among tomato genotypes. The interaction effect of main treatments revealed significant ($p<0.05$) difference on 50% fruit setting date. Longer time for 50% fruit setting was observed on untreated Gelilema and shorter period on Melkashola variety when treated four times with Matco 72% WP (Table 4). Frequently sprayed fungicide might enhance vegetative growth and facilitates flowering and fruit setting.

Table 2: Interaction effect of treatments on final late blight disease development during 2018.

Varieties of Sprays		late blight percent severity index (%) in all dates						
		45 DAT	52 DAT	59 DAT	66 DAT	Final	AUDPC	DPR
Melkashola	Control	15.9k	28.2j	46.2i	50.9i	59.53j	1213.6j	0.0977j
	Once	13.0ij	23.7h	38.7gh	42.3h	50.57i	1019.1hi	0.0857gh
	Twice	11.0g	20.0f	32.4e	35.4f	41.0g	851.1f	0.0787fg
	Thrice	9.1cde	16.7d	28.6d	31.1de	35.63de	740.5d	0.0710cde
	Four times	7.77ab	14.4b	25.9bc	27.5bc	30.07b	650.7b	0.0627ab
Melkasalsa	Control	12.4hi	21.6g	36.5f	39.3g	47.17h	949.4g	0.0854gh
	Once	10.6fg	18.6e	30.8e	32.6e	37.60ef	793.20e	0.0787fg
	Twice	9.1cde	16.2cd	27.4cd	29.7cd	33.57cd	707.7cd	0.0726def
	Thrice	7.8ab	14.2b	25.3ab	27.2ab	30.17b	641.1b	0.0683bcde
	Four Times	6.80a	12.6a	23.7a	25.2a	26.83a	587.5a	0.0604a
Sirinka-1	Control	16.8k	31.0k	51.9k	58.4k	67.30l	1360.0l	0.1051k
	Once	13.9j	26.3i	45.0i	50.8i	60.00j	1181.6j	0.0934ij
	Twice	11.6gh	22.0g	38.2fg	42.5h	51.20i	994.9h	0.0899hi
	Thrice	9.5de	18.1e	31.0e	33.4ef	40.03fg	802.3e	0.0721cdef
	Four Times	8.2bc	15.5c	26.7bc	28.5bc	31.43bc	678.5bc	0.0661abcd
Gelilema	Control	20.97l	37.1l	58.7l	65.2l	74.60m	1558.3m	0.1074k
	Once	16.6k	30.4k	49.4j	55.7j	63.97k	1313.3k	0.0915hij
	Twice	12.9ij	24.1h	40.2h	44.5h	52.43i	1057.8i	0.0808g
	Thrice	9.8ef	18.3e	30.5e	32.9e	46.87h	827.8ef	0.0734ef
	Four Times	8.4bcd	15.3bc	26.9bcd	29bcd	40.10fg	720.8cd	0.0655abc
LSD 5%		1.113	1.106	1.916	2.271	2.611	932.46	0.08
CV (%)		5.8	3.2	3.2	3.5	3.6	2.8	5.4

DAT: Days After Transplanting; AUDPC: Area Under Disease Progress Curve; DPR: Disease Progress Curve

Table 3: Effect of varieties and fungicide spray frequencies on tomato growth and yield parameters.

	Tomato yield and fruit Parameters During 2018 main season			
Tomato Varieties	**50% DF**	**NBPP**	**NFCPP**	**UMFY**
Melkashola	33.87a	11.23c	14.35b	6.68b
Melkasalsa	38.27c	10.17b	16.65a	5.57a
Sirinka-1	36.80b	9.43a	12.73c	6.76b
Gelilema	38.60c	9.37a	12.86c	5.90a
LSD (5%)	1.104	0.725	0.703	0.33
Spray Frequency				
Control	42.50d	8.88a	10.15a	7.50c
Once treated	38.50c	9.33a	12.23ab	6.68b
Twice treated	36.17b	9.58a	13.80b	6.35b
Thrice treated	33.67a	11.04b	16.53c	5.41a
Four Times treated	33.58a	11.42b	18.02c	5.21a
LSD (5%)	1.934	1.352	2.713	0.44
Var* SF	Ns	Ns	Ns	Ns
Mean	36.88	10.05	14.14	6.23
CV (%)	2.8	7.1	10.2	11.7

DF: Days To Flowering; NBPP: Number Of Branches Per Plant; NFCPP: Number Of Fruit Clusters Per Plant; UMFY: Unmarketable Fruit Yield Var: Variety; SF: Spray Frequencies; Ns: Not Significant (At p<0.05).

Number of branches per plant

Branch number per plant was highly significantly ($P \leq 0.001$) affected by the main effect treatments. Melkasholla scored highest branch numbers and lowest from variety Gelilema (Table 3). The variation in branches number is supported by the findings [33-36].

With regard to spray frequencies, Branch number linearly increased as spray frequencies increased. This is in accord with who stated frequent application of fungicide protect the crop from disease stress and encourages for production of primary and secondary branches as compared to unsprayed once [10].

Marketable, unmarketable and total fruit yield

Unmarketable fruit yield was significantly ($p \leq 0.001$) affected by tomato varieties and fungicide application frequencies but their interaction did not. The highest unmarketable fruit yield was obtained on Sirinka-1, Whereas, lowest from Melkasalsa. Untreated plots scored maximum unmarketable yield and the lowest on plots treated four times and similar with thrice sprayed (Table 3). However, the interaction effect treatments revealed significant ($p < 0.05$) difference on marketable and total fruit yields. The lowest marketable and total fruit yield was recorded on unsprayed Gelilema, whereas, highest from four times treated Melkasalsa variety (Table 4). This result is in agreement with Dillard et al. [37] who stated fungicide applications reduces disease intensity, at the same time maximizes tomato fruit yields. Studies reported that fungicides significantly reduced disease severity and gave increased yield over the control [16,26]. Many tomato researchers [33,34,38] ranged total fruit yield between 6.46 and 82.50 t ha^{-1}. In analogous with Rida et al. and Rida et al. [39,40] who indicated noticeable differences in fruit yield of tomato varieties. The study of Shushay et al. [41] also noted Melkasalsa variety showed fruit yield superiority over Melkashola variety in fruit yield.

Number of fruits and fruit clusters per plant

Number of fruit clusters per plant were significantly ($p \leq 0.001$) affected by main effect of variety and spray frequencies, However, fruit number per plant significant ($p \leq 0.05$) influenced by interaction effect main treatments. The highest fruit clusters per plant were found from Melkasalsa variety and lowest in sirinka-1 variety. Concerning spray frequencies, the lowest and highest numbers of fruit clusters per plant were obtained from unsprayed control plots and four times treated plots, respectively (Table 3). Many authors [42,43] reported that the mean number fruit cluster per plant lay between 4 to 16 fruits. The highest fruit numbers per plant of were recorded from thrice and four times treated plots of Melkasalsa (Table 4). Similarly, the least fruit number per plant was found from control plots of Gelilema but at par with untreated plots of Sirinka-1 and Melkashola varieties. In line with the finding of Shushay et al. [41] who confirmed as Melkasalsa variety showed higher fruit number and fruit cluster per plant over Melkashola. The mean number of fruits per plant could vary between 4.46 to 98.30 as reported by Eshteshabul et al [44]. The present study was agreed with results of Emami and Emami [45,46] who reported wide range of differences such as (33-79) and (4-97) in number of fruits per plant among the tested tomato genotypes respectively.

Association of late blight epidemics with tomato fruit yields

The association between disease and yield parameters was examined using simple correlation analysis. Determined Pearson correlation coefficients (r) were used as indices for strength of the association. Tomato fruit yield (Total and marketable, NFPP and NFCPP) fruit were found strong and negatively correlated with all disease parameters of late blight. Likewise, total and marketable fruit yields

Table 4: Effect of integrated management of late blights disease on fruiy yield parameters of tomato.

Treatmets		During 2018 Main cropping season			
Tomato Variety	Spray Frequency	50% FS	FNPP	MFY (tha^{-1})	TFY (tha^{-1})
Melkashola	Control	51.67^{fgh}	39.70^{abc}	31.98^{c}	39.98^{c}
	One time	49.00^{def}	47.80^{ef}	34.04^{de}	41.12^{cd}
	Two times	45.67^{bc}	52.73^{gh}	36.74^{f}	43.58^{e}
	Three times	44.33^{ab}	60.67^{i}	42.01^{h}	47.84^{f}
	Four times	42.00^{a}	60.53^{i}	45.99^{j}	51.65^{g}
Melkasalsa	Control	58.67^{ij}	42.7^{cd}	34.50^{e}	41.50^{d}
	One time	56.33^{i}	54.13^{h}	35.99^{f}	41.91^{d}
	Two times	49.00^{def}	59.03^{i}	39.31^{g}	44.70^{e}
	Three times	50.67^{efgh}	66.33^{j}	46.12^{j}	51.10^{g}
	Four times	48.00^{cde}	64.8^{j}	50.05^{k}	54.64^{h}
Sirinka-1	Control	52.67^{gh}	38.77^{ab}	30.55^{b}	38.38^{b}
	One times	52.67^{gh}	41.53^{bc}	33.43^{d}	40.91^{cd}
	Two times	50.67^{efgh}	45.93^{de}	36.57^{f}	43.48^{e}
	Three times	47.00^{bcd}	53.57^{gh}	41.93^{h}	48.02^{f}
	Four times	48.00^{cde}	55.3^{h}	45.36^{j}	50.86^{g}
Gelilema	Control	59.33^{j}	37.23^{a}	27.84^{a}	35.02^{a}
	One times	57.33^{ij}	41.27^{bc}	30.89^{b}	37.14^{b}
	Two times	53.33^{h}	45.6^{de}	33.81^{de}	40.06^{c}
	Three times	50.33^{efg}	52.63^{gh}	39.12^{g}	43.87^{e}
	Four times	48.33^{cde}	50.73^{fg}	43.95^{i}	49.03^{f}
	LSD (5%)	2.944	3.342	1.045	1.33
	Mean	50.75	50.54	38	44.23
	CV (%)	3.2	3.9	1.7	1.8

SF: Days To Fruit Setting; PSC: Plant Stand Count; FDPP: Fruit Drop Per Plant; FNPP: Fruit Number Per Plant; FY: Marketable Fruit Yield; TFY: Total Fruit Yield were posetively correlated with all growth and fruit parameters of tomato (Table 5). It is in accord with findings [47] who reported that the associated disease parameters had a negative impact on yield parameters. As stated by Regassa et al. [48] highly significant and positively association between yield related parameters and fruit yield for nine evaluated tomato varieties.

In the regression analysis both AUDPC and TFY served as independent and dependent variable, respectively. Linear regression of the AUDPC was used to predict the yield loss in tomato (Figure 1). This is because AUDPC linear regression is better analytical model to indicate the relationship of yield loss with the disease effects. Thus, in linear regression of the area under disease progress curve was used for predicting the yield loss in tomato for 2018 main cropping season. The coefficient of determination (R^2) value indicated that 81.6% the variation of yield was explained by AUDPC. This regression graph showed that for every one unit increase in AUDPC there was 0.01768 unit (tons) loss in yield of tomato genotypes, on the other hand, 81.6% of the variation in this experiment can be accounted by the equation.

Relative yield loss and yield Increase in fruit yields

The losses inflicted on tomato fruit yields for different foliar spray frequencies were calculated relative to the yield of maximally protected plots with the fungicide Matco 72% WP at 10 days interval. The highest fruit yield losses of 36.65% was calculated from unsprayed of Gelilema compared to the best protected plots with the fungicide Matco 72% WP in each variety. The highest yield increment of best treated plots was calculated as 36.54% from variety Gelilema, as compared to the untreated plots of each variety (Table 6). Approximately 30% – 60% fruit yield loss of is accounted due to late blight disease as stated by Nyakanga et al. [13]. In line with [49] also reported yield loss of 38% - 53% due to late blight disease on an unsprayed control plot of potato variety. About 6.5%-70% fruit yield losses due to late blight in Ethiopia were reported by Bekele et al. [50] on improved tomato varieties.

Economic analysis

Only the marketable fruit yield was considered for sale and the cost of water was assumed to be zero. Partial budget analysis showed that all Matco 72% WP foliar spray frequencies used on four tomato varieties gave high gross field benefit and marginal rate of return. The maximum total gross marketable yield benefit of ETB 895,609.8 and 825,698.6 ha^{-1} was obtained on Melkasalsa when treated four times and thrice with Matco 72% WP, respectively compared to the other treatment combinations (Table 7). The

Table 5: Correlation analysis of late blight disease epidemics and fruit yield of tomato under main season.

	FPSI	AUDPC	DPR	MFY	TFY	UMFY	NFPP	NFCPP
AUDPC	.99***							
PDIf	.84***	.86***						
DPR	.91***	.90***						
MFY	-.91***	-.93***	-.85***					
TFY	-.88***	-.91***	-.80***	.99***				
UMFY	.74***	.74***	.82***	-.74***	-.64***			
NFPP	-.87***	-.88***	-.75***	.88***	.86***	-.70***		
NFCPP	-.86***	-.88***	-.81***	.87***	.84***	-.76***	.87***	
NBPP	-.58***	-.57***	-.58**	.61***	.60***	-.45*	.58***	.59***

***Correlation Is Significant at P ≤ 0.001 FPSI: Final Percent Severity Index; AUDPC: Area Under Disease Progress Curve; DPR: Disease Progress Rate; NFCPP: Fruit Clusters Per Plant; NFPP: Number of Fruits Per Plant; NBPP: Number of Branches Per Plant; MFY: Marketable Fruit Yield; UMFY: Unmarketable Fruit Yield; and TFY: Total Fruit Yield.

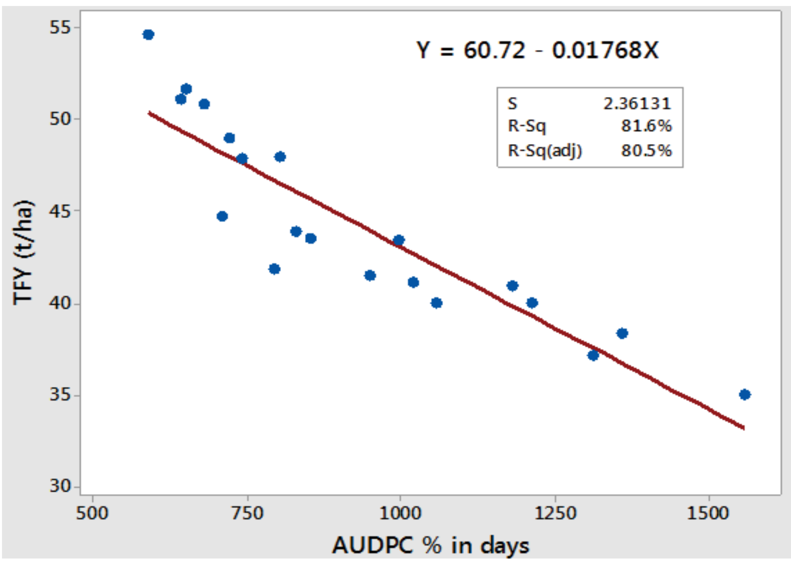

Figure 1: Linear regression of tomato fruit yield and AUDPC during 2018 main cropping season. TFY: Total Fruit Yield; AUDPC: Area under Disease Progress Curve.

Table 7: Partial budget analysis for integrated management of tomato late blight disease.

Treatments		During 2018 Main cropping season					
Tomato Variety	Spray frequency	MFY (kg ha⁻¹)	SR (ETB ha⁻¹)	TVC (ETB ha⁻¹)	NI (ETB ha⁻¹)	Dominance	MRR (%)
MSH	Control	31980	591630	20400.4	5,71,229.60	N	0
	Once	34040	629740	22749.6	6,06,990.40	N	1505
	Twice	36740	679690	24420.6	6,55,269.40	N	2090
	Thrice	42010	777185	27521.4	7,49,663.60	N	2505
	Four times	45990	850815	30315.2	8,20,499.80	N	2514
MSA	Control	34500	638250	20400.4	6,07,934.80	D	0
	Once	35990	665815	22749.6	6,43,065.40	D	1495
	Twice	39310	727235	24420.6	7,02,814.40	D	2360
	Thrice	46120	853220	27521.4	8,25,698.60	N	3058
	Four times	50050	925925	30315.2	8,95,609.80	D	2901
SIR-1	Control	30550	565175	20400.4	5,44,774.60	D	0
	Once	33430	618455	22749.6	5,95,705.40	D	2168
	Twice	36570	676545	24420.6	6,52,124.40	D	2670
	Thrice	41930	775705	27521.4	7,48,183.60	D	2856
	Four times	45360	839160	30315.2	8,08,844.80	D	2663
GEL	Control	27840	515040	20400.4	4,94,639.60	D	0
	Once	30890	571465	22749.6	5,48,715.40	D	2301
	Twice	33810	625485	24420.6	6,01,064.40	D	2647
	Thrice	39120	723720	27521.4	6,96,198.60	D	2830
	Four times	43950	813075	30315.2	7,82,759.80	D	**2905**

MSH: Melkashola MSA: Melkasalsa SIR-1: Sirinka GEL: Gelilema MFY: Marketable Fruit Yield; SR: Sale Revenue; TVC: Total Input Cost; NI: Net Income; And MRR: Marginal Rate Of Return D: Dominated Treatment N: Non Dominated Treatment
*Price of fruit per kilogram was 18.50ETB at the time of fruit selling in 2018.

highest MRR of 3058% in comparison with unsprayed plots was obtained on moderately resistant Melkasalsa tomato variety sprayed thrice plots followed by four times treated Gelilema (2905%). In line with Shiferaw and Tesfaye [49] who found highest MRR from moderately resistant potato variety when treated thrice with Matco 72% fungicide.

CONCLUSION

The cultivated tomato is the world's second most important vegetable after potato in terms of its production. Tomato Late blight (*Phytophthora infestans*) is one of the limiting biological factors for its production in warm humid areas in the world and in Ethiopia. The current study was conducted at Shire Maytsebri Agricultural Research Center, north western Zone of Tigray, Northern Ethiopia, during 2018 main cropping season. Integrated management of late blight disease with resistant/moderately resistant tomato varieties and timely

fungicide Matco 72% WP spray frequencies seems to have affected the disease development and maximizes fruit yield of tomato. The result of the study indicated that, even under the pressing problem of the disease in the rainy season, a moderately resistant tomato varieties, like Melkasalsa combined with three time spray frequencies at 10 days interval and susceptible tomato variety like Gelilema sprayed four times significantly manage late blight disease and gave the highest monetary benefit as compared to the other treatments and the control. In general, during heavy rainy seasons, it is difficult to manage the disease completely, but it could be suppressed through integration of tomato varieties with foliar fungicide applications. The overall study result showed that production of tomato even in main cropping season under high disease intensity is possible if growers integrate resistant/moderately resistant tomato genotype with timely application of recommended fungicids.

RECOMMENDATIONS

Melkasalsa variety appeared relatively resistant to late blight with thrice spray applications and is the promising variety as it managed the disease, gave maximum net benefit and MRR (%) than the remaining combinations. Therefore, all tomato growers such as farmers, private investors, and state enterprises must adopt integrated management practices to restrict the development of late blight and for sustainable tomato production in the study area and in similar agro-ecologies. However, further extensive studies have to be conducted to come up with concrete conclusion and recommendations on the possibility of summer tomato production with fungicide spray applications and other management practices under the challenge of the disease.

ACKNOWLEDGEMENTS

The research was part of the postgraduate research at Mekelle

University. I would like to thank Aksum University for providing me the required financial support for the research work; to Mekelle University for facilitating and advising the overall research works to the end of the study period. I would like to convey a special thanks to Shire Maytsebri Agricultural Research Center for allowing me the site for the experiment.

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