Plant Sciences Research

Review on Major Economically important Diseases of Potato (*Solanum tubersom*.L) and their Management in Ethiopia

Motuma Gemechu Terefe
Department of Horticulture, Mettu University Bedelle College of Agriculture and Forestry, P.O. Box 318 Mettu, Ethiopia

Key words: Potato, bacterial wilt, blight, viral, management

Corresponding Author:
Motuma Gemechu Terefe
Mettu University Bedelle College of Agriculture and Forestry, Department of Horticulture P.O.Box 318 Mettu, Ethiopia

Page No.: 01-17
Volume: 13, Issue 1, 2021
ISSN: 1995-476x
Plant Sciences Research

Abstract: Potato (*Solanum tuberosum* L.) is the fourth major crop of the world after rice, wheat and maize. Ethiopia has possibly the highest potential for potato production of any country in Africa. However in Ethiopia, the yield per unit area of potato is very low compared to those of other countries. There are many factors that reduce the yield of the crop among which the diseases like late blight (*Phytophthora infestans*), early blight (*Alternaria solani*), bacterial wilt (*Ralstonia (Pseudomonas)* solanacearum) and Viruses are play an important role. Hence, the objective of this paper is to review the major potato diseases and some major attempt done to overcome the challenges of diseases in potato growing regions. Bacterial wilt is caused by a pathogen that isn't easily managed. There is need for more research on the epidemiology and the host-pathogen interaction in order to devise the most appropriate management strategy. Late blight of potato, caused by Phytophthora infestans (*Mont. De Bary*) is among its most important diseases, being especially, devastating in the major potato growing areas. Serious economic consequences often result from complete or partial devastation of infected fields. In Ethiopia the disease caused 100% crop loss on unimproved local cultivar and 67.1% on a susceptible variety. Integrated management of late blight through the use of resistant potato clones, fungicides and cultural measures appear to offer the best option for disease management in the tropical highlands of Africa. As potato is propagated by vegetative means, virus diseases could easily disseminate and accumulate in tubers causing degeneration of varieties and subsequent reduction in potato tuber yield. Potato viruses such as PLRV, PVY and PVX are the major causes for degeneration of varieties. Since, there is no viricide available the damage due to viruses can be minimized by managing host genotype and cultural practices. Therefore, adopting Integrated Disease Management (IDM) approach is the most effective, environmentally safe and low costly to the users.

INTRODUCTION

Potato (*Solanum tuberosum L.*) is the fourth major crop of the world after rice, wheat and maize and In terms of human consumption, potato is the third most important non grain food crop in the world after rice and wheat[1]. It is the most important vegetable crop in terms of quantities produced and consumed worldwide[2]. Potato is regarded 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 (mostly <120 days) than major cereal crops like maize. It is an important food source globally.

In Ethiopia, potato ranks first in the category of Root and Tuber Crops (RTCs) in terms of area coverage and total production. Crop production survey results of private peasant holding of the year 2016/17 indicated that of the total land areas of about 496,1489 hectares covered by RTCs, 296, 578 hectare (~60%) and of over 7.21 million tons of RTCs produced over 3.66 million tons (~51%) was potato[3]. Potato is a highly recommended food security crop that can helps low-income countries from the risks posed by rising international food prices[4].

The average national yield of potato in Ethiopia was estimated to be about 6 tons/ha. The current area under potato production is about 51,698 ha and the average national yield 9.86 tons/ha). This is however, very low as compared to the yields of other potato producing countries of the world such as the Netherlands (40 tons/ha), German (28 tons/ha) Egypt (17.4 tons/ha) and Burundi (11 tons/ha)[5]. The potential attainable average yields of the crop on research and farmer's fields are 40 and 20 tons/ha, respectively. The gap between the production potential and the current average national production could be attributed to different factors, among which diseases are the most important ones. Potato is susceptible to a number of diseases including late blight caused by Phytophthora infestans Mont Debary, several viruses and bacterial wilt caused by Ralstonia solanacearum, .Smith.

Even though the country has suitable environmental condition the regional (9.35 t/ha) as well as national (7.99 t/ha)[6] productivity of potato during 2016 season is very low as compared with world average of 17.16 t/ha. A number of production problems that accounts for low regional as well as national yield have been identified. Major ones are lack of stable, well-adapted, high yielding, acceptable and disease resistant cultivars and poor access of the available cultivars and problems of pests and disease still major constraints for potato production. Therefore, the objective of this study is to review the major economically important potato diseases and some major attempt done to overcome the challenges of diseases in potato growing regions.

Major diseases of potato in ethiopia: In Ethiopia, the yield per unit area of potato is very low compared to those of other countries like Rwanda, Egypt and Kenya. There are many factors that reduce the yield of the crop among which the diseases like late blight (Phytophthora infestans), bacterial wilt (Ralstonia (Pseudomonas) Solanacearum), scab diseases (*Streptomyces scabies*), Early Blight (*Alternaria spp.*) and viruses play an important role[7].

Nine fungal, one root nematode, one bacterial and four viral diseases were recorded on potato in Ethiopia. early blight (alternaria solani),bacterial wilt (rastonia Solanacearum),late blight (phytophthora infestans) and viruses were the most widely distributed potato diseases in all of the areas surveyed during 1993 and 1994 seasons.

Severe late blight infection during the main season has been the major reason for shifting the production of potato from the main season to the off season. The incidence of late blight in the in the off season is lower than that of the early blights and bacterial wilt diseases. Moreover, the occurrence of soft rot and powdery mildew was very much limited. The severity of bacterial wilt in the cool highland such as Holeta, Debre Berhan, Selale areas was very low or absent. Studies in the 1993 off season showed that R.Solancearum was high (50%) at Wondogenet followed by Ziway (33%), Holeta (25% and Shashamene (23%) (HARC, 1993-1994, unpublished) (Table 1 and 2).

Two major virus diseases of potato recorded were Potato Virus Y (PVY) and Potato Leaf Vole virus

Table 1: Disease record on potato

Disease name	Scientific name
Early blight	*Alternaria solani*
Leaf spot	*Ascochyta hotorum*
Dry spot	*Fusarium coeruleum*
Powdery mildew	*Leveillula taurica*
Charcoal rot	*Macrophomina phaseoli*
Root rot	*Rhizocotina solani*
Downy mildew	*Oidium sp.*
Late blight	*Phytopthora infestans*
Bacterial wilt	*Ralstonia Solanacearum*
Root knot	*Meloidogyne javanica*
Spindle tuber virus	-
Virus S,Y,PLRV	-

HARC in 2005 as Cited by PPSE in 2009

Table 2: Incidence and severity of potato diseases in central Ethiopia during off seasons on irrigated and rain fed potato crops in 1993 and 1994

Disease	Incidence	Severity
Bacterial wilt	11.10 ± 2.50	32.13 ± 6.00
Early blight	11.85 ± 1.21	12.70 ± 2.52
Late blight	9.33 ± 1.63	10.00 ± 2.24
Powdery mildew	3.17 ± 1.41	6.25 ± 1.60
Soft rot	1.00 ± 0.64	-
Viruses	11.92 ± 2.20	0.0

potato program progress reports of 1993 and 1994 as cited by PPSE in 2009

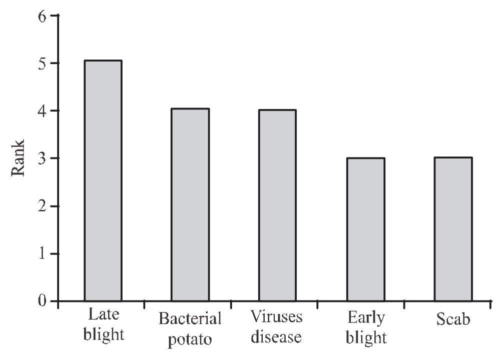

Fig. 1: Rank of diseases in potato production as ranked by group members in Shashemene Bekele Kasa, in 2016

(PLRV). The former was more predominant on the local and the latter was on improved varieties with the incidences ranging from 6-19 and 16-32% respectively.

Bacterial Wilt (Ralstonia (*Pseudomonas*) *solanacearum*): Bacterial wilt of potato was first recorded in 1956 on potato and egg plant in the Keffa region[8]. The pathogen was isolated from potato, eggplant and tomato samples obtained from shewa, Arsi and Keffa regions[9]. Other workers also recorded the diseases on potato and tomato from Ziway, Ambo, Bako and Guder areas. Bekele and Berga reported up to 63% incidences of the disease in some potato growing areas.

Bacterial wilt also known as brown rot is caused by Ralstonia (*Pseudomonas*) solanacearum E. F Smith, a soil-borne bacterial species. It is one of the most destructive plant diseases which are predominantly distributed in the tropical, subtropical and warm temperate regions of the world[10]. It affects as many as 200 plant species representing >50 families of particularly members of solanaeceous plants such as potato, tomato, eggplant, pepper and tobacco. In Ethiopia, R. solanacearum is one of the most important pathogens, threatening[7] the production of potato and tomato in different parts of the country (Fig. 1).

Factors favoring the disease: The pathogen can survive for various periods of time in the soil, depending on the conditions to which it is subjected. Ralstonia solanacearum can survive in the soil for a few months to a few years[11]. Wet soil conditions and moderate temperatures usually favor the survival of the bacteria. Moreover, plant debris and rotting tubers help the pathogen to survive from season to season in the absence of host crops[11]. R. solanacearum race 3 biovar 2 is more adapted to cooler climates but its virulence and density will decline when temperatures drop below 15°C and drastically below 4°C[12]. Therefore, long-term survival ability of the brown rot pathogen in soils of temperate countries is significantly reduced. R. solanacearum can spread in waterways and is known to survive for long periods of time in water. Contaminated irrigation waters help in the spread of the pathogen from field to field[13]. Some weeds can act as reservoir plants allowing the pathogen to survive, multiply and spread to contaminate new lands. Solanum dulcamara has been identified as a host for *R. solanacearum* race 3[14]. Like almost all bacterial phytopathgens, R. solanacearum enters into plants via. wounds made by tools during post emergence cultivation and by nematodes and insects in the soil or natural openings. Once inside the plant, the bacteria will move preferentially towards the vascular bundles to finally colonize the xylem[15].

The presence of the bacteria inside the xylem coupled with the production of exopolysaccharides will block the vascular vessels inducing a water shortage throughout the plant. This causes the plant to wilt and eventually die[15].

Economic significance of the disease: The economic implications of *R. solanacearum* are yet to be fully understood. This is further complicated by the fact that yield losses are influenced by many factors like host, cultivar, climate, soil type, cultural practices and the bacteria itself with some strains being more virulent than others. It is the second most important constraint to potato production in tropical, subtropical and warm temperate regions of the world. It may also occur in cooler climates such as at relatively high elevation in the tropics or higher latitudes. In India, a study conducted on one cultivar of tomato demonstrated that the pathogen killed from 10 to 100% of the plants and induced a yield loss ranging from 0-91%[16].

In the case of Potato, losses are more significant since this crop is a staple food for millions of farming communities around the world. It is currently estimated that bacterial wilt of potato affects 1.5 million Ha of lands in 80 countries and induces a global cost of $ 950 million annually[17]. In some countries losses are outstanding

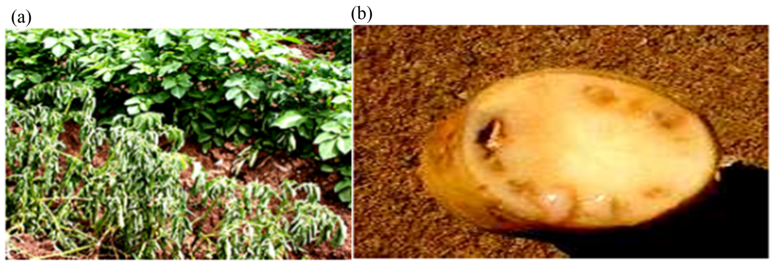

Fig. 2: Damage caused by R. solanacearum on different crop plants: (a) Wilted potato plant and (b) Typical soft rot of tuber/bacterial ooze. Naser Aliyefeto, in 2006, unpublished

in Bolivia many reports stated that yield was reduced from 30-90% and almost all tubers (98%) were lost during storage[17]. In Ethiopia, bacterial wilt has been recorded on potato, tomato and eggplant in many regions[7].

Stewart[8] first recorded the disease in 1956 on potato and eggplant in Keffa region (South West Ethiopia). Stewart and Yirooh[9] in their index of plant disease in Ethiopia, listed bacterial wilt on potato, tomato and eggplant in Keffa (South Ethiopia) and on potato in Arsi and Shewa (Central Ethiopia).

Moreover, Yaynu[7] indicated that bacterial wilt is an important disease of potato and tomato in many parts of Ethiopia and sometimes in the past the disease caused heavy losses at some commercial farms including at the potato seed tuber multiplication farm, Tseday Farm in Central Ethiopia as a result of which potato seed tuber multiplication in the farm has been abandoned. Its importance is increasing from time to time because of latently infected seed potatoes and decreasing land holdings that limit crop rotation.

SYMPTOMS OF BACTERIAL WILT

Bacterial wilt of potato (*Ralstonia solanacearum*) can also cause significant yield loss to potato[18]. Because this pathogen stays in the soil for several years it prohibits subsequent production of potato in the same field. Moreover, this pathogen may stay latent without showing any symptoms in the field with the consequence of high impact on tuber yield in the upcoming season. Detection of latent infections by *R. solanacearum* requires sensitive diagnostic methods but as yet such methods have not been adopted in Ethiopia to inspect potato seed tubers and monitor the status of latent infection and its consequences.

As the crop is vegetatively propagated, the diseases can easily be transmitted through tubers and cause very high economic losses across wide geographic areas bacterial wilt, plant wilting, browning of vascular tissue when cut and oozing of milky fluid from the vascular ring of cross-sectioned tubers were the most commonly encountered disease symptoms (Fig. 2).

Management methods: Bacterial wilt is caused by a pathogen that isn't easily managed. There is need for more research on the epidemiology and the host-pathogen interaction in order to devise the most appropriate management strategy. Currently, several control options can be investigated and an integrated management strategy may be set-up based on local needs. The common control measures employed in other countries include the use of resistant variety, crop sanitation, crop rotation, selection of disease free planting material and other cultural practices as single or integrated disease management have met if at all with only limited success. However, control through the use of resistant varieties alone has yielded little success. This is because such kind of resistance is strain specific and liable to break down by virulent and highly polymorphic strains of *R. solanacearum* at ambient temperature and in nematode infested soil[19]. Successful control of the pathogen through crop rotation is also not always effective, since, rotation practices recommended for one area may not perform well at other locations in addition to differences in the strains involved[19]. However, much research has not been done on this disease in Ethiopia except identification of bacteria and screening of biological control agents and use of resistance varieties[20]. The following Biological control methods have been researched in Ethiopia (Table 3).

Biological control: The use of rhizosphere resident microbial antagonist specifically the fluorescent pseudomonas is noted as a promising control method. The rhizosphere is a habitat in which several biologically important processes and interactions takes place which is primarily due to the influx of mineral nutrients from accumulation of plant roots exudates through mass flow and diffusion[21, 22]. Among the rhizosphere organisms,

Table 3: Bacterial wilt incidence and potato tuber yield as influenced by farmer's disease control interventions, 2011-2012, Shashemene, Oromia region

	Disease incidence (%)			Tuber yield kg plot^{-1}		
Year	Managed plot	Unmanaged plot	Percent reduced	Managed	Unmanaged	Percent increased
2011	21.3	36.4	70.9	2479.5	1763.7	40.6
2012	12.6	47.1	73.8	2948.2	1161.5	53.8
Mean	16.95	41.75		2713.8	1462.6	

Bekele Kasa, 2016

Table 4: Effect of one-season rotation with vegetables and beans on incidence of bacterial wilt and potato yields

Treatment	Bacterial vilt incidence (%)	Latent infection (%)	Total yield tha^{-1}	Marketable yield tha-1	Increase in marketable yield (%)
P-B-P*	22.1b	19.4a	26.4a	25.5a	77.1
P-Cab-P	15.4b	23.2a	24.8b	21.3b	47.9
P-Car-P	27.3b	25.9a	21.3c	19.1b	32.6
P-P-P	45.2a	16.3a	18.1d	14.4c	-
Mean	34.3	21.2	22.65	20.07	-
CV %	11.2	-	9.13	-	-

*P-B-P = Potato-Beans-Potato; P-Cab-P = Potato-Cabbage-Potato; P-Car-P = Potato-Carrot-Potato and P-P-P = Potat-Potato-Potato; Means followed by the sane letter in a column are not significantly different at 5% probability level, Bekele Kasa, 2016

fluorescent pseudomonas strains are often selected for biological control strategies because of their ability to utilize varied substrates under different conditions, short generation time and motility that assist colonization of roots. Moreover, they produce active extracellular compounds such as siderophores responsible for the biological suppression of several soil borne plant pathogens[23]. Henok *et al*.[20] evaluate Ethiopian isolates of Pseudomonas fluorescens as biocontrol agent against potato bacterial wilt caused by Ralstonia (Pseudomonas) solanacearum. According to Henok *et al*.[20] three isolates of Pseudomonas fluorescens i.e., PfS2, PfWt3 and PfW1 showed inhibition against the growth of the pathogen. Bacterization of tubers with isolates Pf S2, Pf Wt3, and PfW1, significantly reduced by 59.83% the incidence of bacterial wilt compared to the pathogen inoculated control and increased plant growth (plant height and dry weight) by 59.83, 76.89 and 28.44%, respectively.

This suggests the importance of the studied isolates as plant growth-promoting rhizobacteria. Therefore, the evidence presented here is suggestive of the potential of the Ethiopian isolates as biological control agents against bacterial wilt of potato by exploiting the interaction between rhizosphere microorganisms.

Lemessa[24] working on biochemical, pathological and genetic characterization of strains of Ralstonia solanacearum (Smith) from Ethiopia and bio control with bacterial antagonists found that the most effective strains (Pseudomonas fluorescent APF1 and Bacillus subtlis B2G) consistently reduced wilt diseases and increased plant weight significantly. The Pseudomonas APF1 strain showed the greatest plant growth promotion effect, increasing plant dry weight up to 63% compared to the untreated control. Generally, plant protection rendered this way can be maximized by combining different methods in an integrated disease management approach such as resistant variety and bio control.

Crop rotation: According to Bekele Kasa Total and marketable tuber yields were significantly ($p<0.01$) increased with a rotation of non-host crops to the pathogen as compared to the mono crop control treatment. The lowest incidence of BW 15.4, 22.1% and the highest marketable potato yields 24.8 and 26.4 t ha^{-1} were recorded after rotations with cabbage and beans respectively. In contrast, the lowest (21.3 t/ha) yield were obtained following rotations with carrots, which allowed slightly highest incidence (27.3%). Rotation with beans carrot and cabbage helped to get 33-77% yield advantage (Table 4).

MANAGEMENT OPTIONS (IDM) OF BACTERIAL WILT IN ETHIOPIA AND SUB-SAHARAN AFRICA

Considerable research has been undertaken on bacterial wilt management both in PRAPACE member countries and elsewhere (e.g. in Cameroon and by CIP worldwide). Unfortunately no source of resistance appears to be available so far but efforts are being undertaken to explore other promising methodologies in search for resistance against bacterial wilt. In particular, marker assisted breeding and genetic engineering to produce transgenic varieties are now being viewed as plausible options in the search for resistant varieties. Other aspects of IDM of bacterial wilt have also been studied including effect of soil fertility and crop rotation on occurrence and severity of the disease[25, 26].

Intensive seed production on small plots under bacterial wilt conditions has also been studied in Kenya[27] and is on-going in Uganda[28]. Various integrated management options for controlling bacterial wilt have been developed in Ethiopia, Kenya and Uganda and are currently being disseminated on-farm in several other PRAPACE member countries[27]. Though the results show positive trends in the management of the disease, bacterial wilt remains a major challenge to potato production in all ASARECA countries. As new varieties for ware and other purposes become available, their integration in bacterial wilt IDM will be key. Clearly, management of bacterial wilt requires a multi-disciplinary approach[29] and can only be effective if backed by systematic and continuous community awareness efforts.

Late Blight of Potato (Phytophthora Infestans (Mont.) de Bary): Among all the crops grown worldwide, potato (*Solanum tuberosum L.*) is known to suffer the greatest losses from disease attack. Late blight of potato, caused by Phytophthora infestans (Mont. De Bary) is among its most important diseases, being especially devastating in the major potato growing areas. Serious economic consequences often result from complete or partial devastation of infected fields[30, 31]. In the past few decades, the frequency and severity of the disease have increased in many parts of the world including Ethiopia and have been a serious threat to potato production[32].

In Ethiopia, the disease has been reported as the most destructive and economical disease on potato[33]. Though the effort made by researchers to reduce the effect of the disease on tuber yield is encouraging, still the loss is very tremendous[34].

Because of the rapid development of late blight, infections occurring during various stages of crop development represent enormous economic threat. With the exception of optimum or scheduled fungicide applications based on the favorable weather conditions or decision support system which is still under development in tropical Africa, the most economically viable disease management options is for the use of host-plant resistance. Occurrence of P. infestans has been closely linked to the introduction of potato varieties in many countries of Sub-Saharan Africa[35, 31]. The introductions of the fungus and its subsequent spread have been accomplished primarily through the movement of potato seed. The major factors affecting potato production such as: use of susceptible varieties, diversity of pathogen virulence and races, lack of adequate disease management tactics and favorable environmental conditions have incidentally and consequently led to perpetuation and increase in late blight disease. Although reports of disease occurrence have been thoroughly documented to date, paucity of information exists concerning the epidemiology and characteristics of late blight fungal isolates in many countries of Sub-Saharan Africa.

Moreover, the impact of environmental factors on disease development has not been adequately addressed. Studies on the epidemiology and fungal population dynamics are important for designing adequate late blight management tactics. Because of the differences in environmental conditions and the diversity of the geographical areas in which potato varieties/clones are grown in tropical Africa, it is important to have a sound understanding of the fungal population dynamics and utilize this to design site specific management options.

Factors favoring the diseases: In Ethiopia, throughout the country the potato crop suffers from the late blight. The climate is conducive to the growth and development of the pathogen. The main sources of the disease are cull piles, volunteer plants, seed tuber and alternate hosts. Even soil contributes to the initial inoculums. Farmers do not cut the foliage and in most cases, after the crop reaches senescence, farmers do not harvest the entire field. They use the piecemeal approach of leaving the tubers in the field for extended periods of time and harvesting as needed.

These practices favor the pathogen remaining in the ground and serving as an inoculum source for the next season. Also, farmers in most areas cultivate potato as mono-crop without rotation. These practices and the presence of alternate hosts significantly contribute to maintaining sources of inoculum in the system[36]. Ideal conditions for late blight are cool nights (50-60°F) and warm days (60-70°F) accompanied by fog, rain or long periods of leaf wetness. Conditions must remain moist for 7-10 h for spore production to occur. Variation in the incidence and severity of late blight on potato has been recorded in many locations and countries. Variability in disease incidence and severity has been reported in Kenya, Ethiopia and elsewhere in Sub-Saharan Africa countries.

The variation of disease incidence and severity may be accounted for by the differences in rainfall patterns between seasons (bi-modal) and years. Variation have also been attributed to susceptibility and resistance of various varieties grown in many areas, different planting dates (disease escape) and various late blight management practices[30]. In Uganda, studies conducted by Mukalazi *et al*.[37] showed that late blight incidence in various countries range from 5 to 85.4% while severity was in the range of 27.9-81.6% during a two year study.

Relationship of environmental factors to late blight development: The impact of environmental parameters on late blight development has mainly been obtained through on station experiments of variety or clonal reactions to late blight. Most of the results have been derivative data since key environmental indicators for late blight epidemics have only been quantified in few central locations in some countries. These parameters often include: temperature, relative humidity, rainfall and hours of solar radiation recorded from the established weather stations located at research stations. In some cases, supplemental weather equipment has been deployed on station for record of additional environmental data. In tropical Africa, the impact of environmental parameters on late blight development has not been adequately quantified. The geographical diversity of the region and the lack of modern equipment imply that there is need to quantify the driving variables for late blight epidemics. Key climatic variables most often associated with severe epidemic development include relative humidity, rainfall and temperature[38, 39].

Derivative data on cumulative climatic variables from Uganda, Kenya and Ethiopia reveal that late blight development is positively correlated with rainfall amount and relative humidity[40]. However, there is very limited data on the use of micro-climate or environmental monitoring for forecasting the development of late blight epidemics at the regional or local levels.

Economic significance of the disease: In the 1940's an outbreak of late blight ravaged potatoes."The ensuing 'potato famine' (in Ireland) was the worst European disaster since the Black Death 500 years before. One million people died and 1.5 million emigrated, out of a total population of around 8 million"[41].

Late blight of potato, caused by Phytophthora infestans (Mont) de Bary is the single most destructive disease of potato the world over[42]. During the last two decades, this disease has increased globally[43]. The average global crop losses of all diseases combined was approximately 12.8% of the potential production but potato alone was subjected to 21.8% loss[44].

In Ethiopia the disease caused 100% crop loss on unimproved local cultivar and 67.1% on a susceptible variety, Al-624[45]. On station results have documented potato yield loss attributed to late blight in the range of 2.7 to 47% at Holetta Research Station[36]. Generally, potato yield loss attributed primarily to late blight is dependent on variety susceptibility or tolerance / resistant and disease management practices. Late blight has an impact on the industry, consumers and country[36]. It is the most devastating disease of potato in countries like Ethiopia where subsistence farmers are not in a position to properly know and control the disease. In Ethiopia, it occurs throughout the major potato production areas. The area under potato is estimated more than100, 000 ha. There are five major potato production regions in Ethiopia such as Central Ethiopia, Eastern Harerge, Northwest Ethiopia, South Ethiopia and Western Ethiopia.

In the central (Ginchi, Jeldu, Galessa and other districts, which are located in an altitude greater than 2800 masl) highlands there is narrow diversification of crop species in rotation to cereals and pulses (such as barley, wheat and to some extent faba bean). In this part of the country, most of the farmers grow potato as a garden crop without rotation but in areas like Shashemene (the major supplier of fresh ware potato to the capital city) potato is grown as a field crop under short rain with supplementary irrigation and/or under irrigation. In the eastern part of the country, it may be planted as relay cropping. During the long rains (June-September) and the short rains (March-May), potato is often intercropped with cabbages, sorghum, beans, maize, eggplant or tomato.

In other parts of Ethiopia, particularly in the eastern part of the country, strip cropping with cabbage may be done under irrigation conditions. In the northwest part of the country potato is the major field crop and has a significant role in the food system of the farmers in the region. In the western part of Ethiopia, although the crop used to be important in the cropping system, due to late blight disease farmers have almost stopped cultivating potato[36].

In Ethiopia potato production is mainly dependent on natural rainfall and smaller proportions of areas the crop is supported by irrigation. Due to the unfortunate shortage of rain in both main and short rain season's potato production was highly reduced throughout the country in 2002. As to the previous years the potato yield has been seriously affected by late blight but during 2003 the disease coupled with the shortage of rain shower that was occurred throughout the country, the yield per unit area and total production was significantly reduced. As a result there was a serious shortage of fresh potato in the local markets and about 50% higher comparing to year 2002 raised the price. Small industries were also seriously affected because of scares in supply. Farmers in marginal potato growing areas whom were partly or fully dependent on potato to feed their family and for market use were critically affected[36].

Symptoms of late blight of potato diseases

Management methods: Used/Researched Worldwide losses due to late blight are estimated to exceed $5 billion annually and thus the pathogen is regarded as a threat to global food security[46]. In the past few decades, the frequency and severity of the disease have increased in many parts of the world including Ethiopia and have been a serious threat to potato production[32]. Despite the fact that much of the success in controlling the disease has been due to the application of large quantities of chemical fungicides, their extensive use is causing a serious pollution problem in the environment[47]. Further, the chemical control of late blight is becoming more difficult due to the appearance of new and more aggressive P. infestans strains[48].

Fig. 3: Stages in potato late blight caused by Phytophthora infestans; (a) Single leaf lesion with sporangiophores and sporangia (b) Blight lesions on many leaflets, (c) Necrosis of stem; (d) Death and collapse of shoots and stem of a potato plant and (e) Death and collapse of blighted plants in the field

Integrated management of late blight through the use of resistant potato clones, fungicides and cultural measures appear to offer the best option for disease management in the tropical highlands of Africa. In Ethiopia, the following management methods (control strategies) were research results used to manage potato late blight (Fig. 3).

Integrated Disease Management (IDM): In Ethiopia, over the past 10 years Integrated Disease Management of Late Blight (IDM-LB) has been adopted as a strategy. IDM-LB includes host resistance in combination with cultural practices such as early planting dates and reduced fungicide use.

These control technologies developed in the research centers are found effective under the farmer's field conditions. The improved technologies were tested under farmer's conditions with their full involvement in pilot sites through Farmer Field Schools (FFS). The only problem with the late blight control is that farmers do not have access to improved resistant varieties and fungicides as required[36].

Fungicide use: According to Ashenafi et al., 2017, during the study period in Holleta, late blight disease is favored by cool and humid conditions and it spread very fast under favorable conditions. Late blight incidence was high in Holleta during the main cropping season. The disease incidence was reached at the maximum of 91.5 % on the unsprayed control susceptible variety, Jalene and 55 and 38.5% was recorded on moderate resistant varieties, Gudene and Gera, respectively.

The percent final disease severity was recorded significant difference in sprayed and unsprayed plots. The highest severity reduction (78%) was recorded in all fungicide treated Gera variety. The highest severity was recorded in varieties of Jalene (83.5%) and Gudene (30%) with untreated control. On the whole, the application of fungicides, Victory 72 WP, Ridomil MZ 68 WG, Mancozeb and Horizon 680WG have arrested disease development more effectively compared to unsprayed control application. In all varieties, the application of fungicides reduced the progress of the disease as compared to unsprayed control, but Victory 72 WP highly reduced the progress of the disease compared to other three fungicides in all varieties. In general, the results of the combined analysis showed that the interaction of varieties (host resistance) and fungicides was significant. The results showed that, no significant variations in late blight incidence and severity among the varieties and fungicides combinations. Nonetheless, significant variations in late blight incidence and severity were obtained when the fungicides were applied on susceptible variety, Jalene. The late blight symptoms appeared to start in treated and untreated plots at about the same time (about 37DAP) with uneven distribution of the pathogen. But gradually the disease severities become varied within treatments (Fig. 4 and 5, Table 5 and 6).

Resistant cultivars: The released improved variety Menagesha has lost resistance to late blight but still is one of the best varieties in the high altitude areas (>2800 masl) if supported by reduced fungicide application and early planting (Integrated Disease Management, IDM). The remaining improved varieties such as Tolcha and Wechecha better express their yield potential when accompanied with IDM[36].

Intercropping: In the central highland of Ethiopia, potato is a garden crop and intercropping with brassica at a lower population being an ordinary practice but crop like garlic is also grown as a sole crop in the same garden. Of the

Table 5: Effect of fungicides and cultivar combinations on disease incidence, disease severity and Area Under Disease Progress Curve (AUDPC) against late blight

Cultivar	Fungicide	Incidence (%)	Severity (%)	AUDPC
Gudene	Mancozeb	6.5	5	302.5
	Victory 72 WP	5	5	268.5
	Ridomil MZ 68 WG	5	6.5	278.5
	Horizon 680 WG	5	6.5	296
	Usprayed control	55	30	480
Jalene	Mancozeb	11.5	8.5	579
	Victory 72 WP	8.5	5	510
	Ridomil MZ 68 WG	6.5	5	442.5
	Horizon 680 WG	6.5	5	556.5
	Usprayed control	91.5	83.5	2457.5
Gera	Mancozeb	5	5	285
	Victory 72 WP	5	5	279
	Ridomil MZ 68 WG	5	5	244
	Horizon 680 WG	5	5	267.5
	Usprayed control	38.5	25	561
Mean	Mean	17.3	13.65	520.5
CV	CV	30.88	69.64	26.86
LSD (5%)	Fungicides	8.78	9.19	135.01
LSD (%)	Varieties	3.88	7.12	104.58

Table 6: Effect of fungicides and cultivar combinations on marketable tuber yield, yield advantage over control and percent yield loss against late blight

Cultivar	Fungicide	Marketable yield (tons/ha)	Yield advantage over control (%)	Yield loss (%)
Gudene	Mancozeb	46.92	137.81	3.2
	Victory 72 WP	43.84	122.2	9.55
	Ridomil MZ 68 WG	46.61	136.24	3.8.4
	Horizon 680 WG	44.45	125.29	8.29
	Usprayed control	35.81	81.5	26.12
Gudene	Mancozeb	39.21	98.73	19.1
	Victory 72 WP	43.21	119.01	10.85
	Ridomil MZ 68 WG	40.13	103.4	17.21
	Horizon 680 WG	30.03	52.2	38.04
	Usprayed control	19.73	0	59.29
Gera	Mancozeb	40.77	106.64	15.89
	Victory 72 WP	48.47	145.67	0
	Ridomil MZ 68 WG	45.07	128.43	7.01
	Horizon 680 WG	41.36	109.63	14.67
	Usprayed control	31.49	59.55	35.04
Mean	Mean	40	-	-
CV	CV	9.65	-	-
LSD (5%)	Fungicides	3.73	-	-
LSD (%)	Varieties	2.89	-	-

Ashenafi *et al.*[49]

(a) (b)

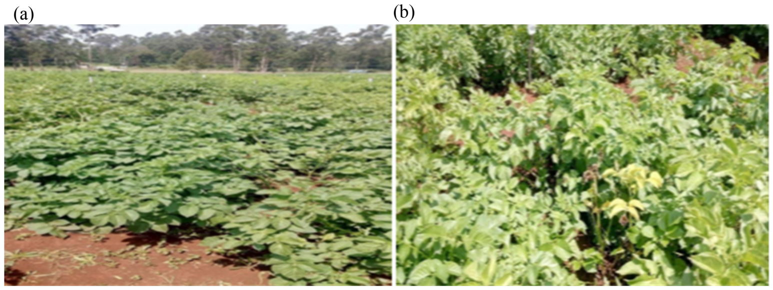

Fig. 4: (a) Experimental field study with Victory 72 fungicide treated of potato cultivar, Gera and (b) Experimental field study site with unsprayed control plot of potato cultivar Jalene Ashenafi *et al.*[49]

various options available in the high altitudes, cropping systems, other than so many advantages related to

Intercropping: In the central highland of Ethiopia, potato is a garden crop and intercropping with brassica at a lower population being an ordinary practice but crop like garlic is also grown as a sole crop in the same garden. Of the various options available in the high altitudes, cropping systems, other than so many advantages related to intercropping mentioned elsewhere,

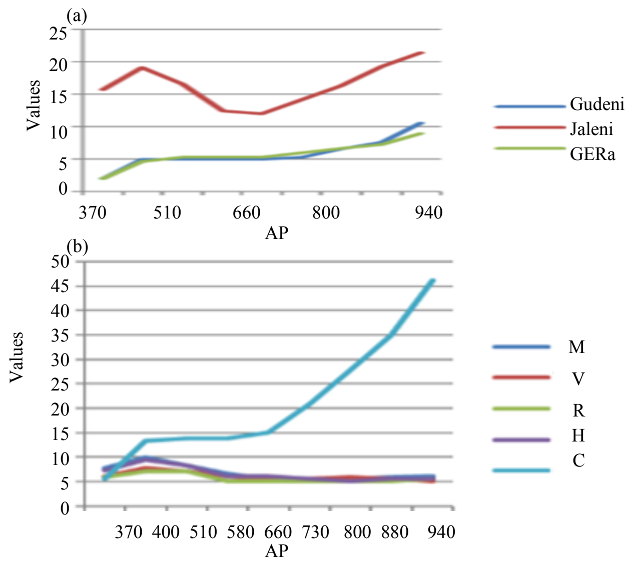

Fig. 5: Disease progressive curves of potato late blight severity on potato varieties DAP = Days after planting

disease problems is intercropping mentioned elsewhere, disease problems is low in an intercropping production systems compared to sole cropping production system[50].

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[51]. Skelsey *et al*.[52] in his report also showed the influence of host diversity on the development of epidemic. Mixture of potato with garlic could also reduce the spread of late blight through inoculums dilution and/or inhibitory effects of volatile compounds[53] that possibly could create an environment hostile to the development of late blight in potato.

Hence, primarily, garlic is widely grown in the highland production system as a garden crop mainly for market; secondly, intercropping can help reduce the disease effect and probably the volatile oil which the crop emits can change the micro climate to be hostile to the pathogen.

Bekele Kassa and Tharmmasak Sommartya had done a research on the effect of intercropping on potato late blight, Phytophthora infestans (Mont.) de Bary development and potato tuber yield in Ethiopia. The result prevailed that, all potato-garlic ratios exhibited superior performance when compared to the fungicide unsprayed treatment. Among the proportions, 75% garlic with 25% potato (3:1) intercropped plots showed significantly ($p< 0.05$) low disease development and high tuber yield. Moreover, at 3:1 combination of garlic to potato the Land Equivalent Ratio (LER) was <1 and the monetary values were high at both testing sites. Significant ($p<0.05$) differences were also observed among potato varieties with regards to the disease development and tuber yield. The study also demonstrated that fungicide treatment provided significant low ($p<0.05$) disease development and higher potato tuber yield when compared to the untreated monoculture control treatment. The findings of this study suggested garlic as a potential intercropping plant for the management of potato late blight disease under Ethiopian condition.

Biological control: Ephrem Debebe *et al*. had done a research on biocontrol activity of Trichoderma viride and Pseudomonas fluorescens against Phytophthora infestans under greenhouse conditions in Ethiopia. The result in In vitro antagonism test carried out between *T. viride* and P. infestans, showed a 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%. In Foliar spray of the suspensions, T. viride was found to be more efficient than *P. fluorescens* and mixed culture. This study revealed that the foliar application of T. viride-ES1 has good potential in controlling the late blight disease of potato.

Late blight management options in SubSaharan Africa Including Ethiopia: The use of protectant as well as systemic fungicides for management of late blight have perhaps been the most studied aspects of disease management[54]. In tropical Africa, fungicide application intervals, frequency of application and timing, fungicide dose response relationships have been experimented routinuely. Fungicide application intervals that have been used include calendar based or scheduled application intervals of 0, 7, 14 and 21 days. Farmer's practices or on-farm fungicide use scenarios often include at least three applications per cropping season. The timing of fungicide application has often frequently been based at the onset of symptom expression.

The use of host plant resistance for management of late blight has received considerable attention in many countries of Sub-Saharan Africa. This has primarily involved the introduction of potato clones from various sources and their evaluation for late blight resistance. This has often involved replicated, randomized experiments conducted under natural late blight epidemics of potato under field conditions. The use of cultural measures for potato late blight management has been investigated in a number of instances. Management practices include manipulation of planting date for potato varieties in order to avoid period of heavy late blight infection have been investigated. Cultural management tactics also include the use of intercropping of non-host crops or low planting density to reduce the spread of fungal inoculum.

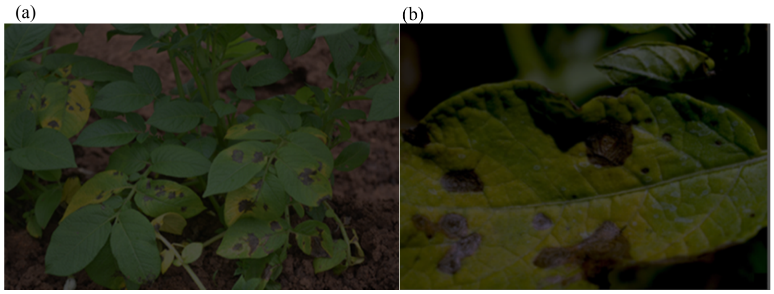

Fig. 7(a, b): Symptom of early blight of potato

Early blight disease of potato: The potato is prone to more than a hundred diseases caused either by bacteria, fungi, viruses or mycoplasms. However, early blight or Alternaria blight is worldwide in distribution and is one of the most important foliage diseases in areas with favorable weather conditions[55]. Early blight, that is caused by two species of genus Alternaria (A.solani and A.alternata), occurs worldwide on potato crops, particularly in the regions with high temperature and alternating periods of dry weather and high humidity and/or irrigated potato soils, light-textured, sandy, low in organic matter. A.solani and A.alternata-causal agents of the early blight are more and more risk-important pathogens on potato crops.

The early blight occurs in all potato production areas but there is a significant impact on the tuber yield and the quality only in warm, wet conditions in the early season, which favours a rapid disease development. Quantity share of both species varies and is dependent on the climate on the weather conditions. Early blight is a very common disease of both potato and tomato. It causes leaf spots and tuber blight on potato and leaf spots, fruit rot and stem lesions on tomato.

According to Tsedaley[56] Potato early blight disease, caused by two species of genus Alternaria (*A.solani and A.alternata*) is the major bottleneck in potato production in the world as well as in Ethiopia. Early blight of potato is prevalent worldwide wherever potatoes, tomatoes, peppers and eggplant are grown. The disease can damage both potato foliage and tubers and can causes yield losses of 5-50%. Early blight is a poly cyclic disease that can cause more than one disease epidemics within a single cropping season. The disease can occur over a wide range of climatic conditions and can be very destructive if left uncontrolled, often resulting in complete defoliation of plants. In contrast to the name, it rarely develops early but usually appears on mature foliage (Rowe etc Undated).

Values in the literature for measured crop losses due to early blight vary enormously from 5-78%[57]. Young and middle-aged plants have low susceptibility to infection being disease influenced by the crop age. Young plants are relatively resistant but the susceptibility increases gradually and continuously from the initiation of tuber formation, so that, mature plants are most susceptible to the disease[58, 59].

Symptom of early blight of potato: The first symptoms usually appear: on older leaves and consist of small, irregular, dark brown to black. Brown, angular, necrotic spots marked internally by a series of concentric rings form on Leaves and to a lesser extent on stems. Leaf lesions are seldom circular because they are restricted by the larger leaf veins.

Lesions usually develop around flowering time and become increasingly numerous as plants mature. Lesions first form on lower leaves. General yellowing, leaf drop, or early death. Tuber rot is dark colored, dry and leathery. Susceptible varieties (usually early maturing) may show severe defoliation[60].

Control of early blight: Effective management of this disease requires implementation of an integrated disease management approach. The disease is controlled primarily through the use of cultural practices, resistant cultivars and foliar fungicides.

Cultural practices: Cultural practices such as crop rotation, removal and burning of infected plant debris and eradication of weed hosts helps reduce the inoculum level for subsequent plantings. Since, *A. solani* persists in plant debris in the field from one growing season to the next, rotation with non-host crops (e.g., small grains, corn or soy bean) reduces the amount of initial inoculum available for disease initiation[61-63]. Other cultural control measures may include the following (Fig. 7).

Use certified pathogen-free seed and resistant varieties: Wait at least 3 or 4 days (preferably 2 weeks) after vine killing before digging potatoes. This practice increases tuber resistance to the early blight fungus:

- After harvest, plow under all plant debris and volunteer potatoe

- Store lesion-free tubers in a clean, dry, dark, well-ventilated location at 40° F.
- Handle tubers carefully to avoid bruising

Select well drained and well aerated fields, promote air circulation and avoid dense plant stands and prolonged overhead irrigation:

- Avoid irrigation in cool cloudy weather and time irrigation to allow plants time to dry before nightfall
- Tubers should be stored under conditions that promote rapid suberization as A. solani is unable to infect through intact periderm

Resistant cultivars: Cultivars with good levels of field resistance are available, however no immunity to early blight has been found in commercial potato cultivars or in their wild parents. Highly susceptible cultivars should be avoided in locations where early blight is prevalent and disease pressure is high. Field resistance to foliage infection is associated with plant maturity. Thus late maturing cultivars are usually more resistant than early maturing cultivars and therefore, one should avoid planting early and late cultivars in the same or adjacent fields.

Chemical control: The most common and effective method for the control of early blight is through the application of foliar fungicides[64] used from early in the growing season to vine kill. Almost as many fungicide formulations are registered for the control of early blight as for all other potato diseases together. It is recommended that contact fungicides be applied regularly in the early stages of the disease to prevent infection. From flowering onwards, 3-4 sprays of a systemic or contact fungicide should be applied. If symptoms appear before flowering, a systemic fungicide must be applied immediately. Proper timing of initial and subsequent fungicide applications can reduce the overall number of sprays with no significant yield loss[64].

A protectant-type fungicide with the active ingredient chlorothalonil, maneb or macozeb should be applied on a 7- to 10-day spray schedule beginning at bloom or according to a weather-timed spray schedule (such as Blitecast) and continue until the foliage dies normally or is killed artificially by a “vine-killing” agent. Intervals between fungicide applications should be shortened in areas where the disease “late blight” is common[62]. Alternate contact and systemic fungicides to control the disease[63]. Follow a complete spray or dust program. Proper timing and thorough coverage of foliage are essential. Start applications when early blight is first seen or just after flowering and continue until the foliage dies normally or is killed artificially with “vine-killers.” If there is a threat of the potentially more serious late blight, applications may need to start when plants are four to six inches tall. Sprays are superior to dusts. Apply dusts and sprays in the early morning or evening when the wind is usually at a minimum (<5 miles per hour for dusting and 10 mph for spraying) and leaf surfaces are damp with dew. Dusts should contain at least 5-10% fungicide. Be sure to follow all directions and precautions for mixing and applying as printed on the container label.

The application of foliar fungicides is not necessary in plants at the vegetative stage, when they are relatively resistant. Accordingly, spraying should commence at the first sign of disease or immediately after bloom. The frequency of subsequent sprays should be determined according to the genotype and age-related resistance of the cultivar. Protectant fungicides should be applied initially at relatively long intervals and subsequently at shorter intervals as the crop ages. Early season applications of fungicides before secondary inoculum is produced often have minimal or no effect on the spread of the disease. Early blight can be adequately controlled by relatively few fungicide applications if the initial application is properly timed. The uses of predictive models to time the first application are commonly used. The first application for early blight control should be timed at 200 P days after emergence. Regular inspection of fields after plants reach 12 inches in height is recommended in order to detect early infections.

Early blight is difficult to control because of its capacity to produce huge amounts of secondary inoculum[57, 58]. In order to suppress early blight and to prevent the losses it causes, potato fields are intensively sprayed with fungicides. Cultural control measures such as eliminating cull piles and volunteer potatoes using proper harvesting and storage practices can be used to reduce the pathogen populations by reducing its survival, dispersal and reproduction[65]. Most approaches to control of foliar early blight have depended on the use of protectant fungicides during the warm-hot weather but the criteria used to determine proper time of initial fungicide have varied widely caused unnecessary sprays.

Viral diseases of potato and its management: Evidence of the occurrence of potato viruses in Ethiopia was first reported in studies conducted in central, South and Southeast Ethiopia during the 1984 and 1985 crop seasons[66]. The results of these consecutive studies indicated the presence of Potato virus X (PVX), Potato virus S (PVS), Potato leafroll virus (PLRV), Potato virus Y (PVY), Potato virus A (PVA) and Potato virus M (PVM). These studies, however, did not include the main production areas in the country. Studies made elsewhere indicate that yield losses as high as 90% can be incurred by viral diseases that can cause varietal degeneration. In addition, symptoms of some potato viruses are often not apparent when in association withthe mosaics caused by PVX, PVY and PVS, so identification by visual observation of symptoms alone is not reliable[67].

As potato is propagated by vegetative means, virus diseases could easily disseminate and accumulate in tubers causing degeneration of varieties and subsequent reduction in potato tuber yield. Potato viruses such as PLRV, PVY and PVX are the major causes for degeneration of varieties. The result of the study at Holeta using virus free seeds of six varieties produced through a rapid multiplication technique and subsequently grown for four consecutive years using seeds from previous year indicated that the incidence of PLRV drastically increased and consequently marketable tuber yield decreased in all the varieties during four consecutive years. The rate of increase in incidence in varieties such as Tolcha and Al -624 was slow as compared to that of other varieties such as Awash and Menagesha. Consecutive use of tubers from the previous season as a seed source caused accumulation of viruses and could cause degeneration of seeds. After the four years of continuous cultivation of potato varieties using seeds from previous season,62%,45%,44% and 41% yield reductions were recorded on varieties Tolcha, Genet, AL-624 and Awash, respectively. Therefore, seeds sources should be periodically renewed from virus free sources for planting in virus prone areas.

Symptom of viral diseases on potato: The most commonly observed virus-like symptoms in potato were: Leaf curling, Interveinal mosaic, Mottling, Reduced leaf size, Deepening of leaf veins, Narrow leaves and Stunting.

Management of potato viral diseases: Potato an important cash crop, suffer moderate to heavy losses due to viral infections under field conditions. Since, there is no viricide available the damage due to viruses can be minimized by managing host genotype and cultural practices. Some of the practices involved in integrated management of potato viruses are as follows.

Quarantine: A large number of viruses which do not occur in country are to be kept out by following strict quarantine measures to protect potato crop against potential pathogens.

Sanitation: Several potato viruses (PVX, PVS and PSTV) are contagious, i.e., they spread by contact. This calls for adopting various sanitation practices such as clean seed, rouging, disinfestations methods, isolation of seed and ware crop for minimizing field spread.

Virus free seed production: diseased mother tubers not only produce diseased plants but also serve as a source of inoculum for field spread. Virus free plants, regenerated from meristem tips, are generally stable and yield true to type plants. A modified scheme 'multi-meristem culture; developed at CIP, Lima has increased rate of multiplication by inducing production of multiple shoots. Thermotherapy: PVY and PVA are easily eliminated at 36-39°C. PSTV is eliminated by chilling (5-6^{o}c for 8-12 weeks).

Chemotherapy: Certain chemicals and antiviral agents are known to reduce viral concentration .growth promoting agents (cytokinin) and GA were reported effective against PVY.

Avoidance and management of vector: several aphids' species are responsible for spread or transmission of potato virus (PVY) from diseased to healthy potato tissue (non-persistent manner). Thus avoiding or management of aphid populations will have direct bearing on status of viral infection in potato crop. Forecasting of viruses: the factor related with host, viruses, insect vector and environment decide the outcome of interaction. Host resistance and transgenic potato.

The drawbacks and challenges of potato diseases management

Fungicide resistance: Recent studies of Ethiopian isolates found all those tested to date to be A1 mating type and the Ia mt-DNA haplotype (Population A, high levels of resistance)[36]. Aboutb 80% of these isolates were metalaxyl-sensitive, 7% resistant and 13% intermediate and the majority of them were collected from unsprayed fields. It should be noted, however that as it was not possible to perform the tests on metalaxyl resistance on freshly collected field material, the isolates could have changed their level of sensitivity during subculturing. The results indicate that the isolates tested could belong to the "new" population of P.infestans. Moreover, the frequency of oospore production through self-fertilization in the tested isolates was as high as 97% [36].

Therefore, the major needs is that understanding the population structure of P. infestans in the country and developing IDM strategies that are more effective, environmentally friendly and economical. There is a great need for healthy seed. This calls researchers to examine and understand the efficiency of the isolates to initiate disease and its role in the disease cycle.

Fungicidal use problems: In Ethiopia, although the use of fungicides at government control prices level was economic, lack of experience in use of fungicides and availability of sprayers are obstacles that hinder the use of the technology. In general, there are still very limited advances in fungicide application methodology and technology. There is limited information on the use of environmental monitoring to aid in proper or adequate fungicide use and application technology. Data on decision support system to optimize fungicide use in conjunction with resistant varieties is still lacking.

Miscellaneous: Inadequate laboratory and growth chamber facilities especially in molecular characterization are often a limiting factor in pathogen population studies. Any environmental monitoring has been a limiting factor in the development and use of decision support systems for the optimization of fungicide spray or utilization in late blight management. However, advances in fungicide application, cultural management in addition to the use of resistant varieties has facilitated late blight management by the small-scale potato farmers.

As improvements in host-plant resistance continue and the quantification and utility of general resistance (stability and durability) receives considerable attention, we are optimistic that optimum potato diseases (late blight and bacterial wilt) management and increased potato production will continue in Ethiopia.

CONCLUSION

Potato (*Solanum tuberosum L.*) is the fourth major crop of the world after rice, wheat and maize. Ethiopia has suitable condition for potato production and Potato can play an important role in improving food security and cash income of smallholder potato growers in Ethiopia. In Ethiopia, potato is grown in four major areas: the central, the Eastern, the Northwestern and the Southern. But the yield per unit area of potato is very low compared to those of other countries there are many factors that reduce the yield of the potato crop production such as diseases like late blight, early blight, bacterial wilt and viruses. Therefore understanding its development, epidemiology and life cycle are most important in selecting and implementing its effective management strategy.

Management of these diseases is therefore very essential. However, much research has not been done in Ethiopia for the management of bacterial wilt of potato disease. It is difficult to control the bacterial wilt diseases, because it is a quarantine pathogen, strict quarantine measures should be followed, but potato late blight can be controlled by using the following Control Strategies:

- Use certified disease-free seed
- Destroy cull piles by freezing or deep burying
- Destroy volunteer potato plants in nearby fields throughout the season
- Destroy infected plants to avoid spread,
- Reduce periods of leaf wetness and high humidity within the crop canopy by appropriately timing irrigation
- Start fungicide spray prior to the arrival of the pathogen
- Desiccate vines prior to harvest
- Use of resistant varieties
- Intercropping and use of selective fungicides are the most important ones

But because of its new strain development, there is no single effective management strategy of this disease. Therefore, adopting Integrated Disease Management (IDM) approach is the most effective, environmentally safe and low costly to the users

RECOMMENDATION

Management of these diseases is therefore very essential. However some research does not done on the management of bacterial wilt, early blight and viruses in Ethiopia researchers should focus on their management. As much as possible farmers us resistant cultivars and adopting Integrated Disease Management (IDM) approach is the most effective, environmentally safe and low costly to the users.

REFERENCES

01. CIP (International Potato Centre), 2017. Fungal diseases of the potato. Report of the Planning Conference on Fungal Diseases of the Potato, September 21-25, 1987, CIP, Lima, -.
02. FAO., 2005. FAOSTAT agricultural data: Agricultural production, crops, primary. Nations Food and Agriculture Organization, March 17, 2005.
03. CSA., 2017/2018. Agricultural sample survey: Report on area and production of crops. Central Statistical Agency of Ethiopia, Addis Ababa, Ethiopia.
04. FAO, 2008. Potato world: Africa-international year of the potato 2008. http://www.potato2008.org/en/world/africa.html.
05. Nganga, S., 1982. The Role of the Potato in Food Production for Countries in Africa. In: Potato Development and Transfer of Technology in Tropical Africa, Nganga, S. (Ed.). CIP, Nairobi, Kenya, pp: 63-69.
06. CSA., 2016. Agricultural sample survey 2015/2016, Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season), Central Statistical Agency, Ethiopia.
07. Yaynu, H., 1989. Characteristics of isolates of Pseudomonas solanacearum in Ethiopia. Ethiopian J. Agric. Sci., 11: 7-13.
08. Stewart, R.B., 1956. Some plant disease occurring in Keffa Province, Ethiopia. Ethiopia, College of Agriculture, Alemaya.

09. Stewart, R.B. and D. Yiroou, 1967. Index of plant diseases in Ethiopia. Bull. Exp. Stn Coll. Agric. Halle Selassie Univ., Vol. 30.
10. Hayward, A.C., 1994. Pseudomonas Solanacearum. In: Pathogens and Host Specificity in Plant Disease: Histopathological, Biochemical, Genetic and Molecular Bases; Prokaryotes, Singh, U.S., R.P. Singh and K. Kohmoto, (Eds.)., Elseveier Science, Tarrytown, New York, pp: 139-151.
11. Van Elsas, J.D., P. Kastelein, J.M. van der Wolf, P.M. de Vries and L.S. van Overbeek, 2000. Survival of Ralstonia solanacearum biovar 2, the causative agent of potato brown rot in field and microcosm soils in temperate climates. Phytopathology, 90: 1358-1366.
12. Stansbury, C., S. McKirdy, A. Mackie and G. Power, 2001. Bacterial wilt: Ralstonia solanacearum-race 3 exotic threat to Western Australia. Factsheet No. 7/2001. Hortguard Initiative AGWEST, the Government of Western Australia. http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/ph/dis/veg/fs00701.pdf.
13. Hay, R.K.M., 2001. Scientific review 1997-2000. Scottish Agricultural Science Agency, Edinburgh, Scotland.
14. Elphinstone, J.G., 2001. Monitoring of the potato brown rot bacterium (Ralstonia solanacearum) in the UK: A case study. Proceedings of the 2nd European Potato Processing Conference, November 14-15, 2001, Institute of Food Science, Lausanne, Switzerland, pp: 1-7.
15. Poussier, S., P. Thoquet, D. Trigalet-Demery, S. Barthet, D. Meyer, M. Arlat and A. Trigalet, 2003. Host plant-dependent phenotypic reversion of Ralstonia solanacearum from non-pathogenic to pathogenic forms via alterations in the phcA gene. Mol. Microbiol., 49: 991-1003.
16. Elphinstone, J.G., 2005. The Current Bacterial Wilt Situation: A Global Overview. In: Bacterial Wilt Disease and the Ralstonia solanacearum species Complex, Allen, C., P. Prior and A.C. Hayward (Eds.). APS Press, St Paul, MN, USA., ISBN: 0890543291, pp: 9-28.
17. Walker, T. and N.H. Collin, 1998. Priority setting at CIP for the 1998-2000. Medium Term Plan International Potato Centre, Lima, Peru.
18. Ajanga, S., 1993. Status of Bacterial Wilt in Kenya. In: Bacterial Wilt, Hartman, G.L. and A.C. Hayward (Eds.), ACIAR Proceedings No. 45, Canberra, Australia, pp: 338-340.
19. Prior, P., V. Grimault and J. Schmit, 1994. Resistance to bacterial wilt (Pseudomonas solanacearum) in tomato: Present status and prospects. In: Bacterial Wilt: The Disease and its Causative Agent, Pseudomonas solanacearum, Hayward, A.C. and G.L. Hartman, CAB International, Canberra, Australia,.
20. Henok, K., A. Fasil and H. Yaynu, 2007. Evaluation of Ethiopian isolates of Pseudomonas fluorescens as biocontrol agent against potato bacterial wilt by Ralstonia (Pseudomonas) solanacearum. MSc. Thesis, Addis Ababa University, Addis Ababa.
21. Sorensen, J., 1997. The Rhizosphere as a Habitat for Soil Microorganisms. In: Modern Soil Microbiology, Van Elsas, J.D., J.T. Trevors and E.M.H. Wellington (Eds.). Marcel Dekker, Inc., New York, USA., pp: 21-45.
22. Bais, H.P., S.W. Park, T.L. Weir, R.M. Callaway and J.M. Vivanco, 2004. How plants communicate using the underground information superhighway. Trends Plant Sci., 9: 26-32.
23. Bagnasco, P., L. de la Fuente, G. Gualtieri, F. Noya and A. Arias, 1998. Fluorescent Pseudomonas spp. as biocontrol agents against forage legume root pathogenic fungi. Soil Biol. Biochem., 30: 1317-1322.
24. Lemessa, F., 2006. Biochemical, pathological and genetic characterization of strains of Ralstonia solanacearum (Smith) from Ethiopia and Biocontrol of R. solanacerum with bacterial antagonists. Ph.D. Thesis, Leibniz Universitat Hannover, Hanover, Germany.
25. Lemaga, B., D. Siriri and P. Ebanyat, 2001a. Effect of soil amendments on bacterial wilt incidence and yield of potatoes in Southwestern Uganda. Afr. Crop Sci. J., 9: 257-266.
26. Lemaga, B., P. Kanzikwera, R. Kakulenzire, J.J. Hakiza and G. Maniz, 2001b. The effect of crop rotation on Bacterial wilt incidence and potato tuber yield. Afr. Crop Sci. J., 9: 257-266.
27. Kinyua, Z.M., J.J. Smith, C. Lungaho, M. Olanya and S. Priou, 2001. On-farm successes and challenges of producing bacterial wilt-free tubers in seed plots in Kenya. Afr. Crop Sci. J., 1: 279-285.
28. Alacho, F.O., B.F. Ngombi, P.M. Persell, M.Y. Mohamed and J.J. Hakiza, 2000. The contribution of the community seed potato production and storage scheme to food security in Kabale district: A case of Africare/Uganda. Afr. Potato Asso. Conf. Proc., 5: 105-108.
29. Adipala, E., G. Tusiime, B.K. Patel, L. Berga and M. Olanya, 2001. Bacterial wilt management: A dilemma for Sub-Saharan Africa. Afr. Crop Sci. Proc., 5: 433-437.
30. PRAPACE, 1996. Evaluation of potato germplasm for field resistance to late blight in Eastern and Central Africa. Recommendations and Summaries from Regional Workshop, September 1-2, 1995, Mukono, Uganda, pp: 1-21.
31. Sengooba, T. and J.J. Hakiza, 1999. The current status of late blight caused by Phytophthora infestans in Africa, with emphasis on eastern and southern Africa. Late Blight a Threat to Global Food Initiative on Late Blight Conference, March 16-19, 1999, Quito, Equador, pp: 25-28.

32. Bakonyi, J., B. Heremans and G. Jamart, 2002. Characterization of Phytophthora infestans isolates collected from potato in Flanders, Belgium. J. Phytopathol., 150: 512-516.
33. Kassa, B. and Y. Hiskias, 1996. Tuber yield loss assessments of potato cultivars with different levels of resistance to late blight. Proceedings of the 3rd Annual Conference of Crop Protection Society of Ethiopia, May 18-19, 1996, CPSE, Addis Abeba, Ethiopia, pp: 149-152.
34. Tarekegne, A. and B. Kassa, 1997. Natural resources management at Galessa Kota Gisher and Garie Arera peasant associations, Dendi Wereda, Western Shewa, Ethiopia. Crop subsystem, Mekonnen, K., H. Beyene and A. Tadesse (Eds.). Participatory Research Appraisal (PRA) Survey Report, Holetta, Ethiopia.
35. Nattrass, R.M. and M. Ryan, 1951. New hosts of Phytophthora infestans in Kenya. Nature, 168: 85-86.
36. Ethiopia Late Blight Profile, 2004. Disease impact on the industry, consumers and country. Ethiopian Agricultural Research Organization, Holeta Agricultural Research Center, Addis Ababa.
37. Mukalazi, J., E. Adipala and T. Sengooba, 2000. Population structure of Phytophthora infestans in Uganda. Crop Protection, USA.
38. Campbell, C.L. and L.V. Madden, 1990. Monitoring Epidemics: Environment. In: Introduction to Plant Disease Epidemiology, Campbell, C.L. and L.V. Madden (Eds.)., John Wiley & Sons, Ltd., London, pp: 43-73,.
39. Zadoks, J.C. and R.D. Schein, 1979. Epidemiology and Plant Disease Management. Oxford Universitiy Press, New York, ISBN: 0-19-502451-6, Pages: 427.
40. Bekele, K. and W. Gebremedhin, 2000. Effect of planting date on late blight severity and tuber yields of different potato varieties. Pest Mana. J. Ethiop., 4: 51-63.
41. Horton, D., 1987. Potatoes: Production, Marketing and Programs for Developing Countries. West View Press, Boulder, USA.
42. CIP., 1989. International potato center: Annual report. International Potato Center, Lima, Peru.
43. Fry, W.E. and S.B. Goodwin, 1997. Reemergence of potato and tomato late blight in the United States. Plant Dis., 81: 1349-1357.
44. James, C.W., 1981. Estimated Losses of Crops from Plant Pathogens. In: Handbook of Pest Management in Agriculture, Pimentel, D. and J.W. Henfling, (Eds.), CRC-Press, Boca Raton, Florida, pp: 80-94.
45. Bekele, K. and H. Yaynu, 1996. Tuber yield loss assessment of potato cultivars with different levels of resistance to late blight. Proceedings of the 3rd Annual Conference of Crop Protection Society of Ethiopia, May 18-19, 1996 Addis Abeba, Ethiopia,
46. Latijnhouwers, M., W. Ligterink, V.G. Vleeshouwers, P. van West and F. Govers, 2004. A Ga subunit controls zoospore motility and virulence in the potato late blight pathogen Phytophthora infestans. Mol. Microbiol., 51: 925-936.
47. Ragunathan, V. and B.J. Divakar, 1996. Integrated Pest Management Strategies. In: Molecular Biology of the Biological Control of Pests and Disease of Plants, Gunasekaran, M. and D.J. Weber (Eds.)., CRC Press, Florida, pp: 191-194,.
48. Fernández-Northcote, E.N., O. Navia and A. Gandarillas, 2000. Basis of strategies for chemical control of potato late blight developed by PROINPA in Bolivia. Fitopatología, 35: 137-149.
49. Ashenafi, M., T. Selvaraj, L. Alemu and K. Bekele, 2017. Evaluation of potato cultivars and fungicides for the management of late blight ,(Phytophthora infestans (mont) de bary) in Holleta, West Showa, Ethiopia. Int. J. Life Sci., 5: 161-179.
50. Proceedings of the International Intercropping Workshop, 1979. Evaluation of plant interactions and productivity in complex mixtures as a basis for improved cropping systems design. Okigbo, B.N., January 10-13, 1979, Hyderabad, India. pp: 155-179.
51. Garrett, K.A. and C.C. Mundt, 2000. Host diversity can reduce potato late blight severity for local and general patterns of primary inoculum. Phytopathology®, 90: 1307-1312.
52. Skelsey, P., W.A.H. Rossing, G.J.T. Kessel, J. Powell and W. van der Werf, 2005. Influence of host diversity on the development of epidemics: An evaluation and elaboration of mixture theory. Phytopathology®, 95: 328-338.
53. Cizcova, H., M.R. Vacek, S. Voldrich and J. Kratka, 2000. Caraway essential oil potential inhibitor of potato sprouting. Rostillinna Vytoba, 46: 501-507.
54. Lunga'ho, C., 1998. Current status of integrated management of late blight in Kenya. Proceedings of Regional Training Workshop on Integrated Management of Potato Late Blight and Bacterial Wilt, November 23-27, 1998, Kabale, Uganda..
55. International Potato Center, 1996. Major Potato Diseases, Insects and Nematodes. International Potato Center, Lima, Peru Pages: 39.
56. Tsedaley, B., T. Hussen and T. 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. J. Biol. Agric. Healthcare, 4: 46-52.

57. Pasche, J.S., L.M. Piche and N.C. Gudmestad, 2005. Effect of the F129L mutation in Alternaria solani on fungicides affecting mitochondrial respiration. Plant Dis., 89: 269-278.
58. Campo, A.R.O., L. Zambolim, F.X.R. Vale, L.C. Costae and C.A. Martyinez, 2001. [Effect of the black spot (Alternaria solani) on the growth and production of the potato (Solanum tuberosum L.) (In Portuguese)]. Fitopatol. Bras. Suppl., Vol. 26,
59. Johnson, K.B. and P.S. Teng, 1990. Coupling a disease progress model for early-blight to model of potato growth. Phytopathology, 80: 416-425.
60. CIP (International Potato Center), 2012. Potatoes for the developing countries. Lima, Peru. pp: 150.
61. Agrios, G.N., 2005. Plant Pathology. 5th Edn., Elsevier Academic Press, Amsterdam, New York, USA., ISBN-13: 9780120445653, Pages: 922.
62. Sikora, E., 2004. Plant disease notes early blight of potato. Alabama Cooperative Extension System: ANR1052.
63. Schultz, D. and R.D. French, 2009. Early blight of potatoes and tomatoes. Texas AgriLife Extension Service; The Texas A&M System: PLPA-Pot009-01.
64. Van der Waals, J.E., 2002. A review of early blight on potatoes. University of Pretoria.
65. Garrett, K.A. and S.P. Dendy, 2001. Cultural practices in potato late blight management, Proceedings of GILB Latin American Workshop I, February 13–16, 2001, Cochabamba, Bolivia. pp: 107-113.
66. Agranovsky, A.A. and J. Bedasso, 1985. Survey on virus diseases of potato and tomato in major growing areas. Sci. Phytopathological Lab. (SPL) Progress Rep., 86: 247-249.
67. Fletcher, J.D., S.L. Lewthwaite, H.J. Boddington, H.M. Nott and R.J. Wood, 1996. Virus disease surveys of ware potato crops, Franklin County, North Island, New Zealand. N. Z. J. Crop Hortic. Sci., 24: 7-12.