Management of Ginger Bacterial Wilt and Leaf Spot Diseases
A Manual for Agriculture Extension Workers and Practitioners

Prepared

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1. INTRODUCTION

Ginger is a monocotyledonous herb, with elongated leafy stems and horizontally oriented underground rhizome. The economically-valuable part is the underground rhizome, which is pungent and aromatic used for culinary purposes as a spice of flavouring agent. 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 in local foods and drinks. Ginger was introduced to east Africa from India in the 13th century and has been present in Ethiopia since then. In Ethiopia, the South Nations, Nationalities and Peoples Regional State (SNNPRS) accounts for 99% of ginger's production. Ginger production has also been extended to some parts of Western Oromia and Northern Amhara.

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 also has other multiple advantages in that it is highly productive per unit area, tolerant to drought, and can be stored for long periods of time in dried form. In areas where vertebrate pests such as porcupine and monkey are serious problems, ginger is the best priority crop to cultivate because wildlife and domestic animals cannot consume both its foliar (leaves) and subterranean organs (rhizomes) due to its pungent principles. Above all, ginger is a good cash crop for many smallholders, significantly improving their livelihoods. Its contribution as a foreign currency earner is notable.

The sudden outbreak of ginger bacterial wilt disease and leaf spot disease in 2012-2013 has devastated ginger varieties all over the country irrespective of variations in cultivars and geographic locations, resulting in a sharp drop in production and supply of the crop. The diseases outbreak had an estimated incidence of 80-100%, which caused up to 90-100% crop loss. Consequently, the socio-economic security of farmers, traders and other members of the societies whose livelihood was based directly or indirectly on production and marketing of ginger have been affected.

This manual is developed by Southern Agricultural Research Institute and Ethiopian Institute of Agricultural Research based on research findings to enhance production and productivity of ginger through capacity development of agents, extension workers and private investors on management of bacterial wilt and leaf spot diseases. The preparation of the manual was sponsored and coordinated by Farm Africa.

2. PURPOSE AND SCOPE OF THE MANUAL

This manual is developed to enhance production and productivity of ginger through capacity building of agriculture agents, extension workers and private investors on management of bacterial wilt and leaf spot diseases. A team of experts from different institutions was involved in the preparation of the manual by the coordination of Farm Africa. This working manual has been produced to be used by ginger producers and other stakeholders in relation to management of the two major diseases of ginger.

3. MANAGEMENT OF GINGER BACTERIAL WILT DISEASE

3.1. Source of Infection and Spread of the Disease

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 (open wounds). 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 the 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.

3.2. Disease Cycle and Epidemiology

Ralstonia solanacearum spreads by infected soil adhering to hands, boots, tools, vehicle tires, field 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 the pathogen adheres inside the host, the bacterium moves to the vascular system where it multiplies rapidly, filling the xylem with bacterial cells and slime. Once infected, it moves up through the vascular system, the xylem, and finally blocks water and nutrient transportation, which causes wilting.

The bacterium returns to the soil when the plant died, 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 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.

3.3. Symptoms and Nature of Damage

Symptoms occur both on the above and underground parts of the ginger plants (Fig 1 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 cell 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.

Figure 1: Above- (a & b) and below ground (c & d) symptoms of ginger bacterial wilt disease

3.4. Detection and Identification of the Pathogen

Symptom identification is the first step for early diagnosis of bacterial wilt of ginger. The wilt progresses upward affecting the younger leaves, followed by a complete yellowing and browning of the entire shoot, before the entire shoot becomes flaccid and dries. In addition, shoots become soft and completely rotted, breaking 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 reveal that the disease is caused by bacteria. 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.

3.5. Management of Ginger Bacterial Wilt

3.5.1.1. 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. Warm climate with an optimum range of 19-28°C is required for best growth and performance of the crop. Compact clay soils characterised by water logging or coarse sands with poor water holding capacity, gravel soils or hardpan soils are not suitable for ginger production. Ginger performs well on medium loam soils. Soils need to be friable and have reasonable depth with rich organic matter content and nutrient availability to harvest maximum rhizome size and yields and to make harvesting easier. Ginger does not thrive well in water stagnant fields and thus water logging sites should be avoided as such sites favour ginger bacterial wilt and other soil-borne diseases. The land should be of gentle slope (0 <15%) and without recent history of cultivation of ginger and crops from the ginger family including turmeric. Ginger should not be planted down slope from another ginger field to prevent runoff water carrying the pathogen to the field. In this regard it is suggested that slight slant land orientation is required to avoid water logging for ginger production. Field performance of ginger planted in a water stagnant field and a gentle slope in the same village is shown in Figure 2.

Figure 2: Field performance of ginger planted in a water stagnant field (left and middle) and a gentle slope (right) in the same village

3.5.1.2. Seedbed preparation

A properly prepared seedbed enables fast rhizome expansion of the ginger plant as it improves the structure and water-holding capacity of the soil. Ploughing the land frequently (three to five times) starting from the end of the main season (i.e. during late September to October) is essential to conserve residual moisture for dry-planting (December to January) particularly in central zones (Wolayta, Kambata-Tambaro and Dawro) of SNNPRS. During seedbed preparation there is high risk of soil contamination particularly with ginger bacterial wilt pathogens. The major sources of contamination are farm tools, contaminated soil, water or infected seeds. Thus, farm tools and other potential sources of contaminants need to be disinfected before every farm operation to minimise the risk of soil contamination and disease spread.

3.5.1.3. Selection of planting material

Before planning to grow ginger at a small holder or at a commercial level, the most important pre-requisite is to choose disease-free planting material. Ginger bacterial wilt pathogens cannot be easily detected as it is embedded in the cell of the rhizome flesh. *Ralstonia solanacearum* , a causative agent of GBW disease, is a seed and soil borne pathogen and can be easily disseminated from one area to the other through latently infected seed rhizome. Ginger seed rhizomes regenerated from tissue cultured plantlets and obtained from early planted rhizomes in dry season with irrigation could be the best source of planting material as such materials are disease-free or may have negligible bacterial load.

3.5.1.4. 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 cut-pieces of seed rhizomes. Cut-pieces are also called setts, rhizome cuttings or bits or propagules. Rhizomes that are large, without wrinkles, and free from marks or without bud and eye injury are selected for planting. 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). Such seed rhizomes have high vigour to withstand biotic and abiotic stresses. However, planting pieces of over-seasoned or perennated rhizomes for two or more growing years must be completely avoided since such rhizomes rarely emerge (Endrias and Asfaw, 2011). There are two types of propagules for a rain-fed ginger propagation: non-sprouted pieces and sprouted propagules (Fig. 3). In both cases, whole seed rhizomes are cut into pieces 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.

Figure 3: Non-sprouted (left) and sprouted (right) ginger propagules

Bacterial wilt-free seed propagules may have a high chance of infection if the soil is contaminated by the pathogen. Thus, the cut or wounded surface of the setts must be cured sufficiently so that the soil-borne wilt bacterium cannot easily enter into the newly planted propagules. 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 required to minimise conditions that may favour bacterial growth.

3.5.1.5. Size and weight of ginger rhizome propagules

The weight and size of each propagule/sett required for ginger production may be 20-50g in weight and 2-5.5 cm in size (Fig. 4). Larger propagules do not decompose or decay until the harvesting stage, providing additional economic benefits.

Figure 4: Recommended size of ginger rhizome propagule

Planting smaller seed rhizomes early in the season under reliable soil moisture condition or with irrigation ensures significant reduction in cost of seed rhizomes. Hence larger propagules (Fig. 5) can be further cut into two or more setts depending on the size of the seed rhizomes.

Figure 5: Recommended size of ginger rhizome propagule

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 unreliable or rain-fed production condition (Fig. 6). In this case, early emerged buds tend to apically dominate the rest of the buds. Occasionally, two or more buds may emerge per propagule if there is adequate soil moisture and applied nutrients from the time of planting.

Figure 6: 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 up

No matter how large the size of the seed rhizome (be it the whole daughter rhizome or a portion of it), large propagules emerge earlier and show vigorous and rapid growth as a result of high initial food reserves accumulated. 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. The fact that large propagules emerge earlier and show vigorous and rapid growth can be considered as a mechanism to escape GBW disease which more often occurs in Ethiopia between June and August, a time with ideal weather conditions for bacterial development.

3.5.1.6. Early planting in dry season using supplemental furrow irrigation

Due to its biennial nature (seven to nine 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. Early planting also facilitates the uptake of available and applied nutrients for better performance of the crop provided that the onset of the rain happens early in the season. In the Ginger Belt of Ethiopia (central administrative zones of SNNPR), dry planting is practiced from January to March, whereas the south-western zones of the country prefer wet planting in March.

Ginger requires light but frequent irrigation (four to seven days) during the vegetative stage if rainfall is insufficient and not evenly distributed along the growing season. But as ginger is sensitive to water logging, application of irrigation water must be avoided during periods of sufficient rainfall that could maintain normal development of the crop.

Various irrigation systems have been developed over time to meet the irrigation needs of ginger. Some of these are sprinkler and drip/micro irrigation. The most appropriate irrigation method for an area depends on physical site conditions, amount of water available, and management skill. Currently, in the Ginger Belt of Ethiopia, the only available irrigation scheme is furrow irrigation. The furrow method is an efficient system if properly managed, but a most inefficient method 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.

Furrow irrigation is less applicable in sand soils 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. 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 slope of the furrow should not cause erosion problems and at the same time improve efficiency of irrigation. Steeper grades lead to higher water velocities and more erosion. Therefore, the slope or grade of the furrow is important to control 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, sandy loam, fine sandy loam and clay are 0.25 cm, 0.40 cm, 0.50 cm, and 1.50 cm respectively. A minimum furrow grade of 0.05% 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 in too 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.

The main purpose of early planting (December to January) of ginger in the dry season using irrigation where there is a bacterial wilt problem is to disturb ideal conditions that favour the disease development by disintegrating the disease triangle. Ideal conditions that stimulate development of the pathogen are the synergetic effect of warm temperature (>27.8^{o}C) and high rainfall (> 288mm of monthly average) or high relative humidity (>90%) when associated with a susceptible ginger (Fig. 7).

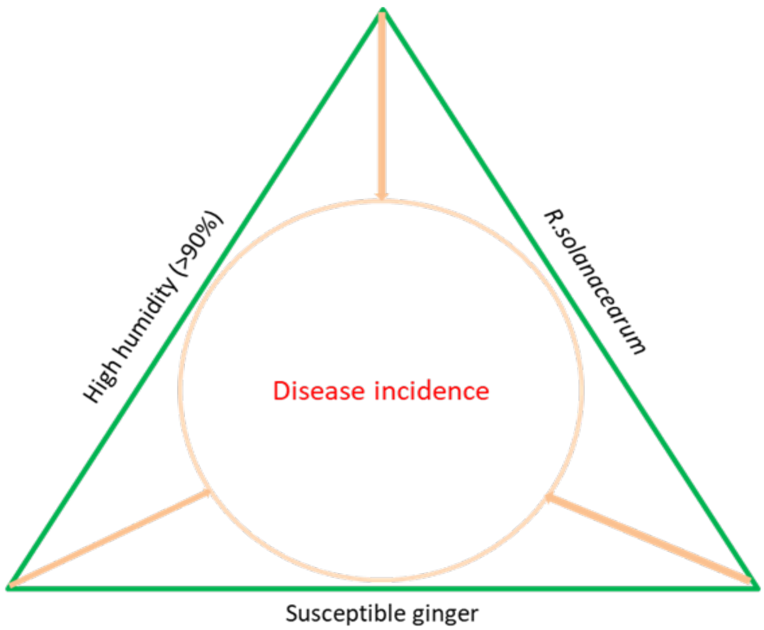

Figure 7: Disease triangle for the incidence of ginger bacterial wilt disease

In the Ginger Belt of Ethiopia, an ideal condition for bacterial growth mainly prevails from June to August, which is a peak period for rainfall. In such areas, planting bacterial wilt-infected ginger early in dry season (December to January) ensures high production of disease-free ginger or ginger rhizomes of negligible inoculum load as a result of an absence of high relative humidity from the disease triangle which otherwise would trigger the development of the pathogen.

Irrigation triggers fast and early emergence of the propagules and ensures emergence of nearly 100% of the propagules planted, maintaining the recommended plant population per unit area. Plants supplemented with irrigation water give large propagules. Large propagules are characterised by high food reserves to enhance rapid development of the newly emerging plantlets that ends up with a high rhizome yield. Irrigated ginger produces large number of actively growing buds (> 20) per individual rhizome. It also results in longer (30 cm) (Fig, 8A) and bigger (600 gm) rhizomes (Fig. 9).

Figure 8: Ginger daughter rhizomes generated from latently infected mother rhizomes planted early in dry season in Himbecho, Wolayta (A) and Hadero-Tunto, Kambata-Tambaro (B) using furrow irrigation.

Overall, early planting in dry season using irrigation could be the best option to produce ginger in areas with GBW present. There is also a possibility of harvesting healthy rhizome yields or rhizomes with negligible bacterial loads through planting latently infected rhizomes early in the dry season using irrigation since there would be no threat of bacterial growth in the absence of high humidity. These rhizomes produced during the dry period could then be used as a seed rhizome.

Figure 9: Individual daughter ginger rhizome (weighing 667 g) obtained from latently infected propagule by ginger bacterial wilt disease; the propagule was planted early in dry season using furrow irrigation in Hadero-Tunto district, Kambata-Tambaro, Ethiopia.

3.5.1.7. Planting depth

Planting depth is one of the most important agronomic practices that affects the 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 (moist soils require less depth). It also influences the 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 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 an extended dry season under rain-fed condition. However, it delays emergence, which may result in the overlapping of the juvenile stage of the crop to the ideal condition for the pathogen development. The common planting depth used for ginger production in Ethiopia is 5-10cm.

3.5.1.8. Plant Population

The total plant population per unit area for ginger production is governed by several factors, including: planting method, moisture (either rain or irrigation), altitude, propagule size, soil fertility, mechanisation, management practices, and region. In Ethiopia, 30cm (between rows) and 15cm (between plants) is recommended for rain-fed production (Fig. 10).

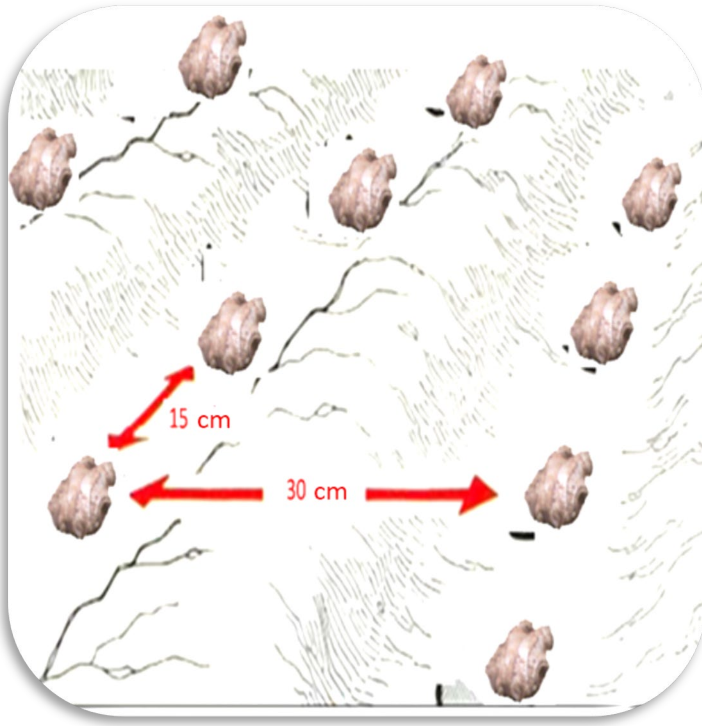

Figure 10: Recommended planting space for rain-fed ginger production in Ethiopia

Earlier recommendation of seed rate, two t ha^{-1} (222.222 seed rhizomes ha^{-1}) for a rain-fed production of ginger in Ethiopia planted at the spacing of 30x15cm is very high in terms of management of bacterial wilt disease. Plant population and spacing also varies with variations in irrigation systems. In sprinkler system, 22cm (row) x 22cm (plant) spacing is used. In the case of drip system 30cm (row) x 22cm (plant) results in better rhizome yield. For furrow irrigation 60x15cm row and plant spacing is used.

When ginger is planted in closer planting spaces with a provision of the required inputs, high humidity and warm temperature 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 symptoms on 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 a 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.

3.5.1.9. Inorganic fertilisers

Ginger is a soil-exhausting crop requiring heavy fertilisation to give high yields. As the soil fertility amendment 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. The recommended rate of 75.9kg nitrogen ha^{-1} with the spacing of 30x15cm in soils having higher amounts of available nitrogen may enhance 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.

3.5.1.10. Organic fertilisers

Organic fertilisers contain organic carbon, nitrogen, phosphorus, potassium, calcium and magnesium coupled with adequate levels of micro nutrients. Farmyard manures, poultry manure and compost are three types of organic manures that have been used in ginger production. Poultry manure is the most impressive on the growth and yield parameters of ginger followed by 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, 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. Organic manures are capable of improving soil quality and increasing yield of cultivated crops.

In addition, organic manures have a strong tendency to neutralise soil acidity and provide micro nutrients such as Zn, B, Cu and Fe that can influence crop production positively. 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.

Ginger requires heavy manuring of up to 40-50 t ha $^{-1}$ for good yields. Growth may be enhanced when the nutritional requirements of ginger are partially met through organic and inorganic sources due to the readily available nutrients through chemical fertiliser. Slowness of nutrient release of organic manures can be compensated through integrated application of organic and inorganic fertilisers. Application of nutrients, particularly nitrogen and well decomposed organic fertilisers 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 wilt disease is a problem, there is a need to minimise the rate of nitrogen particularly in fields, where organic manures were heavily applied during previous cropping season.

3.5.1.11. Mulching

Mulches have several effects on the soil and help to improve plant growth. Mulching enhances germination, prevents washing of soil due to heavy rain and surface run off, increases infiltration and conserves moisture. 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 improving the moisture content and structure of the soil.

Ten to thirty t ha^{-1} is applied twice or thrice: one at planting, second at 45^{th} day and third at 90^{th} day after planting. Dry forest and banana leaves, residues like sugarcane trash, wheat, barely straws and also weeds, farm yard manure and vegetation of the locality are commonly used as mulch materials. Banana and green forest leaves are best.

3.5.1.12. Hilling / earthing up/ hoeing / weeding

Weeds cause about 35-75% yield reduction mainly due to slow emergence and long life cycle (more than 240 days) of the ginger crop. Weed control mechanisms start with good land preparation resulting in finely pulverised tillage which ensures exposure of weed seeds and debris to sun drying, to minimise frequency of post-emergence weeding. Earthing up controls weeds and facilitates adequate aeration for roots. It is essential to prevent exposure of rhizomes and provide sufficient soil volume for the free development and enlargement of daughter rhizomes.

For proper weed management gentle hoeing begins before emergence of 50% of the propagules. Pre-emergence hoeing involves the 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 the destruction of newly emerging weeds and exposes potentially emerging weed seeds and debris to sun drying. It also facilitates faster and full emergence of the propagules to attain uniform growth and maintain the recommended number of plants per unit area. First earthing up may take place on the 45^{th} day and the second in the 120-135^{th} days after planting. The inception of hilling would largely depend on the moisture content of the soil to initiate the emergence of propagules 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. The soil is periodically hilled up (mounded) around the base of the plant to ensure vertical growth of the rhizomes. 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. Earthing up should not be carried out during wet weather conditions and should coincide with the split application of urea. Frequency of hilling varies from five to ten times based on the type of the soil. Clay soils require more frequent hilling.

Hilling operation is mainly practiced using forked digging- or flat blade hoes (rarely) or other modified pointed hoes (Fig 11), depending on the local culture. If these hand tools are not managed properly during the hoeing operation, wounding of the mother or daughter rhizomes and roots is common, which is the main entrance for *Ralstonia solanacearum.*

Figure 11: Hand tool used for hilling ginger in Wolayta and in the low lying southern part of Kambata-Tambaro, Ethiopia

3.5.1.13. Mother seed rhizome re-harvesting

A mother rhizome is an old seed rhizome which gives rise to a daughter (Fig. 12). In ginger, most of the bigger mother seed rhizomes remain undecomposed until crop maturity. Mother rhizomes are characterised by high fibre and low essential oil and oleoresin contents. They exhibit high per cent of drying recovery and hence are preferred to sun-drying by local traders.

Mother seed rhizomes are removed from the daughter rhizomes during a certain crop growth stage without significantly affecting yield of the daughter rhizomes. By mother seed rhizome re-harvesting, 58% of seed ginger from smaller mother setts and 86% from larger ones could be recovered, which ensures regaining of 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 12: Mother seed rhizome and the resulting daughter rhizome

When ginger crop attains 60 days of age, or at the three to four leaves stage, mother rhizome can be removed, leaving the newly emerged plant in the soil. The removed mother rhizome can be sold in the local market. Removal of mother rhizome is believed to give proper space to the developing/daughter rhizome. The other method involves harvesting of the undecomposed mother rhizomes together with matured daughter rhizomes. However, mother rhizomes are rarely re-used as a seed rhizome because they can hardly re-sprout, as they might have lost viability over time. The same is true with over seasoned/perennated rhizomes. Thus, only daughter rhizomes are selected for planting.

In areas where GBW disease is a major problem, removing mother or old seed rhizomes at earlier developmental stages results in injury of daughter rhizomes and roots, which in turn may lead to infection of the whole plantation. It could also be a means of spreading the pathogen to non-contaminated fields through re-planting of the removed mother seeds.

3.5.1.14. Intercropping

Intercropping of ginger with companion crops appears more advantageous as it enables receiving bonus from the same field. Companion crops should be compatible in their growth rate, canopy and root architecture and incidence of pests attacking to each individual crop. Ginger should not be intercropped with crops of *Solanaceae* family, including tomatoes, peppers, tobacco, pepper and eggplant. It is usually inter- or strip-cropped with maize, taro, common been, coffee, coconut and orange plantations. Planting spaces of the companion crops, in terms of GBW disease management should be designed in such a way that high humidity and warm temperature would not be developed under the canopy, which otherwise might result in ideal conditions for the bacterial development.

3.5.1.15. Crop rotation

Crop rotation means planting different crops on the field each season and only returning the same crop after three to four growing seasons. Mono-cropping of ginger in the same unit area every year would result in significant rhizome yield reduction, which could be attributed to soil exhaustion and build-up of pests and diseases. Crop rotation interrupts the life cycle of pathogens and reduces the chance of damage by diseases as well as improving soil fertility. Farmers in Ethiopia prefer short cycle rotation, claiming that the income received from any other rotated crops is incomparable with that of ginger.

In the ginger crop rotation system, including maize, *teff,* sweet potato, taro and haricot bean will result in better outcomes. However, crop rotation using tomato, potato, chilies, and peanut should be avoided, as these plants are hosts for ginger wilt causing bacteria. Crop rotation is one of the important agronomic practices supposed to minimise the inoculum load of GBW disease, though the bacterium persists in the soil for several years. Thus, a long cycle rotation should be practiced with the best suited crops to minimise bacterial effect and ensure high ginger rhizome yield.

3.5.1.16. Planting disease-free seed rhizomes generated by tissue culture technique

Ginger is vegetatively propagated through rhizomes. Conventional propagation method is a slow process yielding only five to six seed rhizomes per mother rhizome per year. Ginger rhizomes produced in conventional propagation method show high chance of infection by various pathogens including *Ralstonia solanacearum. Ralstonia solanacearum* is present systemically in seed rhizomes as both in active and latent infection. Micro-propagation provides a rapid, reliable system for the production of large numbers of genetically uniform and healthy plantlets. Transplanting the acclimatised tissue culture materials directly to farmers' fields requires high horticultural expertise and reliable irrigation systems. Rate of establishment of the acclimatised plants is between 0 to 30% even in research centres and none of the transplants survived in farmers' field. Disease-free mini seed rhizome regeneration steps from infected ginger rhizome is illustrated in Figure 13.

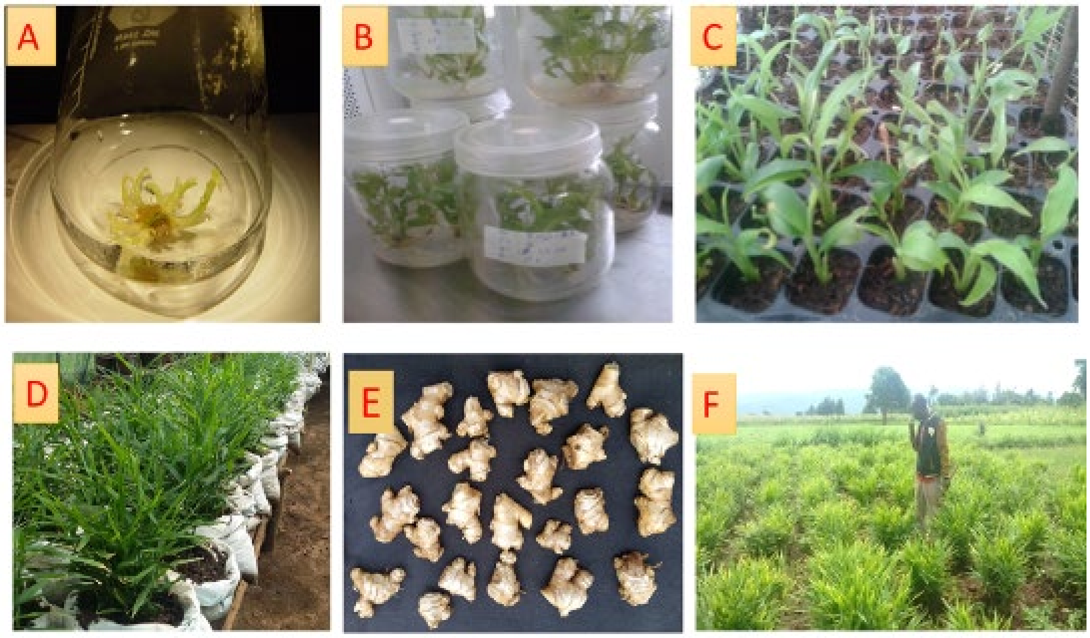

Figure 13: Disease-free mini seed rhizome regeneration steps from infected ginger rhizome. A, B, C, D, E and F denote, regeneration, multiplication, acclimatisation, rhizome regeneration, mini rhizomes preparation and disease free ginger production steps, respectively.

Hence, it is advisable to plant rhizomes generated from tissue culture regenerated plantlets. Such disease-free starting materials can be propagated early in dry season (November to early January) using irrigation. Multiplication should also be extended to mid altitudes where bacterial growth is significantly retarded as a result of low temperature effects or to any of the potential areas for ginger production. Ginger plants, which were developed from disease-free mini rhizomes obtained from tissue culture regenerated plantlets, showing no symptom of bacterial wilt disease are shown in Figure 14.

Figure 14: 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 with disease-free mini seed rhizomes at Humbo district in Wolayta zone.

3.5.1.17. 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 5cm 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 an effective way of treating seeds before planting. But prolonged exposure of the rhizomes in hot water would cause damage to the seed rhizomes.

4. MANAGEMENT OF GINGER LEAF SPOT DISEASE

4.1. Source of Infection and Spread of the Disease

Ginger leaf spot disease caused by *Phyllosticta zingiberi* has become a serious problem across all 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 a greater impact on 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 rainfall frequency and intensity increase, the disease aggravates and spreads very fast. Ginger plants that are up to six to seven months old are susceptible to the disease. A temperature range of 23 to 28°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 reduces the vigour of the plant leading to reduction in the rhizome yield.

4.2. 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. 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. High soil moisture and soil temperature are the most important factors influencing the development of the disease. Severity of the disease increases in areas where rainfall or rhizomes are planted in heavy clay soil with poor drainage.

4.3. Symptoms and Nature of Damage

Initial symptoms of the disease are small oval to elongated spots present on the leaves. Later on, the spots show a 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 develop other new fresh leaves, these get infected subsequently (Fig 15).

a. Initial symptom of phyllosticta on the leaf

b. Severely affected ginger field by phyllosticta

Figure 15: Symptom of ginger leaf spot disease of ginger

4.4. Ginger Leaf Spot Disease Management Methods

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

4.4.1. Cultural practices

Cultural control involves all the activities carried out during agronomic management which alter the micro-climate, 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 5cm after sowing were also important to reduce ginger leaf spot.

4.4.2. Chemical control

Chemical control involves the use of chemical products capable of preventing infection or slowing down the disease once it has shown initial symptoms. 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. Systemic products such as Matico and Ridomil Gold are absorbed through the foliage or roots. Translocation takes place from bottom to top, sometimes the other way round, internally through xylem and phloem. They are able to protect leaves formed after the application. They inhibit some or various specific phases of pathogen development. Repeated use of certain products has caused the appearance of pathogen strains resistant to these fungicides. Therefore, alternative sprays of those fungicides are very important to prevent infection.

In Ethiopia, an experiment conducted at Teppi Agricultural Research Center 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, are effective in the management of *phyllosticta* leaf spot of ginger. It also significantly reduced the incidence of leaf spot. The sprayed plots gave a yield of 18.9 tons per hectare of fresh rhizome, whereas the control plots gave just 8.3 tons per hectare.

4.4.3. Integrated disease management

Management of leaf spot is difficult if following a single approach under field conditions. Therefore, an integrated approach mainly based on cultural practices 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. These fungicide 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 increase ginger yield and reduce disease incidence by 90% over untreated control plot.

5. HARVEST AND POST-HARVEST HANDLING METHODS TO MANAGE GINGER BACTERIAL WILT DISEASE

5.1. Harvesting

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. Ginger is harvested at full maturity stage eight or nine months after planting. The fully matured rhizomes obtained at eight to nine months after planting are used for grinding to produce powdered ginger. At this stage, ginger yields rhizomes with the highest content of essential oils and oleoresins as well as full aroma, flavour and pungency.

Identifying the appropriate stage of harvest for ginger is vital to maintain the desired quality of maturity stage based on end products. Delayed harvesting after maturity could reduce the quality of rhizome. Ginger is harvested either by digger-hoes or by mechanical diggers, mainly depending on the scale of production. In developing countries, farmers use forked (Fig. 16) or flat plate hoes to harvest the rhizomes and collect them manually, often taking no care whether the rhizomes are damaged or not. 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 harvest.

Figure 16: Hand tool for harvesting ginger in southern Ethiopia

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Harvesting methods must ensure that there is no rhizome damage. Damage to the rhizome (splitting or bruising) or injuries can result in fungal infection. Integrity of the rhizomes during harvest and postharvest handling should be assured. Cutting devices, harvesters, and other machines should be kept clean and adjusted to reduce contamination from soil and other materials. 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 main entry for bacterial infection in ginger seed rhizome, it is essential to minimise rhizome injury while using different harvesting tools and means of transportation.

5.2. Ginger Seed Rhizome Storage

Ginger seed rhizomes are bulky and perishable. Storing seed rhizome for two to three months (from harvesting to next planting season) faces many problems, such as dehydration, shrivelling, rotting, sprouting, and rooting, which can result in storage losses as high as 10-15%. 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. 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 because of available soil moisture or erratic rainfall.

Common traditional storage methods to extend the shelf life of ginger seed rhizome until the next planting season are *in situ* and indoor methods. *In situ* storage method involves retaining matured rhizomes in the field until planting time. Other improper traditional methods include soil pits and storage in open dry and shaded places. In indoor storage methods, the bulk of whole or cut pieces of seed rhizomes are heaped up or stacked in sacks until the time of planting, which might take place after two to three months of storage. In this case, the seed rhizomes tend to self-generate moisture, CO_2 and heat as a result of respiration, which stimulate growth and activities of pathogens that can eventually lead to the rotting of seed rhizomes. 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 proper postharvest handling and storage procedures are utilised, which may start with harvesting the seed rhizomes at the proper stage of maturity. Proper curing of the seed rhizomes after harvesting is also a good pre-storage requirement to manage nematodes, rhizome bruises and external pathogens. 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 storage insect pests, rodents, as well as other domestic animals.

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. A dehumidifier fitted to a storage room, by keeping the atmosphere dry, can eliminate mould and insect attacks. The room should be fumigated before storage; further, the walls need to be washed regularly and the facility should be kept dry. Placing materials on the floor beneath sacks or cartons of the rhizomes prevents dampness from reaching produce suited to dry conditions in storage. 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 waterproof sheets and wooden pallets.

The optimal temperature for storage of seed/fresh rhizome and transporting is 12°C. Storage temperature below 12°C will cause chilling injury that intensifies shrivelling and increases the incidence of decay. It also results in tissue softening and breakdown, decay, and skin discoloration. Holding ginger at ambient temperatures (25°C to 30°C) will result in high moisture loss, surface shrivelling, and sprouting of the rhizome. Fresh ginger rhizome shelf life may be extended by storing it at 10-12ºC and high humidity. Storage at 6% relative humidity leads to dehydration and wilting. Under such storage conditions, ginger can be stored for six to eight months. 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.

6. CONCLUSION AND RECOMMENDATION

Currently, all ginger genotypes grown in Ethiopia are infected by *Ralistonia solanacearum,* a causative agent of ginger bacterial wilt disease. It could be both active and latent infection. As a result, it is near impossible to access disease-free planting material and genotype across the country. Ideal conditions that trigger the development of the pathogen are the synergetic effect of high humidity and warm temperatures.

1. **Early planting in dry season using irrigation successfully avoids high humidity from the disease triangle, ensuring multiplication of disease-free rhizomes or rhizomes with negligible bacterial load.**

2. A tissue culture technique is an ideal method for regeneration and mass propagation of disease-free planting material. The regenerated plantlets are acclimatised in a greenhouse. But it should be kept in mind that transplanting the acclimatised plantlets directly to the open field may result in huge economic loss since it requires high horticultural expertise and reliable moisture and nutrient management.
3. An integrated disease management strategy against bacterial wilt and leaf spot diseases is essential. 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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