# EFFECT OF VARIETY AND FUNGICIDE FREQUENCY ON THE MANAGEMENT OF TOMATO LATE BLIGHT (*Phytophthora infestans* (MONT) DE BARY) IN BOMBE WOREDA, WOLAITA ZONE, SNNPR, ETHIOPIA

**MSc Thesis**

**BY:**

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**HAWASSA UNIVERSITY**

**College of Agriculture**

**HAWASSA, ETHIOPIA**

**AUGUST, 2020**

# FFECT OF VARIETY AND FUNGICIDE (RIDOMIL) FREQUENCY ON THE MANAGEMENT OF TOMATO LATE BLIGHT (*Phytophthora infestans* (MONT) DE BARY) IN BOMBE WOREDA, WOLAITA ZONE, SNNPR, ETHIOPIA

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**A Thesis Submitted To the School Of Plant and Horticultural Science, College of Agriculture, Hawassa University**

**In Partial Fulfillment of the Requirements for the Degree of Master of Science in Crop Protection (Plant Pathology)**

**HAWASSA, ETHIOPIA**

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## ADVISORS' APPROVAL SHEET

(Submission Sheet-1)

This is to certify that the thesis entitled "**Effect of variety and fungicide frequency on the management of tomato late blight (*phytophthora infestans* (mont) de bary) in Bombe Woreda, Wolaita Zone, SNNPR, Ethiopia**", submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in **Crop Protection**, the Graduate Program of the School of Plant and Horticulture Science, College of Agriculture, and is a recorded of original research carried out by **Dinkinesh Desta Anshebo**, under our supervision and no part of a thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, we recommend that it be accepted as fulfilling the thesis requirements.

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**(Submission Sheet-2)**

We, the undersigned, members of the Board of Examiners of the final open defense by **Dinkinesh Desta Anshebo** have read and evaluated her thesis entitled "**Effect of Variety and Fungicide Frequency on the Management of Tomato Late Blight (*Phytophthora infestans* (Mont) De Bary) In Bombe Woreda, Wolaita Zone, SNNPR, Ethiopia,** and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of **Master of Science** in plant science with specialization in **Crop Protection(Plant Pathology)**.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the School of Graduate Studies (SGS) through the School Graduate Committee (SGC) of the candidate's school.

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## DEDICATION

This Thesis is dedicated to my husband Mr.W/Gebreal Desta, my Mother Ayelech Detamo and my Father Desta Anshebo for their dedicated partnership in the success of my life; they always inspired and encouraged me to move forward in my education.

## STATEMENT OF THE AUTHOR

I declare that this thesis is my bona fide work and all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Place: Hawassa University, College of Agriculture, Hawassa

School: Plant and Horticultural Sciences

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## ABBREVIATIONS

| | |
|---|---|
| ARPTd2 | ARP Tomatod2 |
| ANOVA | Analysis of Variance |
| AUDPC | Area under Disease Progress Curve |
| CSA | Central Statistical Agency |
| CYI | Change in Yield Increase |
| DAT | Date after Planting |
| DIC | Difference in Input Cost |
| DNI | Difference in Net Income |
| EIAR | Ethiopian Institute of Agricultural Research |
| IDM | Integrated Disease Management |
| MARC | Melkasa Agricultural Research Centre |
| MRR | Marginal Rate of Return |
| NDP | Number of Diseased Plants |
| NPR | Number of Plants Rated |
| PSI | Percent Severity Index |
| RCBD | Randomized Complete Block Design |
| SARI | Southern Agricultural Research institute |
| SNNPR | Southern Nations, Nationalities and People's Region |
| WZFEDD | Wolaita Zone Finance and Economic Development Data |

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**DINKINESH DESTA ANSHEBO (BSc).**

***MAJOR ADVISOR:*** **HIRUT TSEGAYE (PhD*)***

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## ABSTRACT

*Diseases are the major constraints that limit production of tomato in Ethiopia. Late blight is a very severe disease in most tomato growing regions, including in Wolaita zone, where information on disease management options through integration of varieties and fungicide applications are poor. Aim of the present study was therefore, to determine frequency of fungicide spray with respect to host resistance level on the management of late blight of tomato. A field experiment was conducted at Frwocha kebele in Boloso Bombe Woreda during 2019 cropping season. The experiment was laid using RCBD in factorial arrangements with three replications. The treatments consisted of four foliar spray frequencies, and three tomato varieties (Melkasalsa, Metadel and ARPTd2). Important parameters collected were incidence and severity of late blight, and growth and yield related traits of tomato. Significant variations were observed among varieties in reducing late blight of tomato and increasing the fruit yield. The highest late blight severity and AUDPC (43.2 and 629.81, respectively) were recorded from variety Melkaslsa, and the lowest (32.59 and 441.61, respectively) were recorded from variety ARPTd2. Interaction of varieties and fungicide spray frequencies did not show significant difference on most components of late blight epidemics, crop growth and yield related parameters. However, significance differences were observed on marketable and total fruit yield. The maximum marketable (61.70) and total fruit yield (67.30) were recorded from plots treated with three and two time sprayed on ARPD2 tomato variety, respectively, while the lowest marketable (24.06) and total fruit yield (35.43) were recorded from unsprayed plots of Melkasalsa and Metadel varieties, respectively. Correspondingly, the highest disease progress rate of (0.09) was obtained in unsprayed plot of the variety Melkasalsa; however the lowest disease progress rate of (0.04) was recorded from the plots of ARPTd2 and Metadel variety treated with Ridomil four times at 7 days interval. Fruit yield loss of up to 47.04% was calculated on unsprayed plots as compared to highly treated plots. On the other hand, marginal analysis indicates that the highest 87.94% marginal rate of return in comparison with unsprayed plots was obtained where ridomil sprayed two times on ARPTd2 variety as compared to other spray frequencies. In conclusion, integrations of varieties and two times foliar spray of ridomil on ARPTd2 variety were found to be an effective treatment in reducing tomato late blight epidemics and increasing fruit yield. Moreover, ARPTd2 variety appears to have comparative resistance to late blight and is a promising tomato variety. However, further investigation should be carried out for developing concrete recommendation for late blight management options through integration of varieties and fungicide spray frequency that may contribute to sustainability by stabilizing tomato production in the country.*

***Keywords**: AUDPC, disease progress rate, disease severity, marginal analysis, Phytophthora infestans Ridomil sprays, tomato varieties and yield.*

# 1. INTRODUCTION

Tomato (*Solanum lycopersicum Mill*)) is one of the most important vegetable crops of the family Solanaceae. It is considered to have originated in Peru, Ecuador, and Bolivia region of the Andes in South America. Now tomato is the third largest vegetable crop after potato and sweet potato, and as a processing crop, it ranks first among all vegetables (AGRISNETC, 2010). China is the biggest tomato producer in the world with annual production of 34.1 million tons (FAOSTAT, 2018).

The introduction of cultivated tomato (*Solanum lycopersicum* Mill.) into Ethiopian agriculture dates back to 1940 (Samuel *et al*., 2009). The Ethiopian Institute of Agricultural Research (EIAR) was established in 1966 (Setotaw, 2006) in which tomato was recognized as a commodity crop. Since 1969, adaptation trial had been carried out but challenged by diseases (Shushay, 2011). Then, the first record of commercial tomato cultivation started in 1980 with a production area of 80 ha in the upper Awash by Merti Agro-industry for both domestic as well as export markets (Lemma, 2002). The total area increased to 833 ha by the year 1993 and later on the cultivation spread towards other parts of the country. Tomato is one of the most important vegetable crops and widely grown in Ethiopia, ranking 8$^{th}$ in annual national production (Derbew *et al*., 2012). The importance of tomato is increasing and since it is a high value commodity, it has been given top priority in vegetable research too in Ethiopia (Tsedeke, 2007). Currently tomato is one of the major regional export vegetables of the country. In Ethiopia, the crop is produced in the range of 700 up to 2200 meter above sea level, with about 700 to over 1400 mm annual rainfall, in different areas and seasons, in different soils, under different weather conditions, but also at different levels of technology (e.g. with furrow, drip or spate irrigation) and yields (Birhanu and Ketema, 2010). Small-scale

farmers and commercial growers could grow the crop for its fruits in different regions of the country. Over 164,500 households in Ethiopia grow tomato regularly for both household consumption and income generation (FAO, 2019).

Tomato is one of the most popular protective foods because of its high lycopene content and is widely grown vegetable in the world which ranks second in importance after potato (Rana, 2008). Because of its high nutritive value, it is also most commonly grown vegetable in the kitchen gardens and therefore, called as poor man's orange. It is not only the richest source of lycopene, beta-carotene, folate, flavonoids, potassium, vitamin E, vitamin C and vitamin A, but also adds color and flavor to the food (Willcox *et al.*, 2003; Bose and Agrawal, 2007). It is a good promoter of gastric secretions, blood purifier and also considered to be intestinal antiseptic. Its soup is said to be good remedy for patients suffering from constipation (Sameera, 2007).

On the world scale, about 182,301,395 tons of tomatoes were produced in 2017. To achieve this production, almost 5 million hectares were used (FAOSTAT, 2017). Ethiopia's total production and productivity are far below the average of major tomato producers in Sub-Saharan Africa. For instance, in 2016 the total cultivated area was approximately 9,700 hectares, with a total production of 91,300 tons of fresh tomato and average productivity of 9.4 tons per hectare (CSA, 2016). The major constrains that reduced production and productivity are biotic and abiotic factors. Among biotic constraints, fungal diseases are major factors affecting the production and productivity as well as quality of the crop. Many diseases are attacking this crop, and can cause 15-95% crops loss both in lowland and highland areas of the tropics (Jarvis and Mckeen, 2013).

In Ethiopia diseases are major constraints in tomato production. The major tomato disease in Ethiopia, includes; late blight *(Phytophthora infestans*), early blight (*Alternaria solani*), septoria, root-knot nematodes (*Meloidogyne spp*), powdery mildew (*Levillula taurica*), bacterial wilt (*Ralstonia salanacearm*), fusarium wilt (*Fusarium oxysporum*), viruses and other disease with low priority (Eshetu, 2003). Among these diseases late blight is one of the devastating diseases that got higher priority, especially during the main season when the weather is cool and humid.

Late blight caused by the Oomycete pathogen *Phytophthora infestans* is a severe disease of tomato, potato and their wild relatives. Renowned as the cause of the Irish potato famine in the 1840's, *P. infestans* has remained an important pathogen since its discovery over 180 years ago (Large, 1940). Reduction in yield of tomato estimated on plot basis due to late blight was 63.7 - 100% in southern Ethiopia (Lemma, 2011). Hence, it is easy to imagine how much loss can be incurred due to this disease especially under small scale farmers' conditions.

In bombe Woreda of wolaita zone and its surrounding areas, the environmental condition is favorable for tomato production. Late blight (*Phytophthora infestans* (Mont.) de Bary) has aproperty of occurring due to the availability of suitable environmental conditions, which encompass high moisture and low temperature for tomato late blight in the surrounding study areas (Agrios, 2005; Stone, 2014). Tomato growers in this area also use different fungicides like Mancozeb, Metalaxyl and Ridomil for the control of the disease. The regular fungicidal use encourages the development of resistance in *P. infestans*, increases the production cost and more important being it is detrimental to the environment (Siddique *et al*., 2016). In order to effectively manage the disease while reducing the effect of fungicides on the environment and

the cost of production, there have to be an appropriate fungicide use for effective disease management when combined with the varieties inherited resistance.

According to Mark (2015), improved spray of fungicide and its spray frequency has positive effect on yield and the resistance of tomato variety. However, late blight is a big challenge in order to enhance the tomato yield and no report is found on efforts in relation to resistance variety and the right sprays of Ridomil to fully exploit the yield potential of the crop in these districts. Hence, adaptability of improved tomato varieties and applicable frequency of fungicide spray in the study areas were evaluated, and disease tolerant varieties with high yield, were recommended for further investigation.

## 1.1 Statement of the problem

The management of tomato against late blight is important to maximize the productivity and the production of the crop. The disease occurs throughout the major tomato production areas in Ethiopia; especially, in various parts of Bombe Woreda. For the disease management, most of the farmers do not use diseases resistant variety. Instead, they use different fungicides irrespective of the right frequencies and rates. This obviously leads to material wastage, yield losses and health problem for humans and the quality of the crop itself as well as development of resistance by the pathogen to the fungicide(s) (WHO, 2004; Majid *et al*., 2008). Different ranges of yield loss and complete crop failures due to the disease are frequently reported, and it is difficult to produce the crop during the main rainy season without chemical protection (Amin *et al*., 2013). Many strategies have been investigated in the field to control late blight on tomato. However, there have been limited researches efforts that evaluated the effect of integrated management of late blight through fungicides and tomato varieties against late

blight in the study areas. The high efficacy of fungicides and varieties against late blight are the better disease management options for enhancing yield parameter.

The present study was therefore motivated to determine the appropriate fungicide frequency with respect to crop resistance levels in the study area. The result is believed to overcome or reduce the constraints caused by tomato late blight. The disease attack of the tomato varieties were evaluated by integrated management through host plant resistance and fungicide based on the recommended uses of fungicides and finally, recommendations for the disease management in the study areas were provided and also the cost/benefit analysis of the use of fungicides for the management of this disease would help to reduce high tomato production costs.

### 1.2.1. General objective

- To determine frequency of fungicide spray with respect to host resistance level on the management of late blight of tomato in Bombe Woreda.

### 1.2.2. Specific objectives of the study

- To evaluate the effect of fungicide sprays frequency for the management of late blight of tomato, and
- To assess the performance of different tomato varieties against tomato late blight.

## 1.3. Research Hypothesis

**Ho1**: there is no interaction effect of fungicide spray on different tomato variety in the study area.

**Ho2:** there is no any significant difference regarding the performance of different tomato varieties against tomato late blight

**$H_1$:** there is interaction effect of fungicide spray on different tomato variety in the study area.

**$H_2$:** there is any significant difference regarding the performance of different tomato varieties against tomato late blight

## 2. LITERATURE REVIEW

### 2.1. Tomato Production

Tomato (*Solanum lycopersicum Mill.*) belongs to family *Solanaceae* and its origin is the Andean zone particularly Peru-Ecuador-Bolivian areas but cultivated tomato originated in Mexico. Tomato is one of the most highly praised vegetables consumed widely and it is a major source of vitamins and minerals. It is one of the most popular salad vegetables and is taken with great relish (Zahedi and Ansari, 2012).

The cultivated tomato was brought to Europe by the Spanish conquistadors in the sixteenth century and later introduced from Europe to southern and eastern Asia, Africa and the Middle East. More recently, wild tomato has been distributed into other parts of South America and Mexico. Common names for the tomato are: tomate (Spain, France), tomat (Indonesia), faan ke'e (China), tomati (West Africa), tomatl (Nahuatl), jitomate (Mexico), pomodoro (Italy), nyanya (Swahili).

Tomato ranks thrid next to potato and sweet potato in respect of vegetable production in the world. It is widely cultivated in tropical, sub-tropical and temperate. The leading tomato producing countries are China, United States of America, India, Egypt, Turkey, Iran, Mexico, Brazil and Indonesia (FAO, 2006).

Tomato (*Solanum lycopersicum Mill.*) is one of the most important edible and nutritious vegetable crops in Ethiopia. In Ethiopia, the crop is grown between 700 and 2000 m above sea

level, with about 700 to over 1400 mm annual rain fall, in different areas and seasons, in different soils, under different weather conditions, but also at different levels of technology (e.g. with furrow, drip or spate irrigation) and yields (Gemechis *et al*., 2006).

Smallholders have grown tomato for long time for their livelihood needs since the start of its commercialization. Yet, average yield of tomato in Ethiopia is low, ranging from 6.5-24.0 MT ha-1 compared with average yields of 51, 41, 36 and 34 MT ha-1 in America, Europe, Asia and the entire world, respectively. Moreover, growers have been challenged by inconsistent production and low yields. Improving smallholders' tomato production would contribute to enhancing food security and alleviating poverty (Gemechis *et al*., 2012).

**2.2. production constraints of Tomato**

Production challenges for tomato crop include insect pests, diseases, weeds and harsh environmental conditions, like climate change. It is well known that diseases remain and pose the biggest challenges in tomato production. It is estimated that there are more than 200 known diseases affecting tomatoes worldwide. Tomato diseases are rampant in lowlands and highlands in the tropics and can cause 15 - 95% crop loss (Jarvis and McKeen, 2013). Tesfaye and Habtu (1986), Sakhuja *et al.* (2004) and Seid *et al.* (2015) reported that early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), fruit spot (*Xanthomonas campestris pv. vesicatoria*), Septoria leaf spot (*Septoria lycopersici*), powdery mildew (*Leveillula taurica*), bacterial wilt [Ralstonia (*Pseudomonas*) *solanacearum* or *Clavibacter michiganense* subsp. *michganense*], tomato leaf curl (Tobacco virus 16 or Nicotiana virus 10) and plant-parasitic nematodes (genera: *Pratylenchus, Meloidogyne, Helicotylenchus*, and *Longidorus*) are the major and economically important tomato diseases in Ethiopia.

## 2.3. Importance of late blight

*Phytophthora infestans* is economically the most important and most destructive tomato and potato disease worldwide and the disease causes annual losses of several billion dollars and it is a global threat for potato and tomato growers. Late blight can completely destroy the aboveground parts of the plants (stems, leaves and fruits) and can also affect potato tubers within a short period. The disease is a very serious economic threat in the vast majority of potato production systems, and in many tomato growing areas (Bourke, 1993). Late blight caused the Irish potato famine in the mid-1800, s and continues to be a major source of concern for farmers worldwide. The disease was so serious in Ireland where potato constitutes the main diet that one and-a-half million people immigrated the United States, Canada and other countries (Agrios, 2005)

### 2.3.1. Distribution of late bight

*Phytophthora infestans* appears to have evolved on wild potato (*Solanum* species) in a limited area in the highlands of central Mexico (Goodwing *et al*., 1994). For *Solanum* species, this region is a secondary center of diversity (Hawkes, 1966). Before 1980, the A1 mating type of *Phytophthora infestans* was the only strain distributed worldwide, with the A2 mating type only reported in central Mexico where mating and oospores formation occurred in the field. Since 1980, A2 mating type and oospores have been discovered in Switzerland (Hohl and Iselin, 1984), the UK (Tantius *et al*.,198), the Netherland (Frinking *et al*., 1987) and Germany (Dagget *et al.,* 1993). Previously, the A2 mating type occurs in all continents except Australia (Fry *et al*.,1992; Kato *et al.,*1992; Shattock, 1995) but currently it is found in all continents though exception for countries within the continents (Ye Guang *et al*., 2008). First reports of the A2 mating type in Africa were made on Egyptian potatoes in 1984 (Shaw *et al.,* 1985).

A recent study evaluated these two alternate hypotheses and found conclusive support for central Mexico being the center of origin (Goss *et al.,* 2014). Migration from Mexico to North America or Europe has occurred several times throughout, probably linked to the movement of potato tubers and tomato fruits (Goodwin *et al.,* 1994; Yoshida *et al*., 2013). Until the1970s A2 mating type was restricted to Mexico, but now in many regions of the world both A1 and A2 mating type isolates can be found in the same region. The co-occurrence of the two mating types is significant due to the possibility of sexual recombination and formation of oospores, which can survive the winter. Only in Mexico and Scandinavia, however, is oospores formation thought to play a role in overwintering (Gomez- alpizar *et al.,* 2007; fry, 2008). In other parts of Europe, increasing genetic has observed as a consequence of sexual reproduction. This is notable since different forms of *P. infesting* vary in their aggressiveness

on potato or tomato, in sporulation rate, and sensitivity to fungicides. Variation in such traits also occurs in North America; however, importation of new genotypes from Mexico appears to be the predominant cause of genetic diversity, as opposed to sexual recombination within potato or tomato fields. Many of the strains that appeared crop losses (Fry, 2008; Nowakowska, 2014).

Evolution of late blight diversity documented late blight isolates worldwide (Goodwin *et al*., 1994*). Phytophthora infestans* has worldwide distribution, but most severe epidemics occur in areas with frequent cool, moist weather. Late blight is found in nearly all areas where potatoes and tomatoes are grown but is more severe in humid high rainfall areas (Hartman and Huang, 1995). Rainy, cloudy conditions have been providing favorable condition for the pathogen to successfully be dispersed, including long distances and for infection. Clouds protect spores being dispersed in wind from the killing effect of ultraviolet radiation (Magraret, 2009).

Late blight ranks as the most important disease of tomato. This disease can spread rapidly during cool, rainy weather, killing plants within a few days and causing total crop loss. Effects on the plant include extensive defoliation, reduced photosynthetic leaf area, loss of plant vigor, plant death, loss of fruits and reproductive capacity, and of seeds by attacking whole parts of the plants (Scot, 2008). It is favored by cool humid conditions and its spread is very fast under favorable conditions. *Phytophthora infestans* sporulation is abundant at relative humidity near 100% and at temperatures between 16 and $22^0$C (Hartman and Huang, 1995).

The disease can cause total destruction of all plants within a week or two when weather conditions are favorable (Agrios, 1997). And also could causes up to 100% crop losses if not controlled (HCDA, 1996). It is the most important pathogen of garden huckleberry (*Solanum scabrum* Mill), potatoes and tomatoes in the tropical highlands of Cameroon. In this scenario,

a yield loss in tomato fruits is up to 100% (Fontem, 2003). As indicated earlier the loss was about 38-65% on plot basis in Ethiopia (IAR, 1983; Tefaye and Habtu, 1986). Hence, this is an extremely destructive disease when not managed, quickly killing foliage and rotting tomato fruit and potato tubers.

### 2.3.2. Taxonomy

*Phytophthora infestans* is belonging to the class of Oomycete (water molds) of the kingdom chromites and is taxonomically closely related to golden-brown algae and diatoms and is not a fungus as it first was classified as (Erwin and Riberio, 1996; Judelson and Blanco, 2005). The genus *Phytophthora* consists of over 60 different species, all but, three species are plant pathogens. It is grouped under the family *Pythiasceae*, which is include either in the phylum *Oomycota* or *Peronosporomycota*. However, regardless of the groupings of more general tax, it is very clear that the genus *Phytophthora*, the closely related genus *Pythium*, and the downy mildew fungi (i.e. Bremia, *Sclerspora*, *Peronoospore*, etc.) are unrelated to Ascomycetes and Basidiomycets (Becktell *et al*., 2006).

The position of the Oomycete as a unique lineage of Sraminipila eukaryotes, unrelated to true fungi but closely related to heterokont (brown) algae has been well established using molecular phylogenies based on ribosomal RNA sequences, compiled amino acid data for mitochondrial proteins, and four protein encoding chromosomal genes (Kamoun *et al*., 1999)

One of the many features that distinguish Oomycete from true algae is that Oomycete are diploid and lack a free haploid life stage. True fungi are typical haploid or dikaryotic (Judelson ,and Blanco, 2005). The key aspects of their structure, biology and pathology differ from true fungi, their hyphal growth and variety of spores are morphologically and physiologically similar to fungi, for which they are occasionally mistaken, but their parasitic lifestyles have

independent origins (Nicholls, 2004). Although Oomycete are distinguishable from fungi based on metabolism (Pfyffer *et al*., 1990), cell wall composition (Bartnivki-Garcia and Wang, 1983), rRAN sequence (Cooke *et al.*, 2000; Forster *et al.*, 1990) and zoospore motility (Zentmyer, 1983).

Hence, members of *Phytophthora* can be distinguished from the fungi since they based the following characteristics: cell walls composed of glucans and cellulose instead of chitin, motile zoospores with tinsel and whiplash flagella, and several sporangia produced on each sporangiophore, and diploid vegetative cell (Zentmyer, 1980)

Traditionally, specific characterization within the genus *Phytophthora* has been based on structure of the sporangium, antheridia form, and on sexual compatibility incompatibility (Water, 1973). *Phytophthora infestans* in described as having semipapillate sporangium, amphigynous antheridium, and being heterothallic and sexually incompatible (Cooke *et al.*, 2000).

### 2.3.3. Epidemiology of late blight

Where *P. infestans* exists as an asexual organism, it is essentially an obligate parasite. It requires a living host (solanaceous weeds) for long-term survival. *Phytophthora infestans* cannot survive in the absence of a living host cell. However, in locations where sexual reproduction occurs, the resulting oospores can survive for months or years in the absence of living hosts in the soil (Drenth *et al.*, 1995).

Excessive humidity (above 90% RH) coupled with suitable (low) temperature for germination of sporangia and further disease development are the principal pre-disposing factors. Where the mean atmospheric temperature exceeds $25^0$C, the disease is rare. Cool moist conditions

favor dispersal or arrival of viable sporangia. Extended dry periods or rapid dehydration can quickly kill many sporangia but within the temperature range of 15 and $20^0$C and, moisture range of 40 to 80% RH, the life time of sporangia is extended. Maximum spread of the disease occurs when the conditions are favorable for germination of sporangia and zoospores. Optimum temperature for germination of sporangia by zoospores production is 12-$13^0$C and for germ tube production $24^0$C. Minimum temperature for germination of sporangia is as low as 2-$3^0$C, while the maximum may go up to 24-$30^0$C (Singh, 2006).

**2.3.3.1. Environmental factors that favor late blight**

The significance of environment on disease progression is characterized by the disease triangle, which integrates host, pathogen, and environment (Vander, 1968). It has been noted that a key component to the Irish potato famine, aside from the reliance on potato as a staple and the migration of the pathogen into that region of the world, was a period of weather characterized by abnormally low temperatures and increases humidity in 1845 facilitating pathogen establishment (Schumann, 1991). Late blight is highly responsive to weekly or even daily environmental changes (Duniway, 1983). Several components effect the survival germination, penetration, and speculation of late blight. Temperature between 15 and $20^0$C and high relative humidity are optimal for late blight initiation (Watterson, 1986). Zoospore germination is most efficient between 12 and $15^0$C, with temperature higher than $15^0$C resulting direct germination via germ tube production (Agrios, 1997).

.Mycelia growth is optimized at temperatures near $21^0$C, with a relative humidity of 100% (Alxopulos, 1962). Although temperatures of $30^0$C or greater halt progression of the disease, they do not kill it and a return to appropriate environmental conditions can re-initiate infection

(Agrios, 1997). Late blight lesion expansion is primarily a function of temperature (Rotem and Cohen, 1974).

Sporangia can be dispersed by wind or by water splash. As a result the primary factors governing late blight spore dissemination are moisture and air turbulence (Aylor, 1978). Thick-walled oospores of *P. infestans* can survive harsh environmental conditions and are means for overwintering (Carlile and Watkinson, 1994). Oospores have been found to survive in the soil for five to seven months at temperatures ranging between 0 and 20°C (Pities and Shattock, 1994) furthermore, oospores remain capable of germinating after exposure to temperature between 20 and $40^0$c (Fay and Fry, 1997).

**2.3.3.2.Pathogen transmission**

Transmission of *P. infestans* to potato and tomato seedlings at rates of 34 and 18% was demonstrated for moist, discolored seeds in sterilized silo in the greenhouse and under field conditions in natural soil, respectively. No transmission of the pathogen was found in the greenhouse or field for moist, non-discolored seeds of from discolored seeds that had been air-dried before planting (Vartania and Endo, 1985). Spores produced on infected potatoes and tomatoes can travel through the air, land on infected plants, and if the weather is sufficiently wet, cause infections. Sporangia can also be washed through the soil to infect potato tubers, which may rot before harvest, or later in storage. Because the Oomycete that causes late blight produces so many sporangia, and the sporangia can travel long distances thorough the air, it is very important that everyone it, to avoid being a source of sporangia that infect potatoes and tomatoes in neighboring gardens and commercial fields. The disease is capable of wiping out not only the entire potato and tomato crop grow in small fields very quickly under wet

conditions, and farmers who grow potatoes or tomatoes are at serious risk of losing their entire income from these crops (Anonymous2).

### 2.3.4. Host range of *Phytophthora infestans*

*Phytophthora infestans* has been reported to cause infection on a large number of species. Erwin and Ribeiro (1996) listed 89 host species but more than 25% of these were included because artificial inoculation resulted in lesions. In agriculture, the two most important hosts are tomato (*Lycopersicon esculentum*) crops (Judelson, 1997) and potato (*Solanum tuberous)* (Kamoun, 2001) but pear melon (*Solanum muricatum, "pepino*") and other Solanaceous species in the genus Solanum can also be attacked (Turkenteen and Flier, 2003). Other non-Solanum genera in the Solanaceae, such as petunia and calibrachoa, have also been implicated as hosts (Becktell *et al.,* 2006).

### 2.3.5. Symptoms and signs of *Phytophthora infestans*

*Phytophthora infestans* is one of the most common and damaging diseases of tomatoes.*P. infestans* can quickly devastate tomato at any time during plant ontogeny. It can infect all above ground part of the plant, causing leaf stem and stem necrosis, fruit rot and eventual plant death. It can also infect tomato seed (Rubin *et al.,* 2001; Rubin and Cohen, 2004).

The first symptoms are usually on leaves as water-soaked, oily, pale or dark-green or brown/black, circular or irregular lesions near leaflet margins. As the disease progresses, lesions may occur elsewhere on the leaves. Typically, younger, more succulent, tissue is affected first. As the disease progresses leaflets shrivel and die and the disease spreads to the rest of the foliage, leading to extensive defoliation. During periods of abundant moisture, spore of the pathogen can be seen by the naked eye as a white, cottony growth on the

underside of affected leaves and/ or on fruit lesion. Moreover, it is primarily leaf spot and foliage blight, but also may cause a black spotting around the stem end and shoulders of ripe fruits in late autumn. Infected tomatoes have shallow, brownish or purplish lesions on the surface of the leaves and fruits (Schumann and Darcy, 2000; Agrios, 2005).

When wet and cool conditions are prevalent, the disease usually progresses rapidly through the plant canopy and crop, resulting in brown, shriveled foliage. Green and ripe tomatoes are susceptible to severe injury from late blight. Oily, brown/copper in color, and often-sunken lesions from on both green and ripe fruits, this remains firm. Lesions may spread over the surface of the tomato, and secondary decay organisms generally follow the late blight infection causes various fruit rots. Often, the stem end of the fruit is affected first, because spores tend to the top of fruit and small cracks favor infection by the pathogen; however, this is not always the case. Petiole and stems also develop dark, oily lesion.

### 2.3.6. Management of late Blight

Effective management of late blight requires a comprehensive approach, integrating many strategies and tactic. This is important to manage strains that are very aggregative and not especially sensitive to some fungicides.

#### 2.3.6.1. Cultural practice

Cleanliness is the first line of defense against late blight. Avoid piling and leaving culls. Culled tomato and potato should be disked, composted, or otherwise disposed of before the new crop emerges. However, culls are dealt with, the further removed from new production field, the better. Volunteer potatoes, solanaceous (potato family) weeds, and any infected plants should be destroyed as soon as they occur (Inglis and Sandmen, 1993). Growers that

have the option of planting several small, separated fields may have an advantage in containing outbreaks.

Cultural control involves all the activities carried out during agronomic management which alter the microclimate, host condition and pathogen behavior in such a way that they avoid or reduce pathogen activity. Planting time should be scheduled especially in places where planting is made under irrigation, to avoid the period of higher incidence of the disease. This is not always possible in continuous production areas. Soils must have good drainage and adequate aeration, in order to avoid moisture on foliage and ground.

Management of contaminated sources, such as waste heaps, infected tomato seeds or potato tubers, volunteer plants, use of disease –free seeds, destruction of haulms neighboring fields and sound crop rotation can help in the management of the disease (Majid *et al*., 2008; Steen son, 2009). Also, removal of diseased plants or destruction of disease plant immediately after harvest or, alternatively, burial of diseased debris by deep ploughing helps reduce spore levels available for infection of new plants removing late bight diseased plants to prevent spreads so rapidly and produces so many airborne inoculate.

**2.3.6.2. Host plant resistance**

The input to host slowing down disease progress can be large and for the reason resistance has been the principal approach for effective late blight management in both developing and developed countries (Forbes and Javis, 1994; McGrath *et al*., 2014). With the rate of at least partially resistant varieties, the number of fungicide spray and/or the rate of spray can be significantly reduced (Kirk *et al*., 2001; Stevenson *et al.,* 2007), particularly when combined with cultural practices, biological control and blight forecasting (Grunwald *et al*., 2002).

Tomato and potato varieties with varying resistance to races of *P. infestans* have been developed and breeding for resistance in tomato ongoing. However, varieties resistant to all races of the pathogen are not currently available, so late-blight-resistant plants are not reliable in all cases (Nowakowska, 2014).

Host resistance to *P. infestans* is of significance late blight management due to its long-term economic benefits for farmers. Biotechnology is also being employed in the pursuit of late blight resistance (ATTRA, 2004; Agrios, 2005). The use of plants with field resistance can slow down the pathogen growth rates. However, no *Solanum* (potato and/ or tomato) are fully resistant to late blight (ATTRA, 2004; Majide *et al*., 2008; Stone, 2014). It should be noted that varieties with higher level of resistance require less fungicide spray frequencies than varieties with lower levels of resistance.

**2.3.6.3. Biological Control**

There has been research to manage the disease problem using microbial antagonists, for example, *Trichoderma harzianum* and *T. iride* to manage *P. infestans* (late blight of tomato and potato)(Majid *et al.,* 2008). Some reports have indicated that *Aspergillus terreus* and *Penicillium oxalicum* could inhibit the growth of *P. infestans* in potato (Roy *et al.,* 1991). The fungal species belonging to the genus *Trichoderma teichoderma* occur throughout the world and can be easily isolated from soil, decaying wood and organic matter. The potential of this genus in the biological control of pathogens was first noticed in the early 1930s. The success of *Trichoderma* species in plant disease management has leas to the commercial production of several *Trichoderma* species for crop growth and disease management. *Trichoderma atroviride* is a fast growing fungus, which produces profuse spores and is resistant to metalaxyl and captain, while having high tolerance to ridomil and other chemical fungicides

(Ezziyyani *et al*., 2007) *Trichoderma atroviride* forges a symbiotic relationship with plants and has been associated with plant growth promotion in addition to disease suppression (McBeath *et al.,* 2000).

**2.3.6.4. Chemical control**

Chemical management involves the use of chemical products capable of preventing infection or of slowing down the disease once it has started. Products used to control late blight are classified as contact, translaminar and systemic. Contact fungicides act on plant surface and stop germination and/or penetration of the pathogen, reducing primary sources of the disease. They are also known as protestant or residual fungicides. Copper fungicides and dithio-carbanates are among the most important. They only protect the area where fungicide is applied; leaves formed after spray of the product will not be protected against the pathogen. Systemic products are absorbed the foliage or roots. Translocation takes place from bottom top, sometimes the other way round, internally through Xylem and phloem. They are able to protect leaves formed after the spray. They inhibit some or various specific phases of pathogen development. The constant use of certain products has caused the appearance of pathogen strains resistant to these fungicides. Translaminar are products capable of moving though the leaf but not from leaf. For this reason, leaves formed after the product has been sprayed will not be protected against pathogen (Perez and Forbes, 2010).

A number of fungicides can be sprayed to manage late blight. The key for late blight management is to use any of the following materials in preventative manner, and some are better than the others. The protectant fungicides most commonly used are chlorothalonil (Bravo, echo, and others) Mancozeb (manzate 75DF, Dithanse DF, Penncozeb 75 DF, and ManeX II, Maneb (Maneb 75 DF or ManeX). and Metiram (PolyGram 80 DF) in combination

with triphenyl tin hydroxide (Super Tin 80WP) (Thomas, 2000). Bravo weather stick has long been an industry standard, and if used at the very stage of disease development can be quite effective. Current chemical practices to manage late blight include a mixture of fungicides designed to slow the disease progress (Gisi and Cohen, 1996). Systemic fungicides inhibit ribosomal RNA (rRNA) polymerases in fungi by reducing incorporation of uridine (Majid *et al*., 2008)

Contact fungicides are effective against pathogen arrival to the plant and have not resulted in pathogen resistance after many years of use. They coat leaves to prevent infection, but cannot stop infection once. They also must be reapplied at certain intervals to protect new grow when disease threatens. Therefore, they must be applied before plants are exposed to sporangia (Binyam *et al*., 2014). They can only protect new uninfected growth form the disease (McGrath, 2016). The new strains of the Oomycete produced as recombinants of fertilization of the two mating –types (A1 and A2) are resistant to some of the systemic fungicides, like Metalaxyl or Ridomil and, therefore, sprays with such materials are ineffective against such stains. When applying contact fungicides, is complete coverage of the foliage with fungicide is necessary to enable disease prevention; regardless of spray methods (ground or air, traditional or newer technology sprays) (MAFRI, 2002). Farmers can lose the entire crop if timely spray of fungicides is not done.

**2.3.6.5. Integrated late Blight management**

Today a combination of methods, like crop rotation, resistance breeding, chemical treatments, dehaulming of the foliage prior to harvest and the use of high quality seed potato, are need to keep late blight under control. There are also forecast systems, which aims at predicting when the weather is suitable for the pathogen and thus recommend when to spray the fields with

fungicides (Haverkort *et al*., 2008). An effective, economical, and sustainable disease management strategy should incorporate all the available approaches of a disease management program. The first step in integrated control is reducing the primary source of inoculums. Next to that, both partial resistance (lower susceptibility) and fungicides can slow down the development of late blight. Nerstad *et al.* (2007) showed that exploiting high foliage resistance to reduce fungicide input was risky when field resistance to tuber blight was low. When field resistance to tuber blight was high, a medium-high resistance in the foliage cloud be exploited to reduce the fungicide input.

Integrated management of potato late blight has been adopted as a strategy in Ethiopia over the past many years (Kassa *et al*., 2002). In this regard, late blight resistant or tolerant varieties have been released over the years and are now part and parcel of the production systems in different parts of the country. Nonetheless, the ability of *P. infestans* to develop new physiological races and breakdown of varietal resistance has been encountered. To date, the vast majority of improved potato and tomato varieties commonly grown have lost resistance to late blight (Fry, 2008) and must be supplemented with fungicides to reduce the rate of disease progress (Kassa *et al*., 2002). This was achieved through the use of the phenylamide fungicides, like ridomil. The first spray with ridomil MZ 63.5% WP at a rate of 2 kg ha-1 and followed by 2-3 sprays of dithane M-45 at a rate of 3 kg ha-1 were found to be effective in managing late blight in Ethiopia (Bekele and Yaynu, 1996). According to Mesfin and GebreMedhin (2007), three sprays with ridomil gave the lowest area under disease pressure curve (AUDPC) and the highest yield. Mancozeb sprayed treatment at emergence and then followed at 15 days interval gave the second highest yield, while one ridomil spray at

symptom appearance gave the third highest yield and there was no significant difference between ridomil and mancozeb treatments.

# 3. MATERIALS AND METHODS

## 3.1. Description of Study Area

### 3.1.1. Location

The study was conducted at Frwocha kebeles in Boloso Bombe Woreda in Wolaita Zone, SNNPR. The area is situated along Ajora falls in Wolaita Zone with a capital town of Bombe which is located 325 km and 55 km away from Addis Ababa and Wolaita Sodo town through Hossana exit, respectively. The relative location of the Woreda is Kambata Tambaro at North, Boloso Sore Woreda at East, Sodo Zuria and Kindo Koysha Woreda at South, and Damot Sore Woreda at West. The area locates 7.03-7.19 North (Latitude) and 37.44-37.66 East (Longitude).The altitude of the Woreda is 501-2500 meter above sea level. The total 2`area of the Woreda is 272.2 square km and contains 18 rural kebeles and 2 town kebeles in total of 20 Kebele administrations (WZFEDD, 2014).

### 3.1.2. Climate

Agro climatically, the Woreda is classified as Woina Dega which cover 83% of total area and the remaining 17% is Dega (BSWARD offices, 2014), where favorable climate condition for settlement.The average temperature varies between10 to $20^0$C. Rain occurs during June to August and September is a transitional period between rainy and dry season and the annual rain fall of the Woreda is 1201mm to 1600mm (Wolaita Zone Metrological offices, 2014).

### 3.1.3. Soil and agronomic practices

In the study area farmers mainly grow Tomato (*Lycopersicone sculentum Mill*.), Onion (*Allium cepa L.)*, Pepper (*pipernigrum*) pigeon pea (*cajanuscajan*), Ginger (*Zingiber officinale*), Maize (*Zea may*), Haricot-bean (*Phaseolus vulgaris)* Sorghum (*sorghum bicolour)*

Teff (*Eragrostis teff*) Sesame (*sesamum indicum*) and Cabbage (*Brassica oleracea)* are also among the widely cultivated crops in the area (Alemu Anshiso *et al*,. 2017).

### 3.2. Experimental Design and Treatments

A factorial experiment with two factors was conducted under rain fed conditions in 2019 rainy season. Three tomato varieties was tested with five levels of fungicide spray frequencies (unsprayed, one-time spray, two times spray, three times spray, four times spray) within seven days' interval and the first spray was started at the onset of the disease. Experiment was arranged in completely randomized block design (RCBD) with factorial arrangement. The total numbers of treatments were 3*5=15. Each plot had size 3m length and 4m width and distance 1m between plots and 1m between blocks. There were 5 rows per plot. The spacing between rows was 60cm and between plants 30cm.The total experimental area is 45*12(540$m^2$). Natural infection was used as sources of inoculums. The fertilizer rate recommended by Melkasa agricultural research center (Lemma, 2002), i.e. 200kg /ha of NPS was applied rows transplanting and 100kg/ha of urea were outside dressing early flowering stage.

#### 3.2.1. Experimental materials

The experimental materials were different tomato varieties and fungicide (Ridomil MZ Gold 68.5% WG) used at the manufacturer's label dose of 3.5 kg ha-1 (Anonymous, 2011) with five spray frequencies. Seeds of three released tomato varieties, Metadel (moderately resistance), Melkasalsa (highly susceptible) and ARPTd2 (resistance) was evaluated at Bombe Woreda (Frwocha Kebele) (MoARD, 2005; MoA, 2012; Jiregna, 2014). The varieties were obtained from Melkasa Agricultural Research Center, Ethiopia.

### 3.2.2. Seedling raising and transplanting

The appropriate method of raising seedlings recommended by the MARC (Getachew*et al.*, 2014) was used. Seedlings for the field experiment were raised on three seedbeds with width of 1 m and 5 m length for each variety. Width of walking area (path) between seedbeds was 60 cm. The seed was sown at the depth of 0.5 cm with 30cm x 15cm spacing between rows and seeds, respectively in each bed. Grass mulch was applied on each bed and was removed after the seedlings emerged. Weeding and irrigation were out carried as necessity. Seedlings were transplanted at appropriate stage i.e. 25 and 20 days after sowing in the nursery bed. Seeds for the experiment were sown on seed bed on 03/01/2012 E/C. After three weeks, seedling was exposed to hardening before transplanting and transplanting was carried when ready to plant.

Table 1. Descriptions of the treatment combinations used for the field experiment

| Tomato variety | Year of Release | Name | Source | Treatment combinations | Assigned Treatment Code | Reaction to LB |
|---|---|---|---|---|---|---|
| V1 | 2012 | ARP tomatod2 | MARC/EIAR | V1 + $FC_0$ | T1 | R |
| | | | | V1 + $FC_1$ | T2 | |
| | | | | V1+ $FC_2$ | T3 | |
| | | | | V1+$FC_3$ | T4 | |
| | | | | V1+$FC_4$ | T5 | |
| V2 | 1997/98 | Melkasalsa (Serio) | MARC/EIAR | V2 + $FC_0$ | T6 | S |
| | | | | V2+ $FC_1$ | T7 | |
| | | | | V2+$FC_2$ | T8 | |
| | | | | V2+$FC_3$ | T9 | |
| | | | | V2+$FC_4$ | T10 | |
| V3 | 2005 | Metadel (Caraebo) | MARC/EIAR | V3 + $FC_0$ | T11 | MR |
| | | | | V3+ $FC_1$ | T12 | |
| | | | | V3 +$FC_2$ | T13 | |
| | | | | V3+ $FC_3$ | T14 | |
| | | | | V3 + $FC_4$ | T15 | |

Where: V1=ARP Tomatod2 variety; FC = fungicide spray; V2 = Melkaslsa variety; V3= Metadel variety; $FC_0$= fungicide spray zero; $FC_1$= fungicide spray one times; $FC_2$= fungicide spray two times; $FC_3$ =fungicide spray three times; $FC_4$= fungicide spray four times; LB = late blight; R= Resistance; MR = moderately resistant; S = Susceptible. Source: MoARD, 2005; MoA, 2012; Jiregna, 2014.

### 3.3. Data collected

#### 3.3.1. Disease incidence

Incidence of *Phytophthora infestans* was assessed by counting the number of infected plants in the middle three rows and was expressed as percentage of total plants examined.

$$Disease\ incidence\ (\%) = \frac{Number\ of\ Diseased\ plants}{Total\ number\ of\ plants\ examined} x100$$

#### 3.3.2. Disease severity

Disease severity was assessed seven times based on the disease progress from the middle three rows from 10 randomly-selected and pre-tagged tomato plants at 7 days' interval starting from the onset of symptoms until the crop attained its physiological maturity. Disease severity was recorded by using the 1- 9 scale suggested by Horneburg and Becker (2011), where1 =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. The disease severity scores were converted to percentage Severity index (PSI) (Agrios, 2005).

$$PSI(\%) = \frac{Snr}{(Npr)x(Msc)} x100$$

Where $Snr$ is the sum of numerical ratings; $Npr$ is the number of plants rated; and Msc is the maximum score on the scale.

### 3.3.3. Area under disease progress curve (AUDPC)

AUDPC was computed from PSI value for each plot as described by Campbell and Madden (1990).

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

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 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. Moreover, the percentage fruit infection was computed as:

$$PFI\ (\%) = \frac{No.of\ fruit\ infected}{Total\ No.of\ fruits} x100$$

**Disease progress rate:** The rate of foliar disease development was quantified by repeated assessments of the percentage of leaf and stem area affected by late blight in each plot started during the disease onset.

$rL = [\ln(y_f/(1-y_f)) - \ln(y_0/(1-y_0)]/(t_f - t_0)$ (Liberalized equation)

The logistic equation describes an S-shaped growth curve where $dY_t/d_t$ (the absolute rate of disease increase) is proportional to the amount of disease at any given time ($Y_t$) multiplied by a logistic rate constant (rL) and correction factor dependent on the proportion of plants already infected ($1-y_t$).

### 3.3.4. Assessment of Growth, Yield and Yield Related Traits

The following data on crop growth and yield parameters were determined from each plot.

**Days to 50% flowering:** was recorded as the number of days from transplanting until 50% of plants had at least one open flower, flowering per plant.

**Days to 50% fruit setting:** was recorded as the number of days from transplanting until 50% of plants had at least one fruit per plant.

**Stand count:** was recorded as the number of plant stand after transplanting of seedling during at harvesting of fruits.

**Number of branches:** was recorded as the average number of branches per plant of the 10 plants in the middle rows at last harvesting of fruits.

**Number of days to first and last fruit picking:** was recorded as the number of days from transplanting to first picking and the number of days to last picking of fruits, respectively.

**Number of fruit clusters per plant:** was recorded as the number of fruit clusters per plant of the 10 plants in the middle rows.

**Number of fruits per plant:** was recorded as the average number of fruits per plant of the 10 plants in the middle rows.

**Yield (t/ha):** marketable, unmarketable and total fruit yields was recorded from the three middle rows for each treatment and converted to yield (ton per hectare).

**Single fruit weight:** was recorded the weight of fruit randomly taken from marketable harvested fruits, about 20 fruits.

**Relative percent of yield loss and yield increase in fruit yield**

Relative present yield loss from each plot would be calculated using:

$$\text{Relative Yield Loss}(\%) = \frac{Y_{bt} - Y_{1t}}{Y_{bt}} x100$$

Where, $Y_{bt}$ is the yield of best treatment (maximum protected plot) and $Y_{lt}$ is the yield of lower treatments.

### 3.3.5. 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 of each tomato variety per kilogram was obtained from the prevailing 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.

Partial budgeting was employed to assess profitability of any new technologies (practices) to be imposed to the agricultural business practice. Partial budget analysis is a method of organizing data and information about the cost and benefit of various agricultural alternatives (CIMMYT, 1988). Marginal analysis is concerned with the process of making choice between alternative factor-product combinations considering small changes. Marginal rate of return is a criterion which measures the effect of additional capital invested on net returns using new managements compared with the previous one (CIMMYT, 1988). It provides the value of benefit obtained per the amount of additional cost (variable cost) incurred percentage. MRR was calculated using: Percentage. MRR would be calculated using:

$$MRR = \frac{DNI}{DIC} X\ 100$$

Where, MRR is marginal rate of returns, DNI, difference in net income compared with control, DIC, difference in input cost compared with control.

The following points were considered during cost benefit analysis using partial budget:

- ❖ 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.
- ❖ It is assumed that farmers produce this variety under integrated management of tomato late blight when the variety provided 100% marginal rate of returns.

### 3.3.6. 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, using appropriate statistical software, general linear model (GLM) of SAS version 9.2 (SAS, 2009). The treatment mean comparisons were separated using the least significant difference (LSD) test at 5% levels of significance. Correlation analysis was used to determine the relationships between growth, yield and yield related traits, 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.

# 4. RESULTS AND DISCUSSION

## 4.1. Effect of Fungicide spray frequency and tomato variety on incidence and severity of tomato late blight

In 2019 cropping seasons, the main effects of variety and fungicide spray frequency reveal significant difference on disease parameters; interaction effects were presented, on some disease parameters.

### 4.1.1. Late blight incidence

The research result revealed significant ($p \leq 0.01$) differences in tomato late blight incidence among fungicide spray frequency, tomato varieties and interaction effect (Appendix Table1). Fungicide spray frequency and tomato varieties were significantly reduced late blight incidence at all assessment date, 27, 34 ,41 and 48 days after transplant(DAT) as compared to the other unsprayed plots. The maximum disease incidence on interaction effect was recorded from variety Melkaslsa * unsprayed plots (95.26%), while the minimum level of disease incidence (42.34%) was recorded from variety ARPTd2 * four times sprayed plots at 48days after transplanting (Table2). The results of the present study verified the idea of Agrios (2005) that suggested that it is always advisable to use resistant varieties, even when sprays with fungicides are considered the main control strategy. Impervious varieties delay the onset of the disease or reduce its rate of development so that fewer sprays on it may be needed to obtain a satisfactory level of control of the disease.

Table 2.Interaction effect of varieties and fungicide spray frequencies on mean incidence of tomato late blight at Bombe Woreda during 2019 cropping season

| Varieties | Frequency | Tomato late blight incidences % at | | | |
|---|---|---|---|---|---|
| | | 27DAT | 34DAT | 41DAT | 48DAT |
| ARPTd2 | Control | 16.56 [c] | 19.03 [c] | 72.6 [c] | 80.7 [c] |
| | One time | 0. 00 [d] | 0. 00 [d] | 68.7 [c] | 72.68 [d] |
| | Two times | 0. 00 [d] | 0. 00 [d] | 59.4 [d] | 62.57 [e] |
| | Three times | 0. 00 [d] | 0. 00 [d] | 53.58 [e f] | 57.59 [f] |
| | Four times | 0. 00 [d] | 0. 00 [d] | 22.0 [h] | 42.34 [h] |
| Melkasalsa | Control | 28.7 [a] | 42.20 [a] | 92.36 [a] | 95.2 [a] |
| | One time | 0. 00 [d] | 0. 00 [d] | 87.54 [a] | 87.44 [b] |
| | Two times | 0. 00 [d] | 0. 00 [d] | 70.9 [c] | 76.35 [d] |
| | Three times | 0. 00 [d] | 0. 00 [d] | 41.7 [g] | 57.59 [f] |
| | Four times | 0. 00 [d] | 0. 00 [d] | 41.3 [g] | 54.84 [f] |
| Metadel | Control | 20.40 [b] | 35.45 [b] | 90.3 [a] | 91.4 [b a] |
| | One time | 0. 00 [d] | 0. 00 [d] | 81.45 [b] | 82.2 [c] |
| | Two times | 0. 00 [d] | 0. 00 [d] | 57.2 [ed] | 63.8 [e] |
| | Three times | 0. 00 [d] | 0. 00 [d] | 51.6 [f] | 54.4 [g f] |
| | Four times | 0. 00 [d] | 0. 00 [d] | 44.66 [g] | 50.6 [g] |
| LSD % | | 2.39 | 0.95 | 5.04 | 4.07 |
| VAR*FC | | HS | HS | HS | HS |
| CV | | 32.70 | 9.05 | 4.92 | 3.3 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). CV= Coefficient of Variability, HS=highly significant, DAT=days of transplant*

On final assessment of tomato late blight incidence, the result showed significant ($p \leq 0.01$) differences in tomato late blight incidence among fungicides spray frequency and tomato varieties. But interaction effect was not significant at the last date of assessment (55 days after transplant) (Appendix Table 1). Mean late blight incidence did not above 67.987 % on ARPTd2, but reached up to 81.695% on Melkasalsa, and 71.225% on Metadel at final assessment date (55 days after transplant), respectively. Disease incidence on ARPTd2 was reduced by 13.7% over Melkaslsa and 3.24% over Metadel at final date of assessment at Bombe Woreda (Frwocha Kebele). Among the fungicide spray frequencies, at the last date of assessment (55 days after transplant), the highest mean incidence was 91.15% recorded from unsprayed plots of all varieties. Correspondingly, at the same time the lowest mean incidence was 56.77% was recorded from plots treated four times with Ridomil at 7 days' interval on all varieties as compared to the unsprayed plots (Table2). As Berger (1988), Bedi *et al.* (1989), and Fry and Shtienberg,(1990) stated disease incidences between different varieties with reaction to diseases development were variable and increase with time at the rates of epidemic much faster than disease severities for the same pathogenic under the same conditions.

Table 3 Main effect of varieties and fungicide spray frequencies on mean incidence of tomato late blight at Bombe Woreda during 2019 cropping season

| Varieties | Tomato late blight incidences % at 55 DAT |
|---|---|
| | 55DAT |
| Melkasalsa | 81.70[a] |
| Metadel | 71.23[b] |
| ARPTd2 | 67.99[b] |
| LSD% | 9.94 |
| Fungicide Frequency | |
| Control | 91.15 [a] |
| One time | 76.2[b] |
| Two times | 75.51[b] |
| Three times | 68.56[bc] |
| Four times | 56.76[c] |
| LSD % | 12.83 |
| VAR*FC | NS |
| CV | 18.03 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). 55DAT =days after transplant, CV= Coefficient of Variability, NS=non-significant*

**4.1.2. Severity of late blight**

In present study, symptoms of tomato late blight appeared after flowering stage and became more severe after fruiting stage for this particular pathogen, this showed tomato plants were more susceptible at fruiting stage of the plant than early at the vegetative stage. This observation is in line with results of Jones *et al.* (1997) and Naveenkumar *et al.* (2001) stated

that plants are more susceptible to infection by the pathogen during fruiting stage. Neversless, disease scoring have been happening after identification of the pathogen, *Phytophthora infestans,* under laboratory by using cellophane tape method, direct observation of the pathogen under microscope using scoch tape hooding on diseased plant parts and sticking on the slide and observed under compound microscope with 40X objectives at Wachemo university in the plant pathology laboratory.

The analysis of variance showed that late blight disease severity was significantly ($P<0.05$) affected by the main effects of genotypes and fungicide spray frequencies in all the disease severity assessment. However, the analysis did not show significant ($p > 0.05$) difference in respect of interaction effect on late blight severity at all dates of assessments except 34DAT (Appendix Table2). The highest late blight severity was recorded from variety Melkaslsa (43.28) and, the lowest was recorded on variety ARPTd2 (32.59) (Table 4).

This variance might be due to genetic difference among the varieties to resist the epidemics of late blight. The outcome of the current study was in agreement with the findings of Phillips *et al.* (2005) who stated that if diversity is available for plant resistance against late blight, the disease severity would be reduced if any given mixture or variety is developed. All ridomil foliar spray frequencies were significantly ($p \leq 0.05$) different from the unsprayed plots in reducing disease severity (Appendix Table2). Thus, the maximum severity (66.39 %), at 55 days, after transplanting was recorded on unsprayed plots, while the minimum level of late blight severity (20.3%) was observed on the plots sprayed with four time ridomil foliar spray frequency at 7-day interval. From the outcome, different foliar spray frequencies of ridomil would be possible to decrease the magnitude of late blight severity on each variety. Regular foliar applications (4 times) of ridomil can be used for high efficacy; even during the wet

season as it has less chance to be washed off by rainfall. Therefore, it is desirable to use this fungicide accordingly. The result of the present study coincides with the investigation of Abhinandan *et al.* (2004) who reported that frequently applied fungicide by far reduced disease severity as compared to the less frequently sprayed fungicide and unsprayed one.

Table 4 Main effect of varieties and fungicide spray frequencies on mean severity of tomato late blight at Bombe Woreda during 2019 cropping season

| Varieties | Tomato late blight severity (%) | | | |
|---|---|---|---|---|
| | 34DAT | 41DAT | 48DAT | 55DAT |
| Melkasalsa | 1.88 [a] | 24.4 [a] | 41.2 [a] | 43.28 [a] |
| Metadel | 1.57 [b a] | 15.28 [b] | 35.1 [b] | 38.18 [b] |
| ARPTd2 | 1.26 [b] | 14.66 [b] | 30.35 [c] | 32.59 [c] |
| LSD% | 0.42 | 5.7 | 2.37 | 1.87 |
| Frequency | | | | |
| Control | 7.8 [a] | 42.61 [a] | 62.23 [a] | 66.38 [a] |
| One time | 0.00 [b] | 22.7 [b] | 39.1[b] | 41.68 [b] |
| Two times | 0.00 [b] | 13.4 [c] | 32.4 [c] | 33.91 [c] |
| Three times | 0.00 [b] | 7.36 [dc] | 25.85 [d] | 27.8 [d] |
| Four times | 0.00 [b] | 4.5 [d] | 18.2 [e] | 20.3 [e] |
| LSD % | 0.54 | 7.4 | 3.07 | 2.4 |
| VAR*FC | S | Ns | Ns | Ns |
| CV | 36.1 | 42.3 | 8.9 | 6.58 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). 55DAT =days after transplant, CV= Coefficient of Variability, S = Significant at p< 0.05, NS= none significant*

### 4.1.3. Disease progress rate

The analysis of variance showed that disease progress rate was significantly ($p<0.001$) affected by the interaction of varieties and fungicides spray frequencies. Disease progress rate (r) was highly significant for both main effects of varieties and fungicides spray frequencies (Table 5). The varieties ARPTd2, Metadel and Melkasalsa showed disease progress rate (r) of 0.08, 0.08 and 0.09 units per day respectively on unsprayed plots. Conversely, all sprayed plots reduced the disease progress rate significantly. Moreover, among the different foliar spray frequencies, the lower infection rates (0.04, 0.04 and 0.06) per day were recorded from the plots treated with ridomil four times at 7days' interval on varieties ARPTd2, Metadel and Melkasalsa respectively. Hence the rate of late blight progress was faster on unsprayed plots than on sprayed plots, regardless of tomato genotypes (Table5). The highest disease progress rate of (0.09units per day) was obtained on unsprayed plot of the variety Melkasalsa, however the lowest disease progress rate of (0.04 units per day) was recorded from the plots of ARPTd2 and Metadel variety treated with ridomil four times at 7 days' interval (Table 5). Bekele and Hailu (2000) reported that frequent application of fungicide could retard the rate of late blight progress in, alternate host for the pathogen.

Table 5. Interaction effect of fungicide spray frequencies and tomato varieties on disease progress rate (r) at Bombe Woreda during 2019 cropping season

| Varieties | Frequency | DPR(units/day) |
|---|---|---|
| ARPTd2 | Control | 0.08[a] |
| | One time | 0.07[ab] |
| | Two times | 0.06[b] |
| | Three times | 0.05[c] |
| | Four times | 0.04[d] |
| Melkasalsa | Control | 0.09[a] |
| | One time | 0.08[a] |
| | Two times | 0.07[b] |
| | Three times | 0.06[bc] |
| | Four times | 0.06[c] |
| Metadel | Control | 0.08[a] |
| | One time | 0.07[ab] |
| | Two times | 0.06[c] |
| | Three times | 0.06[c] |
| | Four times | 0.04[d] |
| LSD % | | 0.01 |
| VAR*FC | | HS |
| CV | | 16.70 |

Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). DPR = disease progress rate, CV= Coefficient of Variability, HS= highly significant

### 4.1.4. Area under Disease Progress Curve

The area under disease progress curve (AUDPC) used to combine multiple annotations of disease progress into a single value and gives a better indication on disease development over time, which is essential to predict yield losses. In the present study AUDPC showed highly significant ($P \leq 0.001$) difference among the varieties as well as different foliar spray frequencies (Appendix Table 3). Among, varieties the highest AUDPC (629.81 %-days) was observed on variety Melkasalsa and the lowest AUDPC (441.61% -days) was observed on variety ARPTd2. The AUDPC is a very suitable summary of plant disease epidemics that integrates initial disease severity, the rate parameter and the duration of the epidemic, which regulates final disease severity (Madden *et al.*, 2008).

In future the effects of crop disease resistance on disease progress can be evaluated using AUDPC. Normally, the highest degree of significance in the difference AUDPC values among the estimated varieties might be due to their genotypic resistance characteristics to late blight response, (Table 5).

However, the highest mean AUDPC value (1043.8 % days) was observed from unsprayed plots and the lowest mean AUDPC value (230.18% days) was recorded from plots treated with four-time spray frequencies of ridomil at 7day interval.

The results of the current finding were in line with the report of Mesfin and Gebremedhin (2007) and Ayda (2015) who found that, on its alternate host (Irish potato), the moderately resistant varieties had the lowest AUDPC values when supplemented with fungicide treatments in wet season.

Table 6 Main effect of varieties and fungicide spray frequencies on mean AUDPC % days of tomato late blight at Bombe Woreda during 2019 cropping seasons.

| Varieties | |
|---|---|
| | AUDPC ( % days) |
| Melkasalsa | 629.8 [a] |
| Metadel | 481.5 [b] |
| ARPTd2 | 441.6 [b] |
| LSD% | 74.5 |
| Frequency | |
| Control | 1043.86 [a] |
| One time | 544.6 [b] |
| Two times | 439.68 [c] |
| Three times | 329.9 [d] |
| Four times | 230.18 [e] |
| LSD % | 96.18 |
| CV | 19.24 |

Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). AUDPC % days =Area under disease progress curve, CV= Coefficient of Variability

**4.1.5. Percent of fruit infection per plant**

The number of infected fruits per plant was counted and then changed into percentage. The analysis of data on percent fruit infection showed that there was very highly significant difference among fungicide and varieties ($p<0.001$), but there was not interactions effect on

percent fruit infection (Table 6 and Appendix Table 3). The lowest mean was observed on variety ARPTd2 (6.615%) and the highest mean was recorded from Melkasalsa (9.73%) as compared to the other varieties (Table 6). This variation might be due to the inherent genetic variability of the three varieties in the current study (2019 cropping season), symptoms of late blight appeared at flowering stage and became more severe after flowering and fruiting stage for this specific pathogen. This showed that tomato plants were more susceptible at fruiting stage of the plant than early at the vegetative stage. This result coincides with the findings of Jones *et al.* (1997) who stated that plants are more susceptible to infection by the pathogen during fruiting stage. As compared to the different sprayed treatments, unsprayed plots of the three varieties had significantly higher, (14.46%) fruit infection per plant (Table 6). Similarly, the lowest (3.31%) fruit infection per plant was recorded from the plots treated four times with ridomil at 7 days' interval (Table 6). This might be due to the high number of spray times (four times sprays) that blocked the development of the disease under natural environment.

Table 7 Effect of late blight on fruit infection of tomato under integration of variety and fungicide spray frequencies at Bombe Woreda 2019 cropping season

| Varieties | **Mean of Fruit Infection (%)** |
|---|---|
| Melkaslsa | 9.73[a] |
| Metadel | 7.56[b] |
| ARPTd2 | 6.615[b] |
| LSD% | 1.65 |
| Frequency | |
| Control | 14.46 [a] |
| One time | 9.970[b] |
| Two times | 7.171 [c] |
| Three times | 4.926[d] |
| Four times | 3.316[d] |
| LSD % | 2.137 |
| VAR*FC | Ns |
| CV | 27.780 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). CV= Coefficient of Variability.*

## 4.2. Effect of Variety and Fungicide Frequencies on Tomato Late Blight on Crop Growth, Yield and Yield Correlated Parameters

### 4.2.1. Crop Growth Parameters

The interaction of variety and fungicide frequencies did not show significant difference ($P>0.05$) in most components of crop growth parameters such as, first and last harvesting date, days to 50% flowering, number of branches per plant, plant stands per plot and number of fruits per plant; but the main effect of fungicide frequencies and variety were highly significant ($p\leq0.001$). This indicates that each variety responded differently to the different foliar spray frequencies. However, days to 50% fruit setting, number of fruit cluster per plant and single fruit weight in 2019 cropping season, there were significant difference on interaction effect (varieties x spray frequencies).

#### 4.2.1.1. Days to 50% Flowering

The research result revealed, very highly significant ($p\leq0.001$) difference was observed among the varieties and fungicide spray frequencies with regard to days to 50% flowering (Appendix Table 4). Metadel had longer days to 50% flowering than the other varieties (Table 7). This difference might have resulted from the variation in inherited characteristics of the tomato varieties. Among the different varieties, Melkasalsa and ARPTd2 showed earliest flowering, whereas ' Metadel' had delayed flowering. The result was in agreement with the finding of Shushay and Haile (2014) who found that days to 50% flowering ranged from 29 to 38.

With respect to fungicide spray frequencies, the unsprayed plots of the three varieties had also significantly shorter days to 50% flowering (Table 8). Among sprayed frequencies one and two times ridomil spray frequencies showed early to 50% days to flowering as compared to

the other spray frequencies at 7days intervals. This shows that frequent applications of fungicide reduces the disease pressure on the plant and extend the time for flowering and fruit setting.

#### 4.2.1.2. Plant Stand Count at Harvest and Number of Branches per Plant

In the present study the difference in the number of branches per plant and plant stand count at harvest were very highly significant ($p \leq 0.001$) among main effect of varieties and fungicide spray frequencies, but there was not interaction effect on these parameters (Appendix Table 4). The maximum number of branches per plant was recorded in the varieties Melkasalsa (6.39) and ARPTd2 (6.38), respectively, and the minimum number of branches per plant was recorded in the variety Metadel (4.69) (Table 6). ARPTd2 and Melkasalsa had relatively better plant stand count at harvest, while Metadel had less number of plant stand count at harvest than other tomato varieties (Table7). This difference might be resulted from the variation in genetic characteristics of the varieties. In the same way, unsprayed plots of the three tomato varieties had significantly ($p \leq 0.001$) less number of branches per plant (5.30) and plant stand count (9.0) at harvest than the sprayed plots regardless of the spray frequencies of ridomil at 7 days' intervals (Table 7). At the same time, the highest plant stands count and numbers of branches of 6.37and 12.55 were recorded from the sprayed plots of four times spray frequencies at 7 days' intervals, respectively (Table7).

This shows 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 achieve its normal physiological process.

#### 4.2.1.3. First and last picking date

As the result showed, very highly significant ($P \leq 0.001$) difference was observed among the varieties and fungicide spray frequencies with regard to first and last harvesting date (Appendix Table 4). ARPTd2 had relatively shorter first and last harvesting dates than the other varieties while the longest first and last harvesting dates were observed from variety

Metadel (Table 8). The number of days to first harvesting was ranged from 77.73- 88.4 days for the varieties ARPTd2 and Metadel, respectively. Also, the number of days to last harvesting range from 84.26 - 94.6 days for ARPTd2 and Metadel varieties, respectively (Table 7). This difference might come due to variation in genetic properties of the varieties. Moraru *et al*. (2004) and Ketema *et al*. (2016) 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 contract with the present results.

Fungicide spray treatments had highly significant ($p<0.0001$) difference in the duration for first and last harvesting dates (Appendix Table 8). The shortest (85.66) first harvesting date was recorded from unsprayed from all varieties; However, longest (87.0) was recorded from four time sprayed plots of all varieties. Control plots of the three varieties had significantly shorter last harvesting days than the sprayed plots and the longest first and last harvesting duration,87.0 and 94.2 days, respectively, acquired four times ridomil spray plots frequencies at 7 days' intervals (Table 7). Similar results were reported by Getachew (2017) the shortest first harvesting date was recorded from unsprayed plot and one time sprayed plots of all varieties, and the longest was recorded from three and four time sprayed plots of all varieties.

Table 8 Effect of late blight on growth parameter of tomato under integration of fungicide spray frequencies and varieties at Bombe Woreda 2019 cropping season

| Varieties | 50%DF | FPD | LPD | NBPP | PSC |
|---|---|---|---|---|---|
| ARPTd2 | 25.5[c] | 77.7[c] | 84.26[c] | 6.38[a] | 11.93[a] |
| Melkaslsa | 28.5[b] | 85.26[b] | 90.9[b] | 6.39[a] | 11.2[b] |
| Metadel | 33.33[a] | 88.40[a] | 94.6[a] | 4.69[b] | 9.86[c] |
| LSD% | 1.45 | 0.97 | 0.68 | 0.19 | 0.4 |
| Frequency | | | | | |
| Control | 27.6[c] | 80.6[d] | 85.6[e] | 5.3[d] | 9.0[d] |
| One time | 27.22[c] | 82.3[c] | 87.55[d] | 5.57[c] | 10.3[c] |
| Two times | 28.78[cb] | 83.55[c] | 90.1[c] | 5.78[c] | 11.0[b] |
| Three times | 29.8[b] | 85.44[b] | 92.2[b] | 6.06[b] | 12.1[a] |
| Four times | 32.1[a] | 87.0[a] | 94.2[a] | 6.37[a] | 12.55[a] |
| LSD( 5%) | 1.87 | 1.26 | 0.88 | 0.24 | 0.56 |
| CV% | 6.65 | 1.56 | 1.0 | 4.3 | 5.3 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD).50%DF=days to 50% flowering, FPD=First Picking Date, LPD =Last Picking Date,* NBPP*=Number of Branches per Plant, pSC=Plant Stand Count at Harvest, ARPTd2 =ARPTomatod2 CV= Coefficient of Variability.*

### 4.2.2. Yield and Yield Related Parameters

The effects of fungicide spray frequency and variety was very highly significant ($p<0.001$) difference in total yield, marketable yield, unmarketable yield. Also their interaction effect showed highly significant difference, except unmarketable yield.

The interaction of tomato varieties and fungicide spray frequencies showed significant difference (P>0.001) on all components of yield attributes such as number of fruit clusters per plant, single fruit weight, days to 50% fruit setting. All components of yield attributes had highly significant difference (P>0.001) among main effect of variety and fungicide spray frequencies (Appendix Table 5). Melkaslsa variety had the highest number of fruit clusters per plant and fruits per plant as compared to the other varieties 20.22 and 10.27, respectively (Table 9). Several authors, such as Emani *et al.* (2013) and Chernet*et al.* (2013) reported wide spread of differences in number of fruits per plant in tomato genotypes. The highest single fruit weight (128.08 g) was obtained from variety Metadel such as camper to other varieties (Table 9). This difference might have resulted from the dissimilarity in genetic background of the varieties.

Regarding fungicide spray frequencies, the lowest number of fruit per plant (3.31) number of fruit clusters per plant (11.27) and single fruit weight (93.03g) were obtained from unsprayed plots respectively. Also, the highest (15.24) number of fruit clusters per plant and number of fruits per plant (15.5) were obtained from plots treated three times with ridomil at7days' interval (Table 9). While the highest single fruit weight was obtained from plots treated four and three times with ridomil at 7days' interval with values of 105.91g and 104.36g respectively (Table8). Abhinandan *et al,* (2004) and Kaushik *et al.* (2011) reported that fungicides significantly reduced disease severity and gave increased yield over the control

Table 9 Main effect of late blight on yield related parameters of tomato under integration of varieties and fungicide spray frequencies at Bombe Woreda 2019 cropping season

| Varieties | NFPP |
|---|---|
| Melkasalsa | 10.27[a] |
| ARPTd2 | 8.186[b] |
| Metadel | 7.9[b] |
| LSD% | 7.9 |
| Frequency | |
| Four times | 15.578[a] |
| Three times | 12.51[b] |
| Two times | 7.766[c] |
| One time | 4.8[d] |
| Control | 3.31[e] |
| LSD (5%) | 1.47 |
| CV% | 17.3 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD). NFPP =number of fruit per plant, CV= Coefficient of Variability.*

The interaction effect of fungicide spray frequencies and tomato varieties showed significant ($p \geq 0.001$) difference on components of yield attributes such as number of fruit clusters per plant, single fruit weight and days to 50% fruit setting. Metadel with four-time fungicide spray frequencies had longer days to 50% fruit setting (56.33). Whereas, the unsprayed plot of the variety ARPTd2 was recorded shortest days of 50% fruit setting (43.3) (Table 10). Melkasalsa

variety with two times and three-times Ridomil fungicide spray frequencies had observed the highest number of fruit clusters per plant 22.7 and 22.0 as compared to other varieties, respectively. However, the lowest number of fruit clusters per plant (6.8) was recorded from variety Metadel with unsprayed plot compared to other treated plots. Similarly, the highest single fruit weight was obtained from variety Metadel combined with four-time fungicide spray (134.4g) treated plot compared to other varieties (Table 10), But the smallest single fruit weight (54.6 g) was recorded from variety Melkasalsa with control plot than other treated plots.

Table 10 Interaction effects of components of yield attributes tomato late blight under integration of varieties with fungicide spray frequencies at Bombe Woreda 2019 cropping season

| Varieties | Frequency | | | |
|---|---|---|---|---|
| | | DFS 50% | NFCPP | SFW(g) |
| ARPTd2 | Control | 43.3$^{g}$ | 9.767$^{e}$ | 102.833$^{f}$ |
| | One time | 45.3$^{fg}$ | 13.333$^{e}$ | 105.77$^{f}$ |
| | Two times | 46.8$^{fe}$ | 12.767$^{fe}$ | 113.200$^{e}$ |
| | Three times | 47.6$^{df}$ | 13.033$^{fe}$ | 119.700$^{d}$ |
| | Four times | 49.3$^{dc}$ | 11.80$^{feg}$ | 120.967$^{c\,d}$ |
| Melkasalsa | Control | 45.00$^{eg}$ | 17.267$^{d}$ | 54.600$^{i}$ |
| | One time | 46.00$^{fe}$ | 18.867$^{dc}$ | 57.467$^{hi}$ |
| | Two times | 49.0$^{dc}$ | 22.700$^{a}$ | 59.867$^{h\,g}$ |
| | Three times | 49.0$^{c}$ | 22.000$^{ba}$ | 61.400$^{g}$ |
| | Four times | 50.6$^{c}$ | 20.267$^{bc}$ | 62.333$^{g}$ |
| Metadel | Control | 43.6$^{g}$ | 6.800$^{j}$ | 121.667$^{c\,d}$ |
| | One time | 49.6$^{c}$ | 7.267$^{ij}$ | 119.700$^{d}$ |
| | Two times | 53.3$^{b}$ | 7.500$^{ih\,j}$ | 128.000$^{b}$ |
| | Three times | 54.6$^{ab}$ | 10.700$^{fg}$ | 132.000$^{a}$ |
| | Four times | 56.3$^{a}$ | 9.5$^{ihg}$ | 134.433$^{a}$ |
| LSD( 5%) | | 1.90 | 2.34 | 3.85 |
| CV% | | 2.34 | 9.78 | 1.50 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD).* DFS 50%= days to 50% fruit setting, NFCPP *=number of fruit clusters per plant, SFW= single fruit weight CV= Coefficient of Variability.*

#### 4.2.2.1Marketable and Total Fruit Yield

The combined effect of fungicide and variety showed significant ($p \leq 0.01$) difference on Marketable and total fruit yield (Appendix Table 6). The maximum marketable fruit yield (61.705 t ha-1) on interaction effect was recorded from variety ARPTd2*3 combination treated plots and the highest total fruit yield (67.305 t ha-1) was recorded from ARPTd2*2 combination treated plots, while the minimum (24.065 t ha-1) was recorded from Melkasalsa with unsprayed plot. This might indicate that the disease pressure was high during the experiment leading to very low yield. But, when we compared the present study report with, MoARD (2005), Belay (2009) and MoA (2012) yields of the varieties ranged from 31.4 (Roma VF) to 43.5 t ha-1(ARPd2). In general, the fruit yields of the ARPTd2 and Melkasalsa were relatively higher than the yield of the variety Metadel even while being under high disease pressure in this study.

This is in agreement with results of Desta and Yosef. (2015) who reported three times sprays of ridomil can give optimum fruit yield. According to Dillard *et al*. (1997), fungicide applications were found to have a variable effect on tomato yields.

Table 11 Effect of late blight on marketable and total fruit yield of tomato varieties and fungicide spray frequencies at Wolaita zone bombe Woreda during 2019 cropping season.

| Variety | Fungicide | MFY | TFY | RYL(%) |
|---|---|---|---|---|
| **ARPTd2** | Control | 27.21$^{h}$ | 35.64$^{g}$ | 47.04 |
| | One time | 48.90$^{d}$ | 56.23$^{c}$ | 16.44 |
| | Two times | 60.63$^{a}$ | 67.30$^{a}$ | 0.00 |
| | Three times | 61.70$^{a}$ | 67.16$^{a}$ | 0.20 |
| | Four times | 51.12$^{c}$ | 55.99$^{c}$ | 16.80 |
| **Melkasalsa** | Control | 24.06$^{i}$ | 36.56$^{gf}$ | 41.87 |
| | One time | 36.90$^{e}$ | 48.43$^{d}$ | 23.00 |
| | Two times | 40.06$^{d}$ | 49.66$^{d}$ | 21.04 |
| | Three times | 54.33$^{b}$ | 62.90$^{b}$ | 0.00 |
| | Four times | 50.00$^{c}$ | 58.03$^{b}$ | 7.74 |
| **Metadel** | Control | 24.87$^{ih}$ | 35.43$^{g}$ | 16.10 |
| | One time | 32.47$^{g}$ | 41.94$^{e}$ | 0.68 |
| | Two times | 33.94$^{fg}$ | 41.94$^{e}$ | 0.68 |
| | Three times | 35.43$^{fe}$ | 42.23$^{e}$ | 0.00 |
| | Four times | 33.00$^{fg}$ | 38.56$^{f}$ | 8.69 |
| **LSD%** | | 2.56 | 2.88 | |
| **CV%** | | 3.54 | 3.14 | |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD).* MFY= Marketable fruit yield, TFY = total fruit yield, *CV= Coefficient of Variability.RYL= relative yield loss*

#### 4.2.2.2. Unmarketable Fruit Yield

Analysis of variance (ANOVA) showed that the main effect of variety and fungicide spray frequencies highly significantly *(*$P<0.05$) influenced average unmarketable fruit yield. However, variety and fungicide did not interact to pose significant difference ($p>0.05$) on the average unmarketable fruit yield (Appendix Table 6). The highest unmarketable fruit yield. (10.50t $ha^{-1}$) were obtained from control (unsprayed) plots, while the lowest unmarketable fruit yield (6.17 t ha-1) was recorded from four-times fungicide sprayed plot. On the other hand, the highest unmarketable fruit yield was obtained from Variety which received Melkasalsa while the lowest unmarketable fruit yield recorded from variety which received ARPTd2 (Table 11). This is in agreement with results of Desta and Yosef (2015) who reported three times sprays of Metalaxyl (Ridomil) can gave 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 higher yield over the unsprayed plot. Kaushik *et al.* (2011) also reported significant variability in yield produced by six tomato varieties evaluated for pest and disease and productivity in Botswana.

Table 12. Effect of late blight on unmarketable yield of tomato varieties and fungicide spray frequencies at Wolaita zone bombe Woreda during 2019 cropping season.

| Variety | Unmarketable fruit yield |
|---|---|
| Melkasalsa | 10.04[a] |
| Metadel | 8.08[b] |
| ARPd2 | 6.56[c] |
| LSD | 0.39 |
| Fungicide | |
| Control | 10.50[a] |
| One time | 9.44[b] |
| Two times | 8.08[c] |
| Three times | 6.94[d] |
| Four times | 6.17[e] |
| LSD % | 0.39 |
| CV | 6.42 |

*Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance, Least Significant Difference (LSD).* UMFY= Unmarketable fruit yield, *CV= Coefficient of Variability.*

**4.3. Relative Fruit Yields loss**

The losses imposed on tomato fruit yields for different foliar spray frequencies were calculated relative to the yield of maximally protected plots, i.e. treated three times with ridomil at 7 days' interval. The highest fruit yield losses of 47.04%, 41.87% and 16.10% t ha-

1 were calculated from unsprayed plots of ARPTd2, Melkasalsa and Metadel varieties as compared to the best protected plots ARPTd2*2, Melkasalsa and Metadel three times sprayed with Ridomil (Table11). This was because plants on the less frequently treated plots failed to set fruits due to defoliation and dropped their fruits as a result of fruit rots caused by *P. infestans*. The result was in agreement with the report of Gwary and Nahunnaro (1998) who revealed yield losses 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. The fruit yield increases due to each of the different foliar spray frequencies were obtained as relative to the yield of individual treated with untreated plots, i.e. treated two and three times with ridomil at 7 days' intervals showed.

In general, it can be concluded that foliar spraying with ridomil three times and two times at 7 days' interval would better protect tomato from fruit yield losses than other foliar spraying frequencies of the same fungicide at the same interval. In addition use of fungicides and resistant varieties would ultimately reduce cost of crop protection.

**4. 4. Cost benefit analysis**

Cost benefit analysis was performed using partial budget analysis for integrated management of tomato at blight using three tomato varieties having with fungicide sprays. The maximum total gross yield benefits (1202066.66ETBha$^{-1}$ and 1118699.99ETBha$^{-1}$) were recorded from two time ridomil sprayed *ARPTd2 and Melkasalsa*3 time ridomil sprayed respectively (Table13). On the other hand, the lowest total gross yield benefit (640400ETBha$^{-1}$) was obtained from unsprayed ARPTd2 variety (Table 13). Variation in net benefit was observed among combinations of the three tomato varieties and fungicides. The highest net benefit

(1202066.667ETBha$^{-1}$) were obtained from two time ridomil sprayed frequencies *ARPTd2 (Table 13). And also the lowest (negative) net benefit was obtained from unsprayed plots of Metadel followed by ARPTd2 and Melkasalsa (Table13). The highest marginal rate return (87.94ETBha$^{-1}$) was obtained from two time ridomil sprayed frequencies* ARPTd2 followed by three time ridomil sprayed*Melkasalsa (56.21 ETB ha$^{-1}$) (Table 14)

Table 13 Partial budget analysis of fungicide sprays on three tomato varieties at Wolaita zone, 2019 main copping season.

| Varieties | Fungicide | TFY(t/ha) | AJY(t/ha) | SR (Br/ha) | TIC(Br/ha) | NP (Br/ha) | MRR (%) |
|---|---|---|---|---|---|---|---|
| ARPTd2 | Control | 35.64 | 32.07 | 641400 | 1000 | 640400 | 0.00 |
| | One time | 56.23 | 50.60 | 1012000 | 5166.67 | 1006833.33 | 87.94 |
| | Two times | 67.30 | 60.57 | 1211400 | 9333.34 | 1202066.66 | 46.85 |
| | Three times | 67.16 | 60.44 | 1208800 | 13500.01 | 1195299.99 | **D** |
| | Four times | 55.99 | 50.39 | 1007800 | 17666.68 | 990133.32 | **D** |
| Melkasalsa | Control | 36.56 | 32.90 | 658000 | 1000 | 657000 | **D** |
| | One time | 48.43 | 43.58 | 871600 | 5166.67 | 866433.33 | 50.26 |
| | Two times | 49.66 | 44.69 | 893800 | 9333.34 | 884466.66 | 4.32 |
| | Three times | 62.90 | 56.61 | 1132200 | 13500.01 | 1118699.99 | 56.21 |
| | Four times | 58.03 | 52.22 | 1044400 | 17666.68 | 1026733.32 | **D** |
| Metadel | Control | 35.43 | 31.88 | 637600 | 1000 | 636600 | **D** |
| | One time | 41.94 | 37.74 | 754800 | 5166.67 | 749633.33 | 27.12 |
| | Two times | 41.94 | 37.74 | 754800 | 9333.34 | 745466.66 | **D** |
| | Three times | 42.23 | 38.00 | 760000 | 13500.01 | 746499.99 | **D** |
| | Four times | 38.56 | 34.70 | 694000 | 17666.68 | 676333.32 | **D** |

TFY = Total marketable fruit yield; SR = Sale revenue; D=Dominance TIC= total input cost; NP= net profit; MRR = marginal rate of return.*Unit mean price of fruit per kilo gram was 20 birr at the time of fruit selling in 2019 cropping season,AJY=adjusted yield

### 4.5 Association of Late Blight Epidemics with Tomato Fruit Yield and yield components

Correlation analysis between fruit yield and yield components of tomato revealed strong, negative and positive associations between some components (Table, 14). In the analyzing of correlation between disease parameters and yield and yield components was critical since change of either of the parameters influenced the response of the other during the experiment.

Significance of associations between yield parameters and disease was observed using simple correlation analysis. Definite Pearson correlation coefficients (r) were used as indices for strength of the association. The negative correlation of late blight with fruit yield and yield components was found to be stronger with the AUDPC than final severity and incidence (55DAT).

Marketable fruit yield with final severity and percent fruit infection showed significant ($p \leq 0.05$) negatively correlated, r = -0.537 and -0.54. Similarly, AUDPC values also revealed significant ($p \leq 0.05$) and negative association with marketable fruit yield with correlation coefficient values of r = - 0.304 (Table 15). This indicates that the observed value of the disease had a substantial adverse effect on fruit yield of the tomato. This result is contract with the finding of Fekede (2011) who reported that the related disease parameters had a negative influence on yield. In general, percent fruit infection, AUDPC and final severity had significant negative correlations with yield and yield related parameters (total fruit yield, Marketable fruit yield, number of fruit clusters per plant, number of fruits per plant and single fruit) except unmarketable fruit yield for which had positive correlation (Table 14). This shows that the observed levels of late blight epidemics have a considerable adverse effect on yield associated 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 negative correlations between yield and disease indices under natural field conditions (Olanya *et al.*, 2001).

Table 14. Coefficient of correlation between late blight epidemics and yield and yield related traits of tomato under integration varieties and fungicide spray frequencies at 2019 cropping season

***correlation is highly significant at p< 0.01, **correlation is significant at p< 0.05, correlation is significant at p< 0.01, ns= correlation is non-significant at p> 0.05,55 DATi== disease incidence days after transplanting(final incidence), 55DATs= disease severity days after planting final severity, AUDPC=area under disease progress curve, Infpp=infected fruit per plant, NBPP =number branches per plant, NFCPP=number of fruit cluster per plant, NFPP=number of fruits per plant, SFW = single fruit weight, MFY=marketable fruit yield, UNMFY= unmarketable fruit yield, TFY= total fruit yield.

| | 55DATi | 55DATs | AUDPC | InfPP | NBPP | NFCPP | NFPP | SFW | MFY | UNMFY | TFY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 55DATi | 1 | | | | | | | | | | |
| 55DATs | 0.52** | 1 | | | | | | | | | |
| AUDPC | 0.794*** | $0.185^{ns}$ | 1 | | | | | | | | |
| InfPP | $0.066^{ns}$ | 0.793*** | 0.346** | 1 | | | | | | | |
| NBPP | -0.576*** | -0.635** | -0.380** | $-0.25^{ns}$ | 1 | | | | | | |
| NFCPP | $-0.273^{ns}$ | $-0.260^{ns}$ | $-0.095^{ns}$ | $-0.168^{ns}$ | $0.220^{ns}$ | 1 | | | | | |
| NFPP | -0.633*** | -0.82*** | -0.430** | -0.41** | $0.269^{ns}$ | $0.09^{ns}$ | 1 | | | | |
| SFW | $-0.050^{ns}$ | -0.403** | $-0.190^{ns}$ | -0.446** | 0.56*** | $0.71^{ns}$ | 0.38** | 1 | | | |
| MFY | $-0.073^{ns}$ | -0.537* * | -0.304** | -0.54** | $0.0423^{ns}$ | 0.409** | 0.355** | $0.1191^{ns}$ | 1 | | |
| UNMFY | 0.48*** | 0.676*** | $0.138^{ns}$ | 0.328** | 0.704*** | -0.100 | -0.85*** | -0.402** | -0.58*** | 1 | |
| TFY | $-0.2049^{ns}$ | -0.520** | $-0.160^{ns}$ | -0.400** | $0.1298^{ns}$ | 0.451** | 0.435** | $0.037^{ns}$ | 0.971*** | -0.67*** | 1 |

## 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Tomato is broadly known as an important cash crop in Ethiopia. However, its production is constrained by several a biotic and biotic factors among which diseases are the major ones. *Phytophthora infestans* is one of the most severe diseases in most tomato-growing regions. Still, there are gaps of information on the specific management of late blight through combination of tomato varieties and fungicide foliar sprays. In Bombe Woreda where the higher production of tomato yields but late blight is one of the major problems for tomato production. Therefore, this study was recognized to evaluate the integrated effect of fungicide sprayed frequencies and varieties on late blight epidemics, yield and yield components of tomato, and the evaluation also included the cost-benefit of the fungicide used. A field experiment consisting of five spray frequencies * three varieties was conducted at Bombe Woreda during 2019 cropping seasons, treatments were arranged in factorial experiment with randomized complete block design three replications under natural infection. The tomato varieties with different level of resistance to *P. infestans* included; ARPTd2 (resistance), Metadel (moderately resistance) and Melkasalsa (susceptible) were used. The systemic fungicide (ridomil) was applied with zero, one time, two times, three times and four times spray frequencies and relevant disease and crop parameters were measured. The research results showed that, three tomato varieties supplemented with fungicide foliar spray frequencies had pronounced effect in reducing late blight epidemics. However, relatively better result in management of the disease was obtained from the use of ridomil foliar spray at 7 days' interval at a rate of 3.5 kg $ha^{-1}$ with two times (for ARPTd2 variety) and three times (for Melkasalsa and Metadel) spray frequencies after onset of the disease. Likewise, the highest yield and net benefit were also obtained from tomato plots treated with the above

mentioned fungicide spray frequencies. In the present study AUDPC with very highly significant ($P \leq 0.001$) difference was observed among the varieties as well as different foliar spray frequencies. Among, varieties, the highest AUDPC (629.81 %-days) was observed on variety Melkasalsa and the lowest AUDPC (441.61% -days) was observed on variety ARPTd2. In contrast, unsprayed control plots had the highest disease severity, AUDPC and provided minimum yield and marginal net benefit. Therefore, results of the present finding clearly indicate that combination of tomato varieties and appropriate fungicide spray frequencies significantly minimized the intensity of late blight and increased the fruit yield of tomato.

In conclusion, the 2019 cropping seasons study indicated that ARPTd2 variety appears to have comparative resistance to late blight and is a promising tomato variety. This variety can be used in combination with other management measures, wherever the disease is a pressing problem. However, Further investigation should be carried out to verify whether it has a real genetic resistance or not. Also, instead of using several fungicides indiscriminately, two times ridomil foliar applications at 7 days can substantially manage the disease if used in combination with resistant varieties, like ARPTd2 variety. Even with three times foliar spray for susceptible varieties, like melkaseslsa, gave maximum net benefit and avoided risk of development of fungicide resistance by the pathogens and minimizing cost of production.

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APPENDICES

APPENDIX TABLE 1. Mean square of analysis of variance for tomato late blight incidence at different days after transplanting at Bombe Woreda 2019 cropping season

| Sources of variation | DF | Means square | | | | |
|---|---|---|---|---|---|---|
| | | 27DATE | 34DATE | 41DATE | 48DATE | 55DATE |
| Variety | 2 | 23.35** | 85.18*** | 577.5*** | 463.6*** | 770.06** |
| Fungicide | 4 | 864.17*** | 1869.6*** | 3771.8*** | 2452.66*** | 1411.5** |
| REP | 2 | $2.15^{ns}$ | $0.19^{ns}$ | $5.04^{ns}$ | $17.07^{ns}$ | $201.8^{ns}$ |
| Var * Fc | 8 | 23.35*** | 85.18*** | 195.69*** | 45.1*** | $160.2^{ns}$ |
| Error | 28 | 28 | 28 | 28 | 28 | 28 |
| CV | | 32.7 | 9.05 | 4.9 | 3.3 | 18.03 |

SV= Sources of variation; DF = Degree of freedom; DAT = Days after transplanting; Var = variety; Fc = fungicide spray frequency; CV = Coefficient of variation; ** = Significance difference at $p < 0.05$; *** = Significance difference at $p < 0.001$; Var *FC = Interaction effect of variety x spray frequency; and Ns = Not significant ($p > 0.05$)

APPENDIX TABLE 2. Summary of ANOVA for the severity of tomato varieties evaluated against late blight at different days after transplanting (DAT)at Bombe Woreda 2019 cropping season

| Sources of variation | DF | Means square | | | |
|---|---|---|---|---|---|
| | | 34DATE | 41DATE | 48DATE | 55DATE |
| Variety | 2 | 1.410** | 446.06** | 446.08*** | 429.1*** |
| Fungicide | 4 | 111.39*** | 2123.55*** | 2539.25*** | 2819.5*** |
| REP | 2 | $0.54^{ns}$ | 999.0*** | 49.86** | 34.5*** |
| Var * SF | 8 | 1.41** | $62.8^{ns}$ | $7.10^{ns}$ | $6.42^{ns}$ |
| ERR | 28 | 28 | 28 | 28 | 28 |
| CV | | 36.13 | 42. | 8.9 | 6.58 |

SV= Sources of variation; DF = Degree of freedom; DAT = Days after transplanting; Var = variety; Fc = fungicide spray frequency; CV = Coefficient of variation; ** = Significance difference at $p < 0.05$; *** = Significance difference at $p < 0.001$; Var *FC = Interaction effect of variety x spray frequency; and Ns = Not significant ($p > 0.05$)

APPENDIX TABLE 3. Mean square of analysis of variance for tomato late blight area under disease progress curve and percent fruit infection at Bombe Woreda 2019 cropping season

| Sources of variation | DF | | |
|---|---|---|---|
| | | AUDPC (%-days) | FI (%) |
| Variety | 2 | 147503.5*** | 38.25** |
| Fungicide | 4 | 903541*** | 174.8*** |
| REP | 2 | 67448.7** | $0.58^{ns}$ |
| Var * SF | 8 | $11901.3^{ns}$ | $2.87^{ns}$ |
| ERR | 28 | 28 | |
| CV | | 19.2 | 27.78 |

*SV= Sources of variation; DF = Degree of freedom; DAT = Days after transplanting; Var = variety; Fc = fungicide spray frequency; CV = Coefficient of variation; ** = Significance difference at p < 0.05; *** = Significance difference at p <0.001; Var *FC = Interaction effect of variety x spray frequency; and Ns = Not significant (p>0.05), AUDPC (%-days) = area under disease progress curve, FI (%) = percent fruit infection, DPR (Units/day) = disease progress rate*

APPENDIX TABLE 4. Mean square of analysis of variance for effect of late blight on growth parameter of tomato under combination of varieties and fungicide with different spray frequencies at Bombe Woreda 2019 cropping season

| Sources of variation | | | | | | |
|---|---|---|---|---|---|---|
| | DF | 50%DF | FPD | LPD | NBPP | PSC |
| Variety | 2 | 232.20*** | 450.86*** | 416.35*** | 14.450*** | 16.46*** |
| Fungicide | 4 | 34.578*** | 56.18*** | 106.9*** | 1.59*** | 18.2*** |
| REP | 2 | 5 .0$^{ns}$ | 6.06** | 10.28*** | 1.62*** | 0.2$^{ns}$ |
| Var * SF | 8 | 1.89$^{ns}$ | 0.33$^{ns}$ | 1.438$^{ns}$ | 0.028$^{ns}$ | 0.27$^{ns}$ |
| ERR | 28 | | | | | |
| CV | | 6.65 | 1.56 | 1.0 | 4.3 | 5.3 |

*SV= Sources of variation; DF = Degree of freedom; DAT = Days after transplanting; Var = variety; Fc = fungicide spray frequency; CV = Coefficient of variation; ** = Significance difference at p < 0.05; *** = Significance difference at p <0.001; Var *FC = Interaction effect of variety x spray frequency; and Ns = Not significant (p>0.05), 50%DF= days to 50% flowering, FPD =First Picking Date, LPD =Last Picking Date, NBPP= Number of Branches per Plant, PSC= Plant Stand Count at Harvest*

APPENDIX TABLE 5. Mean square of analysis of variance for effect of late blight on yield attributes of tomato under combination of varieties and fungicide with different spray frequencies at Bombe Woreda 2019 cropping season

| Sources of variation | DF | DFS 50% | NFCPP | SFW |
|---|---|---|---|---|
| Variety | 2 | 101.06*** | 551.1*** | 19612.76*** |
| Fungicide | 4 | 86.4*** | 19.97*** | 269.5*** |
| REP | 2 | $1.6^{ns}$ | $4.9^{ns}$ | 48.47*** |
| Var * SF | 8 | 9.3*** | 4.78** | 20.06*** |
| ERR | 28 | | | |
| CV | | 2,34 | 9.78 | 1.50 |

*SV= Sources of variation; DF = Degree of freedom; DAT = Days after transplanting; Var = variety; Fc = fungicide spray frequency; CV = Coefficient of variation; ** = Significance difference at p < 0.05; *** = Significance difference at p <0.001; Var *FC = Interaction effect of variety x spray frequency; and Ns = Not significant (p>0.05), DFS 50%= days to 50% fruit setting, NFCPP =number of fruit clusters per plant, SFW= single fruit weight*

APPENDIX TABLE 6.Mean square of analysis of variance for effect of late blight on yield of tomato under combination of varieties and fungicide with different spray frequencies at Bombe Woreda 2019 cropping season

| Sources of variation | DF | MFY | TFY | UNMFY |
|---|---|---|---|---|
| Variety | 2 | 1210.87*** | 1055.1*** | 45.67*** |
| Fungicide | 4 | 821.78*** | 590.03*** | 28.15*** |
| REP | 2 | $5.95^{ns}$ | 11.3** | $1.8^{ns}$ |
| Var * SF | 8 | $115.07^{***}$ | 120.8*** | $0.43^{ns}$ |
| ERR | 28 | | | |
| CV | | 3.54 | 3.14 | 6.42 |

SV= Sources of variation; DF = Degree of freedom; DAT = Days after transplanting; Var = variety; Fc = fungicide spray frequency; CV = Coefficient of variation; ** = Significance difference at $p < 0.05$; *** = Significance difference at $p < 0.001$; Var *FC = Interaction effect of variety x spray frequency; and Ns = Not significant ($p > 0.05$), MFY= Marketable fruit yield, TFY = total fruit yield and UNMFY=un marketable fruit yield.

## 7. BIOGRAPHICAL SKETCH

The author was born in Gimbichu town in Hadiya Zone on 20 October 1987 E.C. She attended her Elementary and high school at Gimbichu in the years 2001-2003. She completed her preparatory school at Wachamo Preparatory School from 2004-2005 E.C. She joined at Wachamo University in 2006 and graduated in 2008 E.C with bachelor of degree. Soon after her graduation, she joined Hawassa University, School of Graduate Studies and pursuing her Masters of Science study in Crop Protection program through Ministry of Education (MoE).