TECHNICAL GUIDELINE FOR MANAGEMENT OF GINGER BACTERIAL WILT AND LEAF SPOT DISEASES IN ETHIOPIA

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EIAR Ethiopian Institute of Agricultural Research

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ABBREVIATIONS AND ACRONYMS

B	Boron
BoARD	Bureau of Agriculture and Rural Development
C:N	Carbon to Nitrogen Ratio
Cu	Copper
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural Organization of the United Nations
Fe	Iron
FYM	Farm Yard Manure
GWB	Ginger Bacterial Wilt
K	Potassium
MPI	Ministry of Private Institutes
N	Nitrogen
P	Phosphorus
SARI	Southern Agricultural Research Institute
SNNPRS	Southern Nations, Nationalities and Peoples Regional State
Zn	Zinc

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1. INTRODUCTION

1.1. Overview of the Ginger Plant

1.1.1. Botanical description

Ginger (*Zingiber officinale Rosc*.) is a monocotyledonous herb, with elongated leafy stems and horizontally oriented underground rhizome. The economic part is the underground rhizome, which is pungent and aromatic used for culinary purposes (Kandiannan *et al*., 1996; Sharma *et al*., 2010). Ginger is a perennial tropical plant belonging to the family Zingiberaceae with chromosome numbers 2n=2x=22 (diploid) and 2n=4n=48, but chromosome numbers 2n=20 and 2n=32 are also reported (Eksomtramage *et al*., 2002).

Ginger plants have a pseudostem of convolute leaf sheaths. The leaves are radical or cauline and usually membranous. Sheaths are generally large, clasping on stem; lamina with a strong central nerve and pinnately closed secondary nerves. Petioles are short or absent. The ginger plant consists of the thick scaly rhizomes (underground stems). They branch with thick thumb-like protrusions, thus individual divisions of the rhizome are known as "hands." (Awang, 1992; Bisset, 1994). Rhizomes are 7-15cm long and 1-1.5cm wide and laterally compressed. The branches that arise obliquely from the rhizome are about 1-3cm long and terminate in depress scars or in undeveloped buds (Fig. 1). The outer surface is buff coloured and longitudinally striated or fibrous (Evans *et al*., 2002). Fractured surface shows a narrow cortex, a well-marked endodermis and a wide stele (Ali, 1998).

Figure 1: Typical ginger plant (left) and its rhizome (right)

Ginger flowers are hermaphrodite, irregular, solitary or spicate, bracts membranous, bracteoles membranous or toothed or spathaceous tube, inner segments are petaloid, connate in a long or short corolla tube, free or adnate to petaloid staminodes, or five perfect with six imperfect. Anthers are linear and two-celled. The ovary is three-celled, inferior with many ovules, anatropous and axile. The style is usually slender with two short stylodes, crowning the ovary. Stigma is usually entire or sub entire. The fruit is usually loculicidal- a three valved capsule, or indehiscent and membranous or fleshy, usually crowned by the remains of the perianth. Seeds are often arilate, albumen floury and embryo small.

1.1.2. Origin, geographical distribution and production area of ginger

The Arabs, in the 13th century brought ginger from India to east Africa (Jansen, 1981) and it has been perhaps known since then in Ethiopia. Ginger has predominantly been grown in Ethiopia mainly in South Nations, Nationalities and Peoples Regional State (SNNPRS).. Its production to a lesser extent has also been extended to some parts of Western Oromia and Northern Amhara. However, the data from the Ministry of Agriculture and Rural Development indicates that 99% of the crop's production was from SNNPRS (BoARD, 2008). In central part of SNNPR, known as Ginger Belt of Ethiopia, 85%of the total arable land was allotted to ginger and 35% of the farmers were involved in ginger production before the outbreak of Ginger Bacterial Wilt (GBW) disease in 2012 (Endrias and Asfaw, 2011). At a global level, the area under ginger cultivation was estimated at 407,773 hectares in 2016, with a total annual production of 3270762 tons (FAO, 2017), indicating the world average green rhizome yield of 8 t/ha, which was half way below the national average yield of 16 t/ha reported in Ethiopian ginger (Endrias and Asfaw, 2011). In the past (2006-2011), among the 36 countries engaged in ginger production globally, Ethiopia stood 14th in terms of yearly total fresh ginger production (FAO, 2015). Since the outbreak of GBW disease, ginger production has declined incredibly. The total production and area cultivated for ginger in SNNPR was declined from 650,049 tons and 26,972 ha to a level of nil, respectively. In Africa, Ethiopia is the second largest ginger producer, next to Nigeria. Ginger is a good cash crop supporting the livelihood of many smallholders (Sah *et al* ., 2017).

1.1.3. Diversity of ginger

Ginger is a vegetatively propagated plant that comes from the family of *Zingiberaceae*. *Zingiberaceae* is the largest family in the Order Zingiberales that include approximately fifty genera and more than a thousand species (Rashid *et al.,* 2013). Several commercial cultivars of ginger are grown throughout the world including land races and improved cultivars which excel in yield. More quality traits are available (Yadgirwar *et al.*, 2017; Asafa and Akanbi, 2018). Momina *et al.* (2011) identified tremendous genetic diversity among ginger cultivars and accession collections in Ethiopia. Endrias and Asafw (2011) also observed variability among cultivars grown in Ethiopia for number of prominent roots and pungency. Cultivars also vary for maturity stage, per cent of dry recovery, crude fibre, and oleoresin and essential oil contents (Kanadiannan *et al.*, 1996). Considerable variability among ginger cultivars have also been reported in qualitative morphological traits in foliar organs (Momina *et al.,* 2011; Kanadiannan *et al.*, 1996). These include variations in traits of leaf (shape, apex, base colour, margins, arrangement, attachment pattern, pubescence and blade blistering), leaf sheath (type, pubescence, attachment, colour), and leaf collar (region and pubescence).

A good amount of genetic variability has also been reported with regard to growth parameters (plant height, number of tillers and leaves/plant, leaf length and leaf width, leaf size, and stem girth) under different agro-climatic conditions (Melati *et al*, 2016). Variations were also observed for proximate composition (crude protein, crude fibre, total lipid, total ash, and starch and water soluble extract) among ginger cultivars and quality attributes (Asafa and Akanbi, 2018). It should be noted that potential yield and quality attributes of the genotypes may vary with agro-climatic and soil conditions (Melati *et al.*, 2016).

The most frequently reported diversities in ginger have been variations for quantitative morphological characters of the subterranean organs (Fig. 2) that include variability in yield attributing traits *vis-a-vis*., number, length, weight, girth, thickness and fresh yield of primary and secondary rhizomes. Other subterranean quantitative morphological traits including, rhizome expansion, rhizome internodes length, number of finger/ rhizome per plant, rhizome fresh and dry weight per plant have been used to distinguish ginger varieties. Subterranean qualitative morphological traits like rhizome flesh colour and qualitative morphological

traits like rhizome flesh colour and skin appearance are also traits used to differentiate ginger cultivars. The cortex colour of rhizomes is brownish while the flesh colour depending on the variety may be red, yellow or white (Olojede, 2009). The most important trait of subterranean parts in ginger is number of prominent roots. Number of prominent roots may vary between one and thirty. Varieties with large number of prominent roots are less preferred by farmers due to high harvesting and root trimming cost.

Figure 2: Morphological variation in subterranean parts of some ginger cultivars grown under similar growth conditions in SNNPR, Ethiopia

In general, ginger exhibits various levels of polymorphism for the foliar and subterranean qualitative and quantitative morphological traits, as well as for desirable agronomic traits, and also for chemical composition. This shows that ginger has enormous potential for its genetic improvement and for selection of cultivars for commercial production and industrial uses. Therefore, due attention needs to be given to a choice of varieties prior to attempting to import or introduce cultivars from elsewhere to undertake commercial production. Ecological adaptability tests are necessary to explore the soil and climatic conditions as well as the disease and pest reactions before employing large scale ginger production.

1.1.4. Emergence and growth

Under ideal condition, ginger emerges or appears above ground ten to fifteen days after planting, but may be prolonged for up to two months, particularly under conditions of inadequate soil moisture and low temperature (below 15°C) (Kandiannana, 1996). However, emergence may take six weeks for shoots to emerge after planting (Valenzuela, 2011), depending on the level of sprouting of the propagules. Newly prepared cut-rhizome pieces take longer to emerge after planting as compared to the sprouted ones. According to Valenzuela (2011), vegetative growth is maximum until the flowering begins. Flowering marks the beginning of rhizome maturity and increasing fibrous tissue development. Dasaradhi *et al*. (1971) identified 120-135 days after planting as active growth stage. Progressive increase in dry matter production of the whole plant and rhizome was observed up to 240 days after planting, after which there was a decline (Ravisankar and Muthusamy, 1986). Accumulation of dry matter in the above ground portion is observed up to 210 days after planting while in the rhizome it continued up to 240 days after planting and was maintained at more or less the same level even at harvesting. Whiley (1980) observed that crop growth and net assimilation rate declined with age up to flowering and then increased during the later period of rhizome bulking. In the development, rhizome will form parent rhizome, primary rhizome, secondary rhizomes, and tertiary rhizomes. The older the age of the rhizome, the higher the content of secondary metabolites. The older the age of ginger, the higher the fibre content of rhizome (Melati *et al*., 2016).

1.2. Agro-ecological Requirements of Ginger

Ginger has wider adaptability for different climatic requirements (Rao *et al*., 2008). It prefers warm and humid climate and performs well in sunshine but cannot withstand very low temperature (below 15°C). The crop grows at an altitude of 1500 metres above sea level (Valenzuela, 2011), the optimum being 300-900 metres above sea level.. Heavy rainfall and high amount of relative humidity (70-90%are requirements for a promising yield (Ridley, 2012). Dry spells during land preparation and before harvesting are necessary for cultivation. However, ginger is sensitive to water logging, frost and salinity, but tolerant to wind and drought. In some countries there has been a tendency to plant ginger on land with high slope (15-30%However, steep slopes >15% in hilly areas are not recommended for ginger cultivation as it leads to soil

erosion during heavy rainfall and rhizome yield is negatively correlated with slope (MPI, 2011). Ginger should not be planted down slope from another ginger field to prevent runoff water that carries the pathogen to the field. In this regard, Girma *et al*. (2016) suggested that a slightly slanted land orientation is required to avoid water logging for ginger production.

1.2.1. Temperature requirement

The base temperature requirement for ginger growth and performance is 13^{0}C and the upper limit is 32 ^{0}C/ 27 ^{0}C (day/night), whereas the favourable range is 19-28^{0}C (Hackett and Carolane, 1982). Warm sunny days are preferred but a temperature above 32^{0}C can cause sunburn, and a temperature below 15^{0}C can cause crops to stop growing. Xizhen *et al*. (1998) in China noted that air temperature of 22 to 28°C at seedling and early growth stages and 25°C at the rhizome enlargement stage are ideal. According to Evenson *et al. (*1978) seed rhizome sprouts better at a soil temperature of 25-26°C and 27.5°C for growth and development of the crop. Most of lower altitudes, particularly those closer to oceans, are characterised by warm temperature and high humidity. Under such conditions the rate of respiration may surpass that of translocation which explains wastage of photosynthate and eventually lead to low crop yield. On the other hand, the synergetic effect of warm temperature and high relative humidity is a driving force for disease development including GBW. In this regard, Habtewold *et al*. (2015) reported that higher temperatures (more than 13 and 28°C of minimum and maximum, respectively) accompanied with higher relative humidity (>90%aggravated incidence of GBW disease.

1.2.2. Moisture requirement

Ginger can be grown both under rain-fed and irrigated conditions. When ginger is cultivated under rain-fed conditions, light rain during planting and moderate rain, well distributed over the growth season is required for successful cultivation. Moisture requirement for ginger in the tropics is 1500 to 3000mm or more per annum (Kandiannan *et al*., 2015). However, in some east African countries including Ethiopia, ginger is cultivated under sub-optimal conditions with rainfall often less than 1500mm per year (Jansen, 1981). Under such sub-optimal conditions, an average fresh rhizome yield of 16 t/ha was reported in southern Ethiopia (Momina *et al*., 2011). For successful cultivation of the crop, a moderate rainfall at planting time until the rhizomes sprout, fairly heavy and well distributed showers during the growing period and dry weather for about a month before

harvesting are necessary for ease of harvesting, and for harvesting quality rhizomes (Kandiannan *et al.*, 2015).

In areas that receive less rainfall, ginger needs regular irrigation (Kandiannan *et al.*, 1996), particularly in this era of fluctuating climatic conditions as a result of climate change. It is unlikely to attain the required amount and evenly distributed rainfall across the growing season. Thus, to maximize the rhizome yield of the crop, regular or supplementary water supply is essential mainly in areas where irrigation schemes are established. According to Kandiannan *et al.* (2015), the critical stages for irrigation are germination, rhizome initiation (90 days after planting) and rhizome development stages (135 days after planting). The first irrigation should be applied immediately after planting and subsequent irrigations are given at intervals of seven to ten days in conventional irrigation based on prevailing weather and soil types (Kandiannan *et al.*, 2015). However, it should be kept in mind that excess water does not only affect ginger yields, causing waterlogging, but it also aggravates incidence and development of GBW disease when accompanied with warm temperatures. In this regard, Habtewold *et al.* (2015) reported that the synergetic effect of excess rainfall (above the 278.8mm monthly average) and higher temperatures (more than 28°C) favoured the development of GBW disease which totally devastated ginger at Bebeqa. Bebeqa is a low lying (800 metres above sea level) humid pocket area located in western part of Southern Ethiopia, where GBW disease was observed for the first time in the country.

1.2.3. Edaphic conditions

Ginger has wider adaptability for different soil types (Kandiannan *et al.*, 1996). But for optimum yield it prefers sandy loam soils with a good supply of humus that mostly have proper water holding capacity and aeration. The upper layer of the soils needs to be permeable. Soil should be loose, friable and offer minimum resistance to rhizome development. Well drained soil with at least 30cm depth is essential. Deep soils with rich organic matter content and nutrient availability are more suitable for cultivation (Cho *et al.*, 1987).

In heavy clay soils, deep ploughing allows better root penetration and free rhizome development. Stoney soils need to be avoided for ginger production. Virgin forest soils after deforestation are

ideal (Paulose, 1970). Coarse sands without water holding capacity, gravely soils or those with hardpan are not conducive for the production of high yielding healthy ginger plants (Lawrence, 1984). The most favourable soil pH for ginger production ranges between 6.0-6.5 (Cho *et al.*, 1987). If the soil pH is more than 8, growth is retarded. Compact clay soils, which are subject to water logging need to be avoided or amended for ginger production since high moisture, if associated with high soil temperature favours GBW disease.

1.3. Economic Importance of Ginger

Commercially, ginger products are available in various forms, such as green ginger, dry ginger, ginger powder, ginger oil, ginger oleoresin and preserved ginger. Dried ginger is used for the manufacture of several products, such as ginger oil, ginger essence, ginger oleoresin, and vitamin zed effervescent ginger powder used in soft drinks, local foods and drinks (Maghirang *et al.*, 2009). The rhizome of ginger has been valued throughout the world as a spice of flavouring agent for its two major classes of constituents, which are essential oils and oleoresins (Baladin *et al.*, 1998). On the other hand, fresh ginger contains protein, fat, carbohydrates, fibre and ash. The proteoletic enzyme, vitamin B_6, vitamin C and Linoleic acid are also the important constituents of ginger (Vadivel *et al.*, 2006). Ginger also contains minerals namely iron, calcium, phosphorous, zinc, copper, chromium and manganese (Shirin and Prakash, 2010). Owing to its chemical composition, ginger finds immense usage in many of the different medicinal systems of the world for a wide variety of disorders. Ginger is known to be effective as an appetite enhancer, and an improver of digestive system (Grzanna *et al.*, 2005). Ginger rhizome is used in Ethiopia for the preparation of pepper powder and Ethiopian stew (*wat*, Amharic) (Merga, 2019).

Ginger has also other multiple advantages in that it is highly productive per unit area, tolerant to drought, can be stored for long periods in dried form, and can also be intercropped with other crops like beans, maize, coffee and taro. In areas where wildlife (such as vertebrate pests) is a serious problem, ginger is the best priority crop to cultivate because wildlife and domestic animals do not consume both of its foliar (leaves) and subterranean organs (rhizomes) due to its pungent characters. Its contribution as a foreign currency earner is notable. For instance, a few

years before the outbreak of the GBW disease, Ethiopia earned as high as USD $22 million in the year (ICT, 2010).

1.4. A Brief History and Impact of Ginger Bacterial Wilt Disease in Ethiopia

Prior to 2012, no pest was recorded in ginger in Ethiopia. The only bottlenecks reported were shortage of improved varieties and poor pre and post-harvest management practices (Endrias and Asfaw, 2011). Currently, ginger production is constrained by Ginger Bacterial Wilt (GBW) disease caused by *Ralstonia solanacearum.* GBW is a complex disease infecting the crop through all phases of a production cycle. The sudden outbreak of GBW disease shortly devastated all ginger varieties all over the country within two years (2012-2013) irrespective of variations in cultivars and geographic locations (Habtewold *et al*., 2015). As a result, almost all ginger germplasm collections maintained in different agricultural research centres and nurseries, farmers' cultivars, improved varieties as well as those landraces in natural forests in every corner of the country were infected. Consequently, the socio-economic security of farmers' traders and other members of the societies whose livelihoods were based directly or indirectly on businesses related to ginger production have been seriously affected. In Ethiopia, the disease incidence was estimated at 80-100%(Tariku *et al*., 2016) and up to 100%crop loss was observed from the outbreak of the GWB disease (Habtewold *et al*., 2015). *Ralstonia solanacearum* is present systemically in seed rhizomes as both in an active and latent infection (Hepperly *et al*., 2004).

It has been difficult to control GBW by means of chemicals (Zenebe, 2018) and no resistant genotype was reported so far in Ethiopia (Habtewold *et al*., 2015) and elsewhere. Globally, there are no effective measures developed so far to control GBW disease (Yang and Guo, 2010). However, advances in its control measures, such as biological, physical, chemical, cultural, and integrated measures, as well as bio control efficacy and suppression mechanisms were made in different parts of the world over the past decades (Yuliar *et al*., 2015). Management of GBW is also very difficult as it has a wide host range, long survival rate in the soil, spreads in many ways (latently infected seed rhizome, water, farm tools, animals, etc.), survives in vegetation as latent infection and because of the presence of genetically diverse strains of the bacterium (European

Union 2003; American Phytopathological Society 2005). *Ralstonia solanacearum* infects over 250 plant species in over fifty families at a time including crops such as potato, tomato, tobacco, banana, pepper and eggplant (Wicker *et al.*, 2007).

1.5. Previous Efforts to Manage Ginger Diseases

Since the outbreak of ginger diseases in 2012 in Ethiopia, a number of research and development attempts have been made to alleviate ginger bacterial disease problem. Organisations such as the United Nations International Trade Center (UNITC) under the framework of supporting Indian Trade and Investment (SITA) project and Farm Africa provided financial support and organised successive stakeholder's meetings and workshops. Farm Africa also provided research funds to Southern Agricultural Research Institute (SARI) based on agreements made between the two parties. Research institutes both at federal (Ethiopian Institute of Agricultural Research (EIAR)) and regional levels (SARI) together with Bureau of Agriculture and Natural Resource of SNNPR through its Coffee and Tea Development and Marketing Authority have conducted a survey collaboratively in major ginger growing parts of the country in an attempt to undertake field diagnosis by critically observing the bacterial wilt disease symptoms. Consequently, an intensive laboratory diagnosis of the samples was conducted at Ambo Plant Protection Research Laboratory which illustrated that the cause of the disease was *Ralstonia solanacearum biovar 3* (Tariku *et al.*, 2016). Jimma Agricultural Research Center has also contributed vital role in generating disease free planting material using a tissue culture technique. Incidentally some fungal disease complexes, mainly ginger leaf spot caused by *Phyllosticta zingiberi*, have been observed opportunistically affecting the crop;Teppi Agricultural Research Center has conducted a number of research activities aimed at managing both ginger bacterial wilt and leaf spot diseases. The following were also part of the collaborative efforts made by various stakeholders:

1. Awareness creation was made to researchers, producers, exporters, manufactures etc.
2. Policy advice was forwarded in order to give research attention toward management of ginger diseases.

3. Tissue culture protocol was optimised for regeneration of disease-free planting materials.
4. Stakeholders' workshops, organised by Farm Africa, were held to validate the technical guideline.

The workshop participants were researchers and experts from EIAR Head Quarters, SARI, Teppi ARC, Areka ARC, federal and regional (SNNPR) Coffee and Tea Development and Marketing Authority of zone and districts of Kambata-Tambaro and Wolayta.

Objective of the guideline:

The objective of the current technical guideline is to combine and document integrated disease management options on ginger bacterial wilt and leaf spot diseases.

2. METHODOLOGY

EIAR (Teppi, Jimma and Ambo Agricultural Research Centres) and SARI (Areka Agriculture Research Center) have been conducting different research activities independently towards generating disease management technologies since the outbreak of ginger bacterial wilt in 2012. Farm Africa has been supporting Areka Agricultural Research Center financially to develop the diseases management technologies. Thus the efforts made so far by different institutions to develop disease management technologies need to be compiled as a technical guideline to serve as a quick reference for ginger growers and experts. Farm Africa has organised a series of workshops involving researchers from federal and regional research institutes and experts from federal, regional and zonal levels of the Coffee and Tea Development and Marketing Authorities to validate the guideline. This technical guideline was also reviewed by subject matter specialists critically.

3. MAJOR FINDINGS

Most of the findings included in this guideline were extrapolated from research activities conducted by SARI (Areka Agricultural Research Center) funded by Farm Africa and

the Ethiopian Institute of Agricultural Research (Teppi, Jimma and Ambo Agricultural Research Center) supported by national spices and plant pathology research program. Additional information was used from secondary sources and direct expert observations.

3.1. Major Diseases of Ginger

3.1.1. A brief description about ginger bacterial wilt disease

Ginger bacterial wilt pathogen is an aerobic non-sporing, Gram-negative plant pathogenic bacterium. *Ralistonia solanacearum* is soil-borne and motile with a polar flagellar tuft. It colonizes the xylem, causing bacterial wilt in a very wide range of potential host plants. Globally, bacterial wilt, *Ralstonia solaneacearum* was first reported by Burrill in 1890 in Japan on tuber rot of potato. Since then, the disease incidence has been reported in many countries including India in 1941 (Thomas, 1941), Hawaii (Rosenberg, 1962), Australia (Hayward *et al* ., 1967), China (Li *et al* ., 1994) and others. Bacterial wilt was first reported in Ethiopia in 2012 in south western part of the SNNP region at Bebeqa (Habtewold *et al* ., 2015) in the Horizon plantations PLC Share Company. Bacterial wilt of ginger caused by *R. solanacearum* is one of the most devastating diseases.

Bacterial wilt caused by *R. solanacearum* has been described as one of the most devastating plant pathogen mainly in tropical, subtropical and some warm temperate regions of the world. *R. solanacearum* has very wide host range. In addition to ginger some of its economically important *Solanaceae* hosts are tomato, potato, tobacco, banana, cowpea, peanut, and papaya. There are also weeds and asymptomatic hosts that may play a role in the survival and persistence of *R. solanacearum* . The pathogen is a highly heterogeneous bacterial species. The species is divided into five races based on host range and six biovars according to its ability to metabolise three sugar alcohols and three disaccharides. The disease caused by *R. solanacearum* race 4 biovar 3 strains is the causal agent for ginger bacterial wilt in Ethiopia (Tariku *et al.* , 2016).

3.1.1.1. Epidemiology and survival of the pathogen

Ralstonia solanacearum spreads by infested soil adhering to hands, boots, tools, vehicle tires, farm equipment; in water from irrigation or rainfall, and by infected ginger rhizomes. The

pathogen enters roots through wounds created during planting, 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. Once infection is established, the bacterium moves up through the vascular system, the xylem, and finally blocks water transportation, which causes wilting.

The bacterium returns to the soil when the plant dies, living as a saprophytic organism until it infects another host plant. Transmission and dissemination of the pathogen occur through several means. The bacterium can be carried distantly on vegetative propagating materials. Infected seed rhizomes are an important source of inoculum and contribute to short and long distance dispersal of the pathogen. *Ralstonia solanacearum* also survives in wet soil, contaminated irrigation water, and in chicken and cattle manure. Crop residues left in the fields that were infected by *R. solanacearum* also serve as source of disease inoculum in the field.

3.1.1.2. Symptoms and nature of damage of ginger bacterial wilt

Symptoms occur on both the above and underground parts of the ginger plants (Fig 3 a-d). Typical symptoms of bacterial wilt such as yellowing and dwarfing can be observed a few days after infection. Irreversible sudden wilting and death of plants occur by invasion of large quantities of bacterial cells and their *exopolysaccharide* slime in xylem vessels. Death of plant cells is caused by degradation of vessels and adjacent tissues. Further symptoms of bacterial wilt include discoloration of the vascular system from pale yellow to dark brown and droplets of milky bacterial ooze exuding from affected tissue. Young shoots /tillers often become soft and rotten, breaking off easily from the underground rhizome at the soil level. The rotted rhizomes emit a foul smell characteristic of the disease. Subsequently, *R. solanacearum* cells are set free into the soil from roots or collapsed stems that spread to roots of adjoining plants, thereby repeating the cycle (Habtewold *et al*., 2015).

Figure 3: Above- (a & b) and below ground (c & d) symptoms of ginger bacterial wilt disease

3.1.1.3. Source of inoculum

The pathogen *R. solanacearum* is found both in plant propagative material (seed rhizomes) and soil. Ginger rhizomes are normally cut into appropriate size and used as planting material and the pathogen in the soil can enter the rhizomes through the cut ends. So these rhizome pieces form the primary source of inoculum. Infection can also occur through wounds in roots or rhizomes or at sites of secondary root emergence. After the entry, the bacterium colonises the intercellular spaces of the root cortex and vascular parenchyma and produces extracellular enzymes that break down pectin in the cell wall and middle lamella and access the vascular system. Upon death of an infected plant, the bacterial cells reach the soil and remain as saprophytes until it infects a new host plant. The spread of pathogen occurs via soil, irrigation water or rain splash to the adjacent plant within a bed, as well as to other beds in the same field.

3.1.1.4. Diagnosis and identification of the pathogen

Symptom identification is the first step for early diagnosis of bacterial wilt of ginger. In the field, a slight yellowing is observed on the lower leaves. The wilt progresses upward, affecting the younger leaves, followed by a complete yellowing and browning of the entire shoot. Shoots become flaccid and dry concurrently (Fig. 4). In addition, shoots become soft and completely rotted and break off easily from the underground rhizome. The underground rhizomes also produce a foul smell shortly after a day or so of harvesting. A rhizome cross-section cut placed in a water beaker with the end of the section just touching the water surface shows milky white bacterial streaming, distinguishing bacterial wilt from vascular wilts caused by fungal pathogens. These disease symptoms in the field and bacterial streaming from the cut surface of infected rhizome suspended in a beaker of water reveals that the disease is caused by bacteria (Merga and Shamil, 2020). Accurate identification of *R. solanacearum* from either symptomatic or asymptomatic plants and from water or soil samples demands multiple microbiological and molecular methods. A battery of complementary tests that differ in their sensitivity and/or specificity should be used for field or laboratory analyses for unambiguous identification of bacteria to species and biovar level.

Isolation: Isolations from diseased ginger plant samples on 2, 3, 5-triphenyl tetrazolium chloride (TZC) shows development of a bacterium characterized by fluidal, irregular and creamy white with pinkish red colonies (Fig.4).

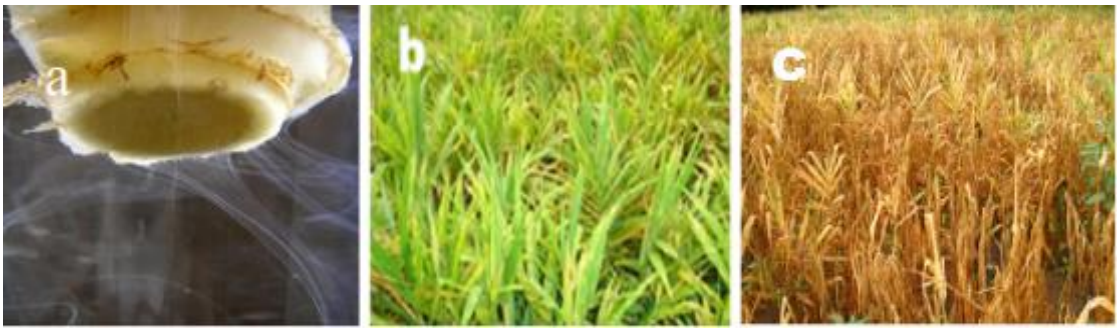

Figure 4: Ginger bacterial wilt showing progressive disease symptoms, milky white bacterial streaming from diseased rhizome suspended in water (a), wilting and yellowing (b) and complete death of the plant (c).

3.1.1.5. Biochemical characterization of the isolates

Lipopolysaccharide (KOH) test: Reveals formation of viscous and slime thread when loop raised

from the bacterial solution indicating that the bacteria is gram negative.

Catalase test: Produce gas bubbles when mixed with a drop of H_2O_2 on glass slide.

Levan production from sucrose: The pathogen is negative for levan production.

Cytochrome oxidase test: The results of cytochrome oxidase testing showed that all of the isolates were able to develop deep blue colour with oxidase reagent.

Starch hydrolysis: all the isolates do not hydrolyse starch when streaked on starch agar. All morphological and cultural characteristics of isolate confirmed *Ralstonia solanacearum* as this was confirmed by serological test using NCM-ELISA.

Serological diagnosis: The results of the NCM-ELISA shows that all the isolates reacted positively confirming that the isolates are *R. solanacearum* (Fig. 5).

Biovar Differentiation: The result of the biovar test showed that all the isolates oxidised disaccharides (sucrose, lactose, and maltose) and sugar alcohols (Manitol, Sorbitol and Dulcitol) within three to five days, indicating that all isolates belong to biovar III of *R. solanacearum.* It has been known that biovar III of R. *solanacearum* oxidizes both disaccharides and hexose alcohols (Tariku *et al.,* 2016).

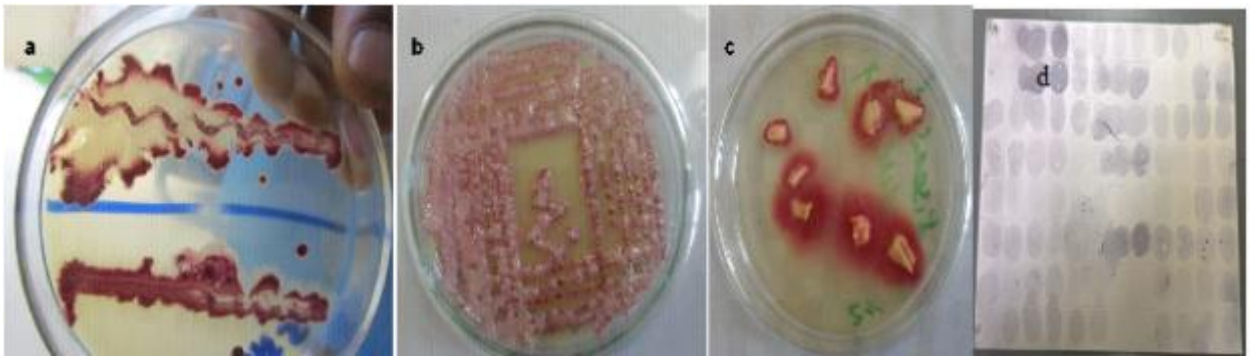

Figure 5: Pure culture on TZC agar isolated from diseased ginger (a, b), pieces of infected rhizome on TTC plate (c) and NCM-ELISA of different isolates from diseased ginger samples (d).

4. MANAGEMENT METHODS OF BACTERIAL WILT DISEASE

4.1. Ginger Bacterial Wilt Disease

Management of ginger bacterial wilt disease caused by *R. solanacearum* is difficult once it has established in the soil. Up to now there is no single and effective control measure against the pathogen. However, some level of bacterial wilt control has been possible through use of a combination of diverse methods. These methods include cultural practices, biological control, chemical control and integrated disease management (IDM).

4.1.1. Cultural practices for management of Ginger Bacterial Wilt

4.1.1.1. Site selection

While selecting sites, particularly for commercial production of ginger, due attention needs to be given to climatic, edaphic and topographic conditions in accordance with ginger bacterial wilt management. According to Hackett and Carolane (1982), warm climate with an optimum range of 19-28°C is required for best growth and performance of the crop. Compact clay soils characterized by water logging or coarse sands with poor water holding capacity, gravelly soils or hardpan soils are not suitable for ginger production (Lawrence, 1984). Ginger performs well on medium loam soils. Soils need to be friable and havereasonable depth, with rich organic matter content and nutrient availability to harvest maximum rhizome size and yields, and to make harvesting easier (Cho *et al*., 1987; Camacho and Brescia, 2009). The best site for rain-fed ginger production has rainfall dispersed evenly throughout growing season, with a drier period near the end, before and during harvest. Ginger does not thrive well in water stagnant fields (Rahman *et al*., 2009). Thus, water logging sites should be avoided because such sites favour ginger bacterial wilt and other soil-borne diseases. The land should be of gentle slope and without recent history of cultivation of ginger and crops of ginger family including turmeric. In some countries there has been a tendency to plant ginger on land with excessive slope (15-30°). However, steep slopes >15% in hilly areas are not recommended as it leads to soil erosion during heavy rainfall because rhizome yield is negatively correlated with slope (MPI, 2011). Ginger should not be planted down slope from another ginger field to prevent runoff water that may carry the pathogen to the field. In this regard, Girma *et al*. (2016) suggested that slight slant land orientation is required to avoid water logging for ginger production.

Growth conditions of ginger planted in a water stagnant field and gentle slope in the same village

is shown in Figure 6. In general, considering climatic, edaphic and topographic conditions while selecting sites, particularly for commercial production of ginger, would have remarkable implications in minimising risk of incidence, transmission, rate of bacterial development and crop loss due to GBW disease.

Figure 6: Growth conditions of ginger planted in a water stagnant field (left and middle) and gentle slope (right) in the same village

4.1.1.2. Seedbed preparation

To produce high rhizome yield of ginger, the soil should be loose and friable (Kandiannan *et al.*, 1996). Properly pulverized land facilitates fast rhizome expansion of the ginger plant (Girma *et al.*, 2016) as it improves the structure and water holding capacity of the soil. In SNNPR, the ginger belt of Ethiopia, the tillage frequency ranges from three to six depending on the soil type, availability of traction power and moisture content of the soils, with the highest frequency being more productive (Endrias and Asafw, 2011). Deep ploughing is necessary to break an impermeable hard sub soil layer, remove the weeds and bring the land to fine tilth, and reduce soil-born pests by exposing the soil to the sun. According to MPI (2011), preparing seedbeds by turning the soil several times kills nematodes by exposing them to direct sunlight on the soil surface.

In areas where soil moisture is limited, a good tillage practice enhances water conservation. According to Endrias and Asfaw (2011), the soil that is pulverised to a fine tilth just at the end of wet season (early September to late October) in Ethiopia- when the soil is still at a moist condition- was observed to conserve residual moisture for two to three months. This is due to the fact that with fine tilth, the soil pores are too small and hence do not easily allow the moisture to

escape. The moisture conserved in such a special tillage practice would allow ginger planting in dry season (December to February) in Ethiopia.

Planting in the dry season is also common in India (Yadgirwar, *et al.*, 2017). It should be noted that the conserved moisture could not guarantee the emergence of the planted seed rhizomes until the on-set of the *Belg* rain in Ethiopia. It ensures early planting of non-sprouted seed rhizomes in dry season and triggers their physiological activities until the inception of the *Belg* (March to May) rain. When the on-set of the rain is early, earlier and uniform emergence will take place, which will eventually result in high rhizome yield. Another advantage of early dry planting (in dry the season) is the opportunity for exhaustive exploitation of the total annual precipitation and uptake of available and applied nutrients by the crop to give a high rhizome yield. The recommended depth of planting (10-15cm) must be maintained to avoid osmotic dehydration of the seed pieces, in case of a prolonged dry season. Nevertheless, planting sprouted seed rhizomes using residual moisture in the dry season is not advantageous; sprouted cut-pieces require adequately moistened soils to avoid the dieback of the sprouts.

According to Kandiannan (1996) seedbed preparation can be done with digging-hoes or plough and if possible harrowed afterwards; without such improvement in tilth, the crop fails to produce good shaped rhizomes, which are desirable for marketing and postharvest processing. Seedbed preparation also discourages root growth of weeds. Mode of seedbed preparation depends considerably on climate, soil type, slope and irrigation and the producers must use their judgment to choose the most suitable method. Generally, it should be kept in mind that during seedbed preparation, there is high risk of soil contamination, particularly with GBW pathogen. The major sources of contamination could be farm tools, contaminated soil, water or infected seeds (Mohumad and Sijam, 2010). Thus, farm tools and other potential sources of contamination need to be disinfected before every farm operation to minimise risk of soil contamination and disease spread.

4.1.1.3. Planting material management

Selection of planting material/varieties

Before planning to grow ginger at a small holder or commercial levels, the most important prerequisite is to have a clear understanding of the overall characteristics and available resources. This starts with the choice of the right variety with respect to meeting the standard parameters of quantity, quality and specific market requirements (Valenzuela, 2011) such as:

1. What is the yield potential i.e., its productivity per unit area?
2. What are the agro-climatic requirements of the cultivars proposed for planting?
3. Could they adapt or tolerate the prevailing biotic and abiotic conditions of the production area?
4. What is its chemical composition mainly in connection with the percentage of essential oil and oleoresin contents, which are the most important quality parameters in ginger industry?
5. How much is the dry recovery percentage and other postharvest handling parameters?
6. Where are the varieties sourced from?
7. Is the source reliable or certified in supplying the required clean/healthy material?
8. What is the mechanism of checking the cleanness of the planting materials before introducing or importing to the production area from elsewhere?

Currently, GBW is the biggest disease concern in ginger production. GBW pathogen cannot be easily detected as it is systemic, being embedded in the cell of the rhizome flesh. *Ralstonia solanacearum, a* causative agent of GBW disease is a seed and soil born pathogen and easily disseminated from one area to the other through latently infected seed rhizome (Habtewold *et al.*, 2015). According to Camacho and Brescia (2009), fresh ginger rhizomes could harbour other organisms on the transportation pathway especially as they are likely to be concealed within the uneven surface of ginger rhizomes. The same authors suggest that high-quality seed is vital to the production of a successful yield and therefore careful selection of pest free planting material is required. Currently, it is difficult to access GBW disease-free planting material and no disease certified seed scheme has been established in Ethiopia. Thus, farmers stressed the need for clean planting material and implementation of a certified ginger seed scheme in order to ensure a

sustainable supply of quality seed ginger. With the current scenario, farmers are facing difficulties to access ginger bacterial wilt-free planting material. Hence careful attention has to be paid while sourcing variety/planting material for a successful ginger production. Ginger seed rhizomes regenerated from tissue cultured plantlets and obtained from early planted rhizomes during the dry season with irrigation could be the best source of planting material as such materials are disease-free or may have negligible bacterial load.

4.1.1.4. Ginger cut-pieces preparation

The ginger plant does not produce true seed (Valenzuela, 2011) and the general mode of propagation is asexual (Kanadiannan *et al.*, 1996), using a small portion of rhizomes known as seed rhizomes (Ravindran *et al*., 2004). Rhizomes that are large, without wrinkles, shiny skin colour, and free from marks or without bud and eye injury are selected for planting (Hasanah and Rusmin, 2004). Whole rhizome is cut into pieces for planting. Cut-pieces are also called setts, rhizome cuttings or bits or propagules. Each sett has at least two good buds and the length and weight of pieces vary from place to place and from variety to variety. Rhizome age positively or negatively affects growth, yield and quality of rhizome. Seed rhizomes aged eight months after planting produce the best growth parameters (plant height, number of tillers, stem diameter, number of leaves) compared with pre-matured seed rhizomes (Melati, *et al.*, 2016). The same authors suggest that seed rhizome aged eight months after planting have high vigour to withstand biotic and abiotic environmental stresses. However, planting cut-pieces of over seasoned or perennated rhizomes for two or more growing years must be completely avoided since such rhizomes tend to emerge rarely (Endrias and Asfaw, 2011). Whole rhizome are cut into pieces and each sett should have at least two active buds. The length and weight of pieces vary from place to place and from variety to variety.

In Ethiopia, farmers practice two types of propagules for a rain-fed ginger propagation. The first method involves planting of non-sprouted pieces, and the other is using sprouted propagules (Fig. 7). In both cases, whole seed rhizomes are cut into pieces of the required sizes of 2-5.5cm having two to four active growing buds. Non-sprouted propagules are planted shortly after cutting or cured for 15 days ahead of planting. For non-sprouted setts, it may take two to three months to emerge depending on the on-set of rain (Endrias and Asfaw, 2011) as planting is practiced early

in dry season. In addition, osmotic dehydration, particularly for shallow planted smaller cut-pieces may occur under a prolonged dry season condition, which may result in a sparsely populated plant stand. Farmers cut seed rhizomes into smaller pieces of the required sizes to prepare sprouted propagules. The cut-pieces are then packaged mainly in polyethylene sacks and stacked in the storage for two to three months until the onset of the *Belg* rain. The cut pieces may emerge after 15-20 days of planting, depending on the soil moisture condition. Cutting seed rhizomes into small pieces may be done by using knives or by hand breaking. In both cases, there is high risk of contamination of the seed pieces by pathogens, particularly by GBW pathogen (Hepperly *et al*., 2004).

Figure 7: Non-sprouted (left) and sprouted (right)

Bacterial wilt free seed propagules can be infected after planting if the soil is contaminated by the pathogen. Thus, the cut surface of the setts must be cured sufficiently through exposing the rhizomes to cool and dry surfaces so that the soil-borne wilt bacterium would hardly enter into the newly planted propagules. It is clear that the bacteria enter into the propagule mainly through wounds (Mohumad and Sijam, 2010). Packing the cut-pieces in polyethylene sacks may generate moisture and heat as a result of respiration of the propagules, which in turn, brings an ideal condition for the pathogen in each of the sacks. Hence, well ventilated packaging materials and storage systems are highly recommended to minimise conditions that may favour bacterial growth and curing the cut surface of the setts is important in minimising entry of the bacterium into the propagule either in the storage or in the soil after planting.

4.1.1.5. Size and weight of ginger rhizome propagules

Farmers in different countries use rhizome cut-pieces of different size having variable number of active buds for ginger production (Rahman, *et al*., 2009; Asafa and Akanbii, 2018). The weight and size of each propagule/sett required for ginger production may be 20-50g in weight and 2-5.5cm in size, containing two to five active growing buds (Fig. 8). Most farmers prefer planting larger propagules than using cut-pieces of the recommended size. They believe that large propagules planted earlier in dry seasons are less prone to osmotic dehydration or desiccation in case of late onset of rainfall during the crop season. It is widely accepted that unlike smaller propagules, larger propagules do not decompose or decay until the harvesting stage of respective daughter rhizomes (Okwuowulu, 1988). Thus, farmers get additional agronomic or economic benefits by taking advantage of re-harvesting them (Endrias and Asfaw, 2011).

Figure 8: Recommended size of ginger rhizome propagule

Some farmers remove the mother rhizomes from growing plants at certain growth stage of the daughter rhizomes and replant them on separate fields within the same season (Kandiannan *et al*., 1996). Others remove them and sell for off-season income generation. In Ethiopia, farmers re-harvest large mother propagules intact with the daughter rhizomes at the right physiological maturity stage of the latter to sell to local collectors (Endrias and Asfaw, 2011). Planting smaller seed rhizomes early in the season under reliable soil moisture condition ensures significant reduction in cost of economic seed rhizomes (Suhaimi *et al*., 2016). In other words, planting individual rhizome setts having large number of growing buds (Fig. 9) with irrigation is a kind of wastage of planting material. Hence, larger propagules can be further cut into two or more setts,

depending on the size of the seed rhizomes to make early dry planting for either rain-fed production or for planting using irrigation. In this case, the maximum recommended depth of planting (15 cm) should be maintained to avoid desiccation of the propagules in case of prolonged dry season, especially under rain-fed production condition.

Figure 9: Ginger seed sett with large number of active growing buds

In ginger, the number of growing buds per propagule, though active, does not correspond to the number of emerging buds. In most cases, only one bud emerges per propagule, irrespective of large number of active buds, especially under a rain-fed production condition (Fig. 10). In this case, early emerged bud tends to apically dominate the rest of the buds. Occasionally, two or more buds may emerge per propagule if there exist adequate soil moisture, in particular and available or applied nutrients, right from the time of planting.

Figure 10: Ginger propagule with more than five active buds exhibiting rise to a single daughter rhizome (bud 'a' only gave rise to daughter rhizomes; others (b-f) are wastage) (left), whereas a small propagule with single active bud (right) gave large rhizome

No matter how large is the size of the seed rhizome (be it whole daughter rhizome or portion of it) or number of active buds per rhizome, the number of emerging buds do not exceed three. If two or three buds per propagule emerge it will correspondingly give rise to equal number of individual daughter rhizomes, the phenomena of which is termed as double or triple rhizome formation. This phenomenon ensures high rhizome yield per unit area, which is common on sandy loam soils when ginger production is practiced using irrigation. Size/weight of seed rhizomes and final yield correlate positively, and can be concluded that the greater the seed rhizome size/weight, the larger is the fresh rhizome yield. Moreover, seed rhizome size determines performance of ginger agronomic and growth parameters as well as some quality (Suhaimi, *et al.*, 2016). According to Girma and Kinde, 2008, large propagules emerge earlier and showed vigorous and rapid growth as a result of high initial food reserves. (Yadgirwar *et al.*, 2017). The use of large planting material (30 and 40 g) gave high yield, crude protein, total oil and crude fibre (Asafa and Akanbi, 2018).

According to Egbuchua and Enujeke (2013) planting large propagules improved proximate composition of ginger. Asafa and Akanbi (2018) also observed that large seed rhizome (40 g) took the least number of days to first sprouting followed by 30 g seed rhizome. Large sett sizes have been also reported to have an influence on the sprouting rate, early growth and development of crops (Lawal, 2016). Similarly, plant height, number of tillers per plant, leaf area index, yield/ha, essential oil and starch contents were recorded in maximum seed rhizome size (Asafa and Akanbi, 2018). Larger seed pieces might result in greater yields when ginger is planted late in the season. However, the size of the seed rhizome does not affect final yields when ginger is planted early in the season. Propagule size also influenced the ginger yield parameters (number of leaves, leaf length, number of tillers, number of rhizome, rhizome length, rhizome weight and rhizome yield) (Asafa and Akanbi, 2018). Larger propagules are characterized by high food reserves, which provide nutrients and energy required for the new sprouts (Girma and Kinde, 2008). They emerge vigorous sprouts, which eventually result in high rhizome yield (Yadgirwar *et al.*, 2017). The fact that large propagules emerge earlier and show vigorous and rapid growth (Suhaimi *et al.*, 2016) is a mechanism to escape GBW disease, which more often occurs between June and August in Ethiopia as theses months are characterised by ideal conditions for bacterial

development.

4.1.1.6. Early planting in dry season using supplemental furrow irrigation

Time of planting has considerable influence on yield of ginger (Kanadiannan *et al.*, 1996) and it depends on the time of occurrence of wet season. Ginger can be planted manually or by using modified potato planters (Camacho *et al.*, 2009), anytime during the year in areas where irrigation facilities exist (Paulose, 1970), but the time of harvest should coincide with the drier months to ensure ease of harvesting and to harvest quality rhizomes. Due to its biennial nature (7-9 months), rain-fed ginger needs to be planted early in the growing season in order to have sufficient time to exploit the limited total precipitation distributed along the entire growing season just starting from the inception of the first shower.

Early planting also facilitates the uptake of available and applied nutrients for better performance of the crop if the onset of the rain is early in the season. Care should be taken while deciding planting time that the critical moisture requirement stages of the crop should not match with the period of long dry spell. In major ginger producing parts of southern Ethiopia, farmers have a tradition of early planting of ginger in the dry season on specially prepared seedbeds (Endrias and Asfaw, 2011). The special seedbeds are those which are well pulverized (4-6 times) starting from about the exit of the wet season with the objective of conserving residual moisture and exposing pests to sun. However, planting time varies within the same country based on variations on the onset of the rainfall across locations.

Farmers in the ginger belt of Ethiopia (central administrative zones of SNNPR) practice dry planting from January to March (Endrias and Asfaw, 2011), whereas the South-western zones of the country prefer wet planting in March (Girma *et al.*, 2016). Rahman *et al*. (2009) reported that ginger planting is done from February to April in Northeast India under rain-fed condition. Overall, planting during very wet weather should be avoided as this promotes dispersal of the pathogen within fields on muddy boots, tools, and vehicles (Camacho *et al*., 2009).

Ginger requires light but frequent irrigation (4 to 7 days) during the vegetative stage, if rainfall is insufficient and not evenly distributed along the growing season (Maghirang et al., 2009). But as long as ginger is sensitive to water logging, application of irrigation water must be held back during periods of sufficient rainfall that could maintain normal development of the crop. According to Islam *et al*. (2015), the yield of ginger can be increased with the adoption of irrigation.

Globally, various irrigation systems have been developed over time to meet the irrigation needs of certain crops in specific areas. Some of these are furrow, sprinkler and drip/micro irrigation. The most appropriate irrigation method for an area depends on physical site conditions, the crops being grown, amount of water available, and management skill. Location, quantity, and quality of water should be determined before any type of irrigation system is selected. However, in the current context of the Ginger Belt of Ethiopia, the only applicable choice of irrigation scheme would be furrow irrigation. The furrow method is an efficient system if properly managed, but a most inefficient one if improperly managed. For this method, fields must have a gentle slope and inflow discharge must be such that advance is not too fast and produce excessive runoff losses, nor too slow to induce excessive infiltration in the upper part of the field. Short blocked furrows with manually controlled water applications are practiced by traditional irrigation symptom.

Furrow irrigation is suitable to most soils except sands that have a very high infiltration rate and provide poor lateral distribution of water between furrows. In soils that absorb water slowly, a wide, relatively shallow furrow is preferable since it gives more area for the water to infiltrate. As such sandy soils which tend to have vertical wetting patterns should have closer furrow spacing than clay soils. To obtain complete wetting of sandy soils to depths of 1 to 1.5 metres, the furrows should not be spaced more than 50 to 60 cm apart. In uniform clay soils complete wetting to the same depth may be obtained with a furrow spacing of one metre or more. Where furrows are long and the soil is quite permeable, narrow deep furrows may be used to discourage excessive percolation at the upper end. A wide and shallow furrow is normally preferable.

It is also desirable that the spacing is such that the lateral movement of the soil moisture wets the ridges by the time irrigation is complete. Furrows should be spaced close enough to ensure that water spreads to the sides into the ridge and root zone of the crop before it moves down below the root zone to replenish the soil moisture uniformly. The lateral movement of water from the furrow in soils with uniform profiles depends primarily on the texture of the soil.

The slope or grade of the furrow is important because it controls the speed at which water flows down the furrow. Uniform wetting of the soil and maximum efficiency of irrigation are impossible unless the grade is uniform. As the furrow grade increases, both the vertical movement and the side spread of water into the crop ridge decrease, so that wastage may occur at the end of the furrow.

Maximum furrow slopes recommended for:

Sand: 0.25

Sandy loam: 0.40

Fine sandy loam: 0.50

Clay: 1.50 cm

A minimum furrow grade of 0.05 per cent is needed to ensure surface drainage.

The optimum length of a furrow is usually the longest furrow that can be safely and efficiently irrigated. Long furrows are an advantage in inter-cultivation. If the length is too long, water soaks into deep at the head of the furrow by the time the stream reaches the lower end. This results in over-irrigation at the upper end or under-irrigation at the lower end.

Despite several attempts made so far, none of them could give convincing results to manage the disease. It is then of paramount importance to understand the ideal conditions that favours the development of the pathogen and disintegrate the disease triangle so as to retard its development. It has been discovered that an ideal condition that stimulates development of the pathogen is the synergetic effect of warm temperature (>27.8^{o}C) and high rainfall (> 288 mm of monthly average) (Habtewold *et al.*, 2015). On the other hand, we have susceptible infected ginger genotypes (Fig. 11).

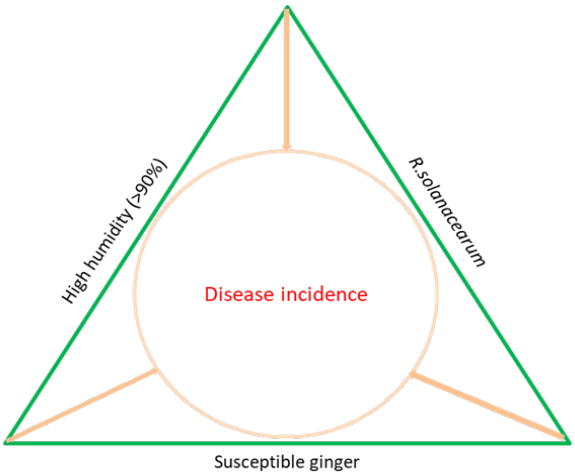

Figure 11: Disease triangle for the incidence of GBW

In the Ginger Belt of Ethiopia, the ideal condition for bacterial growth mainly prevails from June to August, which is the peak period when highest amount of rain fall is received. In this area, planting GBW-infected ginger (matures in 8-9 months of planting (Girma *et al.*, 2016)), early in the dry season (December to January) with irrigation has been noticed to give high rhizome yield (up to 40 t ha^{-1}), retarding the development of the pathogen.

Early planting of November to early January in dry season using irrigation ensures disintegration of the disease triangle or avoids high relative humidity. Consequently, the crop matures ahead of the onset of the ideal condition (June-August based on the amount of rain in the case of Ginger Belt of Ethiopia) for the disease development which enables harvesting of Bacterial Wilt Disease-free rhizomes or rhizomes with negligible bacterial load depending on disease-free mother seed rhizomes as well as the level of soil bacterial inoculum load and seed injury. Thus, early planting in the dry season with irrigation guarantees production of ginger from latently infected or apparently healthy seed rhizomes.

Technically, this can be one of the best options of GBW management practice for multiplication of apparently healthy or disease-free ginger seed rhizomes as there will be no disease development as long as it proves disintegration of the disease triangle. Apart from controlling GBW disease, early planting in the dry season using irrigation, as one of the agronomic practices, remarkably could improve rhizome yield and yield attributes in ginger. Vadivel *et al.* (2006)

reported that yields of ginger is quiet high where adequate attention was given to the better water management of the crop. According to Islam *et al.* (2015) irrigation at the early stage is needed to harvest high rhizome yield per unit area. The same authors reported that planting ginger early in dry season resulted in early emergence, superiority in plant height, larger number of leaves/plant, and number of tillers/plant, weight of primary and secondary rhizome, dry matter percentage, and total yield of rhizome. This is because the propagules planted with irrigation receive the required amount of soil moisture right from the date of planting and continue receiving until maturity, provided that other recommended inputs are also properly applied. Field performance variation of ginger planted early in dry season with irrigation (Fig 12 A) and rainfall (Fig 12C) using apparently healthy ginger in Boloso-Sore district (in Wolayta zone, Ethiopia) in Ethiopia.

Figure 12: Field performance variation of ginger planted early in dry season with supplementary irrigation (A) and rainfall (C) using latently infected ginger in Boloso-Sore district, Wolayta, Ethiopia

Irrigation triggers fast and early emergence of the propagules (Islam, *et al*., 2015) and ensures emergence of nearly 100% of the propagules planted, maintaining the recommended plant population per unit area (Fig. 12A). Furthermore, plants supplemented with irrigation water were observed to give individual propagules weighing as big as 34.5g as compared to 28.8g weighed for the rain-fed propagules. Large propagules are characterized by high food reserve (Girma and Kinde, 2008) to enhance rapid development of the newly emerging plantlets, which eventually end up with high rhizome yield (Asafa and Akanbii, 2018). Large sett sizes have been also reported to have an influence on the sprouting rate, early growth and development of crops (Lawal, 2016).

On-farm observations of irrigated ginger in southern Ethiopia confirmed large number of actively growing buds (> 20) per individual rhizome, whereas the number of active buds, under rain-fed production condition is reported to be 10-15. Similarly, about more than 30 cm long rhizomes (Fig 13A) and a single rhizome weighing as high as over 600 gm (Fig. 14) was also obtained from irrigated plots of the same cultivar. The average length of the rhizome produced in a rain-fed condition was 9.45 cm (Girma and Kinde, 2008). They also reported a small number of fingers (6.2) per rhizome and weight of individual rhizome (60.3 g) obtained from rain-fed ginger production.

Figure 13: Ginger daughter rhizomes (cul. Volvo) generated from latently infected mother rhizomes planted early in dry season in Himbecho (in Wolayta zone (A) (washed)) and in Hadero-Tunto (in Kambata-Tambaro zone (B)) using supplemental furrow irrigation.

Supplementary irrigation confirms a chance of year-round production and supply of ginger seed rhizome. However, each planting time should be adjusted in such a way that the juvenile stage of the crop escapes the possible ideal condition for the bacterial development. Year-round production using irrigation leads to the generation of continuous income and premium price for better income for the producer. It also solves an age-old seasonality problem of ginger seed rhizome shortage. Another merit with irrigation-based production is that predominantly two or more individual rhizomes per single propagule, depending on the number of active buds, are generated provided that all other recommended agronomic practices are timely applied. Another important advantage of using irrigation in dry season is adjusting planting time with dry harvesting time.

Overall, early planting in dry season using irrigation could be an important option to produce

ginger in areas of GBW epidemic. There is also a possibility of harvesting healthy rhizome yield or rhizomes with negligible bacterium load through planting latently infected rhizomes early in dry season using irrigation since there would be minimal threat of bacterial growth in the absence of high humidity. Thus, the rhizomes produced during dry period could be used as a seed rhizome.

Figure 14: Individual daughter ginger rhizome (weighing 667 g) obtained from latently infected propagule by GBW; the propagule was planted early in dry season using furrow irrigation in Hadero-Tunto district, Kambata-Tambaro, Ethiopia.

4.1.1.7. Planting depth

Planting depth is one of the most important agronomic practices that affect productivity of ginger. It may vary depending on the size of the rhizome seed (larger rhizomes require relatively higher depth), soil type (sandy soils require more depth than the clay soils) and soil moisture content (moist soils require less depth) (Kandiannan, 1996). It also influences emergence time of propagule. Deep planting does not allow horizontal development or expansion of rhizomes. Horizontal development of rhizome just beneath the soil surface has a positive correlation with the yield and appearance of ginger rhizome. It also governs rhizome shape. Deep planting is essential to minimise osmotic dehydration of small rhizome setts, when ginger is planted early in the extended dry season. Long ago, Jansen (1981) reported a planting depth of 5-10 cm which has been used for ginger production in Ethiopia.

4.1.1.8. Plant population

Ginger plant population per unit area is governed by several factors including: planting method, moisture (either rain or irrigation), altitude, propagule size, soil fertility, mechanisation, management practices and region (Kandiannan *et al*., 1996; Momina *et al*., 2011; Kandiannan *et al*., 2015;). According to Kandiannan *et al*. (2015), in Kerala, India, 1500 to 1800 kg/ha of rhizome is used for planting. The same authors observed seed rate variations of 2000 to 2500 kg/ha in lower and higher altitudes, respectively. In Hawaii, about 2000 kg of rhizome seed pieces are required to plant a hectare of ginger (Valenzuela, 2011). Kandiannan *et al*. (1996) thus states that seed rate had significant effect on yield and yield components of ginger. Momina *et al*. (2011) used the recommended planting space of 30 cm (row to row) and 15 cm (plant to plant within row) (Fig. 15) that gave higher rhizome yield of ginger.

It has been also reported that a spacing of 20-25 cm along the rows and 20-25 cm between the rows has been used (Kandiannan *et al.*, 2015). In the case of irrigated crop, ridges of 40-45 cm apart were opened and planting was done in shallow pits on top of ridges at a distance of 22-30 cm. Plant population and spacing was also varied with irrigation systems (Yadgirwar *et al*., 2017). Under sprinkler irrigation system, seed rhizomes were placed between rows and plants distances of 22.5 x 22.5 cm and in case of drip system, spacing followed were 30 x 22.5 cm and 30 x 30 cm.

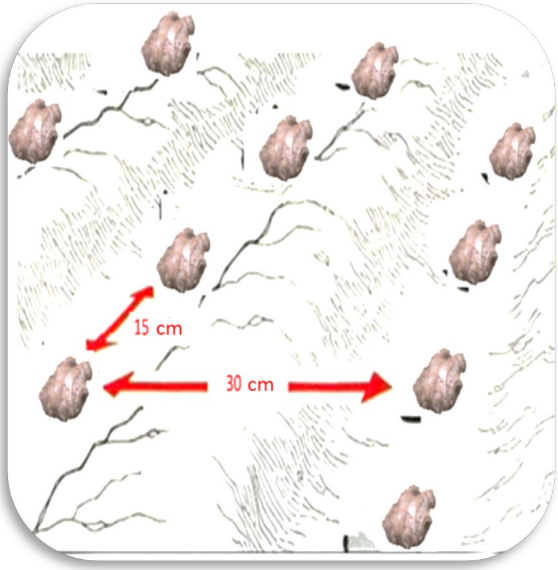

Figure 15: Recommended planting space for rain-fed ginger production in Ethiopia

Currently, ginger production in Ethiopia under rain-fed condition has become great tribulation due to sporadic occurrences of GBW disease. It is evident that high humidity and warm temperature are the major driving forces for the disease development. When ginger is luxuriously grown with the provision of all the required inputs in closer planting spaces, high humidity and warm temperature certainly develop under the canopy of the crop. Such a phenomenon inevitably creates an ideal condition for the development of the bacterial wilt pathogen, resulting in the appearance of disease symptom in the foliar parts of the plants followed by significant rhizome yield loss. This infestation would be worse when latently infected seed rhizomes are used as planting material. Thus, in areas where GBW disease is a serious problem, planting space needs to be tailored in such a way that adequate aeration under the canopy of the crop would be maintained. The earlier recommendation of 2 t ha^{-1} ginger seed rhizomes (222.2 seed rhizomes ha^{-1}) is seemingly narrow in terms of GBW disease management.

4.1.1.9. Fertiliser management

Nutrient amendments provided by the application of synthetic or organic fertilisers may be applied to complement the natural fertility of the soil (Valenzuela, 2011).

Inorganic fertilisers

Ginger is a soil-exhausting crop requiring heavy fertilisation to give high yields. As the soil fertility varies with the climate soil type, variety, agro-ecological conditions or management systems, site specific nutrient management based on the soil test results is advocated (Kandiannan *et al*., 1996; Kandiannan *et al*., 2015). The correct type and rate of chemical fertilizers need to be determined so as to obtain the optimum or quality yield. Ginger crop requires nitrogen, phosphorus and potassium, with nitrogen being used most abundantly. These soil nutrients have been applied in different forms such as urea, ammonium sulphate, ammonium nitrate, and diammonium phosphate as sources of nitrogen. Whereas, Phosphorus has been applied in the form of Triple Super Phosphate and diammonium phosphate. Potassium has been applied in the form of potassium sulphate and potassium chloride. NPK also have been used in mixture. Other sources of fertilisers have also been used in different countries based on the nutrient deficiency level of the soils. Lime is incorporated to adjust the soil pH (Valenzuela, 2011).

Several authors have compared the effect of different nutrients on ginger rhizome yield and yield attributes. Indian farmers applied 36, 40, and 66 kg/ha N P_2O_5 and K, respectively (Jansen, 1981). The N and K fertilizers are top dressed in 2-3 equal split doses at 45, 90 and 120 days after planting. Recently, Asafa and Akmbi (2018) in Ogbomoso, Southwestern Nigeria have recommended 140 kg N ha^{-1}, which enhanced growth, rhizome yield and proximate composition of the crop. Earlier recommendation of 165.6 N with the spacing of 30 x 15 cm enhances luxurious plant growth and faster canopy closure which in turn could develop ideal conditions (warm soil temperature and high humidity) for bacterial development.

Nitrogen results in better rhizome yield with three split applications at the second, fourth and fifth months after planting (MPI, 2011). Full dose of basal application of phosphorus at the time of planting also gave high rhizome yield when placed at the bottom of the furrow and incorporated with the soil prior to planting (Valenzuela, 2011). According to Haque *et al*. (2007), the combined application of N and K was found more pronounced than the single effect of N and K. It is also noticed that effect of nitrogen was more distinct than potassium. The combined effect of N and K had significantly increased the rhizome yield and other yield contributing characters of ginger.

Organic fertilisers

Organic fertilisers contain organic carbon, nitrogen, phosphorus, potassium, calcium and magnesium coupled with adequate levels of micro nutrients (Egbuchua and Enujeke, 2013) and also stabilizer of soil pH (Sanchez and Miller, 1986). Farmyard manures, poultry manure and compost are three types of organic manures that have been used in crop production. According to Egbuchua, and Enujeke (2013), poultry manure was the most impressive on the growth and yield parameters of ginger followed by pig- and cow dung manures. Sources of organic manures could be all kinds of organic materials such as, crop residues, kitchen wastes, garden cuttings, and manures (poultry, pig, cow, sheep goat, etc.). Compost is especially useful for improving the soil structure and fertility. Therefore, it supplies nutrients at the right time in required quantities.

When properly used, organic manures have proven to be very efficient in increasing soil nutrient

contents, ensuring positive residual effects and enhancing soil's physio-chemical properties (Ayeni *et al.*, 2010). On the other hand, organic manures are capable of improving soil quality and increasing yield (Jansen, 1981) of cultivated crops. In addition, organic manures have strong tendency to neutralise soil acidity, raise soil buffering capacity and provide micro nutrients such as Zn, B, Cu and Fe that can influence crop production positively. Adetunji (2004) has reported reasonable high content of macro nutrients in different manure sources including cow dung and in poultry-based manure. Organic fertilisers result in better ginger rhizome yield on sandy soils than on clay soils. Sandy soils will not disintegrate as easily when manures are added; therefore, they will be able to hold more water. The high contents of macro- and micro nutrients of organic fertiliser and its positive role in soil improvement have the capacity to advance yields and other agro-morphologic traits of cultivated crops including ginger.

Some of the research findings have confirmed that organic manures are efficient in all aspects of growth and yield parameters in ginger production. Ginger growers applied heavy dose of FYM, to the extent of about 40-50 t ha $^{-1}$. Large dressing of manure is necessary for good yields, Egbuchua and Enujeke (2013) described that most of the morphological characters of ginger such as plant heights, number of leaves, and leaf area were improved with the application of organic manures. To get good yield, the recommended rate of well decomposed manure or compost are placed at the bottom of the furrow and incorporated with soil prior to planting (Valenzuela, 2011). Some farmers have experiences of applying dry manures into the ginger farm two to three months ahead of planting as fresh manure can damage the sprouting plants.

Unfortunately, the use of organic manures is associated with such problems as inadequate nutrient availability, slowness in nutrient release, high C:N ratio and sometimes heavy metal pollution (Ayeni *et al.*, 2010). In addition, farmers working with organic manures complain that it is a laborious and time consuming especially when it comes to large scale production. The cost of organic manures with respect to input acquisition, preparation, transportation, spreading and incorporation with the soil is also very high. Currently, scarcity of inputs for preparing organic fertilisers in ginger belt of Ethiopia is constraining its use in commercial production since crop residues and other organic materials are being used as a fire fuel and animal feed. Moreover, the quality of any organic manure is very difficult to quantify due to differences in the quality of the

sources (Egbuchua, and Enujeke, 2013). However, using organic fertilisers continues regardless of its demerits owing to its multifaceted benefits in agriculture.

Nutritional requirement of ginger when partially met through organic and inorganic sources may enhance the growth and get early boost due to the readily available nutrients through chemical fertiliser. It follows that slowness of nutrient release of organic manures can also be compensated through integrated application of organic and inorganic fertilisers. In general, as the soil fertility may vary with the soil type, agro-ecological conditions or management systems, site specific nutrient management based on the soil test results for major nutrient is advocated (Kanadiannan *et al.*, 2015).

Application of nutrients, particularly nitrogen and well decomposed organic fertilisers apparently enhance luxurious ginger growth, resulting in rapid canopy closure. With canopy closure, ideal condition (high humidity and warm temperature), which would trigger bacterial growth either in the soil or in the mother or daughter seed rhizome will be created if the soil is previously contaminated or a mother rhizome is latently infected. Thus, while applying nitrogen fertiliser to ginger in areas where GBW disease is a problem, there is a need to minimise the rate of nitrogen or adjust planting space to manage aeration under the canopy.

4.1.1.10. Mulching

Mulching is defined as covering the ground with a layer of loose material such as compost, manure, and straw, dry grass, leaves or crop residues. Mulches have several effects on the soil which help to improve plant growth. Itenhances germination, prevents washing of soil due to heavy rain and surface run off, increases infiltration and conserves moisture (Rahman *et al*., 2009). Since soil moisture is becoming a limiting factor for emergence and early growth of ginger, the use of mulch is beneficial (MPI, 2011). Mulching also regulates temperature, decreases water loss due to evaporation, suppresses weed growth by reducing the amount of light reaching the soil, enhances microbial activity, increases the number of micro-organisms in the top soil and improves soil fertility by adding organic matter. Generally, mulch could change the physical and chemical environment of the soil through increasing availability of macro- and micro nutrients,

and by improving the moisture content and structure of the soil (Kanadiannan *et al.*, 2015).

The quantity of mulch applied varies with availability of material. In general, 10 to 30 ton ha^{-1} is applied twice or thrice, one at planting, second on the 45th day and third on the 90th day after planting (Kanadiannan *et al.*, 2015). Commonly used mulch materials are green and dry forest leaves, residues like sugarcane trash, wheat, finger millet barely straws and also weeds and vegetation of the locality. Farm yard manure and compost are also used. Banana and green forest leaves were found best. Decomposed straw mulching increased yield by 12.2% over unmulched farm. Application of forest leaves at 20 t ha^{-1} in to two equal splits, one at planting and second at 45th day after planting increased yield by 200% (Kanadiannan *et al.*, 2015). Application of mulch soon after planting is beneficial for the culture of some root and tuber crops (Awal *et al*., 1978). Synonymously, mulching influenced the growth and yield of ginger rhizome (Islam *et al*., 2015). As mulching regulates soil moisture and increase the soil temperature, it creates ideal condition for bacterial development either in the soil or in the ginger rhizome. If the soil is previously contaminated or the rhizome is apparently healthy, heavy mulching is not recommended.

Hilling / Earthing up/ Hoeing / Weeding

In ginger culture, hilling up is confused with earthing up, hoeing or weeding, except during the very early growth stage, where hilling does not exist (only hoeing); otherwise, all terms have nearly similar meaning in the operation of the later developmental stages of the crop since hilling is for earthing up.

Weeds compete with crops for sun light, moisture, space and nutrition. It causes about 35-75% yield reduction mainly due to slow emergence and long life cycle (more than 240 days) of the ginger crop (Sah *et al.*, 2017). Several weed control mechanisms are practiced based on scale of production. Weed control mechanism starts with good land preparation prior to planting through finely pulverized tillage (MPI, 2011), which ensures exposure of weed seeds and debris to sun drying, to minimise frequency of post- emergence weeding (Endrias and Asfaw, 2011). Pre- and post-emergence herbicide application are also possible to supplement weed control at early stages but are less applicable in clay or compact soils. In such soil types, hoeing is more preferred since it loosens the soil in addition to removing the weeds thereby to facilitate free development

of rhizomes (Kandiannan *et al.*, 1996).

Earthing up is essential to prevent exposure of rhizomes and provides sufficient soil volume for free development of the rhizomes (Kandiannan *et al.*, 2015). According to Panigrahi and Patro (1985), earthing up also provides adequate aeration for roots and protects the rhizomes from scale insects, apart from controlling weeds. Vevai (1971) explained the importance of earthing up which was to soften the surface of soil that might be hardened after rain or irrigation. Vevai (1971) adds that earthing up is essential as it helps in enlargement of daughter rhizomes.

According to Sah *et al.* (2017), keeping the plots weed free up to 60 days after planting (DAP) significantly reduced the weed population. The same report revealed that integrated management of different levels of hand weeding, herbicide application and mulching significantly affected yield and growth attributes (number of tillers/plant, plant height, rhizome length (cm), rhizome width (cm) and number of fingers/rhizome). Integrated weed management also affected weed population per unit area.

For proper weed management gentle hoeing begins before emergence of 50% of the propagules. Pre-emergence hoeing involves stirring up of the most upper shallow surface of the planted rows, making sure that the sprouted propagules would not be removed and injured. This practice results in destruction of newly emerging weeds and exposes potentially emerging weed seeds and debris to sun drying. It also facilitates faster and fully emergence of the propagules to attain uniform growth and maintain the recommended number of plants per unit area. Later hilling is made to lift up the soil onto the ginger row (Valenzuela, 2011). First earthing up may practice at 45th day and second at 120-135th days after planting (Kandiannan, 1996). The inception of hilling would largely depend on the moisture content of the soil to initiate emergence of propagule and the crop growth rate. Eventually the initial furrows which served as the planting rows, will be mounds at the later stages of the crop, as the soil is moved up during the hilling process (Valenzuela, 2011). The soil is periodically hilled up (mounded) around the base of the plant to ensure vertical growth. In this case, the desired long, plump "hands" result from proper timing of the hilling operation. Thin and elongated ginger rhizomes result from too-deep covering during the hilling operation. Conversely, rhizomes that are knobby and that show horizontal growth

result from inadequate hilling. Three to six hillings are made during the crop cycle, with the depth of cover determined by the rate of growth.

In Ethiopia the frequency of hilling varies from 5-10 times based on the type of soil. Clay soils require more hilling frequency. However, currently the frequency of hilling is dropped to 4-5 times as a result of threat of spread of GBW and Leaf Spot diseases. Earthing up should not be carried out during wet weather and should coincide with the split application of urea. In addition, during hilling care should also be taken not to damage roots and rhizomes, as the crop can be infected with disease through the wounded roots (MPI, 2011). It should be noted that hoeing is the most essential part of the agronomic practices in ginger production. It is often done by hand even in commercial farms (Valenzuela, 2011).

Hilling operation is mainly practiced using forked digging- or flat blade hoes (rarely) or other modified pointed hoes (Fig 16) depending on the culture of societies. If these hand tools are not managed carefully during the hoeing operation, injury of mother or daughter rhizomes is common. Wound is the only entrance, particularly for *Ralstonia solanacearum*, a causative agent for ginger bacterial wilt.

Figure 16: a hand tool used for hilling ginger in Wolayta and in the low lying southern part of Kambata-Tambaro, Ethiopia

4.1.1.11. Mother seed rhizome re-harvesting

A mother rhizome is an old seed rhizome which gives rise to a daughter rhizome during the previous crop (Fig. 17). In ginger, most of the bigger mother seed rhizomes remain undecomposed until crop maturity (Okwuowulu, 1988). Mother rhizomes are characterized by high fibre and low essential oil and oleoresin contents (Rahman *et al*., 2009). They exhibit high per cent of drying recovery and hence are more preferred to sun-drying by local traders (Endrias and Asfaw, 2011). However, no scientific evidence has been reported so far regarding the amount and quality of the products (ginger essential oil and oleoresin) extracted from harvested mother rhizomes.

In another study (Kandiannan *et al*., 1996), mother seed rhizomes were removed from the daughter rhizomes during a certain crop growth stage without significantly affecting yield of the daughter rhizomes. In this practice, it was reported that a mean of 58% of seed ginger from smaller old setts and 86% from larger old setts could be recovered. By this method, farmers can regain 60 to 70% of the seed cost. Detaching and recycling the setts in the same season or later provides a means of achieving rapid seed ginger multiplication and for obtaining a higher aggregate from a given quantity of old setts.

Figure 17: Mother seed rhizome and the resulting daughter rhizome

According to Rahman *et al*. (2009), when ginger crop attains 60 days of age, or 3-4 leaves, farmers remove mother rhizome leaving the sprouted piece of rhizome in the soil. The removed mother rhizome is sold in the local market. In this practice, almost one ton of old/parent/mother rhizome are removed/re-harvested per hectare. This is the reason behind planting big sized rhizomes. Removal of mother rhizome is believed to give proper space to the developing/daughter rhizome. Although the quality of rhizome is inferior, farmers get income due to off-season price advantage. Fifteen days after removal of mother seed rhizomes, farmyard manure is applied once again and earthed up. Farmers in Ethiopia re-harvest the undetached mother rhizomes from respective daughter rhizomes after the right maturity stage of the latter. However, mother rhizomes are rarely re-used as a seed rhizome because they can hardly re-sprout and emerge a new plant at that stage, as they might have lost viability over time. The same is true with over-seasoned/perennated rhizomes. Thus, it is essential to select only daughter rhizomes for planting, recognising that farmers in Ethiopia intentionally plant larger setts to re-harvest them for marketing locally since they are rarely decomposed (Endrias and Asfaw, 2011). Mother rhizomes may be sold in fresh or sun-dried form.

In areas where GBW disease is an important problem removing mother seed rhizomes prior to the maturity stage of the daughter rhizomes may result in infection of the whole plantation. The pathogen may also spread to non-contaminated fields through the removed mother seed rhizomes which would be planted again elsewhere. In both cases, the process of removal of the mother rhizome results in tissue injury which might serve as an entrance for bacterial infection. The effect would be worse when the weather condition is ideal (warm temperature and high humidity) for the development of the pathogen.

4.1.1.12. Intercropping

Ginger can be intercropped with other crops (Lyocks *et al.*, 2013). Intercropping offers the yield advantage relative to sole cropping through yield stability and improved yield (Bhatti *et al*., 2006). The choice of crops is determined by different factors like agro-climatic and edaphic conditions (Pandey *et al*., 2017). It will be an economic waste if the intercropped species is not shade tolerant. Ginger is intercropped with other crops (Lyocks *et al.*, 2013). Intercropping appears more

advantageous as it enables farmers to grow the normal crop (ginger) in addition to receiving bonus of another from the same field as reported by Mkamilo (2004).

There are very few specific recommendations for the best crop combinations that can be utilised in ginger production (Valenzuela, 2011). Farmers should select companion species that are known to be adapted to their particular location. Companion crops should also be compatible based on their growth rate, canopy and root architecture and incidence of pests attracted to each individual crop (Valenzuela, 2011). Ginger should not be intercropped with crops of *Solanaceae* family, including tomatoes, peppers, tobacco and peppers. It is usually inter- or strip-cropped with maize, taro, common bean, coffee, coconut and orange plantations. Lyocks *et al*. (2013) reported that intercropping ginger with maize plants per hectare produced high ginger rhizome yield, which was significantly ($P \leqslant 0.05$) comparable with highest rhizome yields obtained from sole cropped ginger.

4.1.1.13. Crop rotation

Mono-cropping of ginger on the same land every year would result in significant rhizome yield reduction, which could be attributed to soil exhaustion and a build-up of pests and diseases. Crop rotation interrupts the life cycle of pathogens and reduces the chance of damage by diseases or pests in addition to improving fertility of the soil (Camacho and Brescia, 2009). Crop rotation implies planting different crops on the field each season and only returning the same crop after 3-4 growing seasons (MPI, 2011).

However, farmers may not maintain the right rotation cycle in different countries. For example, in North India, the cycle of crop rotation varied from 2-4 years, being highly influenced by size of land holding and market price of ginger (Rahman *et al*., 2009). In Ethiopia, farmers tend to plant ginger every other year on the same unit of land; others may plant it every year on the same plot, amending the soil with a heavy application of organic manures. They prefer short cycle rotation claiming that the income from any other rotated crops is incomparable with that of the ginger. This is somehow in contrast with the finding of Kandiannan, *et al*. (2015) who advocate that it is not advisable to plant ginger consecutively in the same field every year.

Crops that are best suited to the climatic condition of the ginger growing countries can be selected and rotated with ginger using appropriate crop cycles. In Australia, after the harvest period, ginger growers often plant cover crops, including. oats, barley, sorghum, corn, brassica and pasture grasses as they are best suited to the climate of the Sunshine coast region in the winter to break the ginger production cycle (Camacho and Brescia, 2009). Indian farmers used paddy and mustard to rotate with ginger (Rahman *et al.*, 2009). Ethiopian farmers prefer maize, *teff,* sweet potato, taro and haricot bean to include in the rotation system with ginger. Crop rotation is one of the agronomic practices supposed to minimise the inoculum load of GBW disease, though the bacterium persists in the soil for several years. Thus, due attention need to be given to select the best suited crops and long cycle rotation to ensure high ginger rhizome yield.

4.1.1.14. Planting disease-free seed rhizomes generated from micro propagated plantlets

Ginger is vegetatively propagated through rhizomes. However, conventional multiplication produces only 10-15 lateral buds from the rhizome of a single plant aftereight months. The conventional propagation method is a slow process yielding only 5-6 seed rhizomes per mother rhizome per year. Rapid method of multiplication is needed especially for newly developed high yielding varieties which are available in small quantities (Hiremath, 2006). The micro propagation provides a rapid, reliable system for the production of large numbers of genetically uniform plantlets. Micro propagation ensures healthy seedlings with desirable characters and overcomes a dormancy period in ginger. Kirdmanee *et al*. (2004) observed that bacteria-free rhizome produced vigorous growth, high survival percentage and high yield in the ginger plants.

Ginger rhizomes produced in conventional propagation method were infected by various pathogens such as *Ralistonia solanacearum.* It is present systemically in seed rhizomes as both an active and latent infection that contaminates seed-pieces when they are cut and prepared for field planting (Hepperly *et al*., 2004). Therefore, in some countries, conventional propagation using ginger rhizome pieces is at high risk because the rhizome pieces can remain asymptomatic (Tanabe and Baerh, 2000). Production of bacteria-free clones with a rapid multiplication rate and

high survival percentage is necessary for the successful production of this crop (Kirdmanee *et al.*, 2004). Micro propagation is an ideal method for mass propagation of pest and disease free-ginger. Sharma *et al.* (1994) suggested that it is imperative to produce bacteria-free clones using tissue culture techniques. This might be helpful to obtain large numbers of *in vitro* planting material of ginger rapidly for cultivation.

Rhizomes to be regenerated should be carefully selected from the best ginger cultivars available and the best protocol should be optimised prior to attempting *in vitro* regeneration since it is a capital intensive technique. The regenerated plantlets need to be acclimatized before transplanting to a greenhouse or rain shelter or to an open-field. The greenhouse or rain shelter should be clean and disease-free, with a clean source of water, and located well away from any ginger processing activities (Hepperly *et al.*, 2004). In open-field production even when disease-free starting materials are used in a clean field, it is difficult for a grower to prevent introduction of the disease from nearby contaminated fields by different means of transmission such as water runoff (Trujillo, 1964) rain splash, humans, equipment, and animal traffic.

Kavyashree (2009) reported successful establishment of regenerated plantlets in the field with 86% survival frequency after few days of indoor acclimatisation. But it should be taken into account that transplanting the acclimatised tissue culture materials directly to the field should be integrated with soil solarisation of the field for four weeks before planting and integration with foliar spray with fungicides to manage other foliar disease observed during the growing period. Rate of establishment of the acclimatised plants was observed to be between 0 to 30% even in research stations and none of the transplants survived in farmers' fields unless they were integrated with soil solarisation for four weeks, bio-fumigation with lemon grass and palmrosa at 10 t ha-1 before planting and alternative foliar spray with fungicides such as Matico (2.5 kg ha-1), Mancozeb (3 kg ha-1), Ridomil Gold (2.5 kg ha-1) starting from occurrence of symptoms on the field. Figure 18 illustrates steps of regeneration of disease-free mini rhizomes from *Ralistonia solanacearum*-infected ginger rhizomes using a tissue culture technique at Areka Agricultural Research Center.

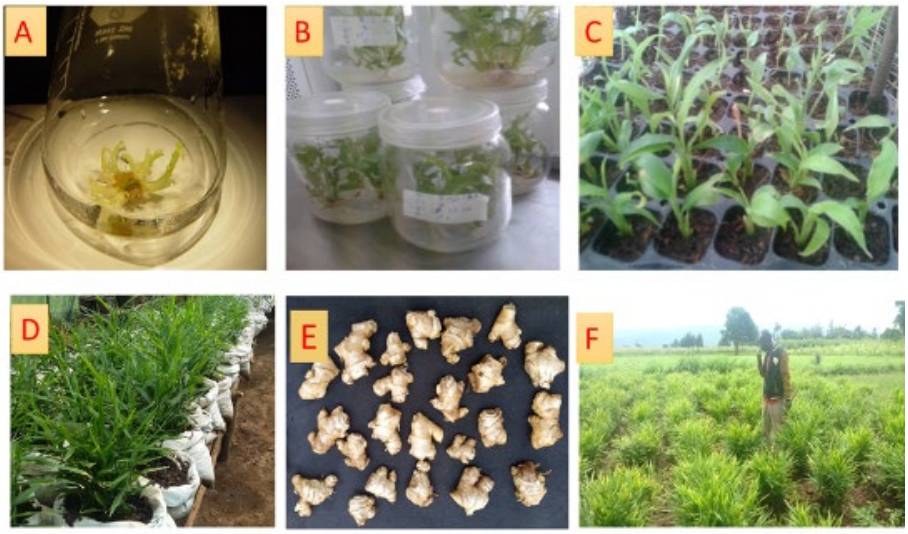

Figure 18: Disease free mini seed rhizome regeneration steps from infected ginger rhizome. A, B, C, D, E and F denote, regeneration, multiplication, acclimatization, rhizome regeneration, mini rhizomes preparation and production steps, respectively.

Thus, direct planting of acclimatised plantlets to open-field should be avoided in developing countries including Ethiopia. Hence, it is advisable to generate rhizomes in greenhouses under close supervision of skilled personnel to develop first generation rhizomes. Then the first generation rhizomes are further propagated to second rhizome generation employing a rapid multiplication technique to distribute to users as a starting disease-free planting material. Ginger producers in Ethiopia are advised to plant disease-free starting materials preferably early in dry season (November to early January) using irrigation. They can also grow it in marginal areas where ginger production was not accustomed earlier. Mid altitudes, characterised by cooler temperatures, can also be used to propagate disease-free rhizome since the effect of low temperature is known to retard bacterial growth remarkably.

Planting disease free rhizomes even in soils having negligible bacterial load as well is possible at times when climatic conditions for bacterial growth remain unfavourable. It should be noted that bacterial wilt disease is sporadic in terms of symptom manifestation and disease symptom will not be expressed unless conditions for the pathogen`s development satisfy and hence planting at hot spot areas is also possible based on meteorological evidences. Figure 19 shows a ginger farm with bacterial wilt-free plants (Figure 19A) and a result of laboratory

analysis of disease-free samples (Fig. 19B) of the same farm. The farm was planted with disease-free mini rhizomes, regenerated from tissue cultured plantlets, using supplementary irrigation.

Figure 19: Ginger plants showing no symptom of Bacterial Wilt Disease (A) and disease free rhizome samples based on a laboratory analysis (B), which were collected from the same farm. The farm was planted at Humbo district, Wolayta, Ethiopia, with disease free mini seed rhizomes at Humbo district in Wolayta zone

4.1.1.15. Heat treatment

To prevent the bacterial wilt outbreaks in the field soil, solarisation or covering of moist soil with white transparent polythene sheet for four weeks (28) days and mulching with lemon grass at 5 cm before planting was effective in reducing the pathogen load in the soil, reducing bacterial wilt incidence and increasing ginger yield up to 16.5 t ha^{-1} (Merga *et al.,* 2018). As soil solarisation is a hydrothermal process, it does not leave any toxic residues. Moreover the process destroys most of the harmful organisms and even seeds of many weed hosts. White polyethylene covers are used to trap sunlight and raise the soil temperature. Heat treatment is an effective way to kill the pathogens inside the seeds rhizome. Dipping of ginger seeds rhizome in hot water at 50 °C for ten minutes before planting is effective way of treating seed before planting. But prolonged exposure of the rhizomes into hot water would cause damage to the seed rhizomes.

4.1.2. Host resistance

Breeding for resistance is an important strategy in disease management, but none of the released varieties of ginger are resistant to *Ralstonia solanacearum.* This may be due to the lack of genetic variability among the ginger accessions since ginger is a vegetatively propagated crop.

4.1.3. Biological control

The biological control of bacterial wilt could be achieved using various species of antagonistic rhizobacteria such as Bacillus and Pseudomonas species isolated from rhizosphere soil of ginger. Also applications of Trichoderma spp. are very effective for the control of ginger bacterial wilt.

Trichoderma spp. are the most widely used biocontrol agents for control of bacterial wilt of ginger. Non-volatile and volatile compounds produced by *Trichoderma viride* could inhibit the growth of R*alstonia solanacearum* by 70% when assessed in vitro.

The percent of bacterial wilt on Trichoderma. Spp. coated ginger was two to three times less than that of the untreated control. Moreover, antagonists also play a role as plant growth promoters. Growth and yield of ginger growing in soil with antagonistic agents were better compared to soil without bio-control agent's application. The possible suppression mechanisms of biological control agents are through competition, antibiosis, and production of enzymes that degrade the cell wall.

4.1.4. Chemical control

Various antibiotics and chemicals were used for bacterial wilt and other foliar disease of ginger on the field. Treatment of ginger seed rhizomes with Tetracycline and Streptomycin, Streptopenicillin at 500 mg/5 L of water for 30 minutes before planting and dipping of ginger seed rhizome in a 10% bleach solution for 10 minutes (one part commercial bleach to nine parts water) were found effective in controlling bacterial wilt of ginger.

4.1.5. Integrated disease management

Several management strategies were developed for the control of bacterial wilt of ginger. However, no single method is effective when applied alone due to wider distribution and host range of the pathogen. Up to now, there is no single effective control measure against it. Therefore, this calls for an integrated disease management strategy which is sustainable and ecologically friendly. Therefore, an integrated approach which was mainly based on cultural

practices and seed rhizome treatment could effectively minimise the incidence of ginger bacterial wilt.

Ginger growers should integrate recommended management strategies such as: rhizome generated from tissue culture plant let, sanitation of the field, crop rotation with non-host crop such as sweet potato, taro, maize and cabbage, treat seed rhizomes with antibiotics (Streptopenicillin and streptomycin) at 500 mg/5 L of water for thirty minutes before planting, soil amendment with compost enriched with effective microorganisms (7 t ha^{-1}) before planting, soil solarisation for four weeks before planting, soil bio-fumigation or amendment with lemon grass and palmarosa at 10 t ha^{-1} and mulching with lemon grass leaf up to 5 cm before planting.

5. A BRIEF DESCRIPTION ABOUT GINGER LEAF SPOT DISEASE

Ginger leaf spot caused by is important disease of ginger due to severe leaf spot and blight it causes in all over ginger producing areas of Ethiopia. The extent of dispersal of *phyllosticta* depends upon the intensity of precipitation. Higher intensity of rain accompanied by wind seems to exert greater impact on target leaf so that spores are splashed to greater distances resulting in liberation of greater amount of spores and increasing disease incidence. The disease begins to appear towards the end of June. Later in July when the number of rainy days and total rainfall increase, the disease aggravates and spreads very fast. Ginger plants up to the age of six to seven months are susceptible to this disease. The temperature range of 23 to 28 ^{0}C with intermittent rain favours disease development. Continuous cultivation of ginger in the same field build-up higher concentrations of inoculum and early infection of the plant reduce the vigour leading to reduction in the rhizome yield.

5.1. Symptoms

Initial symptoms of the disease are small oval to elongated spots on the leaves. Later on the spots show white papery centre and dark brown margins with a yellowish halo surrounding it. The spots increase in size and coalesce to form larger lesions. The affected leaves become shredded and

may suffer extensive desiccation. Symptoms appear first on younger leaves. As the plants put other new fresh leaves, these get infected subsequently (Fig. 20).

a. Initial symptom of phyllosticta on the leaf

b. Severely affected ginger field by phyllosticta

Figure 20: Symptom of ginger leaf spot disease

5.2. Disease Cycle and Epidemiology

The seasonal carryover of the fungus inoculum takes place through infected rhizomes and soil. The fungus survives in soil as chlamydospores which may remain viable for many years in the field. The infected debris or seed serves as primary inoculum for the disease. The secondary spread of the disease can also take place through irrigation water and by mechanical means. The disease is both seed and soil borne. The wet soil conditions, high soil moisture and soil temperature are the most important factors influencing the development of this disease. Severity of disease is more in areas where rainfall is high or rhizomes are planted in heavy clay soil and poor drainage.

The extent of dispersal of *phyllosticta* depends upon the intensity of precipitation. Higher intensity

of rain accompanied by wind seems to exert a greater impact on target leaves so that spores are splashed to greater distances resulting in a greater amount of spores which increase the prevalence of the disease. The disease begins to appear towards the end of June. Later in July when the number of rainy days and total rainfall increase, the disease aggravates and spreads very fast. Ginger plants up to the age of six to seven months old are susceptible to the disease. A temperature range of 23 to 28^{0}C with intermittent rain is the optimal condition for disease development. Continuous cultivation of ginger in the same field builds up higher concentrations of inoculum and early infection of the plant reduce the vigour leading to reduction in the rhizome yield.

5.3. Management of Ginger Leaf Spot Disease

Effective management of ginger leaf spot requires a comprehensive approach, integrating different strategies and tactics.

5.3.1. Cultural practices

Cultural control involves all the activities carried out during agronomic management which alter the microclimate, host condition and pathogen behaviour in such a way that they avoid or reduce pathogen activity. Planting time should be scheduled, especially in places where planting is made under rain-fed conditions, to avoid the period of higher incidence of the disease. Soils must have good drainage and adequate aeration, in order to avoid moisture on foliage and ground. Ginger mono-cropping should be avoided to escape primary inoculum present in plants or rhizome debris infected during the previous season. Mulching of the field with lemon grass and palmarosa up to 5 cm after sowing were also important to reduce ginger leaf spot.

5.3.2. Chemical control

Chemical control involves the use of chemical products capable of preventing infection or slowing down the disease once it has started. Products used to control ginger leaf spot are classified as contact and systemic. Contact fungicides act on plant surface and stop germination and/or penetration of the pathogen, reducing primary sources of the disease. They are also known as protectant or residual fungicides. Copper

fungicides and Mancozeb are among the most important. They only protect the area where fungicide is applied; leaves formed after application of the product will not be protected against the pathogen.

In Ethiopia, an experiment conducted at Teppi showed that alternative sprayings of fungicides Matico (2.5 kg ha-1), Mancozeb (3 kg ha^{-1}), and Ridomil Gold (2.5 kg ha^{-1}) starting from occurrence of disease symptoms on the field, with an interval of ten to fifteen days, is effective in managing *phyllosticta* leaf spot of ginger and significantly reduced the incidence of leaf spot. The sprayed plots produced 18.9 tons per hectare of fresh rhizome yield,compared to 8.3 tons from the control.

5.3.3. Integrated management

Management of leaf spot is difficult if following a single approach under field conditions. Therefore, an integrated approach mainly based on cultural practices, use of disease free planting material and foliar sprays with fungicides should be used. An effective, economical, and sustainable disease management strategy should incorporate all the available approaches of a disease management program. The first step in integrated control is reducing the primary sources of inoculum through cultural practices. Next to that fungicides sprays can slow down the development of ginger leaf spot disease. Fungicides play a crucial role in the integrated control of ginger leaf spot disease. In order to optimise the use of fungicides, it is important to know the effectiveness and type of activity of the active ingredients to control ginger leaf spot. The characteristics of the fungicides can be used to optimise their efficacy by matching their strong points with specific situations in the growing season concerning infection pressure and plant growth. Soil solarisation and alternative application of systemic and contact fungicides could effectively minimise the incidence of leaf spot caused by *Phylollosticta zingiberi*. Alternative sprayings of fungicides Matico (2.5 kg ha^{-1}), Mancozeb (3 kg ha^{-1}), and Ridomil Gold (2.5 kg ha^{-1}) starting from the occurrence of disease symptoms on the field, mulching of the soil with lemon grass up to 5cm before planting and crop rotation reduce disease incidence by 90% over untreated control plot and increase ginger yield.

6. SOFT ROT

In warm and humid conditions, soft rot (*Pythium* spp.) cause significant losses. It is present in almost all ginger growing areas of the world.

6.1. Symptoms

Ginger is affected by this disease throughout the growing period. Almost all parts of the plant including sprouts, roots, developing rhizome and collar region of the pseudostem are vulnerable to infection. Symptoms of soft rot first appear on above ground parts at the collar region in the form of watery, brown lesions. These lesions then enlarge and coalesce, causing the stem to rot and collapse. On the leaves, the initial symptoms caused by the basal infection appear as yellowing of the tips of older leaves first with the chlorosis gradually moving downward along the margin involving the rest of the leaf blade and, eventually, the leaf sheath. As older leaves progress, younger leaves start developing a similar symptom progression until the entire plant dies. Rhizomes from diseased plants appear brown, water soaked, soft and rotten, and will decay gradually.

6.2. Disease Cycle and Epidemiology

There are two ways by which the disease is carried over and perpetuated, firstly through diseased rhizomes as oospores in scales and secondly through oospores in soil. *Pythium* species are capable of saprophytic survival in plant debris. The infected plant debris remaining in the field forms an important source of primary inoculum. Such plant parts may contain large number of perennation oospores. The disease is both seed and soil borne. The wet soil conditions, high soil moisture and soil temperature are the most important factors influencing the development of this disease. Severity of disease is more in areas where rainfall is high or rhizomes are planted in heavy clay soil and poor drainage. The optimum temperature for germination of *Pythium aphanidermatum* and *Pythium myriotylum* is about 34°C (maximum is 40°C). A warm and humid climate predisposes the plant to infection at sprouting stage, because of its tender and succulent tissues.

6.3. Management of Soft Rot

6.3.1. Cultural practices

Cultural practices including crop rotation, organic soil amendment and drainage are commonly employed on ginger fields to control soft rot and limit the spread of the disease.

6.3.2. Chemical control

Chemicals such as Mancozeb and copper oxychloride effectively controlled soft rot when rhizomes were used after dipping in the treatments for thirty minutes.

6.3.3. Integrated management

Management of soft rot is difficult by following a single approach because it does not work effectively to suppress the pathogens under field conditions. Therefore, an integrated approach which was mainly based on cultural practices and seed rhizome treatment with fungicides could effectively minimise the incidence of soft rot.

7. YELLOWS

7.1. Symptoms

Yellowing of the margins of the lower leaves is the initial symptom of Yellows (*Fusarium oxysporum*), which gradually spreads, covering the entire leaves. Older leaves dry up initially followed by the younger ones. Plants may show a premature drooping, wilting, yellowing and drying in patches or in whole field. Plants may show stunting. In rhizomes, a cream to brown discoloration accompanied by shrivelling is commonly observed. Rotting of roots is common and the rhizome formation is affected. In final stages of decay, only the fibrous tissues remain within the rhizomes. A white cottony fungal growth may develop on the surface of stored rhizomes.

7.2. Disease Cycle and Epidemiology

The seasonal carryover of fungus inoculum takes place through infected rhizomes and soil. The fungus survives in soil as chlamydospores which may remain viable for many years in the field.

The secondary spread of the disease can also take place through run off water and by mechanical means. For the development of yellows disease, a temperature range of 15 to 30°C is favourable (the optimum being 23-29°C) accompanied by very high humidity. Maximum disease incidence occurred when soil temperature ranged from 24 to 25°C and the soil moisture from 25 to 30%.

7.3. Management of Yellows Disease

7.3.1. Cultural practices

Soils must have good drainage and adequate aeration, in order to avoid excess moisture from the foliage and ground. Avoid ginger mono-cropping to escape primary inoculum likely to be present in plants or rhizome debris infected during the previous season.

7.3.2. Chemical control

Spraying of systemic fungicides like Ridomil Gold and contact fungicides such as copper oxychloride were effective to manage the disease.

8. STORAGE ROTS

Ginger rhizomes are stored for seed and commercial purposes in different types of storage structures. During storage, rhizomes are attacked by a number of fungi diseases.

8.1. Causal Organism

During storage, different fungi have been found associated with the ginger rhizomes, which results in rotting and decaying of the rhizomes. These fungi include *Fusarium oxysporum, Aspergillus flavus*, *Cladosporium lennissimum, Mucor racemosus* and *Verticillium chlamydosporium*.

8.2. Management of Storage Rots

8.2.1. Cultural practices:

Storage of rhizomes under cooled conditions may prolong storability by reducing weight loss and sprouting.

9. HARVEST AND POST-HARVEST MANAGEMENT METHODS OF GBW DISEASE

9.1. Harvesting

According to Weiss (2002) the best harvesting stage for ginger depends on the end uses of the products. Ginger for fresh consumption and preserved ginger is harvested at five and five to seven months after planting, respectively. At these stages, rhizomes are tender, low in pungency and with less fibre (<40%) for use as candied products. Tender rhizomes, also called green ginger, are used in pickles, and candy preparation for household uses. According to Valenzuela (2011), the fully matured rhizomes obtained at eight or nine months after harvesting are used for grinding to produce powdered ginger. At this stage, ginger yields rhizomes with highest content of essential oils and oleoresins as well as full aroma, flavour and pungency (Sutarno *et al*., 1999; Weiss, 2002). The relative abundance of these components is governed by stage of maturity at harvest (Natarajan, *et al*., 1972). In Ethiopia, ginger is only harvested at full maturity stage of eight to nine months after planting (Girma *et al*., 2008) and harvesting at earlier growth stages has not been practiced so far.

In some cases, farmers deliberately extend harvesting time, and retain the crop *in situ* even after the crop attains full maturity. The purpose of *in situ* retaining of the ginger rhizomes after full maturity is to keep them for the next season planting (Rahman *et al*., 2009). Rhizomes may be delayed in the field for more than a year as per market demand (Endrias and Asfaw, 2011). Delayed ginger harvesting after maturity could reduce the quality of rhizome (Rahman *et al*., 2009; Melati *et al.*, 2016). In Ethiopia, ginger is harvested after the complete die back of the foliar parts. At this stage, the rhizomes have a fairly firm skin and will not bruise easily during harvest and washing operations. Time from planting to maturity may be affected by the type of soil in which ginger is grown (Weiss, 2002). According to Girma *et al*. (2016), identifying the appropriate stage of harvest for ginger is vital to maintain the desired quality of maturity stage based end products.

Ginger is harvested either by digger-hoes or by mechanical diggers, depending on the scale of production. In developing countries, farmers use forked (Fig. 21) or flat plate hoes to harvest the rhizomes and collect them manually, often taking no care whether the rhizomes are damaged or not (Rahman *et al.*, 2009). In some developed countries, however, ginger is harvested either by using mechanical pullers and diggers or by using manual labour where rhizomes are pulled and collected by hand, depending on the size of the operation and time of harvesting (Camacho and Brescia, 2009).

Figure 21: Hand tool for harvesting ginger in southern Ethiopia

According to Douglas *et al.* (2005) harvesting methods of ginger must ensure that there is no rhizome damage. Care is necessary to avoid damage to the rhizome (splitting or bruising) as injuries can result in fungal infection and also to assure integrity of the rhizomes during harvest and postharvest handling. Cutting devices, harvesters, and other machines should be kept clean and adjusted to reduce contamination from soil and other materials. Girma *et al*. (2016) also pointed out that identifying effective and best methods of harvesting is essential. It is not recommended to harvest ginger during rain and when there is dew. During the process of harvesting operation, there are many occasions where ginger seed rhizome could be exposed to bacterial infection. As a wound is the only entry for bacterial infection in ginger seed rhizome, it is essential to minimise rhizome injury while using different harvesting and transportation tools.

9.2. Ginger Seed Rhizome Storage

Ginger rhizomes are bulky and perishable. Storing seed rhizome for two to three months (from harvesting to next planting season) (Yadgirwar et al., 2017) faces many problems such as dehydration, shriveling, rotting, sprouting, and rooting can result in storage losses as high as 10-15% (Kananiannan et al., 1996). Dehydration is a common postharvest disorder of ginger held under low relative humidity conditions (i.e. less than 65%). Shrivelling of the rhizome becomes noticeable after the loss of more than 10% of the initial harvest weight. On the other hand, surface mould will begin to grow at a relative humidity above 90% and sprouting will be stimulated, especially if the temperature is above 16°C. Traditional outdoor storage methods are prone to rhizome sprouting in case of available soil moisture or erratic rainfall.

Farmers in different countries followed more or less similar traditional storage methods to extend the shelf life of ginger seed rhizome until the next planting season, out of which *in situ* and indoor methods are the most common (Yadgirwar *et al*., 2017). *In situ* storage method involves, retaining matured rhizomes in the ground until planting time. Farmers are still using other improper traditional methods like soil pits and storage in open dry and shaded places (Rahman *et al*., 2009). In the case of indoor storage methods, farmers also tend to heap the bulk of whole or cut pieces of seed rhizomes or stack either of them in sacks until the time of planting, which might take place after two to three months of storage. In the case of traditional indoor storage method, the seed rhizomes tend to generate moisture, CO_2 and heat in the sacks as a result of respiration, which stimulate growth and activities of pathogens that would eventually lead to the rotting of seed rhizome. Both the indoor or outdoor traditional storage methods are imperfect ways to maintain the quality and quantity of seed ginger rhizomes.

However, ginger may be successfully stored for several months if the correct postharvest handling and storage procedures are utilised, which may begin with harvesting the seed rhizomes at the proper maturity stage. Proper curing of the seed rhizomes after harvesting is also a good pre-storage requirement to manage nematodes, rhizome bruises and external pathogens. According to Girma *et al*. (2016), the basic principles of proper packaging and storage involve retention of suitable moisture levels and, storage under clean and cool,

well-ventilated conditions, free from any incidence of storage insect pests, rodents, as well as other domestic animals.

Ginger rhizome deteriorates rapidly in adverse conditions and should be stored in well-prepared and maintained storage facilities (Valenzuela, 2011). Essentially, the moisture level of the ginger seed rhizome to be stored should be at a safe level. The storehouses should be damp-proof, vermin- proof, and bird-proof as well as having controlled ventilation and other devices to regulate humidity and temperature, where possible. A dehumidifier fitted to a storage room, by keeping the atmosphere always dry, can eliminate mould and insect attacks. The room should be fumigated before storage, the walls need to be washed regularly and the facility should be kept dry. Storing materials on the floor beneath sacks of the rhizomes prevents dampness from reaching produce. This helps to reduce the chance of fungal infection, while also improving ventilation and/or sanitation in the storeroom. Some examples of useful materials include water proof sheets and wooden pallets.

The optimal temperature for storage of seed/fresh rhizome and transporting is 12°C (Paull, *et al*., 1988). Holding ginger at ambient temperatures (25°C to 30°C) will result in high moisture loss, surface shrivelling, and sprouting of the rhizome. Market life under these conditions is less than 1 month. Below 12°C, ginger is susceptible to chilling injury that intensifies shrivelling and increases the incidence of decay. Fresh ginger rhizome shelf life may be extended by storing it at 10-12ºC and high humidity. In a study on Hawaiian ginger, quality was stable during 28 weeks when stored at 12.5ºC and 90% relative humidity (RH) as determined by dry weight, fibre content, oil content, sugars and phenols (Paull *et al*., 1988). Storage at 65ºC RH leads to dehydration and wilting. Due to the increased intensity of respiration and associated oxygen consumption, fresh ginger has a tendency to self-heat and to elevate CO_2 concentrations in the hold. To counter these phenomena, particularly extensive ventilation measures are required. Under such storage conditions, ginger can store for six to eight months (Venzuela, 2011).

10. CONCLUSION AND RECOMMENDATION

Ginger occupies an important place in spices throughout the world, and Ethiopia is one of the leading producer and exporter of ginger across the globe. However, production of ginger is

threatened by a many diseases caused by different fungal and bacterial pathogens which reduce the potential yields drastically. For reducing the losses caused by these pathogens, a sound knowledge of their occurrence, distribution, symptoms, biology, perpetuation, transmission and epidemiological factors is required. Further, an insight into management practices such as cultural practices, host resistance, biological, chemical control and integration of these practices is needed. In the preparation of this guideline, an effort has been made to review geographical distribution, losses, symptoms, causal organism, disease cycle, epidemiology, host resistance, cultural, biological, chemical and integrated disease management strategies of diseases infecting ginger.

Currently, all ginger genotypes grown in Ethiopia are infected by *Ralstonia solanacearum,* a causative agent of GBW disease. It could be both active and latent infection. As a result, it is hardly possible to access disease-free planting material and genotype from across the country. Ideal conditions that trigger the development of the pathogen are the synergetic effect of high humidity and warm temperature. Early planting in the dry season using irrigation successfully avoids high humidity from the disease triangle, ensuring multiplication of disease-free rhizomes or rhizomes with negligible bacterial load.

A tissue culture technique is an ideal method for regeneration and mass propagation of disease-free planting material. The regenerated plantlets should be acclimatised in a greenhouse. But it should be kept in mind that transplanting the acclimatised plantlets directly to the open field could result in huge economic loss since it requires high horticultural expertise and reliable moisture and nutrient management.

Integrated disease management strategy against the devastating bacterial wilt and leaf spot diseases is essential. Ginger leaf spot disease is also becoming the most important problem in ginger production in Ethiopia.

No single effective control measure against both diseases has been developed and hence an integrated disease management approach is critical. Further investigation is required to identify

the disease complex in the country so that an effective control strategy can be developed to ensure successful production of the crop.

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