International Journal of Research in Agriculture and Forestry
Volume 7, Issue 5, 2020, PP 41-49
ISSN 2394-5907 (Print) & ISSN 2394-5915 (Online)

Epidemiology and Management Strategies of Ginger Bacterial Wilt (Ralstonia Solanacearum) in Ethiopia

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ABSTRACT

Ginger is a slender herbaceous perennial herb belonging to Zingiberaceae family and propagated by rhizomes. It has originated in India and currently cultivated in different countries worldwide. In Ethiopia, cultivation of ginger started during 13thc when Arabs introduced it from India to East Africa. Like most cultivated crops, ginger is affected by biotic and abiotic factors in different parts of the world. Bacterial wilt (Ralstoniasolanacearum) is one of the most commonly known to cause disease in Many crops including ginger. The pathogen enters to the roots through wounds made by transplanting, cultivation, insects or certain nematodes and through natural wounds where secondary roots emerge. Once inside the host, the bacterium has an affinity for the vascular system, where it multiplies rapidly, filling the xylem with bacterial cells and slime. After the infection is established, it moves up through the vascular system and blocks water transportation in the xylem and causes wilting. Bacterial wilt disease caused by R. Solanacearum widely distributed mainly in tropical, subtropical and temperate regions of the world and results severe yield losses. Symptoms of the plant due to the disease ranged from flagging or wilting to plant death. Hence, knowing these features of the disease is quite useful to analyze the conditions that determine disease development and plan sound disease management strategy. Up to now, there is no single control effective measure against the pathogen. However, some level of bacterial wilt control has been possible through the use of a combination of diverse methods.

Keywords: *Bacterial wilt, Epidemiology, Management*

INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) is one of the oldest known spice, has been used by man since several centuries not only as a spice but also as medicine. Ginger is indigenous to tropical India and South East Asia, Australia and Japan, with the main center of diversity in Indo- Malaysia (Jansen, 1981). In India, ginger in its fresh and/or dried form has innumerable uses in culinary and medicinal preparations. India and China are the world's largest producers and exporters of ginger. Other important producers are Jamaica, Nigeria, Sierra Leone, Thailand, and Australia (Yiljep *et al*., 2005).

Ginger is known to be introduced to Ethiopia as early as the 13th century and perhaps its cultivation has also been started since then (Jansen, 1981). The statistical information from the Ministry of Agriculture and Rural Development indicated that 99 % of ginger production was from the Southern Nations, Nationalities and Peoples Regional State (SNNPRS) and about 1 % was from the Oromia National Regional State. The productivity of fresh rhizome ginger is about 11,522 kg/ha in the SNNPRS, 2615 kg/ha in the Oromia National Regional State and 7050 kg/ha nationally (MOA, 2003).Despite, the increasing demand for ginger the current production capacity of ginger was very low when compared to its immense potential of the crop is not as such encouraging. The primary reason is due to outbreaks of bacterial wilt, which affect quality and yield of ginger in major producing area.

Bacterial wilt (BW) is one of the most important, widespread and lethal bacterial diseases of plants (Lando, 2002). Hayward (1991) reported that more than 55 crops and wild species are affected by R. *solanacearum* crops such as potato, tobacco, tomato, eggplant, banana, chili, bell pepper and peanut are highly susceptible to the disease. Recently it was shown that certain ecotypes of the model plant *Arabidopsis thaliana* are also susceptible to the pathogen (Hayward, 2000). It is common in tropical, subtropical and warm temperature regions where temperature and moisture conditions are favorable for its development (Singh, 1978). The bacterium may also be present in cooler climates such as relatively high elevation in the tropics or higher latitudes.

The bacterium responsible for bacterial wilt is *Ralstonia solanacearum* (E. F. Smith) Yabucchi *et al*., (1996) formerly known as *Pseudomonas solanacearum* E. F. Smith. It is a Gram negative, aerobic, non-spore-forming, non-capsulate, nitrate reducing, catalase-positive, ammonia-forming, and monotrichous short rod (1.5 x 0.5 mm) (Stanier *et al*., 1966). The wild type bacterium is usually non-motile and does not form a polar flagellum in a liquid medium.

Bacterial wilt is described by Agrios (2005) as sudden wilt. Infected plants die rapidly. Older leaves may first show leaf dropping and discoloration or one-sided wilting and stunting before completely wilts and permanently dies. Severely infected rhizomes are blackened and when cut, vascular ring turns brown. In general, the symptoms are wilting, stunting and yellowing of the leaves, followed by the collapse of the entire plants (Agrios, 1997).

Symptoms occur both above and belowground parts of the host plants. Above ground symptoms include wilting, stunting, and yellowing of leaves. Infection is characterized by initial wilting only of a part of the stems of the plant, or even one side of the leaf or stem. The entire plant wilts quickly without yellowing when development of the disease is rapid (French, 1996). External symptoms on the rhizomes are visible at harvest when infection is severe. Bacterial ooze collects at tuber eyes causing soil to adhere. Brownish discolorat-ions on the vascular rings are observed. When tubers are slightly squeezed, ooze comes out naturally from the rings. In more advance stages of the disease development, the vascular ring or the whole tuber may disintegrate completely (Martin and French, 1996).

Bacteria live in fallow soil for several years and may persist indefinitely in the presence of susceptible plants. R. *solanacearum* is capable of surviving under high moisture. This proves that BW is more serious in wet, humid, tropical areas than in desert areas, even under irrigation. However, survival depends on race involved and deep soil layer (Persley, 1995).

French (1996) stated that the inherent variability of R. *solanacearum* and the strong influence of environmental conditions on resistance make disease management difficult. In managing the disease, crop rotation, prevention and use of resistant cultivars are employed (Lando, 2002). Using areas free of the bacterium reduces the chance of rhizomes become infected later. Planting pathogen-free seed rhizomes will decrease severity and incidence in infested field and will prevent the introduction of the pathogen into non-infected area. The elimination of alternate hosts can decrease pathogen population inoculum in the soil. The use of resistant cultivars plays an important role but the extreme variability found in *R. solanacearum* makes breeding for resistance to the pathogen difficult (Rich, 1983).

Generally, there is a trend of increased incidence and economic importance of GBW due to climate change and use of susceptible varieties. Therefore, studying the epidemiology of the pathogen is very important to design appropriate management strategies of GBW.

Objectives of this paper is to review:

- The epidemiology of the bacterial wilt of ginger
- Possible management strategies to fight against the diseases and reduce crop losses.

Taxonomy and Botanical Description of Ginger

Ginger belongs to the order Scitaminae, family Zingiberaceae that consists of about 47 genera and 1400 species of perennial tropical and subtropical herbs (Anteneh *et al*., 2008). Ginger is biennial or perennial reed-like herb, grown for the pungent, spicy underground stem or rhizome born horizontally near the surface of soil, bearing leafy shoots close together usually 30- 100 cm tall. Inflorescence generally arises directly from the rootstock and is carried on a slim, leafless stem, 15-30 cm tall. Flowering is a cultivar characteristic; some flower rarely; others regularly, especially when grown undisturbed as perennials. Fruits are seldom produced, thin walled, 3-valved capsule with small black aril late seeds (Weiss, 2002).

Ginger grows well in tropical and subtropical climates from sea level to 1600m above sea level with an annual rainfall of 1500 - 3000 mm (Pruthi, 1998). It requires warm and humid climate for commercial production. The temperature requirement varies from 20 to 30°C for normal growth and production. A friable fertile loam soil of moderate depth with pH of 6.0 - 7.0 is the most suitable for annual ginger since rhizomes and roots proliferate in the top 25 cm. Ginger is, however, very adaptable and almost any soil will produce an acceptable rhizome with good management (Jansen, 1981).

Economic Importance of Wilt Disease

Bacterial wilt caused by *Ralstonia solanacearum* is a major plant disease of economic importance since it destroys a variety of plants of commercial value in most of the tropic and subtropical countries.

A century has elapsed since Smith (1896) first described the bacteria affecting potato and tomato. In ginger, the disease can bring about total destruction of the crop during rainy season in all ginger growing areas of Ethiopia. In Ethiopia, the loss in yield due to the disease in ginger is 100 per cent (Habtewold *et al.*,2015).

Bacterial wilt (BW) is one of the most important, widespread and lethal bacterial diseases of plants (Lando, 2002). It is considered a dreaded disease in many parts of Asia, Africa, and Central and South America. (ACIAR, 2000) the Australia Centre for International Agricultural Research recognized it as one of the most important diseases of bacterial origin in the world. Hayward. (1991) reported that more than 55 crops and wild species are affected by R. *solanacearum* crops such as potato, tobacco, tomato, eggplant, banana, chili, bell pepper, ginger and peanut are highly susceptible to the disease. Recently it was shown that certain ecotypes of the model plant *Arabidopsis thaliana* are also susceptible to the pathogen (Hayward, 2000). It is common in tropical, subtropical and warm temperature regions where temperature and moisture conditions are favorable for its development (Singh, 1978). The bacterium may also be present in cooler climates such as relatively high elevation in the tropics or higher latitudes.

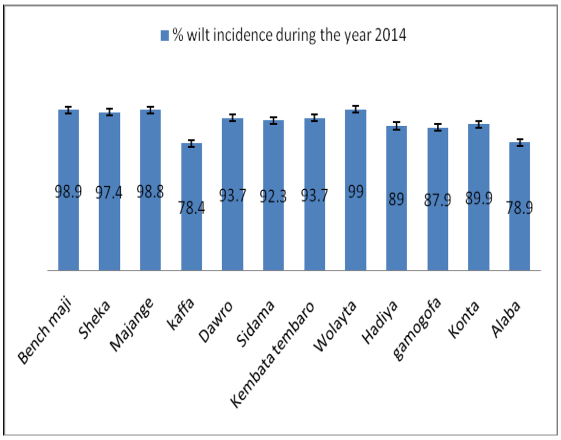

Fig1. *Incidence of ginger bacterial wilt in different parts of Ethiopia*

Source: *Habtewold et al., 2015*

In the year 2014 survey result, SNNPRS (Dawro, Wolayta, Kenbata tenbaro, Hadiya, Gomogofa, Konta, Alaba, Sheka, and Bench maji) and Gambella region (Majang) zone ginger were found devastated by the bacterial wilt and cause yield loss up to 98%. This is due to the prevailing ideal weather condition for the bacteria epidemics (average rain fall, 287.9mm, Tmax, 27.8^{O}C & T min. 17.1^{O}C) and using of latently infected seed rhizome. The pathogen transmitted through rhizome seed caring latent infection (Tall, 1997), Bowman, 1980 reported that *R. solanacearum* is seed and soil born and easily disseminated from one area to the other through planting material.

The Causal Organism

The bacterium responsible for bacterial wilt is *Ralstonia solanacearum* (E. F. Smith) Yabucchi *et al*. (1996) formerly known as *Pseudomonas solanacearum* E. F. Smith. It is a Gram negative, aerobic, non-spore-forming, non-capsulate, nitrate reducing, catalase-positive, ammonia-forming, and monotrichous short rod (1.5 x 0.5 mm) (Sands *et al*., 1980). The wild type bacterium is usually non-motile and does not form a polar flagellum in a liquid medium. Avirulent variants that develop in culture are actively motile. Colonies on agar are opalescent which became darker with age. Rich (1983) described them as small, irregular, smooth, wet and shiny.

The virulent colonies are pink in tetrazolium chloride agar (TCZA). The optimum temperature for growth ranges from 35^{0}C- 37^{0}C (Rich, 1983) and the thermal death point lies at about 52^{0}C (Kerr, 1983). R. *solanacearum* cannot hydrolyze starch and it can liquefy gelatin slowly or not at all. The bacterium is inhibited by relatively low concentrations of salt in broth culture and is sensitive to desiccation. The cultured bacterium in un aerated liquid media losses its virulence and viability rapidly and change from the fluidal (non-motile) wild type to the avirulent, highly motile variants (Sands *et al*., 1980).

Symptoms

Bacterial wilt is described by Agrios (2005) as sudden wilt. Infected plants die rapidly. Older leaves may first show leaf dropping and discoloration or one-sided wilting and stunting before completely wilts and permanently dies. Severely infected rhizomes are blackened and when cut, vascular ring turns brown. In general, the symptoms are wilting, stunting and yellowing of the leaves, followed by the collapse of the entire plants (Agrios, 1978).

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(a) Initial symptom (b) wilted tiller

(c) Infected rhizome (d) Rotted rhizome

Fig 2. *Areal and below ground symptom of ginger bacterial wilt diseases*

Source: *Habtewold et al., 2015*

Favorable Environments for Ralstonia Solanacearum

Temperature is an important environmental factor that affects *R. solanacearum* multiple plant patho systems and their interactions with their hosts (Hayward, 1991). High ambient temperatures have been shown to induce growth of *R. solanacearum* incidence ata faster rate than moderate temperatures (Ciampi and Sequeira, 1980). An increase of temperature to a range of 30 to 35ºC is associated with an increase in severity of the disease caused by *R. solanacearum* in several hosts. That is, plants resistant to *R. solanacearum* at moderate temperatures become more susceptible at high ambient temperatures (Hayward, 1991). For instance, in tomato, the *R. solanacearum* pathogen rapidly moves through the plant at temperatures above 28º C and thus cultivars that seem resistant in lower temperatures become susceptible when exposed to temperatures higher than 28ºC (Prior *et al.*, 1996).

Understanding host-pathogen interactions and the effect of temperature on disease caused by *R. solanacearum* development may offer information to advance breeding and disease management strategies. These results confirm that temperatures between 30 and 35ºC significantly increase wilting severity in tobacco as it has been reported in other hosts (Hayward, 1991).High temperatures (*i.e.* 30-35°C) promote occurrence of these disease caused by *Ralstonia solanacearum*, whereas soil temperatures below 20°C are not suitable for the disease (Wang and Lin, 2005).

Table 1. *Correlation result of ginger bacterial wilt incidence, temperature and rain fall*

Correlation					
		RF	**T.min.**	**T.max.**	**GBW incidence**
RF	Pearson Correlation	1	-.057	.227	.991**
	Sig. (2-tailed)	.785	.275	.000	Sig. (2-tailed)
	N	25	25	25	25
T.min	Pearson Correlation	-.057	1	-.024	-.106
	Sig. (2-tailed)	.785	.909	.614	Sig. (2-tailed)
	N	25	25	25	25
T.max	Pearson Correlation	.227	-.024	1	.191
	Sig. (2-tailed)	.275	.909	.359	Sig. (2-tailed)
	N	25	25	25	25
GBW Incidence	Pearson Correlation	.991**	-.106	.191	1
	Sig. (2-tailed)	.000	.614	.359	
	N	25	25	25	25
** Correlation is significant at 0.01 level (2-tailed)					

Bekele *et al.*, 2015

The correlation result of bacterial wilt incidence to weather parameter (Rain fall, Temperature maximum and Temperature minimum) shows that high Rain fall and high temperature were found a positive significant correlation whereas, low daily temperature and low rainfall were found negatively correlated. It also noted that PH, Soil and air temperature and moisture, have great influence and relationship on the survival and incidence of the pathogen (EPPO, 2004).

Ecology and Epidemiology of the Pathogen

In order for the bacterium to cause disease, it must first enter the host. Most of the time *R. solanacearum* strains enter through wounds on the host. Normal agricultural practices can result in wounding. The roots can also be injured by nematodes and during normal plant growth, as the roots expand and lateral roots are produced (Denny, 2006). The pathogen can be vectored by bees or other insects unintentionally (Buddenhagen and Kelman, 1964). The disease is favored by high temperature and moist soil. The disease develops rapidly when temperatures are greater than 20ºC. Other soil factors that affect the pathogens ability to cause disease include soil depth, organic matter, host plant debris, and soil type (Denny, 2006). The pathogen has been reported to be present in virgin soil (Kelman, 1953). Once the bacterium has entered and colonized the host, it multiplies and moves systemically through the xylem.

Survival is one of the main obstacles a pathogen faces in the disease cycle. *R. solanacearum* is able to survive in soil in the absence of host plants for up to 2 years. Survival is dependent on soil temperature and soil moisture (McCarter, 1991). The bacterium has been reported to survive in pure water at 20-25°C for more than 40 years (Denny, 2006). The bacterium can overwinter in irrigation water in close association with asymptomatic aquatic weed hosts, thus aiding in the spread of the pathogen throughout the waterways in Europe (Elphinstone *et al.*, 1998).

Disease Management

Cultural Practices

One of the reasons why GBW continues to be one of the most important ginger diseases worldwide is that it is very difficult to control is due to soil and seed-borne nature of the bacteria. The infection by this disease can be significantly reduced by using non-susceptible crops and crop rotation for 5-7 years (Smith *et al*., 1995). Use of crop rotation has been shown to reduce disease incidence, it is limited in management as the pathogen population continues to proliferate because the pathogen is able to survive in the soil over a long time but also complicated with existence of weeds and volunteer crops of solanaceous family (Fajinmi and Fajinmi, 2010). Crop rotation with a non-susceptible crop provides some control, but this can be limited as the diseases has a very wide host range (Saddler, 2005).

There is significant reduction of the disease when organic manure is used. Islam and Toyota (2004) bacterial wilt of tomato was suppressed when poultry and farmyard manure was added to the soils increasing microbial activity. The application of the organic amendment and compost released biologically active substances from crop residues and soil microorganisms such as allelochemicals have been reported to reduce the disease (Chellemi *et al*., 1997).

Site selection is one of the most important factors that contribute to the successful control of bacterial wilt of ginger. It has been observed that a soil with no history of bacterial wilt often results in healthy crops of ginger if the rhizomes are free from the pathogen. In locations where the pathogen is not present, it is critical to prevent introduction and if inadvertently introduced, subsequent movement of the pathogen should be prevented. Planting certified disease-free seedling from registered plant raisers, disinfecting equipments after working in a field, controlled use of flood irrigation and avoiding overhead irrigation can reduce spread of the disease (McCarter, 1991). Growers should monitor potentially infected sites for early detection and subsequent eradication of pathogen (Fajinmi and Fajinmi, 2010). Weeds can also host the pathogen and their control will contribute to the disease management (Champoiseau and Momol, 2009).

Solarization of soil prior to planting has been widely used to control soil borne pathogens and pests in various crops (Stapleton, 1994). In more temperate regions soil is covered with clear plastic in order to trap solar radiation and raise the temperature sufficiently to suppress or eliminate soil borne pathogens and pests (Kumar *et al.,* 2003). Solarization can be effective against a broad spectrum of soil borne diseases caused by pests such as fungi, nematodes, and bacteria. But the effectiveness of this method is directly linked to climate (Katan and DeVay, 1991). Solarization causes complex biological, physical, and chemical changes that improve plant growth, quality, and yield for up to several years (Stapleton, 1994). The success of soil solarization is based on the fact that most plant pathogens and pests are mesophiles, which do not produce heat-resistant spores, and they are unable to survive for long periods at high temperature. Death of the organisms at high temperature involves inactivation of enzyme systems, especially respiratory enzymes (DeVay *et al.,* 1990).

Disinfection of seed pieces prior to planting is an important approach to the control of bacterial wilt of ginger. contaminated planting material is one of the primary inoculum sources for field infection. Soaking of ginger seed in hot water at 50ºC for 10 minutes (Nishina *et al.,* 1992) is the usual pre-plant preparation. Shorter exposure times give insufficient heat penetration, and longer soaking periods result in heat injury to the seed piece and growth of stunted crops (Nishina *et al.,* 1992).

Biological Control

Use of biological controls products for soil borne pathogen has gained popularity in recent years due to environmental concerns raised on the use of chemical products in disease control (Haas and De'fago, 2005). Biological control methods have been widely accepted and advocated for as key practice in sustainable agriculture with the biggest potential of the biological control being microorganisms, arbuscular mycorrhizal fungi (AMF) (Tahat *et al*., 2010) and some naturally occurring antagonistic rhizobacteria such as *Bacillus* sp., *Pseudomonas* sp. (Guo *et al*., 2004). Use of AMF in agricultural crops can provide protection against soil-borne pathogens by reducing the root diseases caused by a number of soil pathogens (Sharma *et al*., 2004). A number of mechanisms are involved in controlling and suppression of the pathogen by mycorrhizal fungi roots among them exclusion of pathogen, changed nutrition, lignifications of cell wall, and exudation of low molecular weight compounds (Tahat *et al*., 2011).

Other biological agents that have been used for the disease management include; Fluorescent pseudomonads such as *Pseudomonas fluorescens* which are antagonistic to soil-borne pathogens by production of antimicrobial substances, competition for space, nutrients and indirectly through induction of systemic resistance (Kavitha and Umesha, 2007).

Host Plant Resistance

Host resistance is an efficient and effective component in integrated management of bacterial diseases and some tomato cultivars provide moderate resistance against bacterial wilt disease (Peregrine, 1982). This is having been made possible by genetic improvement on varieties to increase tolerance against *R. solanacearum* (Liao *et al*., 1998). The use of resistant varieties has been reported to be the most effective and practical method to control bacterial wilt (Black *et al*., 2003). *R. solanacearum* is a complex and heterogeneous species group with a wide host range, high variability in its biochemical properties (Cuppels, 1978), serological reactions, membrane proteins and phase susceptibility (Okabe and Goto, 1963) confirming the existence distinct strains posing a challenge in breeding for resistance. Although the species occur worldwide, distribution of individual strains is not uniform leading to resistance breakage of a highly tolerant variety from a different geographical area (Black *et al*., 2003).

Resistance to *R. solanacearum* has been reported in some tomato genotypes but incorporation of resistance into materials with good horticultural characteristics has been difficult (Peterson *et al*., 1983). *R. solanacearum* strain type, genetic variability of the plant and reproducibility of the inoculation technique may affect the selection of resistant material (Prior *et al*., 1990a). Some *R. solanacearum* resistant cultivars have been developed from the Asian Vegetable Research and Development Center (AVRDC). However, their resistance is restricted to locations, climate, and strains of the pathogen and soil characteristics. A number of tomato varieties have been developed with significant levels of resistance for certain environments; in a number of cases the stability in regions with high temperatures and humidity especially in lowland tropics is difficult to achieve as resistance breaks when variety is transferred to a different region (Hanson *et al*., 1996). Use of resistance varieties provide a more stable strategy in management but performance will vary with temperature and location (Wang *et al*., 1998).

Chemical Control

Bacterial wilt control using chemicals is a challenge because of the localization of the pathogen inside the xylem and its ability to survival in the soil. There are no known eradication bactericides available for chemical control of the bacterial wilt disease (Hartman *et al*., 1994), while others reported that it is difficult to control bacterial with chemicals (Grimault *et al*., 1994). Earlier use of the banned soil fumigant such as methyl bromide in controlling bacterial wilt disease did not succeed (Chellemi *et al*., 1997). Ji *et al*. (2005) reported some control by use of phosphoric acid. Soil treatments, including modification of soil pH, solarization and application of stable bleaching powder reduced bacterial populations and disease severity on a small scale (Saddler, 2005). There is a report of significance control of *R. solanacearum* with application of urea fertilizer as well as potassium Nitrate fertilizer but their use on commercial scale has not yet been tested. Use of chemical product to manage the disease ultimately contributes to environmental degradation apart from being labor intensive and expensive (Fajinmi and Fajinmi, 2010).

The bactericides Terlai has been tested in Taiwan under both greenhouse and field conditions (Hartman *et al*., 1994) and it was found that chemical control through soil fumigation and antibiotics (Penicillin, Ampicillin, Tetracycline and Streptomycin) has shown suppression of the pathogen. Application of a resistance inducer such as acibenzolar-S-methyl (Actigard -Syngenta) or in combination with moderately resistant varieties can give increased control against the disease. Similarly, application of another product Thymol, a plant -derived volatile chemical has also shown to give positive results in managing the disease (Champoiseau and Momol, 2009).

Integrated Disease Management

Integrated Disease Management (IDM) is a combination of methods such as cultural, host resistance, biological, and chemical applications that are environmentally compatible, economically feasible, and socially acceptable to reduce damage caused by diseases to tolerable levels. Combination of control measures is required to combat plant diseases (Agrios, 2005). These integrated approaches reduce or delay disease severity during the critical periods of vegetative and reproductive plant growth. Ginger growers must carefully integrate recommended strategies: crop rotation, sanitation, use of treated or healthy seeds, tolerant varieties, soil solarization, soil bio-fumigation, in organic soil amendment and proper seeds treatment to minimize the impact of bacterial disease on ginger (Hartman *et al*., 1994).

SUMMARY AND CONCLUSION

Ginger is the most important spice crop in Ethiopia. Ginger yields are, however, low due to many factors, of which ginger bacterial wilt diseases are the major constraints. Ginger bacterial wilt, which is caused by *R. sonacearum*, is the most common and economically important diseases of ginger.

Bacterial wilt causes sudden wilt of the crops. Older leaves may first show leaf dropping and discoloration or one-sided wilting and stunting before completely wilts and permanently dies. Severely infected rhizomes are blackened and when cut, vascular ring turns brown. Temperature is an important environmental factor that affects *R. solanacearum*. An increase of temperature to a range of 30 to 35ºC is associated with an increase in severity of the disease caused by *R. solanacearum*. The ability of the pathogen to survive depends on the initial inoculum and its ability to tide over the adverse condition. It was found that discontinuity of cropping pattern forces the pathogen to lead a saprophytic existence. The saprophytic survival of the pathogen takes place in the soil, plant parts, seeds and insects.

Ginger bacterial wilt are fully capable of causing significant reductions in yield and/or marketability if left unchecked. Bacterial wilt can be managed with Cultural practices, Host plant resistance, Biological, Chemical and Integrated disease management. Therefore, different investigations should be conducted to determine effective management strategies for Ginger bacterial wilt and to sustainable ginger production in Ethiopia.

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Citation: *Merga Jibat and Shamil Alo "Epidemiology and Management Strategies of Ginger Bacterial Wilt (Ralstonia Solanacearum) in Ethiopia", International Journal of Research in Agriculture and Forestry, 7(5), 2020, pp. 41-49.*