BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF PLANT SCIENCES

MSc IN PLANT PROTECTION

ASSESSMENT AND MANAGEMENT OF LATE BLIGHT [*Phytophtora infestans*) (MONT.) DE BARY] OF POTATO (*Solanum tuberosum* L.) AT AWI ADMINISTRATIVE ZONE, AMHARA REGION, ETHIOPIA

MSc Thesis Research

By:

Zemenu Fentahun Biress

Major Advisor: Merkuz Abera (PhD)

Co-Advisor: Abaynew Jemal (PhD)

December 2020

Bahir Dar, Ethiopia

BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF PLANT SCIENCES

MSc IN PLANT PROTECTION

ASSESSMENT AND MANAGEMENT OF LATE BLIGHT [*Phytophtora infestans*) MONT.) DE BARY] OF POTATO (*Solanum tuberosum* L.) AT AWI ADMINISTRATIVE ZONE, AMHARA REGION, ETHIOPIA

MSc Thesis Research

By:

Zemenu Fentahun Biress
(BSc in Plant Science)

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (MSc) in Plant Protection

December 2020

THESIS APPROVAL SHEET

As a member of the Board of Examiners of the Master of Sciences (MSc) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Zemenu Fentahun Biress** entitled **"Assessment and Management of Late Blight [*Phytophtora infestans*) (Mont.) De Bary] of potato (*Solanum tuberosum* L.) at Awi Administrative Zone, Amhara Region, Ethiopia''.** We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (MSc) in **Plant Protection**.

Board of Examiners

Negash Hailu Legesse (PhD)	[signature]	08/12/2020
Name of External Examiner	Signature	Date
Tesfaye Melak (PhD)	for [signature]	21st Dec 2020
Name of Internal Examiner	Signature	Date
Derege Ayalew	[signature]	21/04/2020
Name of Chair Person	Signature	Date

College of Agricultural & Environmental Sciences, Department of Plant Sciences [stamp]

DECLARATION

This is to certify that this thesis entitled **"Assessment and Management of Late Blight [*Phytophtora infestans* (Mont.) De Bary] of Potato (*Solanum tuberosum* L.) at Awi Administrative Zone, Amhara Region, Ethiopia''** submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "Plant Protection" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Zemenu Fentahun Biress** (ID. No. 1100552) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for the award of any degree or diploma to the best of our knowledge and belief.

Name of the Student

Zemenu Fentahun Biress

Signature ______________________ Date______________________

Name of the Advisors

1) Dr. Merkuz Abera (Major Advisor)

Signature Date 21st Dec 2020

2) Dr. Abaynew Jemal (Co-advisor)

Signature ______________________ Date______________________

ACKNOWLEDGEMENTS

First and foremost, extraordinary thanks for Almighty God who give strength for the success of my thesis work.

I would like to express my special gratitude and heartfelt thanks to my major thesis research advisors Dr. Merkuz Abera and Co-advisor Dr. Abaynew Jemal for their encouragement, comments, and advice from the beginning to the completion of my thesis write-up. My gratefulness and thanks go to Bahir Dar University for providing a chance for free education.

I am also grateful to Adet Agricultural Research Center (AARC) for giving me potato seed tubers. My immense thanks go to my colleagues and friends of plant protection students for their encouragement and support during my study. My sincere thanks also extended to Farmer's/respondent's willingness to give information during data collection.

Last but not least, I express my heartfelt thanks to my family for their encouragement and support during the study period.

DEDICATION

This Thesis work is dedicated to my beloved mother, Mr. Yirgedu Hunegnaw.

TABLE OF CONTENT

Contents **Page**

ABBREVIATIONS AND ACRONYMS

AARC	Adet Agricultural Research Center
AUDPC	Area Under Disease Progress Curve
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CSA	Central Statistical Agency
DAP	Days after Planting
DTFDSA	Days to First Disease Symptom Appearance
EIAR	Ethiopian Institute of Agricultural Research
FAOSTAT	Food and Agricultural Organization Statistics
GILB	Global Initiative on Late Blight
GPS	Geographical Positioning System
HARC	Holetta Agricultural Research Center
IDM	Integrated Disease Management
MAFRI	Manitoba Agriculture, Food and Rural Initiatives
MB	Marginal Benefit
MC	Marginal Cost
MRR	Marginal Rate of Return
PYI	Percent Yield Increase
RCBD	Randomized Complete Block Design
RYL	Relative Yield Loss
SAR	Systemic Acquired Resistance
WG	Wettable Granule
WP	Wettable Powder

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

Appendix Tables **Pages**

LIST OF APPENDIX FIGURES

Assessment and Management of Late Blight [*Phytophthora infestans* (Mont.) De Bary] of Potato (*Solanum tuberosum* L.) at Awi Administrative Zone, Amhara Region, Ethiopia

By: Zemenu Fentahun Biress
Major Advisor: Merkuz Abera (PhD) and Co-advisor Abaynew Jemal (PhD)

ABSTRACT

Potato (Solanum tuberosum L.) is the most important tuber crop in Ethiopia. Late blight caused by the fungus Phytophthora infestans is widespread and destructive disease of potato. Survey for prevalence, incidence and severity of late blight of potato was conducted in the two major potato growing districts of Awi administrative Zone namely Fagita Lekoma and Banja. Field experiment was conducted at Amesha Shinkuri Kebele administration at Farmers training center in Fagita Lekoma district during 2019 main cropping season to evaluate the effect of variety and fungicide combinations for late blight management. A total of 60 potato fields were surveyed from two districts in 10 Kebeles and in field experiment four potato varieties and three fungicides including unsprayed control were used with a total of 12 treatment combinations. The experiment was laid out in factorial arrangement in RCBD with three replications. The survey data revealed that late blight of potato was prevalent in 70.4% of potato fields with varied incidence and severity. Mean prevalence (61.78 and 79.00%), incidence (51.06 and 70.63%) and severity (25.57 and 45.71%) of potato late blight were recorded at Fagita Lekoma and Banja districts, respectively. The highest disease incidence (100%) at 52 days after planting (DAP) and percent severity index (76.68 and 63.92%) at 87 DAP was obtained from unsprayed plots of Key and Zengena varieties, respectively. On the other hand, the lowest disease incidence and percent severity index was obtained from Belete and Gudene varieties both sprayed with Ridomil Gold 68% WG. Lower disease incidence was recorded from all varieties sprayed with Ridomil Gold 68% WG. The highest rate (0.0930unit day^{-1}) and AUDPC (1630.70%-days) were obtained from unsprayed plots of Key variety. Whereas, the lowest rate (0.0405unit day^{-1}) and AUDPC (258.35%-days) were calculated from Belete variety sprayed with Ridomil Gold 68% WG. The highest tuber yield, 31.66 t ha^{-1}, was obtained from Belete variety sprayed with Ridomil Gold 68% WG. The maximum MRR (1631.18%) obtained from key when sprayed with Ridomil Gold 68% WG. The highest net profit was obtained from Belete sprayed with Ridomil Gold 68% WG. Therefore, combination of moderately resistant variety (Belete) with the different fungicide applications, especially Ridomil Gold 68% WG is better for the management of late blight and sustainable production of potato at Fagita Lekoma district and also recommended that further repeated experiment is needed for confirmation.

Key words: AUDPC, Disease severity, Fungicides, *Phytophthora infestans*, Potato

1. INTRODUCTION

1.1. Background and Justification

Potato (*Solanum tuberosum* L.) belongs to the tuber crops in the family Solanacous. Potato (*Solanum tuberosum* L.) belongs to the tuber crops in the family Solanacous. The crop was introduced to Ethiopia in 19th century by a German Botanist; Wilhelm Shimper (Gebremedhin Woldegiorgis *et al.*, 2006). It is the most important crop in terms of quantities consumed and produced worldwide (FAO, 2005). It ranks fourth after rice, wheat and maize for human consumption (Bowen, 2003). The total potato production in the World, Africa and Ethiopia is estimated to 368.17, 26.04 and 0.74 million tons from 17.58, 1.9 and 0.07 million ha of land, respectively (FAOSTAT, 2018).

The national average tuber yield is lower than the world average yield (Gebremedhin Woldegiorgis *et al.,* 2006). In Ethiopia, the national average potato tuber yield on farmers' fields is also only 13.76 t ha^{-1}, which is much lower than 38 t ha^{-1} reported from experimental plots (FAO, 2005). Potato becomes a valuable source of cash income for low-income farmers (FAO, 2008).

The potato is prone more than a hundred diseases caused either by bacteria, fungi, viruses or mycoplasmas (Ephrem Guchi, 2015). However, late blight is the most devastating and destructive disease of potato in areas where potato is grown (Ephrem Guchi, 2015; Biruk Kemaw *et al*., 2017). A number of production problems account for the low yield of potato production in Ethiopia: viz, the absence of well-adapted varieties, shortage of high-quality seed potatoes, inadequate storage and marketing facilities, problems of disease, especially late blight, early blight, bacterial wilt and tuber rots are economically important (APR, 1980; Adane Hirpa *et al*., 2010; Ephrem Guchi, 2015). Potato late blight, which is caused by *Phytophthora infestans* is the major bottleneck in potato production in Ethiopia (Bekele Kassa and Yaynu Hskias, 1996). Late blight was responsible for the Irish potato famine in the 1840s. Millions of people in Ireland starved or were forced to emigrate when the entire potato crops rotted in the field or in storage because of infection by *Phytophthora infestans* (Mercure, 1998). Late blight causes serious loss in yield and quality as well as reduces its marketability values (Getachew Asefa *et al*, 2017; Gebremariam Asaye *et al.*, 2020). Late blight caused tuber yield losses ranging from 31-100% in Ethiopia depending on the variety used (HARC, 2007). According to Olanya *et al*. (2001) late blight is a major problem for potato production in high humid elevations of Ethiopia; with average yield losses of about 30–75% on susceptible varieties. Research centers estimated losses ranging from 6.5-61.7%, depending on the level of susceptibility of potato varieties (GILB and CIP, 2004). Fekede Girma *et al*. (2013) also reported 29-57% tuber yield losses caused by late blight in Ethiopia.

No potato varieties are fully resistant to late blight disease in the world (ATTRA, 2004). Most resistant varieties are not immune to late blight but possess varying degrees of resistance to various races of the pathogen (ATTRA, 2004). According to GILB and CIP (2004) report, some released improved varieties have lost their resistance to late blight, but still, some are best in tolerating late blight when supported by reduced dose and rates of fungicide application (Gebremariam Assaye *et al*., 2020).

The use of protectant and systemic fungicides for the management of late blight has been the most studied aspect of late blight management in temperate countries (Olanya *et al*., 2001; Majeed *et al*., 2017). The use of fungicide combined with resistant varieties has evolved as one of the most important options in the management of potato late blight (Getachew Asefa *et al.*, 2017). Excellent control of the late blight disease was achieved through the use of phenyl amide fungicides, like Ridomil across the Sub-Saharan Region (Forbes *et al*., 2007). According to Mesfin Tesserra and Gebremedhin W/Giorgis (2007), the failure of Ridomil in giving perfect control of the disease in some countries of the Sub-Saharan Region and some cases the intensive frequency of usage (Schiessendoppler *et al*., 2003), leads to the development of an integrated disease management strategy involving resistant and susceptible varieties and fungicide sprays. Adopting an integrated management strategy is suggested as a better measure to suppress the pathogen by many workers. Getachew Asefa *et al.* (2017) suggested the highest total tuber yield (26.8 t ha^{-1}) was harvested from the released variety, Ararsa, on which late blight was controlled by spraying Mancozeb 80% WP at 7-days interval whereas the lowest (14.3 t ha^{-1}) was from unsprayed plots of the local variety. The varieties which become susceptible to late blight due to the ability of the pathogen to overcome resistance genes could be useful when combined with other sources of resistance (Struik, 2010; Gebremariam Assaye *et al.*, 2020). In Africa, there is limited research on application of fungicide, spraying frequency, time and rate of fungicide application (Kankwatsa *et al*., 2002).

1.2. Statement of the Problem

In the District, potato late blight has been serious and devastating the crop totally. Potato late blight caused yield losses ranging from 31-100% in Ethiopia depending on the variety used (HARC, 2007). Hirut Getinet *et al*. (2017) reported that potato yield loss due to late blight ranged from 16 to 88% at Injibara and from 6 to 46% at Adet. Several potato varieties with different levels of resistance have been released by the Ethiopian National Potato Research Project. But, some of them lost their resistance soon after dissemination. It leads to the use of an integrated disease management strategy involving varieties and fungicides.

Despite the prevalence and seriousness of late blight causing losses to the potato crop in the field and storage, adequate studies have not been done and limited research work is done. In addition, only the application of fungicides, such as Ridomil, has been used in the management of late blights. Potato production in the rainy season (main cropping) in Ethiopia could not be envisaged without fungicide application to control late blight (Ashenafi Mulatu *et al*, 2017). Farmers do not know the different management options such as resistance varieties combined with fungicides. Integration of fungicide with potato cultivars could reduce the risk to human health, environmental contamination, and increase the economic benefit of farmers (Shiferaw Mekonen *et al.*, 2011). The profound ability of late blight to reach an epidemic level within short periods, the inadequate efficiency of cultural practices to reduce high level of disease severity, and rapid development of resistance to fungicides and breakage of plant resistance in potato varieties within a short period has made use of different disease management combinations important in late blight disease management. Information on integration of potato varieties with different levels of resistance and fungicide application for the management of late blight disease is not sufficiently known. The use of fungicides combined with different potato varieties have evolved as one of the most important alternatives in late blight disease management (Namanda *et al*., 2001). Integrated management alternatives, such as using resistant varieties together with fungicide sprays, have not been tried. Hence much remains to be done on the management of potato late blight. So, it is important to develop suitable integrated management alternatives for the management of the disease for sustainable production of potato and increasing the income of farmers in the study area. Besides this knowing the status of the disease in the area is very important which will help giving information for the management of the disease.

1.3. Objectives of the Study

1.3.1. General Objective

- ✓ To assess the damage status of potato late blight and evaluate the Integrated Disease Management options for the control of late blight disease of potato to increase production and productivity in Awi Administrative zone, Amhara Region

1.3.2. Specific objectives

- ✓ To assess potato late blight disease at Fagita Lekoma and Banja districts in Awi administrative zone, Amhara Region
- ✓ To evaluate the effect of integrated fungicides and varieties on potato late blight disease

2. LITERATURE REVIEW

2.1. Potato (*Solanum tuberosum* L.) and its production

Potato (*Solanum tuberosum* L.) is the most important food security crop that can help shield low-income farmers and countries from the risks posed by rising international food prices (FAO, 2008). Potato is grown in about 150 countries throughout the world and more than a billion people worldwide eat potato (FAO, 2008). Ethiopia is the leading among sub-Saharan Africa countries in terms of area of potato production (FAOSTAT, 2018).

In Ethiopia, potato is grown in four major areas: the Central, the Eastern, the North Western and the Southern (Ephrem Guchi, 2015). In Amhara Region, total cultivated area of potato is 19,199.47ha from which 287,801.92 tons is harvested (CSA, 2018). Despite its potentiality and having the advantage of the agro ecology with good weather condition, the productivity of potato is very low, which is 8.2 t/ha (Gebremedhin W/Giorgis *et al*., 2006). However, the potential yield of potato can reach up to 50 t/ha (Hirut Getinet *et al.*, 2017; Biruk Kemaw *et al*., 2017). Potato is the fast-growing major crop in the world with an important economic impact on many resource-poor farming families (Forbes *et al.*, 2007). Potato production in Africa as a whole has increased at a very fastest rate for the last 47 years, from 2 million tones' in 1960 to a record 16.7 million tones' in 2007 (FAO, 2008). With its short vegetative cycle, high yields within 100 days; it fits well into double-cropping systems with rice, and is also suitable for intercropping with maize and soybeans (FAO, 2008). Potato can be produced in the *Belg* season, which is a short rainy season, during the *Meher* season, which is a long rainy season with bulk of production is undertaken and irrigation (Agegnehu Shibabaw *et al*., 2014; Biruk Kemaw *et al*., 2017).

2.2. Economic Importance of potato

The potato holds great promise for improving the livelihoods of millions of smallholder farmers in the highlands of Ethiopia (Semagn Asredie *et al*., 2015). The potential for high yield, early maturity, and excellent food value gives the potato great potential for improving food security, increasing household income, and reducing poverty (Devauxe *et al.*, 2014).

Potato is one of the very important foods and cash crops in Ethiopia, especially in the high and mid-altitude areas (Abraham Tadesse, 2009; Yazie Chanie *et al*., 2017) when the grains get depleted from the store. It supplements or replaces grain-based diets where rice, wheat, or maize availability has lessened or price has become unaffordable (Camire *et al*., 2009; Hailu Gebru *et al*., 2017). From the national production, 63.67% is used for human consumption while 20.36% was reserved for planting material (CSA, 2012). Potato is regarded as a high-potential food security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (less than 120 days) than major cereal crops like maize (Adane Hirpa *et al*., 2010; Ephrem Guchi, 2015) and favorable response to intensive gardening techniques. In many developing countries, the poorest and most undernourished farm households depend on potato as a primary or secondary source of food and nutrition (FAO, 2008). It has a high content of carbohydrates, significant amounts of quality protein, and vitamins, especially vitamin C (FAO, 2008). Potato provides food and income as a cash crop for over 2.3 million households in different parts of Ethiopia (Seifu Fetene and Betewulign Eshetu, 2017).

2.3. Potato Production Constraints

Despite the presence of conducive environmental factor for potato production in Ethiopia, a number of constraints limit the production and productivity, particularly under smallholder farmers (Ephrem Guchi, 2015; Biruk Kemaw *et al*., 2017). Both biotic and abiotic constraints threaten potato production, of which the former include primarily disease, insect pests (*Phthorimaea operculella* (Zeller), weeds and nematodes (Ephrem Guchi, 2015; Biruk Kemaw *et al*., 2017). Even though, in most potato growing areas of Ethiopia the crop is attacked by a number of diseases, the major one is late blight of potato (Biruk Kemaw *et al*., 2017). It is common in all potato-growing areas of Ethiopia, and it is the most important and damaging potato disease worldwide (Bezabih Emana and Mengistu Nigussie, 2011). Abiotic constraints such as the occurrence of natural hazards, inadequate storage, lack of seed tubers, low market prices of potato at harvesting time were important factors that significantly influence potato productivity (Hailu Gebru *et al*., 2017).

Several other constraints faced by smallholder farmers include the lack of improved, high yielding, disease-resistant and good quality seed potato varieties (Adane Hirpa *et al*., 2010; Gebremedhin W/Giorgis *et al*., 2006). Hence, access to good quality and improved seed potato varieties is widely recognized as fundamental to ensure increased production and productivity (Schulte-Geldermann, 2013). The Ethiopian agriculture, challenged by subsistence production, rainfall dependent with recurrent drought, using hoe technology and inadequate rural market, the potato production specifically and agricultural production, in general, is very low (MoARD, 2010; Biruk Kemaw *et al*., 2017). In addition to the above, Gebremedhin W/Giorgis *et al*. (2006) indicated; depending on seed that has poor quality, greatly affects potato production in the country in that only 3% of Ethiopian farmers apply improved or not contaminated potato seed. Moreover, limited knowledge on postharvest handling of the produce, poor technology transfer systems (Adane Hirpa *et al.*, 2010; Hailu Gebru *et al*., 2017), practicing traditional farming system and giving less focus on tackling late blight disease reduce potato yield. Still, now, farmers are facing different problems such as the use of local inputs, spread of pests and diseases, inadequate logistical facilities (storage, transport and handling) and low production and productivity (Semagn Asredie *et al*., 2015). Crop production in Ethiopia is challenged by many factors, of which climate-related disasters like drought and flood, pests and diseases, climate system is unequivocal, shift in rainfall pattern and decline in available water are the major ones (Temesgen Deressa *et al.*, 2007; Adane Hirpa *et al.*, 2010). Bezabih and Mengistu (2011) further explained that 62–63% of the producers in Ethiopia stated shortage of warehouse as the major problem resulting in postharvest losses of potato. Potato is also easily susceptible to damage and cannot be stored longer conventionally (Hailu Gebru *et al*., 2017).

2.4. The Pathogen, *Phytophthora infestans*

The causal organism of potato late blight is *Phytophthora infestans* (Jones, 1998). The genus *Phytophthora* belongs to the Oomycetes, which are unrelated to the true fungi, which are pseudo fungi (Shaw and Khaki, 1971). The mycelium of the oomycete consists of hyaline, much-branched, coenocytic hyphae which are intercellular with single or double club-shaped haustoria (Fry, 2008). The sporangiophores arise from the internal mycelium through stomata and through lenticels on the tubers. They are slender, hyaline branched, and intermediate. The branching is sparse. The sporangiophores are relatively thick-walled, show cross partitions (septa), and the side branches show bulbous enlargements at intervals. The branched sporangiophore, with swellings at the points where sporangia were attached, is distinctive for *P. infestans.* The swelling indicates the position, where sporangia are attached. The sporangium first develops at the tip of the branch as soon as it is mature; the tip swells slightly, proliferates and turns the sporangium to a side as elongation of the branch proceeds (Agrios, 2005). The sporangia are multinucleate (7 to 30 nuclei), thin-walled, hyaline, lemon, oval or pear-shaped with definite papillae at the apex (Paris and Lamatina, 2010). The sporangia may germinate by means of a germ tube, but most commonly the contents of the sporangium cleave to form a number of zoospores that emerge through the papilla and swim away (Forbes *et al*., 2007). Relative humidity above 90% is necessary for the germination of sporangia (Paris and Lamatina, 2010).

A satisfactory answer to the origin, migration and population diversity of *P. infestans* in Ethiopia is yet to be resolved (Fry, 2008). Although the presence of the disease was first reported in 1930s (Laufer, 1938), potato has been cultivated since 1850 in Ethiopia (Berga Lemaga *et al.*, 1992). This suggests presence of potentially undocumented cases of opportunities for migration of *P. infestans* earlier than first reported in 1930's (Laufer, 1938). However, this particular period could also mark the change in genetic structure of *P. infestans* population in Ethiopia associated with the second migration of *P. infestans* observed at the global level (Fry, 2008). *Phytophthora infestans* has a large number of physiological races differing in pathogenecity to host genotypes (Samen *et al*., 2010). Apart from sexual recombination, where the opposite type is present, virulence and other genetic changes occur during asexual reproductions (Samen *et al.,* 2010). The multiplicity of races poses new challenges in the use of race-specific resistance (Garrett and Mundt, 2000).

2.5. Life Cycle of Late Blight

Wherever the two mating types A1 and A2 are present together in the same plant tissue, fertilization may take place and oospores may be produced (Forbes *et al*., 2007). Both A1 and A2 compatibility types need to be present for sexual spores or oospores to be produced (Montarry *et al*., 2010). These compatibility types must infect the same plant or tuber for oospores to form in the field. A single oospore is produced within a larger oogonium (mother cell) and the antheridium (male cell) at the base (Forbes *et al*., 2007; Subhani, 2016). Sporangia are formed on specialized branches called sporangiophores. The sporangia of *P. infestans g*erminate either directly with a germ tube or indirectly, by liberating zoospores (Krik *et al*., 2009). Sporangia may germinate at temperatures between 7 and 13 °C when free water is present on leaves and form 8 to 12 motile zoospores per sporangium. These swim freely in water films, attach to the leaf surface and infect the plant (Kirk *et al*., 2013). Encysted zoospores infect leaves by penetrating the leaf surface with a germ tube, either through stomata or by means of direct penetration (Kirk *et al*., 2013). The germ tube penetrates directly or enters through stomata, and the mycelium grows profusely between the cells, sending long, curled haustoria into the cells (Fry, 2008). Older infected cells die while the mycelium continues to spread into fresh tissue. In any case, as the disease develops, established lesions enlarge and new ones develop often killing the foliage and reducing potato tuber yields (Agrios, 2005).

The infection of tubers starts in the field during wet weather when the spores from the blighted tops are washed down on the soil, where they penetrate different depths reaching the healthy tubers and infect those (Figure 2.1). Heavy and frequent rains at a time, when about 50% of the foliage is infected cause maximum infection of underground tubers (Samen *et al*., 2010). Spores present in the soil also source of infection of tubers. Emerging zoospores germinate and penetrate the tubers through lenticels or through wounds (Forbes *et al*., 2007). In the tuber, the mycelium grows mostly between the cells and sends haustoria into the cells (Fry, 2008). Tubers contaminated with living sporangia present on the soil or on diseased foliage may also become infected and results tuber rot in the ground or during storage (Agrios, 2005). Successful infection and establishment of late blight disease influenced by several factors such as availability of moisture, prevailing temperature, virulence capacity of the pathogen and degree of resistance of host plants (Majeed *et al*., 2017). The fungus grows and sporulates most abundantly at a relative humidity near 100% and at temperatures between 15 and 25°C (Agrios, 2005; Razukas *et al*., 2008).

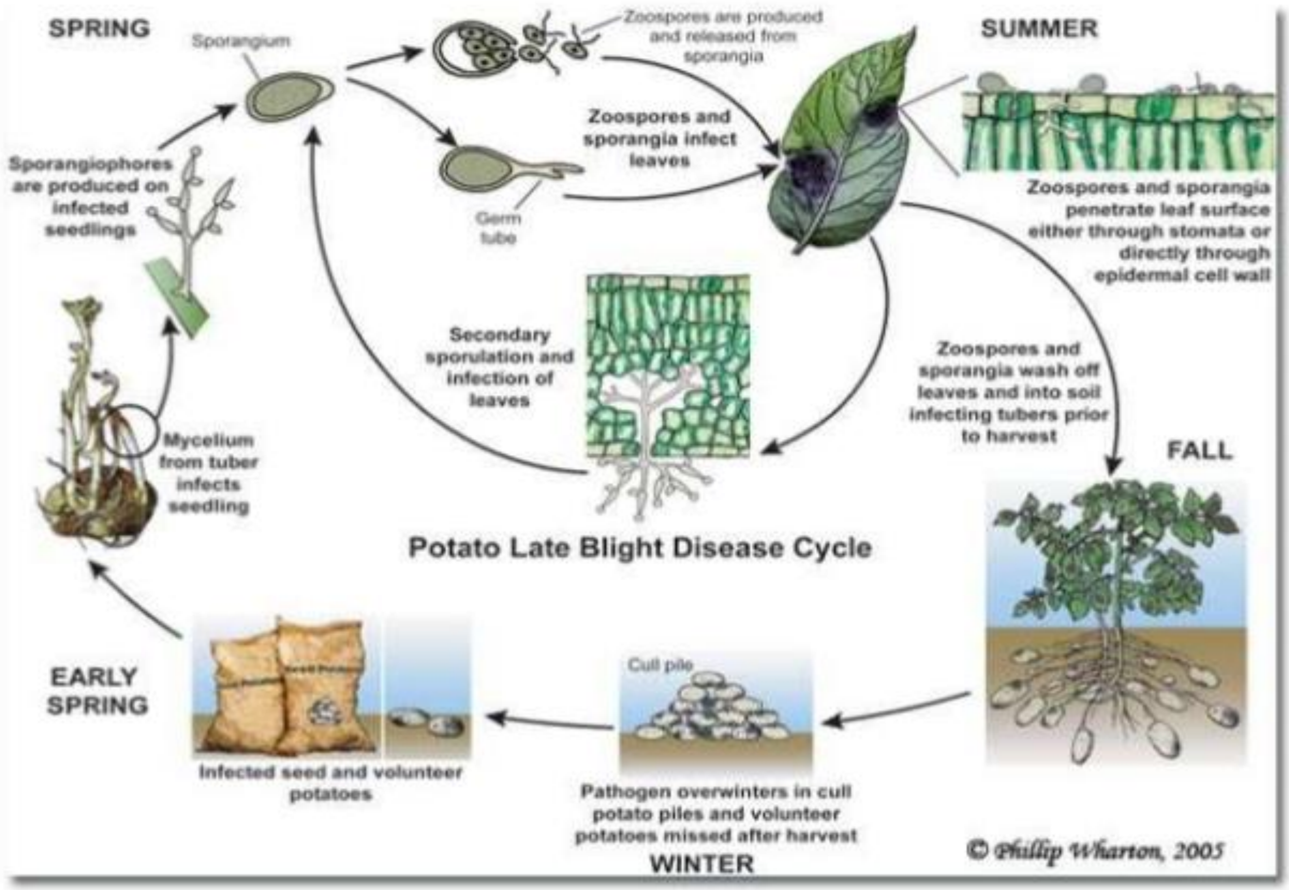


Figure 2.1. Disease cycle of late blight of potato (Wharton, 2005).

2.6. Epidemiology of Late Blight

Phyhtophthora infestans can survive in living host tissue, such as in seed tubers, cull piles, and volunteer potatoes that over-winter in the field (Shinners *et al*., 2003), on other solanaceous plants and in the soil (Kirk *et al*., 2009). Oospores can survive adverse conditions outside the host plant, e.g., in soil and can function as an additional source of infection (Fry, 2008). It usually survives from year to year in infected tubers placed in storage, in piles of cull potato or in infected tubers missed during harvest that remain unfrozen over the winter (volunteer potatoes) (Forbes *et al*., 2007). In the spring, the pathogen can be transmitted from infected tubers in cull piles or volunteers to potato foliage by airborne spores. Infected seed-potatoes are also important sources of the disease. Some infected tubers may rot in the soil before emergence, and not every plant that emerges from an infected tuber will contract late blight. Sporangia of *Phytophthora infestans* may be spread from infected plants in one field to healthy plants in surrounding fields by wind, splashed rain, mechanical transport and animals **(**Kirk *et al*., 2013). At temperatures of 13- 21 °C, sporangia germinate by means of a single germ tube. Night temperatures of 10 to 16 °C accompanied by light rain, fog or heavy dew and followed by days of 16 to 13 °C with high relative humidity are ideal for late blight infection and development (Kirk *et al*., 2013; Yitagesu Tadesse, 2019). Temperatures above 30 °C slow or stop the growth of the fungus in the field but do not kill it, and the fungus can start to sporulate again when the temperature becomes conducive, provided, that the relative humidity (near 100%) is sufficiently high (Agrios, 2005).

2.7. Symptom of Late Blight

The first symptoms of late blight in the field are small, light-to-dark green, and circular-to irregularly-shaped, water-soaked lesions (Kirk *et al*., 2009). These usually first appear on the lower leaves where the microclimate is more humid (Yitagesu Tadesse, 2019). However, they may occur on upper leaves if weather conditions are favorable and the pathogen has been carried into the field by air currents (Kirk *et al*., 2009). In moist weather, the lesions enlarge rapidly and form brown, blighted areas with indefinite borders. A white mildew growth can be observed during humid conditions at the border of lesions on the ventral surface of the leaves (Subhani, 2016). Soon entire leaves are infected, die, and become wither (Agrios, 2005). Conditions must remain moist for a minimum of seven to ten hours for spore production to occur. Because of this relationship, spores or lesions are most apparent after wet nights or periods of rainfall. The fungus may appear as a white, mildew-like growth at the edge of the lesion, primarily on the underside of the leaf. It is this white growth that distinguishes late blight from several other foliar diseases of potato. The spores are carried by wind and rain to healthy plants where the disease cycle begins again. The fungus can complete many reproductive cycles in a season, accounting for the rapid increase of disease once it becomes established in a field (Agrios, 2005).

When conditions are continuously wet all tender aboveground parts of the plants become blight and rot away giving off a characteristic odor (Agrios, 2005). Entire potato plants and plants in entire fields may become blighted and die in a few days or a few weeks. In dry weather, the activities of the pathogen are slowed or stopped and existing lesions stop enlarging, turn black, curl, and wither, and no oomycete appears on the underside of the leaves (Subhani, 2016). When the weather becomes moist again the oomycete resumes its activities and the disease once again develops rapidly (Agrios, 2005).

Tubers may be infected by *P. infestans* whenever sporangia and tubers come into contact, from early in the tuberization process until harvest. Infections most commonly occur when sporangia are washed from lesions on stems and foliage to the soil and then through the soil to tubers. Infections can occur on developing or mature tubers, but contact between tubers and sporangia is more likely when the tubers are enlarging; tuber enlargement creates cracks in the soil and gives sporangia ready access. Tubers become infected most often when soils are cool and wet; soil temperatures higher than 18 °C seem to suppress infections. Because sporangia can survive days or weeks in soil, tubers can become infected for a period of time after infections in the foliage are no longer producing sporangia (Fry, 1998). The affected tubers at first showed more or less irregular purplish-black or brownish blotches, when cut open the affected tissue appears water-soaked, dark, somewhat reddish-brown and extends 5-15 mm into the flesh of the tuber. Later the affected areas become firm and dry and somewhat sunken. Such lesions may be small or may involve almost the entire surface of the tuber without spreading deeper into the tuber. The rot, however, continues to develop after the tubers are harvested (Agrios, 2005). Infected tubers may be subsequently covered with Sporangiophores and spores of the pathogen, or infected tubers may be subsequently invaded by secondary fungi and bacteria, causing soft rots and giving the rotting potatoes a putrid, offensive odor (Agrios, 2005). The extent of rotting in a tuber depends on the susceptibility of the cultivar, temperature, and length of time after the initial infection (Kirk *et al*., 2009).

2.8. Economic Importance of Late Blight

Late blight is one of the few plant diseases that can absolutely destroy a crop, producing a 100% crop loss (Mercure, 1998). The potential economic and social impact of this disease is best illustrated by the well-publicized role it played in the Irish Famine in the middle of the 19th century when it destroyed a large portion of the potato crop, either by eliminating foliage before the harvest or by causing massive tuber rot in storage (Bourke, 1993). As a result of the famine, millions of Irish died or emigrated (Bourke, 1993).

Potato late blight is considered to be the most serious potato disease worldwide (Agrios, 2005). Late blight may destroy all plants in a field within a week or two when the weather is cool and wet (Agrios, 2005). The disease is also very distractive to tomatoes and some other members of the family Solanaceae (Yitagesu Tadesse, 2019). Late blight may kill the foliage and stems of potato and tomato plants at any time during the growing season. It also attacks potato tubers and tomato fruits in the field, which rot either in the field or while in storage (Agrios, 2005).

Late blight attacks the leaves, stems, and tubers of potato plants (Mercure, 1998; Agrios, 2005). In Ethiopia, late blight caused 100% crop loss on unimproved local cultivar, and 67.1% on a susceptible variety (Bekele Kassa and Yaynu Hiskias, 1996; Merkuz Abera, 2017). Late blight is a major limitation to potato production in high humid elevations; with estimated average yield losses of about 30–75% on susceptible varieties (Olanya *et al*., 2001). Research centers have made estimates of losses ranging from 6.5 to 61.7%, depending on the level of susceptibility of the varieties (GILB and CIP, 2004).

Late blight can occur at any time during the growing season, it is more likely to be seen in late summer and early autumn (Bevacqua, 2000). In the temperate regions of North America, potato late blight has caused tremendous economic impact over many years due to potato crop loss or destruction (Guenthner *et al*., 2001). Late blight is the most devastating disease of potato in countries like Ethiopia where subsistence farmers do not know the cause, epidemiology and control the disease (Forbes *et al*., 2007). In Ethiopia, the disease occurs throughout the major potato production areas (GILB and CIP, 2004; Ayda Tsegaye, 2015). Late blight is a very serious economic threat in the vast majority of potato production systems, as well as many tomato production systems worldwide. In a national assessment, the economic impact of potato late blight in all of the USA was estimated to be about 210 million US Dollar (Guenther *et al*., 2001).

2.9. Host Ranges of *Phytophthora infestans*

P. infestans has been reported to cause infection on a large number of species. Studies in Ethiopia showed that all *Phytophthora infestans* isolated from potato samples from Adet, Galessa, Holetta, Kossober, Shashemene and Wolmera Research sites were found to be pathogenic to tomato (HARC, 1999). All isolates produced typical late blight symptoms. However, the degree of infection varied with the location and the isolates were more aggressive to the host from which they were isolated (HARC, 1999). Potato (*Solanum tuberosum* L) and tomato (*Lycopersicon esculentum*) crops are the two most important hosts of *p. infestans* in agriculture but pear melon (*Solanum muricatum*, “pepino”) and other solanaceous species in the genus Solanum can be also attacked (Kamoun, 2001; Turkensteen *et al*., 2003). *P. infestans* also can infect other solanaceous plants, including tomatoes, petunias and hairy nightshade that can act as a source of inoculum to potato (Turkensteen *et al*., 2003).

2.10. Management of Late Blight

A number of management techniques of late blight have been developed and used. Effective control of this disease requires implementing an integrated disease management approach. The most important measures are cultural, use of resistant cultivars, chemical controls and integrated disease management.

2.10.1. Cultural practices

There are different methods of cultural practices applicable for late blight management and cultural practices are the first line of defense against late blight ((MAFRI, 2002; Kirk *et al*., 2009). Cultural practices can be applied to reduce the pathogen population; by reducing its survival, reproduction, dispersal and penetration of the pathogen. Survival of *P. infestans* to initiate epidemic can be reduced through avoidance of introducing late blight into a field by planting only disease-free seed tubers, preferably certified seed, destroying all cull and volunteer potatoes, avoid frequent or night-time overhead irrigation and good soil coverage (Draper *et al.,* 1994; Subhani, 2016). High hilling, and prevention of crack development in hills, can reduce the movement of late blight spores through the soil to tubers, thereby reducing tuber late blight risk (Stone, 2014). Late blight is controlled by eliminating cull piles and volunteer potatoes (Forbes *et al*., 2007), using proper harvesting and storage practices, and applying fungicides when necessary (Olanya *et al*., 2001). The most effective strategy for managing late blight is to avoid sources of inoculums. The initial sources of inoculums are likely to be infected potatoes in cull piles, infected volunteer potato plants that have survived the winter, and infected seed tubers. Therefore, it is important to keep a clean operation by destroying all cull and volunteer potatoes (Agrios, 2005).

Seed sources should be selected carefully to avoid bringing in late blight on seed, especially new strains of the pathogen (Kirk *et al*., 2009). When partially blighted leaves and stems are surviving at harvest time, it is necessary to remove the aboveground parts of potato plants or destroy them by chemical sprays (herbicides) or mechanical means to prevent the tubers from becoming infected (Agrios, 2005). The cultural measures such as the use of disease-free/healthy seed destroy volunteer potato plants, infected plants to avoid spread, hilling with adequate amounts of soil and management of plant nutrition (Garrett and Dendy, 2001; Ephrem Guchi, 2015). Avoiding conditions that favor late blight development is very important in managing the disease. Fields with good water infiltration and drainage characteristics are desirable for planting potatoes. Although weed species are not late blight hosts, they can contribute to conditions that favor disease development by restricting air movement within the canopy. Heavy weed infestations also prevent adequate coverage of potato foliage with fungicides (Kirk *et al.*, 2013). Cultural management practices also include manipulation of planting dates for potato varieties to avoid periods of heavy late blight infection and the use of inter-cropping of non-host crops or low planting density to reduce the spread of fungal inoculum (Olanya *et al*., 2001).

2.10.2. Use of resistant varieties

Host resistance to late blight is of significance in integrated late blight management due to its long-term economic benefits for farmers (Binyam Tsedaley *et al*., 2014).. It also minimizes changes in the population structure of *P. infestans*, decreasing the likelihood of fungicide resistance (Mukalazi *et al.*, 2001). The use of resistant varieties is among the most effective and environmentally safe means of managing the disease (Njualem *et al*., 2001). Variations in resistance to late blight among different potato varieties have been demonstrated by several researchers (Njualem *et al*., 2001).

Potato cultivars with high blight resistance can be destroyed by new strains of the fungus since the resistance is controlled by single gene (Fry, 2008). Some varieties have a low level of resistance which can give some protection in drier seasons but offer little advantage

(Olanya *et al*., 2004). Blight can be controlled in partially resistant varieties governed by minor genes combined with reduced dose of fungicide (Schulte-Geldermann *et al*, 2013). Cultivars having high levels of resistance can allow them to be grown without chemical protection even in the wettest growing seasons (GILB and CIP, 2004; Agrios, 2005). Early-maturing varieties are usually susceptible to the disease while late maturing potato varieties had higher resistance (Razukas *et al*., 2008). Some varieties have useful foliage resistance but poor tuber blight resistance (Anonymous, 2007). Yet, others have good tuber-blight resistance but poor foliage-blight resistance (Anonymous, 2007). Ideally, a variety should have good resistance to both foliage and tuber blight (Anonymous, 2007). The use of durable or polygenic resistance is sometimes interpreted to be synonymous with intermediate resistance levels but cultivars ranging from complete susceptibility to very high resistance (ATTRA, 2004). Polygenic resistance has proved to be helpful in reducing the amount of fungicides (Jones, 1998). There is diversity among commercial potato cultivars in terms of resistance to late blight and these levels can be incorporated into an overall management strategy (Jones, 1998). However, no potato varieties are fully resistant to late blight (ATTRA, 2004).

There are some released improved varieties that have lost their resistance to late blight, but still, some are best in tolerating late blight when supported by reduced dose and rates of fungicide application (GILB and CIP, 2004). Generally resistant potato varieties and improved cultural practices can reduce late blight (FAO, 2008). Shiferaw Mekonen and Tesfaye Tadesse (2018) suggested that the maximum disease score (5) was recorded in moderately resistant variety, while on the moderately susceptible variety the disease score (8) was recorded. According to Ashenafi Mulatu *et al.* (2017) potato tuber yield was higher in the resistant than the susceptible variety, Jalene.

2.10.3. Biological Management

Several soil fungi (*Penicillium*, *Rhizoctonia* and *Trichoderma*) have been found to inhibit late blight growth, while others such as *Aspergillus*, *Fusarium* and *Mucor*seem to effectively compete with it and a foliar spray composed of a common fungus, *Fusarium proliferatum*, which prevents blight blight infection when applied to foliage (Dolatabadi *et al*., 2011).

Trichoderma species have shown bio-control potential against many plant pathogens including late blight (Dolatabadi *et al*., 2011).

In Ethiopia, biocontrol activity of *Trichoderma viride* and *Pseudomonas fluorescens* against *P. infestans* under greenhouse conditions indicates that antagonism test between *T. viride* and *P. infestans*, showed radial growth inhibition of the pathogen by 36.7% and a complete overgrowth of *T. viride* on *P. infestans* later, whereas *P. fluorescens* inhibited the radial growth of the pathogen by 88% (Ephrem Debebe *et al*., 2011). Microbial antagonists, such as *Trichoderma harzianum* and *T. viride* to manage *P. infestans* occur throughout the world and can be easily isolated from soil, decaying wood and organic matter (Majid *et al*., 2008). According to Bekele Kassa *et al*. (2006) using crude garlic extract shows significant inhibition effect on the growth of *P. infestans*. He also suggested that the extract was more efficient when it was applied before infection starts, *i.e*. time of application of the extract was a crucial factor in the use of the crude garlic extract to inhibit the infection.

Extracts of *Datura stramonium* (Jimson weed), *Nicotiana tabacum* (Tobacco), *Cymbopogon citratus* (Lemon grass), *Moringa stenopetala* (Shiferaw), significantly inhibited the mycelium growth of *P. infestans* in a concentration-dependent manner (Abayhne and Chauhan, 2016).

2.10.4. Use of Fungicides

Fungicides that are used against late blight can be classified into two basic mobility groups: protectant and penetrant (Beckerman, 2008; Majeed *et al*., 2017). Fungicides can slow or stop the development of new symptoms if applied in a timely fashion, but fungicides will not cure existing blight symptoms (Beckerman, 2008). Hence, most fungicides need to be applied before disease occurs or at the first appearance of symptoms to be effective (Yitagesu Tadesse, 2019). Fungicides can only protect new uninfected growth from the disease. Generally, few fungicides are effective against pathogens after they have infected a plant (McGrath, 2004; Merkuz Abera, 2017).

Several broad-spectrum and systemic fungicides are used against potato late blight control (Yitagesu Tadesse, 2019). 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 and, therefore, sprays with such materials are ineffective against such strains (Subhani, 2016; Yitagesu Tadesse, 2019). The disease occurs throughout the major potato production areas and it is very challenging to produce the crop during the main rainy season without chemical protection measures (Abraham Tadesse, 2009).

The use of fungicides in controlling late blight was found to boost potato yield in Ethiopia (Mesfin Tessera and Gebremedhin W/Giorgis, 2007). Fungicide mixtures having both systemic and contact fungicides are more efficient in controlling late blight as compared to fungicides applied individually (Subhani, 2016). In Ethiopia the first spray with Ridomil Gold 63.5% WP at a rate of 2 kg ha^{-1} followed by 2-3 sprays (need base application) of Dithane M-45 (Mancozeb) at a rate of 3 kg ha^{-1} was found to be effective in controlling late blight (Yitagesu Tadesse, 2019). When applying fungicides, complete coverage of the foliage (stems and leaves, top to bottom of canopy) with fungicide is necessary to enable disease prevention, regardless of the application methods (ground or air, traditional or newer technology sprays) (MAFRI, 2002). Mesfin Tessera *et al.* (2009) reported that Ridomil and Mancozb were used to control potato late blight disease. Reduced rates of Ridomil application resulted in better management of potato late blight with the highest marginal rate of return (Binyam Tsedaley *et al*., 2014). Metalaxyl was found to provide disease management by reducing sporulation, germination, and intercellular growth of the fungus (Forbes *et al*., 2007). Even though fungicide use increases production costs and has negative consequence on environment and human health, the efficacy of fungicide is appealing to resource-poor farmers and fungicide use is a common practice in developing countries (Bekele Kassa and Hailu Beyene, 2001; Forbes *et al*., 2007).

2.10.5. Integrated late blight disease management

Integrated pest management has helped farmers drastically reduce the need for chemical controls while increasing production (FAO, 2008, Merkuz Abera, 2017). Effective control of late blight requires implementing an integrated disease management approach (Kirk *et al*., 2009). Integration of different management options, including cultural practices (good crop husbandry), resistant varieties and fungicides are required to control late blight (Agrios, 2005). Fungicides and host plant resistance are among the most efficient control options available to farmers (Habtamu Kefelegn *et al*., 2012). Application of Ridomil WG reduced the disease development and increased tuber yield in all cultivars compared to the other two fungicides, Chlorothanoil and Mancozeb (Habtamu Kefelegn *et al*., 2012). Ashenafi Mulatu *et al*. (2017) reported that the application of fungicides; Victory 72 WP, Ridomil MZ 68 WG, Mancozeb and Horizon have arrested disease development more effectively compared to unsprayed control application.

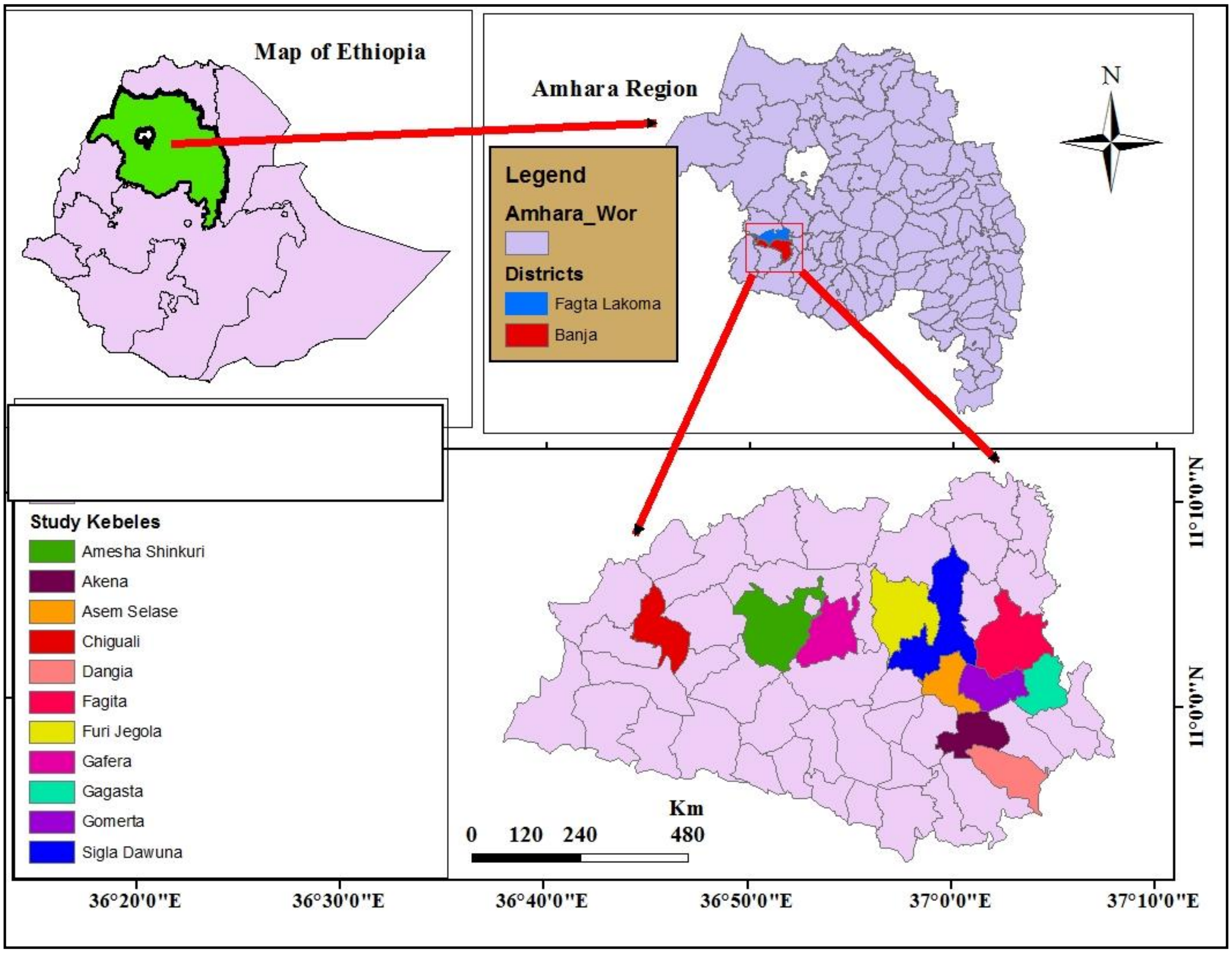
Late blight of potatoes can be controlled successfully by a combination of sanitary measures, resistant varieties, and well-timed or scheduled chemical sprays (Agrios, 2005; Gebremariam Assaye *et al*., 2020). In integrated management of disease, the host resistance contributes to reducing the number of sprays required to keep late blight below an economic threshold level (Jones, 1998; Yitagesu Tadesse, 2019). Integration of late blight management has often been thought of as one of the better disease management options in tropical regions where fungal inocula are abundant in most months of the year (Olanya *et al.,* 2004). These include a variation of frequency of application based on host resistance of potato varieties (reduced fungicide use), early planting and improved variety (early and mid-maturity, tolerant variety (Kankwatsa *et al*., 2002).

Application of Ridomil at the first two sprays followed by Mancozeb at the next two sprays proved the best management schedule on each variety and gave the highest yield on variety Gabbissa, Badhasa and Chiro (Fekede Girma *et al.,* 2013). Other control measures include: use of disease-free seed; eliminating cull piles; planting resistant cultivars; and killing potato foliage 10 to 14 days before harvesting (Majeed *et al*., 2017). For effective control of late blight, integrated management must be adopted by all producers, including large and small-scale farmers (MAFRI, 2002). Fungicides cannot be used alone for effective control of late blight but must be used as one tool in an integrated management strategy. Cultural practices are the first line of defense, and forecasting techniques and proper application technology are essential for efficient, targeted applications of fungicides (MAFRI, 2002). Integrated disease management of late blight includes host resistance in combination with cultural practices such as early planting dates and reduced dose and rate of fungicide use (Kankwatsa *et al*., 2002). Experimental plots with IDM-LB yielded 50% and 75% more than late planting alone (GILB and CIP, 2004).

3. MATERIALS AND METHODS

3.1. Survey of Potato Late Blight Disease

3.1.1. Description of survey area



Source: From GIS map of Ethiopia, 2020
Figure 3.1. Location map of the study area

Note: Field experiment was conducted at Amesha Shinkuri *Kebele* Administration which is green shaded.

Survey of potato late blight was carried out during the 2019 main cropping seasons in the two districts of potato growing areas of Awi administrative zone (Figure 3.1); namely: Fagita Lekoma and Banja districts, respectively. The two districts were selected based on potato production and coverage, disease problem and accessibility, discussing with district extension workers and Development Agents. Fagita Lekoma district is 17 km far from Injibara, which is the center town of the Awi Administrative zone. The elevation of Fagita Lekoma lies between 1800 and 2900 meter above sea level and located 10°57′23″ to 11°11′21″ North latitude and 36°40′01″ to 37°05′21″ longitude. The minimum and maximum temperature is 9.4°c and 25°c , respectively and the mean rainfall is 2434.6mm (Achamyeleh Kassie, 2015). The agro ecology is moist temperate 16% *Dega* and 84% *Woina dega*. Major crops produced are wheat (*Triticum aestivum* L.), potato (*Solanum tuberosum* L.), barley (*Hordeum vulgare* L.), maize (*Zea mays*) and *teff* (*Eragrostis teff*).

Banja district is 122 km far from the regional Administrative city Bahir Dar to the south. The district is a district which is the center town Kossober is located. The elevation of Banja lies between 1870 and 3300 meter above sea level. It is located 10°57′17″to 11°03′05″ North latitude and 36°39′09″ to 36°48′25″ East longitude. The minimum and maximum temperature is 9.4°C and 26°C. The mean annual rainfall is 2300 mm from June to September. The agro ecology based on in % is Sub-humid or 80% *Dega* and 20% *Woina dega*. The major crops produced in the district in the order of area coverage include potato (*Solanum tuberosu m* L.), *teff* (*Eragrostis teff*), wheat (*Triticum aestivum* L.) and maize (*Zea mays)* (ANRS-BoFED, 2006).

3.1.2. Sample unit and disease assessment

Two districts were considered for survey. In each district 5 (five) *Kebele* administrations (*KAs*) [lower administrative unit] were selected based on disease problem and potato production (Figure 3.1). In each *Kebele* administration 6 (six) potato growing farmer fields were selected randomly. Totally 60 farmer fields in the two districts were assessed. In each sample field, five quadrates (1m x 1m) were sampled by moving diagonally across each field from one end to the other in an 'X' pattern as cited by (Merkuz Abera and Getachew Alemayehu, 2012).

The prevalence of disease was calculated by using the number of fields affected divided by the total number of fields assessed and expressed in percentage.

$$\text{Disease prevalence (\%)} = \frac{\text{Number of fields affected by disease}}{\text{Total number of fields assessed}} \times 100$$

Disease incidence (the number of diseased plants, expressed as a percentage of the total number of plants assessed) of potato late blight was assessed by visual examination and counting of stands with disease on the leaves symptom of potato plants. Disease incidence data was recorded on the whole potato plants in a quadrate. The data on disease severity was recorded from seven randomly taken potato plants using a 0-9 rating scale (percent rating scale) of Shutong *et al.* (2007) (Appendix Table 1). The severity grades were converted into Percentage Severity Index (PSI) according to the formula by Wheeler (1969).

Biological and physical factors like the previous crops, cropping system, variety grown, planting time, growth stage and altitude were recorded as per the checklist (Appendix Table 2). The previous crop, fungicide sprayed or not, variety grown and planting time was recorded by interviewed the owner of the farm, while cropping system (sole and intercropped) and gro wth stage were recorded by visual observation. Altitude is also measured by using GPS in each field. The altitude in the surveyed fields were classified into $\geq$ 2300 and < 2300 meter above sea level based on the agro ecological classification system of Ethiopia.

3.1.3. Farmers practice for potato production

Intercropping of potato with other crops such as maize, faba bean, barley and wheat is widely practiced in the districts of both Fagita Lekoma and Banja. Intercropping of potato with maize, faba bean, field pea, brassica, linseed and wheat is commonly practiced in the districts of Amhara region (Semagn Asredie *et al.*, 2015). In addition bean, barley and wheat are grown in potato fields after flowering and maturity but before harvest. This helps farmers not only to save tubers in the soil but also to get additional yields and reduce losses due to late blight. In addition, reduce the need to buy or use commercial fertilizers because the leaves of potato fall and are used as a nutrient. This is a common practice in the surveyed districts in which the majority of the farmers have a small and fragmented landholding system.

The local potato varieties widely grown in the surveyed districts are *Key* or *Mirit denich, Abalo,* and *Samune* while improved varieties Belete, Gudene, Guassa and Zengena are grown in the surveyed districts of Awi Administrative zone. Semagn Asredie *et al*. (2015) reported the farmer variety *Abalo, samune, Key denich, Siquare* are grown in the cool highlands of the Amhara region (Lai-Gaint, Banja, Quarit and Yilmana) while *Agazer* and *Nech Ababa* are the two dominant local varieties grown in Shashemene. Improved varieties were grown mainly for market value, distributed to neighbor farmers and seed source for next season production due to limited access and high price of these varieties. Agegnehu Shibabaw *et al*. (2014) repor ted that improved varieties are not commonly found in the hands of the farmers. Now, a day's farmers shift to cultivation of *Acacia decurrens* (locally called *Chiggn*) plantation. This plantation plays a significant role in the improvement of soil fertility (Achamyeleh Kassie, 2015), rehabilitation of degraded land and the major source of income in the surveyed districts. However, most farmers especially those who have no cultivated land, appealing for this practice due to the reduction of crop production, shading effect, takes a lot of time to mature (4-5years) and imbalance of sales for the tree and costs for household needs such as food.

Moreover, *Meher* season production was also shifted to *Belg* season and irrigation production due to the impact of late blight on potato during *Meher* season production. Severe late blight infection in the *Meher* season forced farmers to limit their potato production to the dry season (Bekele Kassa and Eshetu Bekele, 2008; Abraham Tadesse, 2009). Smallholder farmers have small land, low access and high prices of seed tubers of improved potato varieties reduce potato production in the surveyed districts. Furthermore, prevalence of diseases such as late blight and bacterial wilt and insect pests (potato tuber moth) are the major challenges of potato production in the districts. Yazie Chanie *et al*. (2017) also reported that disease, insects, storage (decay/sprouted), marketing (price drop after harvest) are major challenges in Awi zone, East Gojjam and South Gonder.

3.1.4. Characteristic features of the surveyed fields

The altitude of the surveyed fields ranged from 2139 in Fagita Lekoma district to 3045meter above sea level in Banja district. Among the varieties grown in the survey fields around 41.67% of potato fields were improved varieties while the remaining 58.33% of the potato fields were widely cultivated local varieties (Table 4.2). Farmers use local potato varieties starting from a long period of time and local potato variety is the dominant variety grown in North Western Amhara Region (Agegnehu Shibabaw *et al*., 2014; Yazie Chanie *et al*., 2017).

Out of the total surveyed 60 potato fields, 58.43% of them were sole cropped, while 41.57% had been intercropped with wheat, barley, maize and bean. The fungicides commonly used during the survey were Ridomil, Mancozeb and Victory 72%. In the surveyed areas 26.67% and 53.33% of the interviewed farmers (from 60 farmers) used fungicides at Banja and Fagita Lekoma districts, respectively. On the other hand, (73.33%) at Banja and 46.67% at Fagita Lekoma districts were not used fungicides. Potato fields were at two growth stages during the survey, with 36.67% at vegetative and 63.33% at flowering stages. About 65% of potato fields were sown in the month of May, while 35% were sown in the month of June. Of the surveyed field 8 fields (13.34%) were planted with solanaceous crops (potato) in the previous year while 52 fields (86.66%) were planted with cereal crops (Table 4.2). Potato is commonly rotated with barley, wheat, faba bean, maize and *teff* fields (Yazie Chanie *et al*., 2017).

3.2. Field Experiment to Evaluate the Effects of combination of Fungicide and Variety for Potato Late Blight Management

3.2.1. Description of experimental site

Field experiment was conducted under rain fed conditions at Amesha Shinkuri *Kebele* administration on farmers training center in Fagita Lekoma district, Awi administrative zone, during the 2019 main cropping season (June-September). The exact altitude of the experimental field is 2413 meter above sea level, located North latitude 11°06′ to 36°85′ East longitude. The average annual temperature is ranging from 8.25°C to 23°C. The area is hot spot for potato late blight disease.

3.2.2. Experimental materials used

Four varieties of potato viz: Belete, Gudene, Zengena and local *Key* or *Mirit denich* were used in the experimental study. The three varieties were obtained from Adet Agricultural Research Center (AARC). Belete (CIP 393371.58) is known as moderately resistant variety to late blight while Gudene (CIP 386423.13) and Zengena (CIP 380479.6) are moderately susce ptible varieties. The farmers' cultivar *Key* is susceptible to late blight were used as local control (check). Belete was released in 2009, Gudene was released in 2006 and Zengena was released in 2001 (MANR, 2016). These potato varieties are the most adapted and widely grown around the study area. Two fungicides were used in this study viz: Ridomil Gold 68%WG (Metalaxyl 4% + Mancozeb 64%) and Mancozeb 80% WP against potato late blight disease. The fungicides were obtained from legally authorized importers.

3.2.3. Experimental design and treatments

The experiment was laid out in Randomized Complete Block Design (RCBD) with three repli cations in factorial arrangement. Each potato varieties combined randomly with both fungicides including unsprayed (control). The experiment had twelve treatments with three replications (Table 3.1). The size of each plot was $9m^2$ (3m*3m). Each plot has consisted of four rows (middle two harvestable) with inter and intra-row spacing of 0.75 and 0.3m, respectively. Each row consists of 10 plants thus, there were 40 plants per plot and net plot area was $3.6m^2$. The distance between blocks and plots was 1.5 and 1m, respectively. The gross area was $564m^2$.

3.2.4. Experimental procedure

The experimental field was selected and all unwanted materials like stones, straw and other unwanted substances were removed. The experimental field was prepared by plough to a depth of 25 - 30 cm and plots were prepared manually with the help of hand tools. Medium-sized and sufficiently sprouted potato tubers (with 2-3 cm long sprouts) were planted on ridges at the specified spacing in each treatment. At planting, NPS (180 kg ha^{-1}) was applied. The rate of urea (117 kg ha^{-1}) was applied in split application that is one half of urea was applied at sowing date and the remaining half of urea was applied one month after planting when the first weeding and hoeing activity was done. Weeding, cultivation and all other agronomic management were employed as recommended for the crop (EIAR, 2007). Ridomil Gold 68% WG and Mancozeb 80% WP were applied as per the recommendation of the manufacturer (at a rate of 2.5 and 3 kg ha^{-1}) using a manually-pumped knapsack sprayer. During fungicide spraying, plastic sheets were used as a buffer zone to prevent the fungicide drift effect (Appendix Figure 3). Spraying of the fungicides was started 45 days after planting (DAP) when the first late blight symptom appeared.

Table 3.1. Treatment combinations

Potato varieties	**Fungicide type**	**Treatment combination**
Belete	Mancozeb 80% WP	Belete + Mancozeb
	Ridomil Gold 68% WG	Belete + Ridomil
	Unsprayed	Belete + Unsprayed, check
Gudene	Mancozeb 80% WP	Gudene + Mancozeb
	Ridomil Gold 68% WG	Gudene + Ridomil
	Unsprayed	Gudene + unsprayed, check
Zengena	Mancozeb 80% WP	Zengena + Mancozeb
	Ridomil Gold 68% WG	Zengena + Ridomil
	Unsprayed	Zengena + unsprayed, check
Key (Local)	Mancozeb 80% WP	*Key* + Mancozeb
	Ridomil Gold 68% WG	*Key* + Ridomil
	Unsprayed	*Key* + unsprayed, check

3.2.5. Disease assessment

Days to first disease symptom appearance: was recorded by counting the number of days from planting to first disease symptoms observed on the leaves of the plant.

Disease incidence: was assessed on the whole plants in each plot and plants showing symptoms of the disease were counted.

$$\text{Disease incidence} = \frac{\text{Number of diseased plant}}{\text{Total number of plant inspected}} \times 100$$

Disease severity: was taken on the basis of the percentage of leaf area affected by late blight. The reading was started right from the appearance of the first disease symptoms.

After the appearance of the disease, scouring was continued at an interval of seven days until physiological maturity of the crop. The 0-9 disease score scale described by shutong *et al*. (2007) was used (Appendix Table 1). The severity grades were converted into Percentage Severity Index (PSI) according to the formula by Wheeler (1969).

$$PSI\ (\%) = \frac{\sum \text{Individual numerical ratting}}{\text{Total no. of. Plants assessed X Max. Score in the scale}} X\ 100$$

Disease progress rate (r): was calculated for each treatment by using the formula below.

Linear Logistic model, r = ln [(X/1-X)], Van der Plank (1963) and

Gompertz model, r = -ln[-ln(X)], Berger (1981).

Where r is disease progress rate, X is disease severity and Ln = Natural logarithm.

The goodness of fit of the models was tested based on the magnitude of the coefficient of rate determination (R^2). Most of the treatments had higher coefficient of rate determination (R^2) in the Logistic model than the Gompertz model (Appendix Table 10). Therefore, disease progress rate was calculated by using linear logistic model for each treatment and the values were analyzed.

Area under disease progressive curve: The effect of variety and fungicide combinations on disease severity data was integrated into area under disease progress curve (AUDPC), as described by Campbell and Madden (1990).

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

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

AUDPC were expressed in percent-days because the severity (X) is expressed in percent and time (t) in days. The rate of disease progress in time was determined by recording the severity of late blight at 7 days intervals right from the appearance of the first disease symptoms till the maturity of the crop in the different treatments.

3.2.6. Assessment of yield

At maturity, potato tubers were harvested from the central two rows on each plot of each treatment. In addition, the weights of marketable and unmarketable yield of potato tuber per plot were recorded. Tuber yield per plot was converted in to yield of tons per hectare.

Days to 50% flowering: was recorded by counting the number of days from planting until 50% of plants had open flower.

Days to physiological maturity: was recorded by counting the number of days from planting to 50% of the leaves in each plot turned yellow.

Plant height (cm): the parameter was recorded as measure the height of 10 randomly selected plants in each plot from the ground surface to the tip of the main stem and averaged to get the mean plant height.

Number of tuber per plant: was recorded by counting the number of tubers in the two harvested middle rows and dividing by the number of plants.

Marketable tuber yield (t ha^{-1}): was calculated as all the weight of harvested tubers which was disease-free and with weight of greater than or equal to 20g.

Unmarketable tuber yield (t ha^{-1}): the weight of tubers which was diseased, insect attacked, and those having weighs less than 20g was calculated.

Total tuber yield (t ha^{-1}): The sum of weights of marketable and unmarketable tuber yield of harvestable row plants per plot was recorded and converted to tone per hectare.

Relative yield loss: Relative yield loss of each treatment was determined as the percentage of that of protected plots of the experiment and the yield loss was computed based on the formula of (Robert and Janes, 1991).

$$RL\ (\%)\ \frac{(Y_1\ - Y_2)}{Y_1}\ X\ 100$$

Where, RL = relative loss (reduction of the parameters yield and yield component),

Y1 = mean of the respective parameter on protected plots (plots with maximum protection) and Y2 = mean of the respective parameter in unprotected plots (i.e. untreated plots or treated plots).

The percent yield increase (PYI): Was calculated using the following formula suggested by (Lung'aho *et al.*, 2003).

$$PYI = \frac{\text{tuber yield of a fungicide treated plot} - \text{yield of control plot}}{\text{yield of control plot}} \times 100$$

3.2.7. Cost benefit analysis

The prices of potato tubers (Birr/ton) were assessed from the local market and the total sale of the yield obtained from each treatment was computed on hectare basis. The price of tuber was 10 Birr/kg and this value was changed to price per ton which became 10000 Birr/ton. Input costs like fungicide and labor were converted into hectare basis. Price of Mancozeb 80% WP was 400 Birr kg^{-1}, Ridomil Gold 68% WG was Birr 1200 kg^{-1} and total price incurred to spray one hectare of potato fields was calculated. Cost of labor Birr 75 man-days and spray equipment (knapsack sprayer) rent Birr 50 was used. Costs for all agronomic practices were uniform for all varieties and treatments. Costs return and benefit, were calculated on hectare basis.

Based on the data obtained from the site, cost-benefit analysis was done using partial budget analysis. Partial budget analysis is a method of organizing data and information about the cost and benefit of various agricultural alternatives (CIMMYT, 1988).

Partial budgeting is employed to assess the profitability of any new technologies (practices) to be imposed on the agricultural business. 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 that 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 incurred. The formula is as follows:

$$MRR = \frac{MB}{MC} \times 100$$

Where, MRR = marginal rate of returns, MB= marginal benefit, MC = marginal cost.

3.2.8. Statistical Data Analysis

Survey data were analyzed using SPSS software version 20 and simple descriptive statistics were used to summarize data obtained from field survey. In field experiment Analysis of variance (ANOVA) was performed for the disease parameters (Incidence, severity, AUDPC) and yields parameter (marketable, unmarketable and total tuber yield) using Statistical Analysis System (SAS) version 9.0 software (SAS, 2002). Least significance difference (LSD at 5% probability level) was used to separate treatment means (Gomez and Gomez, 1984). Correlation analysis was performed to determine the relationship between disease parameters (the independent variable) and tuber yield parameters in the field plots. Disease incidence, PSI and AUDPC were correlated with plant height, marketable, unmarketable and total tuber yield per hectare of each treatment combinations.

4. RESULTS AND DISCUSSIONS

4.1. Survey Results and Discussion

4.1.1. Disease prevalence

From the total surveyed fields 70.39% of the fields were infested with potato late blight disease. Late blight of potato was prevalent in both districts surveyed, which was minimum (61.78%) at Fagita Lekoma and maximum (79%) at Banja respectively (Table 4.1). Lower temperature and higher rainfall were recorded at Banja during the survey seasons (Appendix Table 3). These conditions are often favorable weather factors for late blight epidemics. Similarly, Kankwatsa (2002) reported heaviest rainfall and cool weather conditions favored rapid late blight development. Late blight prevalence to varying extents in conditions of higher humidity, low night temperature accompanied by light rainfall or heavy dew and in fields previously sown with solanaceous crops has also been reported (Kirk *et al.,* 2013).

Table 4.1. Mean, minimum and maximum prevalence, incidence and percent severity index of late blight in the surveyed areas during 2019 main cropping season

District	*Kebele*	N	Prevalence (%)			Incidence (%)			PSI (%)		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Fagita Lekoma	Fagita	6	0	100	50.83	0	90	48.46	0	66.66	24.57
	Sigla dawuna	6	0	100	69.44	0	94.44	56.87	0	53.70	22.04
	Furi jegola	6	0	100	56.66	0	85	41.45	0	66.66	22.76
	Gafera	6	0	100	49.16	0	81.40	44.28	0	46.60	21.84
	Chiguali	6	50	100	82.77	25.45	96.00	64.25	16.34	9600	64.25
	Mean		0.0	100	61.78	0.00	96.00	51.07	0.00	66.66	25.56
Banja	Asem selasse	6	75	100	92.50	75.60	100	87.02	40.00	84.40	62.04
	Gomerta	6	80	100	96.66	66.66	100	83.25	30.00	87.50	52.67
	Gagasta	6	0	100	75	0	100	65.69	0	79.52	39.86
	Akena	6	0	100	76.66	0	100	71.96	0	80.27	29.77
	Dangia	6	0	100	54.16	0	82.50	67.00	0	60.40	27.12
	Mean		0.00	100	79.00	0.00	100	70.64	0.00	87.50	45.71
	Grand Mean		0.00	100	70.39	0.00	100	60.85	0.00	87.50	35.64

N= Number of farmer potato fields, Min= Minimum, Max= Maximum

4.1.2. Disease incidence

The mean incidence of late blight of potato was prevalent in both districts surveyed with varying degrees of incidence. Higher (70.63%) mean incidence at Banja and lower (51.06%) mean incidence were recorded at Fagita Lekoma (Table 4.2). Similarly, the maximum disease incidence 100% was recorded from Banja district and the minimum disease incidence 96% was recorded from Fagita Lekoma district (Table 4.1). Variations in incidence between locations might be due to differences in environmental factors. Late blight epidemics are severe only when weather conditions are suitable, i.e. heavy rains, cool temperatures and presence of moisture on the potato leaves for an extended period (> 8–10 h for several consecutive days) (Kankwatsa *et al*., 2002). The mean disease incidence for both districts was 60.85% (Table 4.1).

Among the *Kebele* Administrations *(KAs)*, the highest mean disease incidence was recorded at Asem selasse (87.02%) followed by Gomerta (83.25%) and Akena (71.96%), whereas the lowest disease incidence was recorded in Furi jegola (41.45%), followed by Gafera (44.28%) and Fagita (48.65%) *KAs*. Other *KAs* were recorded in the ranges of 56.87-67% mean disease incidence (Table 4.1). The highest late blight mean disease incidence of (80.45, 64.32 and 70.92%) were recorded from farmer potato fields planted previously with potato, in the month of June and the altitudinal range of $\geq$2300 meter above sea level, respectively. While, the lowest mean incidence (41.00, 58.98 and 37.35%) were recorded from fields previously with *teff*, in the month of May and the altitudinal range of <2300 meter above sea level, respectively (Table 4.2). The result is primarily attributed to the delay in the onset of the disease on early-planted potatoes. On the other hand; the highest mean incidence (85.38%) was recorded from fungicide unsprayed field when compared with fungicide sprayed fields recorded the lowest (24.05) incidence. Fungicide application reduced disease incidence and severity (Hirut Getinet *et al*., 2017). Beka Biri and Pichiah (2020) reported at high altitude with high precipitations resulting into a conducive environment to boost late blight development.

In some fields, potato was intercropped with other crops such as maize, barley and wheat had the lowest (50.16%) mean incidence of late blight was recorded from these fields; on the other hand the highest (68.47%) mean incidence was recorded from potato planted as sole cropping system. The highest (80.45%) mean incidence of late blight was recorded from fields planted with solanaceous (potato) crop in the preceding year. High levels of disease in these fields may be due to monoculture of solanaceous crops and the presence of favorable temperature and rainfall during cropping season. Bekele Kassa and Eshetu Bekele (2008) explained that when the environmental conditions become conducive the disease can spread rapidly and might have the potential to destroy the potato fields completely within three weeks. The highest (80.82 and 66.72%) mean incidence was observed when fields planted with *Key* variety and at flowering stage, whereas the lowest (13.49 and 47.93) was observed when fields planted with Belete variety and at vegetative stage, respectively (Table 4.2). Disease incidence depends on meteorological conditions, cultivars susceptibility to potato late blight, and growth stage of the potato during disease attack (Razukas *et al*., 2008).

4.1.3. Disease severity

The overall mean disease severity for both districts was 35.64% (Table 4.1). The highest mean disease severity was obtained at Banja district while the lowest mean disease severity was obtained at Fagita Lekoma district (Table 4.2). This is due to the variation in env ironmental conditions of the surveyed districts; there was higher rainfall and lower temperature availability in Banja district than Fagita Lekoma district (Appendix Table 3). These conditions may ideal for late blight development. Harrison (1992) reported that moderate temperatures (10–25°C) and wet conditions (100% relative humidity) are required for sporulation. Majid *et al*. (2008) also reported cloudiness or heavy wetness following lower temperature favors disease development.

Among the *KAs*, the highest mean disease severity was recorded in *kebele* Chiguali (64.25%) followed by *kebele* Asem selasse (62.04%) and *kebele* Gomerta (52.67%) whereas, the lowest disease severity was recorded in *kebele* Gafera (21.84%), followed by *kebele* Furi jegola (22.7 6%) and *kebele* Sigla dawuna (22.04%), respectively. Other *kebeles* were recorded in the range of 24.57-39.86% mean disease severity (Table 4.1). Disease severity of late blight on potato in many locations recorded in the range of 27.9 to 81.6% (Mukalazi *et al*., 2001).

The mean disease severities obtained at different independent variables viz: altitude, planting date, varieties, preceding crops, cropping system, crop growth stage and fungicide were varied in the surveyed areas. Among which the mean maximum disease severities (PSI%) (52.59, 50.18, 50.15, 44.66, 41.75, 38.82 and 36.66%) were obtained from unsprayed fields, previous crop with potato, local cultivars, altitude $\geq$ 2300 meter above sea level, sole cropping, and flowering growth stage and at June planted, respectively in the surveyed districts. On the other hand, the least mean severity (PSI%) 6.24, 10.19, 14.56, 17.49, 27.07, 29.72 and 35.08% were recorded from Belete variety, sprayed fields, altitude < 2300 meter above sea level, previous crop planted with *teff*, intercropping, vegetative growth stage and at May planted, respectively in the surveyed districts. Disease severity mainly attributed to susceptibility and resistance of various varieties grown in many areas, different planting dates (disease escape), and various late blight management practices (GILB and CIP, 2004; Ephrem Guchi, 2015) and early planting at the time of rainfall onset contributed to the delay in disease development (Kankwatsa *et al*., 2002).

Potato intercropped with none host crops reduces the development of the disease. The result of the current study coincides 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 grown. For pathogens like *phytophthora* which mostly disperse by wind and rain, interrupting with none host crop for a disease may physically interfere and be able to entrap the spores, thereby reduce the available inoculum (G arret and Munndit, 2000; Bekele Kassa and Sommartya, 2006). Garlic, faba bean and barley intercropped with potato showed lower disease severity compared to monoculture potato plant (Bekele Kassa and Sommartya, 2006).

Table 4.2. Mean incidence and percent severity index of potato late blight for different independent variables in the surveyed districts during 2019 main cropping season

Variable	Variable Class	N	Percent	Disease incidence (%)			Percent severity index (PSI) (%)		
				Min	Max	Mean	Min	Max	Mean
District	Fagita Lekoma	30	50	0.00	96.00	51.06	0.00	66.66	25.57
	Banja	30	50	0.00	100	70.63	0.00	87.50	45.71
Altitude	<2300	18	30	0.00	90.00	37.35	0.00	66.66	14.56
	≥2300	42	70	0.00	100	70.92	0.00	87.50	44.66
Planting Date	May	39	65	0.00	100	58.98	0.00	87.50	35.08
	June	21	35	0.00	96.00	64.32	0.00	74.67	36.66
Variety	Belete	8	13.33	0.00	82.50	13.49	0.00	33.33	6.24
	Gudene	10	16.67	0.00	81.40	41.57	0.00	55.78	20.04
	Zengena	3	5.01	0.00	86.54	51.51	0.00	60.24	20.96
	Guassa	4	6.66	0.00	82.50	46.63	0.00	55.00	25.23
	Key	22	36.75	0.00	100	80.82	0.00	87.50	50.15
	Abalo	13	21.58	0.00	100	77.56	0.00	80.27	47.73
Previous crop	Barley	5	8.33	0.00	100	70.75	0.00	75.50	48.57
	Wheat	6	10.00	0.00	96.00	63.57	0.00	66.00	29.15
	Teff	15	25.00	0.00	90.00	41.00	0.00	50.00	17.49
	Maize	26	43.33	0.00	100	63.74	0.00	80.27	37.56
	Potato	8	13.34	0.00	100	80.45	0.00	87.50	50.18
Cropping system	Inter	25	41.67	0.00	100	50.16	0.00	79.52	27.07
	Sole	35	58.33	0.00	100	68.48	0.00	87.50	41.75
Growth stage	Vegetative	22	36.67	0.00	100	49.94	0.00	87.50	29.72
	Flowering	38	63.33	0.00	100	66.72	0.00	84.40	38.82
Fungicide	Sprayed	24	40	0.00	66.66	24.05	0.00	32.00	10.19
	Unsprayed	36	60	70.00	100	85.38	12.20	87.50	52.59

N= Number of farmer potato fields, Min= Minimum, Max= Maximum

4.2. Effect of Potato Varieties and Fungicides on Potato Late Blight Disease

4.2.1. Days to first disease symptom appearance

Analysis of the data for days to first disease symptom appearance (DFDSA) revealed highly significant effect ($p<0.01$) among varieties and fungicides but non-significant effect ($p>0.05$) among their combinations (Appendix Table 4). The disease first appeared within 45 days after planting (DAP) on local (*Key*) varieties and 47 days on Zengena, which were susceptible and moderately susceptible varieties, respectively (Table 4.3).

In the moderately resistant varieties Belete the disease appeared within 52 days after planting followed by Gudene (51 DAP). On the other hand, the disease appeared within 45 days after planting (DAP) in the fungicide unsprayed plots and it was delayed by 7 and 5 days from plots sprayed with Ridomil Gold 68%WG and Mancozeb 80% WP application, respectively (Table 4.3). This may be due to fungicides prevent the entrance of late blight. This observation is in line with findings of Binyam Tsedaley *et al.* (2014) who reported that the disease appeared earlier on moderately susceptible and susceptible varieties than on moderately resistant ones. Solano *et al.* (2014) also reported that potato genotypes which developed late blight symptom early are susceptible and genotypes that developed late blight lately in the crop cycle are resistant.

Table 4.3. The main effect of potato varieties and fungicides on days to first disease symptom appearance at Fagita Lekoma district during 2019, cropping season

		DFDSA
	Belete	52.11a
Variety	Gudene	51.22a
	Zengena	47.22b
	Key	45.78b
LSD		3.68
CV (%)		7.15
	Mancozeb 80% WP	49.92a
Fungicide	Ridomil Gold 68% WG	52.33a
	Unsprayed	45b
LSD (0.05)		3.19
CV (%)		7.15

DFDSA= days to first symptom appearance, LSD = Least significant difference at 0.05 probability level, CV = coefficient of variation, values following by the same letter within the column are not significantly different

4.2.2. Disease incidence

Analysis of data on disease incidence showed significant effect (<0.05) among interaction effects of the potato varieties and fungicide application at both dates of assessment (Appendix Table 5).

In the first date of assessment (45DAP), the highest disease incidences (61.33) was recorded from the unsprayed control of *Key* variety followed by 55.78% from unsprayed control of Zengena variety (Table 4.4). The lowest incidence (25.57%) was recorded from the Ridomil Gold 68% WG sprayed Belete variety followed by 26.53% from Ridomil Gold 68% WG sprayed Gudene variety. Gudene sprayed with Mancozeb 80%WP recorded 47.03% disease incidence, while unsprayed plot record 55.20% disease incidence (Table 4.4). Minimum initial percent disease incidence was observed in fungicide treated plots (Mohammed Amin *et al*., 2013).

Similarly, in the second date of assessment (52DAP), the highest disease incidence (100%) was recorded from treatment combinations of the varieties (*Key* and Zengena) without application of fungicides (Table 4.4). The lowest (36.67 and 46.67%) disease incidence was recorded from the variety Belete and Gudene combination with Ridomil Gold 68% WG applications. Moreover, the potato variety Gudene sprayed with Mancozeb 80% WP recorded 70% disease incidence (Table 4.4). In general, lower disease incidence was recorded on all varieties combination with Ridomil Gold 68% WG and Mancozeb 80% application as compared to unsprayed. Fungicide application on potato varieties reduced disease incidence. This result also supported by Bekele Kassa and Hailu Beyene (2001) that fungicide sprayed plots had lower disease incidence of late blight than unsprayed.

Table 4.4. The effect of different potato varieties and fungicide application on incidence of potato late blight at Fagita Lekoma district during 2019 main cropping season

Variety	Fungicide	Disease Incidence (%)	
		45DAP	52DAP
Belete	Mancozeb 80% WP	42.25d	63.33d
	Ridomil Gold68%WG	25.57f	36.67e
	Unsprayed	52.50bc	90.00ab
Gudene	Mancozeb 80% WP	47.03cd	70.00cd
	Ridomil Gold68%WG	26.53f	46.67e
	Unsprayed	55.20b	90.00ab
Zengena	Mancozeb 80% WP	51.95bc	80.00bc
	Ridomil Gold68%WG	32.60e	46.67e
	Unsprayed	55.78ab	100.00a
Key	Mancozeb 80% WP	13.20g	80.00bc
	Ridomil Gold 68%WG	33.75e	60.00d
	Unsprayed	61.33a	100.00a
LSD (0.05)		5.60	7.43
CV (%)		7.56	6.32

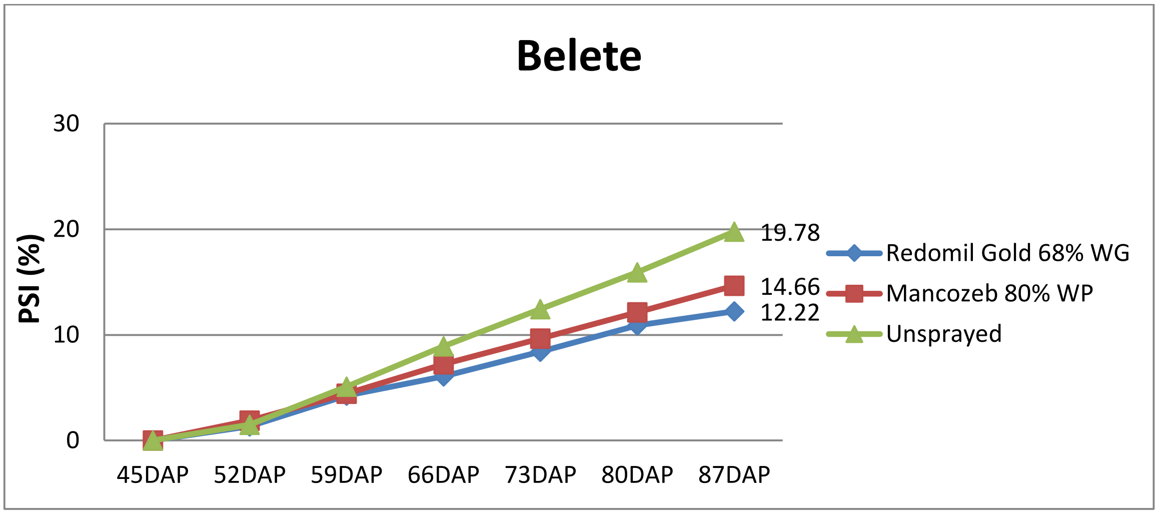
DAP= days after planting, LSD = Least significant difference at 0.05 probability level, CV = coefficient of variation, values following by the same letter within the column are not significantly different

4.2.3. Disease severity

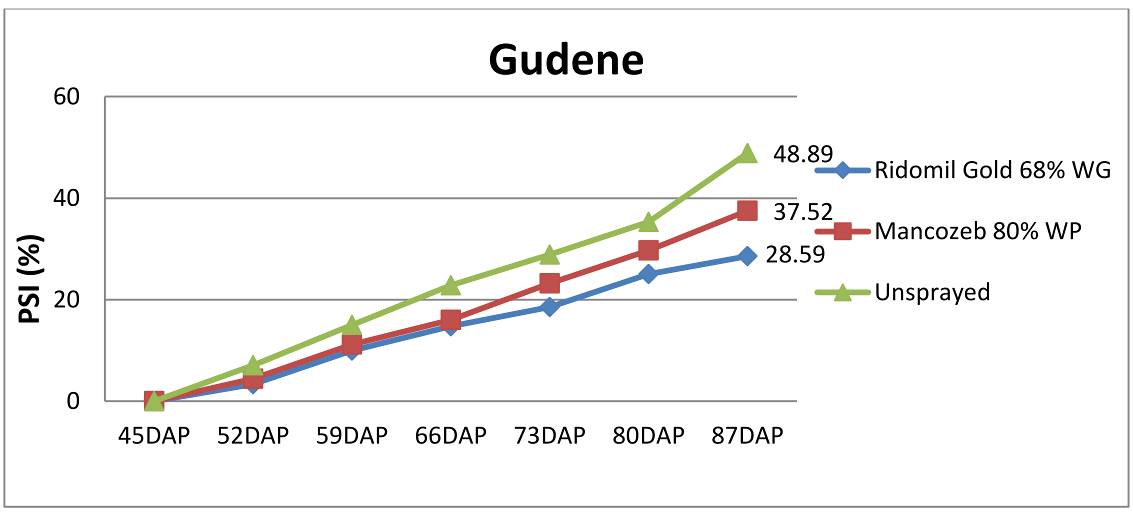
Analysis of percent severity index (PSI %) revealed highly significant ($p<0.01$) differences among the interaction effect of varieties and fungicides at all dates of assessments (Appendix Table 6).

In the final date of assessment (87DAP), the maximum PSI (76.68%) was recorded on unsprayed plots of the susceptible variety *Key* followed by (63.92%) unsprayed moderately susceptible Zengena variety (Figure 4.1). However, the minimum (12.22%) disease severity was recorded on moderately resistant Belete variety sprayed with Mancozeb 80% WP applications (Figure 4.1). The potato varieties, Gudene, local (*Key*) and Zengena plots sprayed with Ridomil Gold 68% WG were recorded PSI of 28.59, 36.54 and 37.61%, respectively. Moreover, these varieties sprayed with Mancozeb 80% WP were recorded PSI of 37.52, 53.44 and 45.03%, respectively (Figure 4.1). In general, late blight progress was faster on *Key* and slower on Belete and Gudene varieties while moderate progress was observed on Zengena variety.

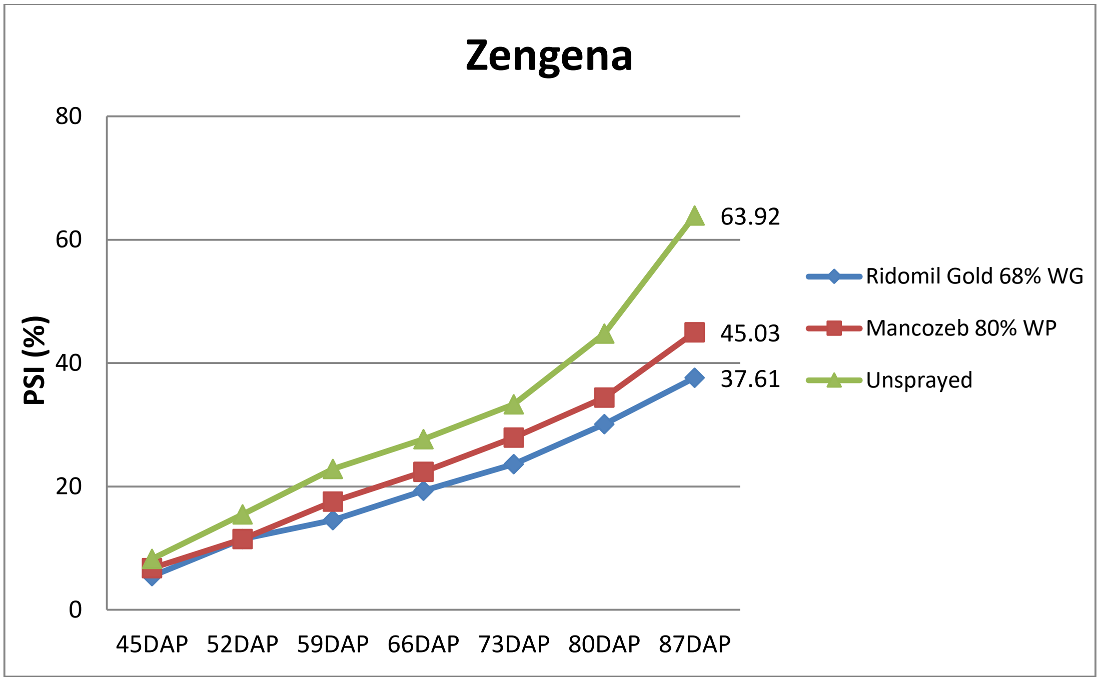
Fungicide sprayed on all potato varieties significantly reduced disease severity as compared to unsprayed varieties (Figure 4.1). Variety fungicides combinations reduce disease severity by inhibit the expansion of area lesion on the leaf. The results of the present study confirmation with the findings of Mohammed Amin *et al.* (2013) who suggested the least percent disease severity was recorded in Ridomil gold treatments with mean values of 40.74% and the highest percent final disease severities (69.72%) was recorded from untreated control plots. Effective control of potato late blight can be attained by combining host resistance and managed fungicide applications even in a cultivar that is highly susceptible to potato late blight (Muhinyuza *et al.,* 2008). Timely applications of fungicides on potato varieties have enabled to limit the fungus growth and development (Ashenafi Mulatu *et al*., 2017; Gebremariam Asaye *et al*., 2020). The disease severity score on sprayed plots consistently smaller than unsprayed plots (Shiferaw Mekonen and Tesfaye Tadesse, 2018). Fungicides and host plant resistance are among the most efficient control options available to growers (Habtamu Kefelegn *et al.*, 2012).



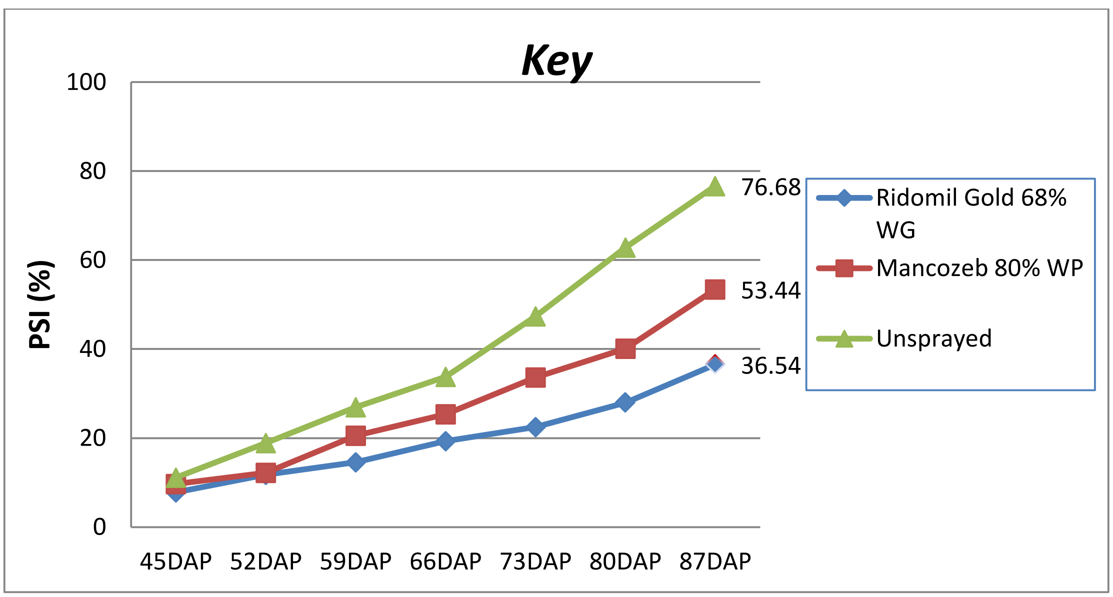
A)



B)



C)



D)

Figure 4.1. Effect of different fungicides on potato late blight progress curve of disease severity under four potato varieties Belete (A), Gudene (B), Zengena (C) and *Key* (D) at Fagita Lekoma district during 2019 main cropping season.

4.2.4. Disease progress rate (r)

Analysis of disease progress rate showed highly significant ($p<0.001$) differences among interactions of varieties and fungicides application (Appendix Table 7). The highest disease progress rate (0.0930 and 0.0879 unit day^{-1}) were obtained on unsprayed plots of *Key* and Mancozeb 80% WP fungicide sprayed plots of Gudene, respectively. Whereas, the lowest disease progress rate (0.0405 and 0.0543unit day^{1}) was obtained from Ridomil Gold 68% WG fungicide sprayed plots of the varieties Belete and *Key*, respectively (Table 4.5). The applicat ion of fungicide on Belete and local variety reduced the progress of the disease as compared to unsprayed (controls). However, Ridomil Gold 68% WG fungicide highly reduce d the progress of the disease compared to Mancozeb 80% WP (Table 4.5). This might be due to fungicide application and variable resistance levels of the genotypes. This result is supported by Habtamu Kefelegn *et al*. (2012) who suggested that application of fungicides arrested disease development more effectively compared to no fungicide application. Hence, late blight progress rate was faster on unsprayed plots of the susceptible variety *Key* than the control plots of other varieties. Generally, variation in late blight progress rate might be due to the variable resistance levels of the genotypes. Ermias Misganaw (2016) reported that the integration of resistance variety with fungicide reduced the progress of late blight disease. Bekele Kassa and Hailu Beyene (2001) also suggested that frequent application of fungicide could retard the progress rate of potato late blight in the field. Disease progress rate increased rapidly on unsprayed plots than the sprayed once, regardless of the varieties (Gebremariam Asaye *et al*., 2020).

Table 4.5. The combination of different potato varieties and fungicide application on disease progress rate of potato late blight at Fagita Lekoma district during 2019 main cropping season

Variety	Fungicide	r (unit day^{-1})
Belete	Mancozeb 80% WP	0.0737d
	Ridomil Gold 68%WG	0.0405i
	Unsprayed	0.0768d
Gudene	Mancozeb 80% WP	0.0879b
	Ridomil Gold 68%WG	0.0834c
	Unsprayed	0.0738d
Zengena	Mancozeb 80% WP	0.0507gh
	Ridomil Gold 68%WG	0.0476h
	Unsprayed	0.0642f
Key	Mancozeb 80% WP	0.0682e
	Ridomil Gold 68%WG	0.0543g
	Unsprayed	0.0930a
LSD (0.05)		0.004
CV (%)		3.52

r = disease progress rate, LSD = Least significant difference at 0.05 probability level, CV = coefficient of variation, values following by the same letter within the column are not significantly different

4.2.5. Area under disease progress curve (AUDPC)

Analysis of area under disease progress curve (AUDPC) showed highly significant (p<0.001) differences among interaction of potato varieties and fungicide application (Appendix Table 7). The highest mean AUDPC value (1630.70 %-days) was recorded on unsprayed plots of *Key* variety which were significantly different from all the sprayed plots. On the other hand, the lowest AUDPC value (258.35 %-days) was recorded on Belete variety sprayed with Ridomil Gold 68% WG followed by Mancozeb 80% WP (305.77 %-days) applications (Figure 4.2). In addition, lower AUDPC values were recorded from sprayed plots of Zengena and *Key* varieties as compared to unsprayed plots of both varieties. This might be due to different fungicide variety combinations reduced late blight development. In agreement to this study, Habtamu Kefelegn *et al.* (2012) explained that fungicide non-sprayed plots had the highest AUDPC values while fungicide sprayed plots had the lowest values. These result also supported by the idea of Ashenafi Mulatu *et al.* (2017) reported that minimum AUDPC 244% days and 267.5 % days was observed on Gera treated with Ridomil and Horizoon, respe ctively. Mohammed Amin *et al.* (2013) also reported that Victory 72 WP was retarded late blight development consistently when combined with all varieties. Integrating host resistance with fungicide application significantly reduced the rate of disease progress (Kankwatsa *et al.*, 2002).

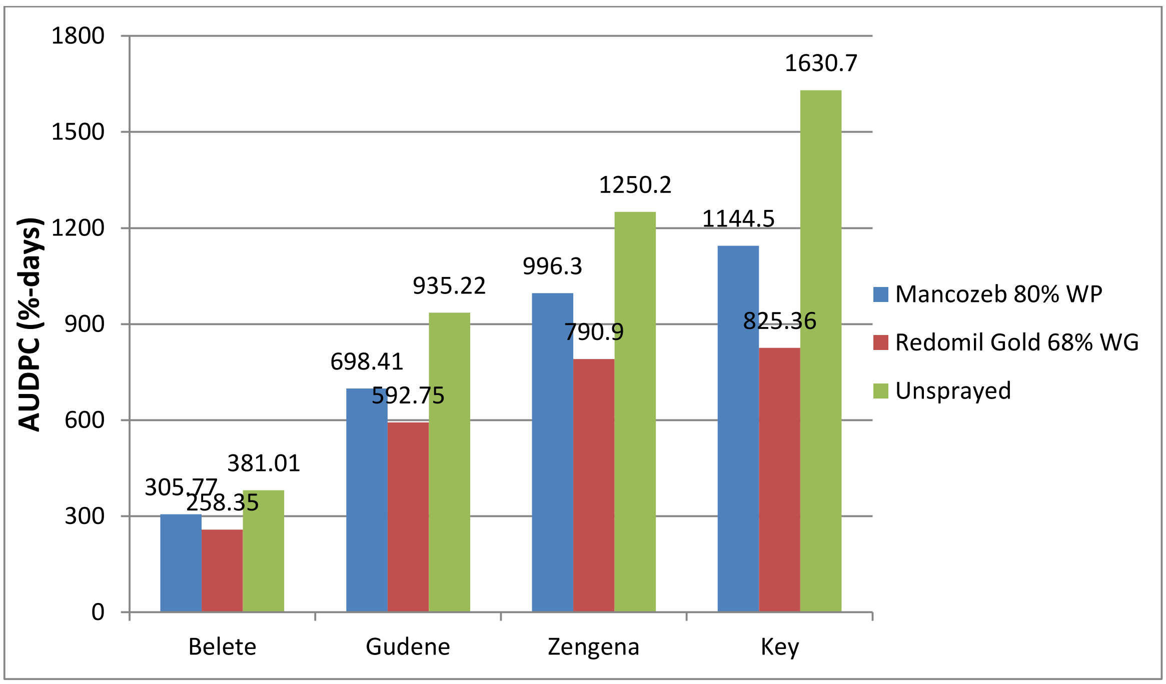


Figure 4.2. Area under disease progress curve (AUDPC) of potato late blight as affected by potato varieties sprayed with fungicides.

4.3. The Combination Effect of Potato Varieties and Fungicides on Yield and Yield Components

4.3.1. Days to 50% flowering

Analysis of variance (ANOVA) on days to 50% flowering revealed highly significant differences ($p<0.01$) among varieties and significant ($p<0.05$) among fungicides. However, the interaction effect did not show significance ($p>0.05$) on days to 50% flowering (Appendix Table 8). Belete had longer days to 50% flowering than the other varieties (Table 4.6). With regard to fungicide application, unsprayed plots hastened days to flowering whereas sprayed plots had delayed days to flowering. Integration of potato varieties with fungicide application did not affect the flowering time (Jejaw Tsedaley, 2011).

Table 4.6. The main effect of potato varieties and fungicide applications on days to 50% flowering at Fagita Lekoma, during 2019 main cropping season

		Days to 50% flowering
Variety	Belete	62.78a
	Gudene	59.00c
	Zengena	60.44b
	Key	55.33d
LSD (0.05)		1.04
CV (%)		5.00
Fungicide	Mancozeb 80% WP	59.42ab
	Ridomil Gold 68% WG	60.00a
	Unsprayed	58.75b
LSD (0.05)		2.47
CV (%)		5.00

LSD = least significant difference, CV = coefficient of variation, values with the same letter within the column are not significantly different at 0.05 probability level

4.3.2. Days to physiological maturity

Analysis of variance (ANOVA) on days to physiological maturity revealed that the interaction effect of varieties and fungicides significantly ($p<0.05$) affect days to physiological maturity (Appendix Table 8). Days to physiological maturity ranged from 89.00 to 107.66. The longest Days to physiological maturity were recorded from the variety Belete sprayed with Ridomil Gold 68% WG (Table 4.7); whereas the lowest days to maturity were recorded on the local variety without fungicide application. Fungicide application in each treatment extended the time required by the potato varieties to attain days to physiological maturity. According to Fekede Girma (2011) fungicide application extended physiological maturity and that could be attributed to the indirect increment of photosynthesis process and controlled ability of foliage reduction with late blight intensity. Fungicide application on potato varieties lengthened to reach physiological maturity and correspondingly could increase tuber yield (Ayda Tsegaye, 2015).

Table 4. 7. The effect of potato varieties and fungicide combinations on physiological maturity at Fagita Lekoma, during 2019 main cropping season

Variety	Fungicide	Physiological Maturity(days)
Belete	Mancozeb 80% WP	105.00b
	Ridomil Gold68% WG	107.66a
	Unsprayed	104.00bc
Gudene	Mancozeb 80% WP	103.00cd
	Ridomil Gold68%WG	101.67d
	Unsprayed	99.33e
Zengena	Mancozeb 80% WP	94.00g
	Ridomil Gold68%WG	96.67f
	Unsprayed	92.00h
Key	Mancozeb 80% WP	89.67i
	Ridomil Gold68%WG	93.33gh
	Unsprayed	89.00i
LSD (0.05)		1.88
CV (%)		1.13

LSD = least significant difference, CV = coefficient of variation, values with the same letter within the column are not significantly different at 0.05 probability level

4.3.3. Plant height

The main effect of varieties and fungicides showed that highly significant (p<0.01) difference on plant height. However, the interaction effect showed non-significant difference (p>0.05) on plant height (Appendix Table 8).

The mean plant height 61.53, 54.82, 48.82 and 42.80cm was recorded on the varieties Belete, Zengena, Gudene and *Key*, respectively (Table 4.8). This might be due to genetic differences between the varieties. The fungicides significantly differed from each other on plant height. The tallest (55.16 and 53.24cm) plant height was recorded on Ridomil Gold 68% WG and Mancozeb 80% WP sprayed plots, respectively, whereas the shortest (53.24cm) plant height was recorded on unsprayed plots (Table 4.8). According to Ayda Tsegaye (2015) and Fekede Girma (2011), fungicide application could increase plant height due to the encouraging ability of the fungicides that reduce defoliation via late blight and the plant continues in its physiological process. .

Table 4.8. The major effect of potato varieties and fungicide applications on plant height at Fagita Lekoma, during 2019 main cropping season

		Plant height(cm)
	Belete	61.53a
Variety	Gudene	48.82b
	Zengena	54.82c
	Key	42.80c
LSD (0.05)		5.21
CV (%)		9.35
	Mancozeb 80% WP	53.24b
Fungicide	Ridomil Gold 68% WG	55.16a
	Unsprayed	47.57b
LSD (0.05)		4.56
CV (%)		9.35

LSD = least significant difference, CV = coefficient of variation, values with the same letter within the column are not significantly different at 0.05 probability level

4.3.4. Number of tubers per plant

The interaction effect of varieties and fungicides revealed that highly significant ($p<0.01$) differences on number of tubers per plant (Appendix Table 8).

The highest (13.67) number of tuber per plot was obtained on Gudene variety combined with Ridomil Gold 68% WG followed (12.66) by Mancozeb 80% WP. The lowest (6) number of tubers per plant was obtained from unsprayed plots of local variety (Table 4.9). Fungicide application increases the number of tubers on potato varieties. The present study is supported by Fekede Girma (2011) research finding there was a significant difference among interaction effect of variety and fungicide on tuber number per plant and the author also suggested that the highest number of tuber per plot was obtained fungicide treated plots compared to control. Fungicide application for late blight management increases potato tuber yields irrespective of the potato variety (Olanya *et al*., 2004; Fekede Girma, 2011).

4.3.5. Marketable tuber yield

The data on marketable tuber yield revealed highly significant ($p<0.01$) differences among the interaction effects of varieties and fungicides (Appendix Table 9). The highest (29.16 and 25.50 t ha^{-1}) marketable tuber yield was recorded from Belete and Gudene varieties sprayed with Ridomil Gold 68%WG applications, respectively, which was significantly higher than from other treatment combinations (Table 4.9). The second highest (25.43 t ha^{-1}) marketable tuber yield was recorded from Belete variety sprayed with Mancozeb 80%WP fungicide applications, followed by Zengena (22.83 t ha^{-1}) variety sprayed with Ridomil Gold 68%WG. This is might be due to fungicides can inhibit the germination and growth of late blight which results in increase of marketable tuber yield. Similar result was obtained from Habtamu Kefelegn *et al.* (2012) suggested that the improved variety Jallene and Gudene combined with fungicide application had higher marketable yields as compared to the local varieties.

On unsprayed plots of the variety Belete (18.63 t ha^{-1}) marketable tuber yields were obtained while it gave 14.90 t ha^{-1} marketable tuber yields in Gudene. On the other hand, the lowest (4.26 and 9.26 t ha^{-1}) marketable tuber yield was obtained from unsprayed *Key* and Zengena varieties, respectively (Table 4.9). Late blight had a significant effect on marketable yield leading to average reduction of 44% (Hirut Getinet *et al*., 2017). In general, the highest marketable tuber yield was obtained from the moderately resistant Belete variety sprayed with Ridomil Gold 68%WG fungicide application. However, the lowest marketable tuber yield was obtained from unsprayed susceptible local variety (*key*). The results of the present study was in line with the result of Mantecon (2009), in which yield differences obtained from treated and untreated controls were higher in marketable tubers than in total yield. Ngoju *et al.* (2014)

also explained that the protection of potato leaves by using fungicide increases potato yielding ability in sprayed plots compared to the unsprayed plots.

4.3.6. Unmarketable tuber yield

Analysis of Variance on unmarketable tuber yield revealed highly significant ($p<0.01$) differences among combinations of different varieties and fungicides (Appendix Table 9). The highest (11.56 and 9.16 t ha^{-1}) unmarketable tuber yields were obtained on unsprayed plots of the variety *Key* and Zengena, respectively (Table 4.9). The lowest (1.10 and 2.50 t ha^{-1}) unmarketable tuber yield was obtained from Ridomil Gold 68% WG sprayed plots of the variety Gudene and Belete, respectively (Table 4.9). The highest unmarketable tuber yield was obtained from unsprayed plots of each variety as compared to the sprayed plots. According to Hirut Getinet *et al*. (2017) lowest unmarketable tuber yields were registered from Belete variety and she noted that higher unmarketable yield in potato is due to late blight infection.

Table 4. 9. The interaction effect of different potato varieties and fungicide application on Marketable and unmarketable tuber yield at Fagita Lekoma district during, 2019 cropping season

Variety	Fungicide	Number of tubers/plant	Marketable Tuber Yield (t ha^{-1})	Unmarketable Tuber Yield (t ha^{-1})
Belete	Mancozeb 80% WP	11.67bc	25.43b	5.38e
	Ridomil Gold 68% WG	12.33ab	29.16a	2.50g
	Unsprayed	10.23cd	28.63e	6.40d
Gudene	Mancozeb 80% WP	12.66ab	20.83d	4.65f
	Ridomil Gold 68%WG	13.67a	25.50b	1.10h
	Unsprayed	8.33efg	14.90f	7.86c
Zengena	Mancozeb 80% WP	9.67de	15.93f	7.40c
	Ridomil Gold 68%WG	10.00d	22.83c	3.16g
	Unsprayed	7.33gh	9.26h	9.16b
Key	Mancozeb 80% WP	8.00fg	13.20g	5.16ef
	Ridomil Gold 68%WG	9.33def	19.73de	4.50f
	Unsprayed	6.00h	4.26i	11.56a
LSD (0.05)		0.79	1.42	0.83
CV (%)		8.47	4.59	8.56

Note: LSD = least significant difference, CV = coefficient of variation values with the same letter within the column are not significantly different at 0.05 probability level

4.3.7. Total Tuber yield

Analysis of total tuber yield showed highly significant ($p<0.01$) differences among potato varieties with different levels of resistance sprayed with fungicides (Appendix Table 9).

The highest (31.66 and 30.81 t ha^{-1}) total tuber yields were obtained from the variety Belete plots sprayed with Ridomil Gold 68% WG and Mancozeb 80% WP, respectively (Table

4.10). The next highest (26.60 t ha^{-1}) yield was obtained from Ridomil Gold 68% WG sprayed plots of the variety Gudene.On the other hand, the lowest (15.83tha^{-1}) total tuber yield was obt ained from unsprayed plots of the variety *Key*, followed by Mancozeb 80% WP sprayed plots of the variety *Key* (18.36 t ha^{-1}) (Table 4.10). This might be due to early onset of late blight on the variety *Key* which results in reduction of total tuber yield. According to Habtamu Kefelegn *et al.* (2012) and Bika Beri (2019) varieties with early-season infection are highly susceptible to late blight, contributing significantly to the lower yields observed.

Generally, varieties sprayed with fungicide produced more yields as compared to the unspraye d plots of each variety (Table 4.10). Habtamu Kefelegn *et al.* (2012) and Ashenafi Mulatu *et al.* (2017) indicated that application of fungicide increased the total yield of potato and gave highest yield as compared to other treatments. Kankwatsa *et al.* (2002) reported that integration of host resistance and fungicide application reduced the late blight severity by more than 50% and resulted in yield gains of more than 30%. Mesfin Tessera *et al.* (2009) also reported that Ridomil and Mancozeb were used to control potato late blight disease.

4.3.8. Relative yield loss

The yield loss was calculated for treatment combinations relative to the yield of maximum protected plots of each variety. Tuber yield loss was varied among different variety and fungicide combinations. The highest (34.66) yield loss was recorded on the unsprayed plots of susceptible variety *Key* followed by moderately susceptible Zengena (29.11%) compared to other treatment combinations (Table 4.10). This result coincides with the finding of Olanya *et al*, (2001) estimated losses due to late blight to average about 30–75% on susceptible cultivars; however, in Ethiopia, the disease causes 100% yield loss on unimproved local cultivar, and 67.1% on susceptible cultivar (Bekele Kassa and Yaynu Hiskias, 1996).

According to Ashenafi Mulatu *et al.* (2017) research finding, the highest tuber yield loss (59.29%) was recorded from untreated Jalene variety followed by untreated Gera (35.04%). Lowest yield loss was recorded on sprayed plots of all varieties. In addition, lower (2.68 and 4.21%) yield loss was recorded on the moderately resistant variety Belete and Gudene sprayed with Mancozeb 80% WP, respectively (Table 4.10). In comparison, tuber yield losses in unsprayed plots were higher than sprayed plots. In Ethiopia, tuber yield losses due to late blight ranged from 31-100%, depending on the variety used (HARC, 2007). Bradshaw (1992) and Thind *et al.* (1989) reported that potato yield loss attributed primarily to late blight is dependent on variety susceptibility or tolerance/resistant and disease management practices.

4.3.9. The percent yield increase

The calculated values of percent yield increase (PYI) showed high difference among potato varieties sprayed with different fungicide applications. The highest (53.06%) yield increase was obtained from the local variety sprayed with Ridomil Gold 68% application, whereas the lowest (11.95%) yield increase was obtained from the variety Gudene plots sprayed with Mancozeb 80% WP application (Table 4.10). In this study, up to 53.06, 41.07, 16.87 and 26.49% percent yield increase was recorded on the varieties *Key*, Zengena, Gudene and Belete plots sprayed with Ridomil Gold 68% WG application, respectively (Table 4.9). In addition, up to 26.59, 23.09, 15.98, 11.95 percent yield increase also recorded on the varieties Zengena, Belete, *Key* and Gudene sprayed with Mancozeb 80% WP. All potato varieties significantly increase in yield when sprayed with different fungicide applications. In general, percent yield increase and fungicide application in the treatment combinations had positive relationship. Ashenafi Mulatu *et al.* (2017) that the combination of host resistance varieties an d fungicide applications increase the potato tuber yield more than 52.2%.

Table 4.10. The integration of potato varieties and fungicide applications on total tuber yield and relative yield loss evaluated at Fagita Lekoma, during 2019 main cropping season

Variety	Fungicide	TTY (t/ha)	RYL (%)	PYI (%)
Belete	Mancozeb 80% WP	30.81a	2.68	23.09
	Ridomil Gold 68% WG	31.66a	0	26.49
	Unsprayed	25.03cd	20.94	0
Gudene	Mancozeb 80% WP	25.48bcd	4.21	11.95
	Ridomil Gold 68%WG	26.60b	0	16.87
	Unsprayed	22.76f	14.43	0
Zengena	Mancozeb 80% WP	23.33ef	10.26	26.59
	Ridomil Gold 68%WG	26.00bc	0	41.07
	Unsprayed	18.43g	29.11	0
Key	Mancozeb 80% WP	18.36g	24.22	15.98
	Ridomil Gold 68%WG	24.23de	0	53.06
	Unsprayed	15.83h	34.66	0
LSD (0.05)		1.43		
CV (%)		3.52		

Note: TTY= Total tuber yield, RYL= relative yield loss, PYI= percent yield increase, LSD = least significant difference; CV = coefficient of variation, values with the same letter within the column are not significantly different at 0.05 probability level

4.4. Correlation between Disease and Yield Parameters

The analysis of correlations among disease incidence (52DAP) and PSI (87DAP) showed very highly significant ($p<0.001$) and negative correlations with total tuber yield, correlated at r= -0.75 and -0.93, respectively (Table 4.11). Similarly, AUDPC (%-days) values also showed very highly significant ($p<0.001$) and negative correlations with total tuber yield, correlated at r= -0.91 (Table 4.11). The results of the present study are consistent with the result of Ayda Tsegaye (2015), who suggested that highly significant and negative correlation was found between late blight severity and AUDPC with tuber yield. Kankwatsa *et al.* (2002) also indicated highly significant and negative correlation existed between late blight and tuber yield. Habtamu Kefelegn *et al.* (2012) also reported that the highly significant correlation between disease severity and percentage reductions in tuber yield due to late blight. Disease incidence (52DAP), PSI (87DAP) and AUDPC (%-days) had highly and significant negative correlations with yield parameters (plant height, marketable and total tuber yield) except unmarketable tuber yield which had highly positively correlated (Table 4.11).

Therefore, the correlation analysis showed that the disease parameters associated had negative effect on tuber yield of potato. However, all disease parameters had positively correlated with each other. This is in agreement with the results of Binyam Tsedaley *et al.* (2014) reported that disease parameters PSI at 87DAP and AUDPC were positively correlated. Misgana Mitiku and Yesuf Eshete (2017) suggested that disease incidence had positive and significant correlation with disease severity. The highest and negative value of correlation coefficient indicated the negative effects of late blight on yield of potato varieties (Ayda Tsegaye, 2015).

Table 4.11. Correlation coefficient (r) between disease and yield parameters of potato late blight disease at Fagita Lekoma district, during 2019 main cropping season

Variables	DI	PSI	AUDC	PH	MTY	UMTY	TTY
DI	1						
PSI	0.75**	1					
AUDPC	0.67**	0.943**	1				
PH	-0.47**	-0.669**	-0.66**	1			
MTY	-0.86**	-0.933**	-0.93**	0.66**	1		
UMTY	0.87**	0.76**	0.785**	-0.46**	-0.88**	1	
TTY	-0.75**	-0.93**	-0.91**	0.71**	0.957**	-0.70**	1

**= significant at p< 0.05, **= highly significant at p<0.01, ns= non-significant at p> 0.05, DI= disease incidence at 52DAP, PSI= percent severity index at 87DAP, AUDPC= Area under Disease Progress curve, r= disease progress rate, PH= plant height, MTY= Marketable tuber yield, UNMTY= Unmarketable tuber yield, TTY= Total tuber yield*

4.5. Regression between AUDPC and Total Tuber Yield

Linear regression of the AUDPC was used for predicting the potato tuber yield loss (Figure 4.3). AUDPC linear regression better indicated the relationship between yield loss and disease. On the other hand, disease progress curves are highly sensitive to fluctuations in epidemiological factors during disease development so they are not good predictors of the relationship of yield and AUDPC (Fekede Girma, 2011). The AUDPC accounts for all these factors as the crop yield loss depends upon severity as well as on the duration of the disease. The slope of the regression line for late blight observed in this study on combination of potato varieties and fungicide applications were a= -0.016 t ha^{-1}. The slope indicated that 0.016 t ha^{-1} of yield loss was observed on these treatment combinations for every increase of AUDPC (%-days). Therefore yield and AUDPC are inversely related.

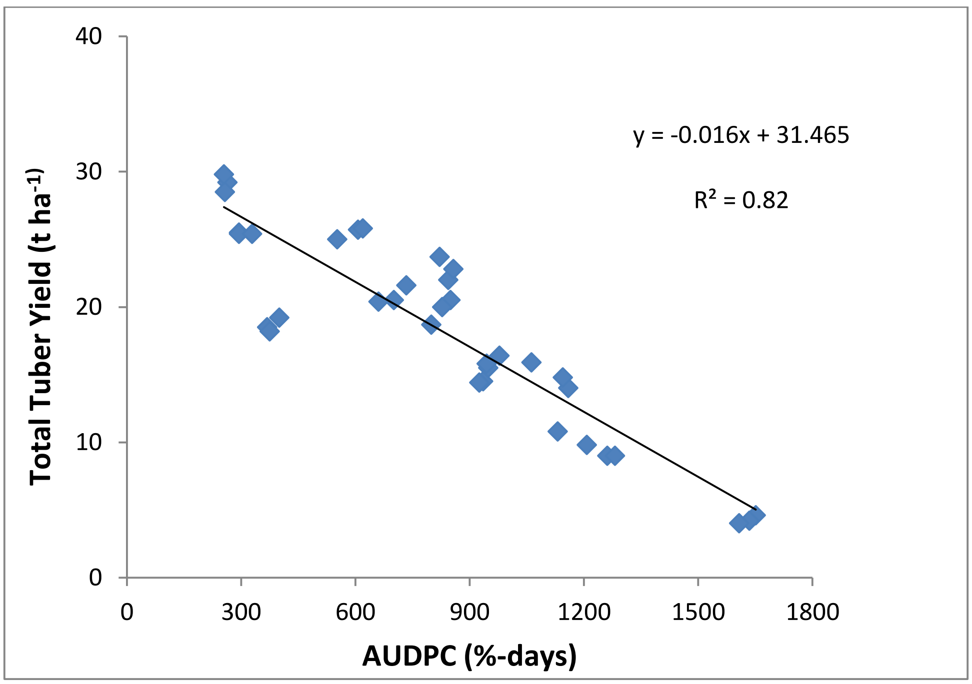


Figure 4.3. Linear regression of AUDPC (%-days) of late blight with tuber yield (t ha^{-1}).

4.6. Cost Benefit Analysis

The price of potato tubers was assessed and 10birr kg^{-1} was used to compute the total sale (Gross field benefits) and Net benefit of the total produce obtained. The cost of chemicals for hectare was calculated to be 3000 birr for hectare. The Partial budget analysis showed that fungicide application on the four potato varieties gave high net profit, marginal benefit and marginal rate of returns as compared to unsprayed treatments (Table 4.12).

The maximum (252,350 and 228,495 ETB ha^{-1}) net profit was recorded from the moderately resistant variety Belete and Gudene sprayed with Ridomil Gold 68% WG whereas; the minimum (38,300 and 83,300 ETB ha^{-1}) net profit was recorded from unsprayed plots of the local susceptible (*Key*) and moderately susceptible (Zengena) varieties. Even though lower net profit was obtained from plots sprayed with Mancozeb 80% WP fungicide; it gave higher net benefit as compared to unsprayed plots. The highest marginal benefits (129,250 and 112,150 ETB ha^{-1}) were recorded from the combination of Ridomil Gold 68% WG with *key* and Zengena varieties, respectively. Whereas, the lowest marginal benefit (55,450ETB ha^{-1}) were recorded on unsprayed Zengena variety.

The highest (1,631.18 and 1,286.07%) marginal rate of return was recorded from *Key* variety combined with Mancozeb 80% WP and Ridomil Gold 68% WG, respectively. On the other hand, the lowest (841.29%) marginal rate of return was obtained from Belete variety followed by Gudene variety (939.25) both sprayed with Ridomil Gold 68% WG (Table 4.12). Fungicid e application on potato varieties have resulted reasonable benefit and marginal rate of returns (Gebremariam Asaye *et al*., 2020).

The highest (1:48.23) cost-benefit ratio (CBR) was calculated from Belete sprayed by Mancozeb 80% WP fungicide while the lowest (1:16.67) calculated from *Key* sprayed by Ridomil Gold 68% WG fungicide (Table 4.12). Therefore, investing one Ethiopian Birr on Belete variety can produce 48.23 Ethiopian Birr.

Table 4.12. Partial budget analysis of fungicide and potato varieties at Fagita Lekoma during 2019 main cropping season

Variety	Fungicide	MTY (t/ha)	1AMTY (t/ha)mtyx0.9	2P(Br/t)	3SR(1x2)(Br/ha)	4TIC(Br/ha)	5MC(Br/ha)	6NP(3-4)(Br/ha	7MB(Br/ha)	8MRR (7/5) (%)	9CBR(6/4)
Belete	Mancozeb	25.43	22.89	10000	228900	4650	4650	224250	56450	1213.98	48.23
Belete	Ridomil	29.16	26.24	10000	262400	10050	10050	252350	84550	841.29	25.11
Belete	Unsprayed	18.63	16.78	10000	167800	0	0	167800	0	0.00	….
Gudene	Mancozeb	20.83	18.74	10000	187400	4650	4650	182750	48650	1046.24	39.30
Gudene	Ridomil	25.50	22.95	10000	229500	10050	10050	228495	94395	939.25	22.74
Gudene	Unsprayed	14.90	13.41	10000	134100	0	0	134100	0	0.00	….
Zengena	Mancozeb	15.93	14.34	10000	143400	4650	4650	138750	55450	1192.47	29.84
Zengena	Ridomil	22.83	20.55	10000	205500	10050	10050	195450	112150	1115.92	19.45
Zengena	Unsprayed	9.26	8.33	10000	83300	0	0	83300	0	0.00	….
Key	Mancozeb	13.2	11.88	10000	118800	4650	4650	114150	75850	1631.18	24.53
Key	Ridomil	19.73	17.76	10000	177600	10050	10050	167550	129250	1286.07	16.67
Key	Unsprayed	4.26	3.83	10000	38300	0	0	38300	0	0.00	….

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

Potato late blight was the main constraint that threatens potato production in subsistence farming and widely distributed over the surveyed area due to the availability of conducive environments (temperature and rainfall). From the total surveyed fields majority of the fields were infested with potato late blight disease with varied incidence and severity from place to place. The mean disease incidence, severity and prevalence at Banja district were higher than Fagita Lekoma district. Potato variety *Key* and *Abalo* in the district showed susceptibility to the disease. Fields with intercropping cereal crops and fungicide management recorded the lowest incidence and severity of late blight compared to other respective variable classes.

In field experiment, potato varieties combined with fungicides score lower disease incidence and severity. Fungicide application on all potato varieties reduced the progress of the late blight as compared to unsprayed. Ridomil Gold 68% WG fungicide highly reduced the progress of the disease compared to Mancozeb 80% WP. Application of fungicide on potato varieties significantly reduced late blight disease progress rate, incidence and severity with a corresponding decrease in AUDPC and increase in total tuber yields. In this study, Ridomil Gold 68% WG retarded late blight development consistently when combined with all varieties and the highest marketable and total yields were recorded from plots sprayed with this fungicide. AUDPC and yield loss was higher in the susceptible variety than the moderately resistant variety. On unsprayed plots yield loss up to 34.66, 29.11, 14.13 and 2.68% tuber was recorded on the varieties *Key*, Zengena, Gudene and Belete, respectively, as compared to plots of the same varieties sprayed with Ridomil Gold 80% WG fungicide.

PSI, disease progress rate, AUDPC and tuber yield losses of potato varieties were minimized by combination of moderately resistant potato varieties with fungicide applications. However, Ridomil Gold 68% WG highly reduced the progress of the disease and tuber yield loss compared to Mancozeb 80% WP. Cost benefit analysis revealed that the highest net benefit and marginal rate of return were obtained from fungicide sprayed plots of all varieties.

5.2. Recommendations

The result that is Ridomil Gold 68% WG combined with Belete variety was found to be better for the management of late blight and recommended at Fagita Lekoma district, which is conducted in a specific location and single year. Hence, it should be repeated and conducted in different years and agro-ecologies. In addition to this, further research could be carried out on dosage, spraying frequencies, intervals of Ridomil Gold 68% WG fungicide applications and variety screening.

The resistance ability of potato varieties may loss due to the variability of late blight pathogen and more on improvement on the resistance ability of varieties and dissemination to target area should be given attention and information/extension work and research on integrated potato late blight disease management is important.

6. REFERENCES

Abayhne M.A. and Chauhan N.M. 2016. Antifungal activity of various medicinal plants against late blight of potato from Ethiopia. *Journal of Scientific Research and Reports*, pp.1-9.

Abraham Tadesse. 2009. *Increasing Crop Production through Improved Plant Protection Volume II*. Plant Protection Society of Ethiopia (PPSE). PPSE and EIAR, Addis Ababa, Ethiopia. 500p.

Achamyeleh Kassie. 2015. *Integration of Acacia decurrens (J.C. Wendl.)Willd.into the farming system, its effects on soil fertility and comparative economic advantages in North Western Ethiopia.* MSc Thesis, Bahir Dar University.

Adane Hirpa, Meuwissen M. P., Agajie Tesfaye, Lommen M. J., Lansink, O. A., Admasu Tsegaye and Struik P.C. 2010. Analysis of Seed Potato Systems in Ethiopia. *American Journal of Potato Research*, 87:537–552.

Agegnehu Shibabaw, Getachew Alemayehu, Yigzaw Desalegn, Enyew Adgo, Yoseph Tewod ros Germer J., Asch F., Merene Y. and Freyer B. 2014. Exploratory Survey on Climate Change Effects, Value Chain Processes and Supportive Services: Case Study from Potato Based Farming System of Awi-Zone, Ethiopia. *International Journal of Agriculture Innovations and Research*. Volume 2, Issue 4, ISSN (Online) 2319-1473.

Agrios G.N. 2005. *Plant Pathology*. 5th Edition. Academic Press, London, New York, 421-426p.

Anonymous. 2007. Knowing Your Enemy-Blight. Available at http://sarvari-trust.org/late .blight.html /05/07/2010.APR (Annual Progress Report), 1980. Scientific Phythological Laboratory (SPL). Ambo.1979/80

ANRS-BoFED (Amhara National Regional State, Bureau of Finance and Economic Development). 2006. Frameworks and Approaches for the Developing World. Cabi, UK the Amhara National Regional State (ANRS), Bureau of finance and economic development, 2005/06 Budget year Annual Statistical Bulletin.

APR (Annual Progress Report).1979/80. Scientific Phythological Laboratory (SPL). Ambo, Ethiopia.

Ashenafi Mulatu, Thangavel Selvaraj, Alemu Lencho and Bekele Kassa. 2017. Evaluation of potato cultivars and fungicides for the management of late blight (*Phytophthora infestans* (mont) De bary) in Holleta, West Showa, Ethiopia; *International J. of Life Sciences*, 5 (2): 161-179.

ATTRA (Appropriate Technology Transfer to Rural Area). 2004. Organic Alternatives for Late Blight Control in Potatoes. *National Sustainable Agriculture Information Service*. George Kuepper & Preston Silivan. #IP131. NCAT Agriculture Specialists. http://attra.ncat.org/ 29-10-2010.

Ayda Tsegaye. 2015. *Effect of fungicides and resistant genotypes on severity of potato late blight [Phytophthora infestans (Mont.) De Bary] and yield and yield components at Haramaya, Eastern Ethiopia.* MSc. Thesis, Haramaya University, Dire Dawa, Ethiopia, PP, 101.

Beckerman J. 2008. Understanding fungicide mobility. Purdue Extension BP-70-W.

Bekele Kassa and Eshetu Bekele. 2008. Potato disease management. In Gebremedhin Woldegiorgis, Endale Gebre and Berga Lemaga (Ed.), *Root and tuber crops: The untapped resources,* overview of trends in root and tuber crops research in Ethiopia. EIAR, Addis Ababa, Ethiopia, pp.79-96.

Bekele Kassa and Hailu Beyene. 2001. Efficacy and economics of fungicide spray in the control of late blight of potato in Ethiopia. Ethiopian Agricultural Research Organization. Holetta Agricultural Research Center. *Journal of African Crop Science*, 9(1): pp.245-250.

Bekele Kassa and Sommartya T. 2006. Effect of intercropping on potato late blight, *Phytophthora infestans* (Mont.) de Bary development and potato tuber yield in Ethiopia. *Agriculture and Natural Resources, 40*(4), pp.914-924.

Bekele Kassa and Yaynu Hiskias. 1996. Tuber yield loss assessment of potato cultivars with different levels of resistance to late blight. In: *Proceedings of the 3rd Annual Conference, of Crop Protection Society of Ethiopia.* 18-19 May, Addis Abeba, Ethiopia.

Bekele Kassa, Sommartya T., Rakvidhyasastra V., Singburaudom N., Sukprasert P. and Berga Lemaga. 2006. Crude garlic extracts effect on the growth of mycelia, germination of zoospores and sporangia and time of application on the infection of *Phytophthora infestans* (Mont.) de Bary of potato under controlled conditions in Ethiopia. *Kasetsart J. (Nati. Sci.*), 40:914-924.

Berga Lemaga, Gebre-Medhin W/Giorgis, Teriessa J. and Bereket Tulu. 1992.Potato agronomy research. In: Herath, E., and Lemma Dessalegne (eds.), *Horticulture Research and Development in Ethiopia*, Institute of Agricultural Research, Addis Ababa, Ethiopia, 354p.

Berger R.D. 1981. Comparison of the Gompertz and Logistic equation to plant disease progress. *Phytopathology* 71: 716-719.

Bevacqua K.J. 2000. Late Blight of Potato and Tomato.Yard and Garden.Mannesota University Extension Service.169-176.

Bezabih Emana and Mengistu Nigussie. 2011. Potato Value Chain Analysis and Development in Ethiopia: Case of Tigray and SNNP Regions. *International Potato Center (CIP-Ethiopia),* Addis Ababa, Ethiopia.

Beka Biri, Pichiah G. 2020. Management of potato late blight (*Phytophthora infestans*) by the combination of potato variety with different fungicide in Horo Guduru Wollega Zone. *Agricultural and Biological Sciences Journal* Vol. 6, No. 3, pp. 148-157.

Binyam Tsedaley, Temam Hussen and Tekalign Tsegaw. 2014. Efficacy of Reduced Dose of Fungicide Sprays in the Management of Late Blight (*Phytophthora infestans*) Disease on Selected Potato (*Solanum tuberosum* L.) Varieties Haramaya, Eastern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 4(20): 46-52.

Biruk Kemaw, Diriba Shiferaw, Seid Sani and Tamiru Chalchisa. 2017. Opportunities and Constraints of Ware Potato Value Chain Analysis: West Showa Zone, Central Ethiopia. *Journal of Economics and Sustainable Development*.www.iiste.org ISSN 2222-1700 (Paper) ISSN 2222-2855 (Online) Vol.8, No.11.

Bourke A. 1993. *'The Visitation of God'? The potato and the great Irish famine*.Dublin, Ireland, Lilliput Press, Ltd. 1993 pp.x + 230 pp.

Bowen W.T. 2003. Water Productivity and Potato Cultivation. *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, *1*, p.229.

Bradshaw N.J. 1992. The use of fungicides for control of potato late blight (*Phytophthora infestans*). *Aspects of Applied Biology* 33: 101-106.

Camire M.E., Kubow S. and Donnelly D.J. 2009. Potatoes and human health. *Crit Rev Food Sci Nutr*. 49:823–40.

Campbell C.L. and L.V. Madden. 1990. *Introduction to Plant Disease Epidemiology*. John Wiley and Sons, NewYork, 532p.

CIMMYT (International Maize and Wheat Improvement Center).1988. *Farm agronomic data to farmers' recommendations: Economic training manual. Completely revised edition.*(International Maize and Wheat Center), Mexico, 124p.

CSA (Central Statistical Agency). 2018. *Agricultural sample survey: Report on area and production of major crops. (private peasant holdings, meher season) (CSA) 2017/2018*.Addis Ababa, Ethiopia. Volume I, statistical bulletin 586P.

CSA. 2012. The Federal Democratic Republic of Ethiopia Central, Statistical Agency, Agricultural Sample Survey on Crop and Livestock Product Utilization, Volume Vii, Addis Ababa, Ethiopia.pp.11-97.

Devaux A.P., Kroman N. and Ortiz O. 2014. Potatoes for sustainable global food security. Pot ato Research.doi:10.1007/s11540-014-9265-1.

Dolatabadi K.H., Goltapeh E.M., Varma A. and Rohani N. 2011. In vitro evaluation of arbuscular mycorrhiza-like fungi and Trichoderma species against soil-borne pathogens. *Journal of Agricultural Technology*, 7(1): 73-84.

Draper M.A., Secor G.A., Gudmestad N.C., Lamey H.A. and Preston D. 1994.Leaf blight diseases of potato. *NDSU Extension Service: [publication] (USA).*

EIAR (Ethiopian Institute of Agricultural Research). 2007. Crop production technologies and their application, Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia.

Ephrem Debebe, Amutha Santhanam, Dereje Gorfu, Mesfin Tessera and Bekele Kassa. 2011. "Biocontrol activity of *Trichoderma viride* and *Pseudomonas fluorescens* against *Phytophthora infestans* under greenhouse conditions." *Journal of Agricultural Technology* 7, no. 6: 1589-1602.

Ephrem Guchi. 2015. Disease Management Practice on Potato (Solanum tuberosum L.) in Ethiopia. *World Journal of Agricultural Research*, vol. 3, no. 1: 34-42. doi: 10.12691/wjar-3-1-8.

Ermias Misganaw. 2016. Host resistance and reduced fungicide application for management of Potato late blight (*Phytophthora infestans*) in Southwest Ethiopia. *Asian Journal of Plant Science and Research,* 6(2): 13–17.

FAO (Food and Agriculture Organization). 2008. *Potato World: Africa-International Year of the Potato* 2008. http://www.potato2008.org/en/world/africa.html. Accessed on: 15/5/2017.

FAO. 2005. FAOSTAT Agricultural Data. *Agricultural production, crops, primary*. Available at http://faostat.fao.org/faostat/collections?subset=agriculture Accessed on 10 February 2005; verified on 17 March 2005. United Nations Food and Agriculture Organization.

FAOSTAT. 2018. Data base of agricultural production. Food and Agriculture Organization.

Fekede Girma. 2011. *Management of late blight (Phytophthora infestans) of potato (Solanum tuberosum* L.*) through potato cultivars and fungicides in hararghe highlands, Ethiopia*. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia, 45-54.

Fekede Girma, Amare Ayalew, and Nigussie Dechass. 2013. Management of Late Blight (*Phytophthora infestans*) of Potato (*Solanum tuberosum* L.) through Potato Cultivars and Fungicides in Hararghe Highlands, Ethiopia. *International Journal of Life Sciences*, 2(3): 130-138.

Forbes G.A., Grünwald N.J., Mizubuti E.S., Andrade Piedra J.L. and Garrett K.A. 2007. Potato late blight in developing countries.*Current Concepts in Potato Disease Management. Kerala, India: Research Signpost*.

Fry W.E. 2008. *Phytophthora infestans*: the plant (and R gene) destroyer. *Molecular plant Pathology* 9:385-402.

Fry W.E. 1998. Vegetable Crops. Late Blight Potatoes and Tomatoes.Cornell University Cooperative Extension.New York State. USA. This document is available at: (http://vegetablemdonli ne.ppath.cornell.edu/factsheets/Potato_LateBlt.htm (Fact Sheet Page: 726.20 Date 7-1998).

Garrett K.A., and Dendy S.P. 2001. Cultural practices in potato late blight management, 107–113. In: Fernandez- Northcoted, N. (Ed.), Complementing resistance to late blight (*Phytophthora infestans*) in the Andes. Proceedings of GILB Latin American workshop I, 13–16 February, 2001, Cochabamba, Bolivia.

Garrett K.A. and Mundt C.C. 2000. Host diversity can reduce potato late blight severity for focal and general patterns of primary inoculum. *Phytopathology*, *90*(12), pp.1307-1312.

Gebremariam Asaye, Merkuz Abera and Adane Tesfaye. 2020. The Fungicide and Variety integration effect on late blight (*Phytophthorainfestans*) disease of Potato (*Solanumtuberosum* L.) in Western Amhara Region, Ethiopia, *International Journal of*

Sustainable Agricultural Research, 7:1, 15-29, *DOI:10.18488/journal.70.2020.71.15.2*
.

Gebremedhin Woldegiorgis, Atsede Solomon, Endale Gebebre, Agajie Tesfaye, Bekele Kassa, Dagnachew Bekele, Yoliannes Lemma and Kiflu Badane. 2006. Transforming the traditional potato production through improved technologies in the central highlands of Ethiopia. In: Tsedeke Abate (ed) Successes with value chain. *Proceeding of scaling up and scaling out agricultural technologies in Ethiopia: an international conference, 9-11may 2006*, Addis Ababa.

Getachew Asefa, Seyfudin Mehadi, Yonas Worku and Mohammed Beriso. 2017. Integrated Management of Potato Late Blight in the Bale Highlands, South Eastern Ethiopia, Using Varieties and Fungicide. *Int. Inv. J. Agric. Soil Sci*. Vol. 5(2): 35-38.

GILB (Global Initiative on Late Blight) and CIP (International Potato Center). 2004. *Ethiopia Potato Production Areas and Average Yields*. Pp, 14. Available at: http://gilb.cip.cgiar .org/countryprofiles/africa/ethiopia/29/3/2010.

Gomez K.A. and Gomez A.A. 1984. *Statistical procedures for agricultural research* (2nd Ed.). John Wiley and Sons, New York, 680p, USA.

Guenthner J.F., Michael K.C. and Nolte P. 2001. The economic impact of potato late blight on US growers. Potato Resource, 44: 121–125.

Habtamu Kefelegn, Alemayehu Chala, Bekele Kassa and Tiwari P. K. 2012. Evaluation of different potato varieties and fungicide combinations for the management of potato late blight (*Phytophthora infestans*) in Southern Ethiopia. *International Journal of Life Sciences* Vol.1 No.1. pp. 8-15.

Hailu Gebru, Ali Mohammed, Nigussie Dechassa and Derbew Belew. 2017. Assessment of production practices of smallholder potato (*Solanum tuberosum* L.) farmers in Wolaita zone, Southern Ethiopia. *Agriculture & Food Security*, *6*(1), p.31.

HARC (Holetta Agricultural Report Center). 2007. In: "Impact of farmers' selected IDM options on potato late blight control and yield". (Mesfin Tesserra & Gebremedhin

W/giorgis. 2007). *Impact of farmers' selected IDM options on potato late blight control and yield.Printed in El-Minia- Egypt*. *African Crop Science Conference Proceedings*, 8: 2091-2094.

HARC (Holetta Agricultural Research Center). 1999. Progress reports for the year 1999. Holetta.

Hirut Getinet, Shimelis Hussein, Melis R., Fentahun Mengistu and Jong W. 2017. Yield, Yield-related Traits and Response of Potato Clones to Late Blight Disease, in North-Western Highlands of Ethiopia. *Journal of Phytopathology*, *165*(1), pp.1-14.

Jejaw Tsedaley. 2011. *Tuber yield loss assessment of potato (Solanum tuberosum L.) varieties due to late blight (Phytophthora infestans) and its management in Haramaya, Eastern Ethiopia*. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Jones G.D. 1998. *The Epidemiology of Plant Diseases*.3rd Edition. Kluwer Academic Publishes London. 371-388P.

Kamoun S. 2001. Non-host resistance to *Phytophthora*: Novel prospects for a classical problem. *Current Opinion in Plant Biology* 4: 295-300.

Kankwatsa P., Hakizab J.J., Olanya M. and Kidenamariam H.M. 2002. Efficacy of different fungicide spray schedules for control of potato late blight in Southwestern Uganda. Crop Protection 22(2003): 545–552.

Kirk W.P., Wharton R., Hammerschmidt F., Abu-el S. and Douches D. 2009. Late Blight [Online]. Michigan State University Extension Bulletin E-2945. East Lansing, MI. Available at: http://www.potatodiseases.org/lateblight.html (Updated - June 07, 2009).

Kirk W., Wharton P., Hammerschmidt R., Abu-el Samen F. and Douches D. 2013. Late Blight. Michigan State University Extension Bulletin E 2945. East Lansing, MI. Avail able on: http://www.potatodiseases.org/lateblight.html.

Laufer B. 1938. The American Plant Migration. Part I: The Potato Archeology Series. Field Museum of National History 28(1): 418.

Lung'aho C., Nyongesa M. and Wakahiu M. 2003. Evaluation of globe (6% cymoxanil/ 70% Mancozeb) for potato late blight management. At http://www.kari.org/fileadmin/publications/10thproceedings/Volone/EvaluationGlobe.pdf/05-10-2010.

MAFRI (Manitoba Agriculture, Food and Rural Initiatives). 2002. *Integrated Management of Late Blight in Potatoes.* Published by the Pest Management Regulatory Agency.

Majid R.F., Heather L.M. and Hamid A. 2008. Genetics, genomics and breeding of late blight and early blight resistance in tomato. *Plant Sciences*, 27:75 – 107.

Majeed A., Muhammad Z., Ullah R. and Ahmad H. 2017. Late Blight of Potato (*Phytophthora infestans*): Fungicides Application and Associated Challenges. *Turkish Journal of Agriculture - Food Science and Technology*, 5(3): 261-266.

MANR (Ministry of Agriculture and Natural Resources). 2016. Crop Variety Release, Protection and Seed Quality Control Directorate, Issue number 19, Addis Ababa, Ethiopia.

Mantecon J.D. 2009. Importance of potato late blight in Argentina, and the effect of fungicide treatments on yield increments over twenty years. *Ciencias Investigation Agrarias*. 36(1):115-122. MAFRI.

McGrath M.T. 2004. AP Snet Education Center- *Introductory Topics- What are Fungicides?* Cornell University, USA.

Mercure P. 1998. Early Blight and Late Blight of Potato. University of Connecticut. *Integrate d Pest Management.* 2 p. www.hort.uconn.edu/IPM/VEG/HTMS/BLTPOT.HTM.

Merkuz Abera and Getachew Alemayehu. 2012. Distribution and Severity of Sorghum Covered Kernel Smut in North Western Ethiopia. *International Journal of Current Research*. 4(04): 041-045.

Merkuz Abera. 2017. Agriculture in the Lake Tana Sub-basin of Ethiopia, In K. Stave, Goraw Goshu and Shimelis Aynalem (Eds) Social and Ecological System Dynamics, Characteristics, Trends, and Integration in the Lake Tana Basin, Ethiopia, AESS Interdisciplinary Environmental Studies and Sciences Series, ISBN 978-3-319-45753-

6, DOI 10.1007/978-3-319-45755-0_2, Springer International Publishing Switzerland 2017.

Mesfin Tessera, Wondirad Mandefro and Bekele Kassa. 2009. Review of research on diseases of root and tuber crops in Ethiopia. In; Abraham Tadesse Ed. crop production through improved plant protection. Addis Ababa, Ethiopia; Plant Protection of Ethiopia, 169-230.

MesfinTesserra and Gebremedhin W/Giorgis. 2007. Impact of farmers' selected IDM options on potato late blight control and yield. *African Crop Science Conference Proceedings*, 8: 2091-2094. At (http://www.acss.ws/Upload/XML/Research/542.pdf) 2/5/2015.

Misgana Mitiku and Yesuf Eshete.2017. "Management of potato late blight through host plant resistance and fungicide use in South Omo Zone, SNNPR, Ethiopia."*International Journal of Research - Granthaalayah*, 5(5), 342-348. https://doi.org/10.5281/zenodo.802344.

MoARD (Ministry of Agriculture and Rural Development). 2010. Animal and plant health regulatory directorate, crop variety register Issue No. 12. Addis Ababa, Ethiopia. pp: 15.

Mohammed Amin, Negeri Mulugeta and Thangavel Selvaraj. 2013. Field Evaluation of New Fungicide, Victory 72 WP for Management of Potato and Tomato Late Blight (*Phytophthora infestans* (Mont) de Bary) in West Shewa Highland, Oromia, Ethiopia. *Journal of Plant Pathology and Microbiology*, Vol. 4: 1-8.

Montarry J., Andrivon D., Glais I., Corbiere R., Mialdea G. and Delmotte F., 2010. Microsatellite markers reveal two admixed genetic groups and an ongoing displacement within the French population of the invasive plant pathogen *Phytophthora infestans*. *Molecular Ecology*, *19* (9), pp.1965-1977.

Muhinyuza J.B., Nyiransengiyumva S., Nshimiyimana J.C. and Kirk W.W. 2008. The effect of the application frequency and dose of Mancozeb on the management of potato late blight in Rwanda. Institut des Sciences Agronomiques du Rwanda (ISAR), Rwanda;

National University of Rwanda (NUR), Rwanda. *Journal of Applied Biosciences* Vol. 3: 76 - 81. ISS No. 1997–5902.

Mukalazi J.E. Adipala T. Sengooba J.J. Hakiza M. Olanya and Kidanemariam Hayle Mariam. 2001. Metalaxyl resistance, mating type and pathogenicity of *Phytophthora infestans* in Uganda. *Crop Protection*, 20: 379–388.

Namanda S., Adipala E., Olanya OM., Hakiza J.J., El-Bedewy R. and Bhagsari A.S. 2001 Integration of host resistance and minimum fungicide application for management of Potato late blight in Uganda. In *Fifth Biennial Conference of the African Crop Science Society*, October 19–26, Lagos, Nigeria, pp.33-39.

Ngoju M., Nyankanga R., Muthomi J. and Muindi E. 2014. Studies on the effects of stinging nettle extract, phosphoric acid and conventional fungicide combinations on the management of potato late blight and tuber yield in the highlands of Kenya. *Direct Research Journal of Agriculture and Food N Science*, *2*(8): 119–127.

Njualem D.K., Demo P., Mendoza H.A., Koi J.T. and Nana S.F. 2001. Reaction of some potato genotypes to late blight in Cameroon. *African Crop Science Journal*, 1(1): 209-213.

Olanya O.M., Adipala E., Hakiza J.J., Kedera J.C., Ojiambo P., Mukalazi J.M., Forbes F. and Nelson R. 2001. Epidemiology and population dynamics of *Phytophthora infestans* in Sub-Saharan Africa: Progress and Constraints. African Crop Science Journal, 9: 181-193.

Olanya O.M., Hakiza J.J. and Crissman C.C. 2004. Potato production in the tropical highlands: constraints, fungicide use and the impact of IPM strategies. *Growing potato in tropical highlands*. Outlook on pest management- August. 182p.

Paris R. and Lamattina L. 2010.*Phytophthorainfestans* secretes extracellular protease with necrosis-inducing activity on potato. *European Journal Plant Pathology*.105: 753.

Phillips S.L., Shaw M.W. and Wolfe M.S. 2005.The effect of potato variety mixtures on epidemics of late blight in relation to plot size and level of resistance. *Annals of Applied Biology*, 147(3): 245 - 252.

Razukas A., Jundulas J. and Asakaviciute R. 2008. Potato cultivars susceptibility to potato late blight (*Phytophthora infestans*). Penkala Bt. Budapest Hungary. *Applied Ecology and Environmental Research* 6(1):95-106.

Robert G.D. and Janes H.T. 1991. Biometrical Approach. Principles of Statistics.(2nd Ed.). New York, USA.

Subhani Nasir. 2016. *Phytophthora infestans* (Mont.) de Bary: A Review of Life History, Evolutionary Status of Pathogen, Host Range, Mating Types, Symptomology, Disease Cycle, Means of Dispersal, Extent of Losses, and. *Journal of Global Agriculture and Ecology*, *5*(2), pp.108-126.

Samen F.N., Sector G.A. and Gudmestad N.C. 2010. Variability in virulence among asexual progenies of *Phytophthora infestans. Phytopathology* 93(3): 293.

SAS (Statistical Analysis System) Software. 2002. Version 9.0 inc. Carry, North Carolina. USA.

Schiessendoppler E., Molnar U., Glauninger J., Olaniya M. and Bekele Kassa. 2003. Characte rization of *Phytophthora infestans* populations in Sub-Saharan Africa (SSA) as a basis for simulation modeling and integrated disease management. *Ages, Vienna*.

Schulte-Geldermann E. 2013. Tackling Low Potato Yields in Eastern Africa: An Overview of Constraints and Potential Strategies. In: Seed Potato Tuber Production and Dissemination, Woldegiorgis, G., S. Schulz and B. Berihun (Eds.). Ethiopia Institutes of Agricultural Research, Bahir Dar, Ethiopia, pp: 72-80.

Seifu Fetene and Betewulign Eshetu. 2017. Research Article Evaluation of Released and Local Potato (*Solanum tuberosum* L.) Varieties for Growth Performance. J. Agronom. 16(1): 40-44.

Semagn Asredie, Halseth D., Jong W., Perry K., Wolfe D., Fentahun Mengistu and Schulz S. 2015. Potato Variety Diversity, Determinants and Implications for Potato Breeding Strategy in Ethiopia. *Am. J. Potato Res*. 92:551–566.

Shaw D.S. and Khaki I.A. 1971."Genetical evidence for diploidy in *Phytophthora*."*Genetic Research*, 17: 165-167.

Shiferaw Mekonen and Tesfaye Tadesse. 2018. Effect of Varieties and Fungicides on Potato Late Blight (*Phytophthora infestans*, (Mont.) de Bary) Management. *Agrotechnology* 7:182. doi: 10.4172/2168-9881.1000182.

Shiferaw Mekonen, Tameru Alemu, Bekele Kassa and Forbes G. 2011. Evaluation of contact fungicide spray regimes for control of late blight (*Phytophthora infestans*) in southern Ethiopia using potato cultivars with different levels of host resistance. *Tropical Plant Pathology*, *36*(1): 21–27.

Shinners C.T., Bains P., McLaren D.and Thomson J. 2003. Commercial Potato Production - Disease Management. Guide to commercial potato production prairies. Western Potato Council. Pp, 60-69. Available on: http://www.gov.mb.ca/agriculture//crops/potatoes/bda04s07.

Shutong W., Tongle H.U., Fengqiao Z., Forrer H.R. and Keqiang C.O. 2007. Screening for plant extracts to control potato late blight. Front. *Agric. China*., 1(1): 43-46.

Solano J., Acuna I., Esnault F. and Brabant P. 2014. Resistance to *Phytophthora infestans* in *Solanum tuberosum* landraces in Southern Chile. *Tropical Plant Pathology*, 39(4): 307–315.

Stone A. 2014. Organic management of late blight of potato and tomato (*Phytophthora infestans*). Sustainable Agriculture Research and Educations, Organic article. Oregon State University, Oregon, USA, 15P.

Struik P.C. 2010. Modeling the crop: from system dynamics to systems biology. *Journal of Experimental Botany*, *61*(8), pp.2171-2183.

Subhani N.M. 2016. *Phytophthora infestans* (Mont.) De Bary: A review of life history, evolutionary status of pathogen, host range, mating types, symptomology, disease cycle, means of dispersal, extent of losses, and management. *Journal of global agriculture and ecology* 5(2): 108-126.

Temesgen Deressa, Hassan R.M., Ringler C., Tekie Alemu and Mahmud Yesuf. 2007. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environ. Change.doi:10.1016/j.gloenvcha.2009.01.002.

Thind T.S., Chander-Mohan J.S., Bedi R.K., Grewal and Sokhi S.S. 1989. Role of application time of fungicides in the control of late blight of potato. Plant Disease Research 4(2): 113- 117.

Turkensteen LJ., Flier WG. and Hintum TV. 2003. Host and non-host resistance against *Phytophthora infestans*, the causal organism of late blight of potatoes and tomatoes. Eucarpia Leafy Vegetables: 23-25.

Van der Plank, J.E. 1963. *Plant diseases: Epidemics and control*. New York, London: Academic Press.

Wharton P.S. 2005. *Potato disease in Michigan*. Crop and Soil Sciences Extension Bulletin.EC- 2945.

Wheeler B.E. 1969. An Introduction to *Plant Diseases*. John Wiley and Sons, London.

Yazie Chanie, Akalu Teshome, Yalfal Temesgen and Baye Berihun. 2017. Characterization of potato production, marketing, and utilization in North Western Amhara Region, Ethiopia. *Journal of Horticulture and Forestry*, Vol. 9(3), pp. 17-25.

Yitagesu Tadesse. 2019. Integrated Potato (*Solanum tuberosum* L.) Late Blight (*Phytophthora infestans*) Disease Management in Ethiopia. *American Journal of Bio Science*. Vol. 7, No. 6, 2019, pp. 123-130.

APPENDICES

Appendix Table 1. Rating scale for the assessment of late blight of potato leaves (Shutong *et al*., 2007).

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

Appendix Table 2. Parameters to be recorded during survey of potato late blight

No.	**Parameters**	**Classes**	**Remark**
1	Region	- to be set	
2	Woreda	- to be set	
3	Kebele	- to be set	
4	Sample No.	- to be set	
5	Altitude	- to be set	Use of GPS
6	Rainfall	- to be set	From the nearest metrological station
7	Temperature	- to be set	From the nearest metrological station
8	Variety	- to be set	
9	Crop growth stage	- to be set	
10	Planting date	- Early - Late	
11	Cropping system	- Intercropping	

		- Sole cropping
12	Previous crop	- to be set
13	Disease incidence	- to be set
14	Disease severity	- to be set
15	Other associated diseases	- to be set

Appendix Table 3. Total rainfall (mm), mean minimum and maximum temperature (°c) of the surveyed districts, during 2019 main cropping season

District	Parameters	May	Jun	Jul	Aug	Sep
Fagita Lekoma	Rainfall	161.4	275.8	235.5	35.5	29.6
	Max T	22.1	21.1	20.9	20.5	21.6
	Min T	11.1	11.6	14.8	14.9	14.9
Banja	Rainfall	215.3	329.7	361.7	374.3	372.7
	Max T	26	23.8	21.4	21.6	21.8
	Min T	8.5	8.5	8.5	8.3	8.9

Source: Western Amhara Meteorology Agency, 2019
Max T=Maximum Temperature and Min T=Minimum Temperature

Appendix Table 4. ANOVA for days to first disease symptom appearance at Fagita Lekoma district during 2019 cropping season

SV	DF	SS	MS	F Value	Pr level
Fun	2	335.17	167.583	11.69	<.001
Var	3	180.39	84.398	5.89	0.003
Var*Fun	6	344.00	30.065	2.10	0.091
Rep	2	72.67	36.33	2.95	
Error	22	271.33	12.33		
Total	35	1112.75			

S.V= source of variation, DF= degree of freedom, SS= sum square, MS= mean square, Fun= fungicides, Var= varieties, Rep= replication

Appendix Table 5. ANOVA for disease incidence (%) of potato late blight at 45 and 52 days after planting (DAP) at Fagita Lekoma district during 2019 main cropping season

Date	SV	DF	SS	MS	F Value	P level
45DAP	Fun	2	4333.45	2166.72	180.10	<.0001
	Var	3	264.79	88.26	7.34	0.001

	Var*Fun	6	178.53	29.75	2.47	0.0388
	Rep	2	1.29	0.64	0.06	
	Error	22	264.67	12.03		
	Total	35	5042.72			
52DAP	Fun	2	10238.9	5119.44	285.54	<.0001
	Var	3	1230.6	410.19	22.88	<.0001
	Var*Fun	6	361.1	60.19	3.36	0.0167
	Rep	2	72.22	36.11	2.01	
	Error	22	394.44	17.93		
	Total	35	12297.22			

DAP= days after planting, S.V= source of variation, DF= degree of freedom, SS= sum square, MS= mean square, Fun= fungicides, Var= varieties, Rep= replication

Appendix Table 6. ANOVA for percent severity index (PSI) of potato late blight at different days after planting (DAP) at Fagita Lekoma district during 2019 main cropping season

Date	SV	DF	SS	MS	F Value	P level
45DAP	Fun	2	10.603	5.302	23.72	0.0001
	Var	3	598.366	199.455	892.3	0<.0001
	Var*Fun	6	12.499	2.083	9.320.0026	
	Rep	2	0.667	0.334		
	Error	22	4.247	0.224		
	Total	35	626.382			
52DAP	Fun	2	56.348	28.174	56.97	<.0001
	Var	3	132.319	44.106	89.19	<.0001
	Var*Fun	6	50.771	8.462	17.11	<.0001
	Rep	2	0.132	0.662		
	Error	22	10.880	0.495		
	Total	35	250.449			
59DAP	Fun	2	283.21	141.607	196.89	<.0001
	Var	3	306.83	102.276	142.21	<.0001

	Var*Fun	6	120.031	20.005	27.82	0.0005
	Rep	2	61.901	30.951		
	Error	22	15.823	0.719		
	Total	35	787.798			
66DAP	Fun	2	533.76	266.88	29.48	<.0001
	Var	3	1121.54	373.84	41.30	<.0001
	Var*Fun	6	262.40	43.73	4.83	0.0259
	Rep	2	154.29	77.147		
	Error	22	199.16	9.053		
	Total	35	2271.15			
73DAP	Fun	2	953.17	476.583	472.46	<.0001
	Var	3	2857.34	952.448	944.22	<.0001
	Var*Fun	6	362.78	60.464	59.94	0.0018
	Rep	2	10.67	5.337	24.59	
	Error	22	60.15	2.73		
	Total	35	5873.66			
80DAP	Fun	2	1108.80	954.40	117.68	<.0001
	Var	3	3523.85	1174.62	144.84	<.0001
	Var*Fun	6	246.37	41.06	5.06	<.0001
	Rep	2	134.48	67.24	4.59	
	Error	22	60.15	2.73		
	Total	35	5873.66			
87DAP	Fun	2	3460.5	1730.27	3032.10	<.0001
	Var	3	8376.0	2792.10	4892.69	<.0001

	Var*Fun	6	860.1	143.36	251.22	<.0001
	Rep	2	3.8	1.92	3.36	
	Error	22	12.6	0.57		
	Total	35	12713.1			

DAP= days after planting, S.V= source of variation, DF= degree of freedom, SS= sum square, MS= mean square, Fun= fungicides, Var= varieties, Rep= replication

Appendix Table 7. ANOVA for disease progress rate (r) and area under disease progress curve (AUDPC) of potato late blight at Fagita Lekoma district during 2019 main cropping season

Parameters	**S.V**	**DF**	**SS**	**MS**	**F- Value**	**Pr** level
AUDPC	Fun	2	280325.17	140162.58	790.02	<.0001
	Var	3	502866.16	167622.05	944.80	<.0001
	Var*Fun	6	94969.25	15828.21	89.22	<.0001
	Rep	2	9719.25	4859.63	27.39	
	Error	22	3903.16	177.42		
	Total	35	891782.99			
R	Fun	2	0.001766	0.000883	166.74	<.001
	Var	3	0.006847	0.002232	430.95	<.001
	Var*Fun	6	0.000632	0.000105	19.89	<.001
	Rep	2	0.000020	0.000010	1.92	0.1708
	Error	22	0.000116	0.0000053		
	Total	35	0.009382			

AUDPC= area under disease progress curve, r= disease progress rate, S.V= source of variation, DF= degree of freedom, SS= sum square, MS= mean square, Fun= fungicides, Var= varieties, Rep= replication

Appendix Table 8. ANOVA for days to flowering, physiological maturity, plant height and number of tubers at Fagita Lekoma district during 2019 main cropping season

Parameters	S.V	DF	SS	MS	F- Value	Pr level
DF	Fun	2	9.389	4.6944	4.31	<.0263
	Var	3	262.778	87.5926	76.91	<.0001
	Var*Fun	6	1.056	0.1759	0.15	0.984
	Rep	2	3.389	1.6944	1.90	
	Error	22	27.333	1.1388		
	Total	35	300.55			
PHM	Fun	2	84.388	42.194	33.76	<.0001
	Var	3	1226.11	408.70	326.96	<.0001
	Var*Fun	6	23.388	3.898	3.12	0.0210
	Rep	2	2.89	1.444	0.80	
	Error	22	30.00	1.25		
	Total	35	1363.889			
PH	Fun	2	373.80	186.900	7.91	0.0060
	Var	3	1742.29	580.763	24.58	<.0001
	Var*Fun	6	338.09	56.348	2.38	0.1175
	Rep	2	182.24	91.119	3.86	0.0672
	Error	22	519.80	23.627		
	Total	35	3156.22			
NTP	Fun	2	72.222	36.11	54.17	<.001
	Var	3	93.889	31.296	46.94	<.001
	Var*Fun	6	11.778	1.963	2.94	0.0268
	Rep	2	0.389	0.194	0.20	
	Error	22	16.00	0.667		

	Total	35	193.889			

DF= days to 50% flowering, PHM= physiological maturity, NTP= number of tubers per plant, S.V= source of variation, DF= degree of freedom, SS= sum square, MS= mean square, Fun= fungicides, Var= varieties, Rep= replication

Appendix Table 9. ANOVA for total tuber yield, marketable and unmarketable tuber yield of potato at Fagita Lekoma district during 2019 main cropping season

Parameters	**SV**	**DF**	**SS**	**MS**	**F – Value**	**Pr** level
MTY	Fun	2	949.0416	474.5208	637.01	<.0001
	Var	3	736.6608	245.553	329.64	<.0001
	Var*Fun	6	29.2450	4.874	6.54	0.0002
	Rep	2	0.632	0.316	0.42	0.659
	Error	22	16.388	0.709		
	Total	35	1731.967			
UMTY	Fun	2	211.367	105.683	617.79	<.0001
	Var	3	44.0076	14.669	85.75	<.0001
	Var*Fun	6	30.314	5.052	29.53	<.0001
	Rep	2	2.039	1.019	5.96	0.086
	Error	22	3.763	0.171		
	Total	35	291.4908			
TTY	Fun	2	265.719	132.859	186.97	<.0001
	Var	3	450.802	150.267	211.47	<.0001
	Var*Fun	6	35.554	5.925	8.34	<.0001
	Rep	2	1.627	0.813	1.14	0.3365
	Error	22	15.633	0.7106		
	Total	35	769.337			

S.V= source of variation, DF= degree of freedom, SS= sum square, MS= mean square, Fun= fungicides, Var= varieties, Rep= replication, PH= plant height, MTY= marketable tuber yield, UMTY =unmarketable tuber yield, TTY= total tuber yield

Appendix Table 10 . Summary of models fit components explaining the temporal progress of potato late blight at Fagita Lekoma district during 2019 main cropping season

Variety	**Fungicide**	**Rep**	**Logistic Model (L)**		**Gompertz Model (G)**		**MF**
			DPR(unit/day)	R^2 (%)	DPR(unit/day)	R^2 (%)	
Belete	Ridomil Gold 68% WG	1	0.068002	88.98	0.020402	92.98	G
		2	0.066551	87.05	0.019934	90.37	G
		3	0.070133	94.83	0.021063	92.09	L
	Mancozeb 80% WP	1	0.072833	89.94	0.022412	93.98	G
		2	0.072545	89.34	0.022463	93.67	G
		3	0.075863	92.23	0.023792	89.06	L
	Unsprayed	1	0.081897	90.89	0.02657	95.31	G
		2	0.072545	78.83	0.02388	82.37	G
		3	0.074237	89.67	0.024338	84.70	L
Gudene	Ridomil Gold 68% WG	1	0.083795	89.26	0.031075	95.93	G
		2	0.083009	91.49	0.030442	90.37	L
		3	0.08339	88.63	0.030905	94.90	G
	Mancozeb 80% WP	1	0.088098	90.00	0.034536	97.38	G
		2	0.089202	98.27	0.034886	92.55	L
		3	0.086643	95.52	0.034069	87.15	L
	Unsprayed	1	0.092586	85.93	0.03949	95.95	G
		2	0.092343	94.65	0.03956	85.25	L
		3	0.094085	86.83	0.040302	96.24	G
Zengena	Ridomil Gold 68% WG	1	0.048479	98.37	0.023266	99.30	G
		2	0.049803	98.65	0.023904	98.31	L
		3	0.044269	99.32	0.021517	98.61	L
	Mancozeb 80% WP	1	0.052119	99.22	0.026617	99.20	L
		2	0.05131	96.06	0.026094	95.67	L
		3	0.0448801	95.72	0.025549	97.28	G
	Unsprayed	1	0.061561	97.47	0.035689	94.33	L
		2	0.067436	96.51	0.038171	93.45	L
		3	0.0636	98.04	0.037135	95.08	L
Key	Ridomil Gold 68% WG	1	0.043164	98.77	0.020978	99.19	G
		2	0.041045	99.51	0.020119	98.46	L
		3	0.037355	97.07	0.01847	94.50	L
	Mancozeb 80% WP	1	0.057432	96.27	0.031096	97.45	G
		2	0.054055	98.76	0.029876	97.60	L
		3	0.051254	98.30	0.028841	95.30	L
	Unsprayed	1	0.075105	99.06	0.048609	96.63	L
		2	0.072865	96.19	0.04723	99.08	L
		3	0.073369	97.83	0.04786	93.98	L

Rep= replications, MF= model fitted, DPR = disease progress rate unit per day, R^2=Coefficient of determination

Appendix Figure 1. The potato plant at vegetative stage.

Appendix Figure 2. Potato late blight in susceptible variety.

Appendix Figure 3. Plastic sheets used as a buffer.

BIOGRAPHICAL SKETCH

The author was born on March, 1996 G.C in Awi Administrative Zone at Fagita Lekoma district Amhara Region. He attended his elementary education from 2002 to 2009 at Bessena Primary School and secondary education from 2010 to 2013 at Addis Kidame General Secondary and Preparatory School and was awarded Ethiopian Higher Education Entrance Qualification Certificate in 2013. He joined Debre Markos University College of Agriculture and Natural Resource Management in September, 2014 and graduated with the Degree of Bachelor of Science in Plant Science in June, 2016.

After graduation, he was searching for job (jobless) until 2018. After that Bahir Dar University provides him free education (scholarship). Then he joined the School of Graduate Studies at Bahir Dar University in September 2018 to pursue his MSc degree in Plant Protection Program.