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Original scientific paper

Management of ginger bacterial wilt (*Ralstonia solanacearum*) epidemics by biofumigation at Tepi, southwestern Ethiopia

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SUMMARY

Bacterial wilt of ginger, caused by *Ralstonia solanacearum*, is the most damaging disease, which brings rapid and serious wilting, and reduces the quality and yield of ginger rhizome in Ethiopia. Thus, an experiment was carried out to evaluate the effect of different biofumigants on bacterial wilt in Ethiopia during the 2019 and 2020 main cropping seasons. The experiments were conducted at the Tepi Agricultural Research Center. Different biofumigation soil amendments (citronella, palmarosa, mint, lemongrass and Chinese chive) were applied before planting. The trials were arranged in a randomized complete block design with three replications. Examination of variance showed that soil amendments with biofumigants strongly decreased bacterial wilt severity and improved rhizome yield and components. Rhizome yield gains of about 90.2% were achieved by soil biofumigation with lemongrass, as compared to untreated control. The relative mean rhizome yield damage due to bacterial wilt in the control plot was 47.4%. Wilt severity was inversely and very significantly ($p \leq 0.01$) proportional ($r = -0.90^{**}$) to rhizome yield. The overall results of the study show that soil amendments with botanicals, particularly lemongrass, before planting should be used to manage ginger bacterial wilt in experimental areas and further similar agro-ecologies.

Keywords: ginger, bacterial wilt, biofumigants, yield, Ethiopia

INTRODUCTION

Ginger (*Zingiber officinale* Rosc.), which belongs to the family Zingiberaceae, is a herbaceous plant with rhizomes which are used as spice. For small scale farmers in southwestern Ethiopia, ginger is one the most important cultivated spices. In southwestern parts of the country ginger has a major share in cropping systems. According to Geta & Kifle, A, (2011), of the total arable land owned by farmers in the Southern Nations, Nationalities and Peoples Regional State, 85% of the land and 35% of the growers are associated with ginger production. It has been one of the leading spice export commodities in Ethiopia over the past almost 10 years, and it earned the country 22.6 million $USD (Wubshet, 2018). However, ginger production is largely affected by diseases caused by bacteria, fungi, viruses, mycoplasma and nematodes (Paret et al., 2010;

Sharma et al., 2010). Bacterial wilt of ginger (*Ralstonia solanacearum*) imposes serious economic losses and it is widely disseminated in most tropical and subtropical areas of the world (Yabuuchi et al., 1995; Kumar & Sarma, 2004). Bacterial wilt is a very significant disease in major ginger growing areas of southwestern Ethiopia, where ginger is extensively and mainly produced for marketable purposes (Habetewold et al., 2015).

The use of essential oils to kill or suppress a pathogen causing disease is called biofumigation. Those oils are constituents of some green compost plants, viz. mint, palmarosa, citronella and lemon-grass. After these florae are mixed or cultivated into soil for 2 or 3 months prior to planting, they decay and release vital oils that are poisonous to the virulent pathogen present in that soil. According to a report by Paret et al., (2010), palmarosa and lemongrass oils highly reduced the incidence of bacterial wilt both in the laboratory and under greenhouse conditions.

Also biofumigation is a cultural practice that uses explosive chemicals released from decaying *Brassica* cells to overcome soil-borne pathogens and pests. The main volatile oils released during decomposition of *Brassica* tissues are isothiocyanates. Isothiocyanates are associated with the active ingredient of the marketable fumigants dazomet and metham sodium, and are very toxic to different pathogens and pests. They are produced subsequent to tissue injury, after myrosinase enzyme hydrolyses glucosinolates at neutral pH. Glucosinolates containing sulfur (thioglucosides) are released as secondary metabolites by *Brassica* species and most investigators have confidence in their initial role as deliverers of resistance against pathogens and pests. Bactericidal effect of different isothiocyanates produced by *Brassica* tissues is known (Brown & Morra, 2005). Thus it is very important to have a certain level of bacterial wilt management through soil amendments with different biofumigants as disease management schemes. Therefore, the present study was designed to determine the magnitude of bacterial wilt disease epidemics and ginger rhizome yield losses through soil amendments with biofumigants.

MATERIAL AND METHODS

Description of experimental area

Field trials were conducted at the Tepi Agricultural Research Centre during the 2019 and 2020 main growing periods. It is located at 35°08' longitude and 7°08' latitude and 1200 m asl. The lowest and highest mean temperatures are 15 and 30 °C, respectively. Its annual mean rainfall is 1630 mm (Jibat et al., 2018).

Soil amendment with biofumigant plants, viz. citronella, lemongrass, palmarosa, mint and chinese chive, applied at 10 tones/ha one month before planting and mulching after planting, was implemented as a cultural management practice to reduce pathogen inoculum and prevent disease epidemics, and an unamended plot was used as a control or check plot. The experiment relied entirely on a natural epidemic of bacterial wilt because the sites had been confirmed as hot spots of disease in previous field history.

A total of six treatments, including controls, were laid out in a randomized complete block design with three replications. Planting was carried out on a gross plot size of 18 m^2 (3 m width and 6 m length) with ten rows of ginger and four harvestable central rows. A recommended spacing of 0.15 m between plants and 0.3 m between rows were used. Spacing between plots and blocks were 1.5 and 2 m, respectively.

Data collected

Growth and yield parameters

Data about ginger growth and yield parameters were recorded from the central four rows of each plot. The number of tillers per plant (NTPP) was recorded as the number of tiller shoots produced by 12 sample plants and their mean was considered as the number of tillers per plant per plot at the time of physiological maturity. The number of fingers per plant (NFPP) was determined as the number of rhizome fingers that arose from mother rhizomes of 12 plants and their mean was taken to represent the number of fingers per rhizome per plot at the time of harvesting. Total rhizome yield (kg ha^{-1}) was also calculated as the rhizome yield per kilogram harvested from four central rows and converted to per hectare using the following formula:

$$\text{Yield (kg ha}^{-1}\text{)} = \frac{\text{Yield (kg) of four central rows} \times 10{,}000 \times \text{m}^2}{\text{Net area (m}^2\text{) of four central rows/plot}}$$

Relative yield loss (%) from each plot was calculated using the formula suggested by Sharma et al. (2008):

$$\text{RYL (\%)} = \frac{(\text{Y1}-\text{Y2}) \times 100}{\text{Y1}}$$

where RYL = relative yield loss in rhizome yield (reduction in rhizome yield); Y_1 = maximum mean rhizome yield of the best treatment in the experiment; and Y_2 = mean yield of the other treatment/control plots.

Wilt incidence assessment

Ginger bacterial wilt occurrence (number of plants wilted) was calculated visually starting from the observance of symptoms in the field. Ginger plants that showed either complete or partial wilting were all considered wilted and staked to avoid double counting in subsequent assessments. Wilt incidence was then calculated for each treatment as the percentage of total number of plants emerged, and the result on the final assessment date was presented in Table 1.

Data Analysis

Analysis of variance (ANOVA) was run for growth, yield and wilt incidence data to compare the effects of treatments. The least significant difference at 5% level of significance was used for mean separation. Analysis of variance was done using the SAS GLM procedure version 9.3 (SAS, 2014). Correlation coefficients of ginger growth, yield and yield components with the last date of disease incidence assessment were computed to establish their associations.

RESULTS AND DISCUSSION

Disease incidence

Two years data were pooled because of homogeneity of variances as tested using Bartlett's test (Gomez & Gomez, 1984) and the F-test was non-significant for most of the parameters studied in each year. Therefore, data were combined for analysis. The analysis of variance shows significant differences among different biofumigant plants evaluated and control treatments at the final date of wilt assessments and area under disease progress curve (AUDPC). The minimum mean disease incidence was found in the plot amended with lemongrass (49.43%), while the maximum mean wilt disease incidence was recorded in control plots (61.13%) at the final date of assessment. Similar trends were also observed for AUDPC (Table 1).

To date there is no single and effective control measure against the bacterial wilt-causing pathogen (Jibat et al., 2018). In this study, however, lower wilt incidence and higher reductions in mean wilt incidence were possible through the application of lemongrass alone, compared to control plots. This might be because lemongrass suppresses certain microorganisms in soil and also it could have stimulated development and growth of other microorganisms as biofumigation might have augmented the soil organic matter, which is the energy basis for microbial activities (Wang et al., 2012).

A related study also revealed that tomato yield from a biofumigated field was higher than in a control field as biofumigation decomposition increased soil fertility, thus encouraging further growth and yield of the crop (Katan et al., 1980). Similarly, it was found that biofumigation of soil maximizes nitrogen, calcium and magnesium accessibility (Stapleton et al., 2000).

Table 1. Effects of biofumigation on bacterial wilt (*Ralstonia solanacearum*) disease at the final date of disease assessment (%) and AUDPC (%-days) at Tepi, Ethiopia, during the 2019 and 2020 main cropping seasons

Treatments	PSI (%)[1]	AUDPC (%-days)[2]
Citronella	55.4^{abc}	112.29^{a}
Palmarosa	49.66^{c}	101.79^{ab}
Mint	56.43^{ab}	111.53^{a}
Lemongrass	42.43^{d}	84.84^{b}
Chinese chive	53.23^{bc}	107.23^{a}
Control	61.13^{a}	113.25^{a}
LSD (5%)	6.63	17.51
CV (%)	6.87	9.15

[1]Percent severity index 120 days after planting (DAP), [2]Area under progress of bacterial wilt disease of ginger. Values in each column followed by the same letters are not significantly different at 5% probability level

Effects of biofumigation on ginger growth parameters

The management practices of biofumigation soil amendment produced highly and significantly ($P < 0.01$) different effects in both growth and yield parameters, except for rhizome length and width, which showed non-significant difference. The maximum number of tillers per plant (4.8) was recorded in plots treated with lemongrass but it was statistically on par with the plots treated with citronella and palmarosa. In contrast, the lowest number of tillers per plant was recorded in the untreated control plots (2.83) (Table 2).

A marked difference was also observed between treated and untreated control plots in rhizome length, rhizome width and number of fingers per rhizome. Higher rhizome length (11.21 cm) and width (4.11 cm) were measured in plants from the plots amended with lemongrass. The highest number of fingers per rhizome was also counted in lemongrass plots (6.3), compared to the rest of the treatments. The lowest number of tillers per plant, rhizome length, rhizome width and number of fingers per rhizome were recorded in the control plots, i.e. 2.83, 7.66, 2.88 and 2.53, respectively.

The advantage in comparative growth resulting from the application of soil amendment could be due to increased soil health and its improved physical and chemical status, which in turn reduced infection by soil pathogens. In this context, Bailey et al. (2003) indicated that organic amendments to soil have direct effect on plant health and crop productivity by improving the physical, chemical and biological properties of soil, which then have positive effects on plant growth. On the other hand, degradation of organic matter in soil directly affects the viability and existence of pathogens in soil by limiting available nutrients and releasing natural chemical substances with variable inhibitory properties, and stimulates the activities of microorganisms that are antagonistic to those pathogens (Akhtar & Malik, 2000), and increases soil microbial activities thereby leading to intense competition (Bailey et al., 2003).

Table 2. Effects of biofumigation on growth, yield and yield components at Tepi, Ethiopia during the 2019/2020 main cropping seasons

Treatments	NTPP*	RL*	RW*	NFPR*	Yield (t ha^{-1})
Citronella	4.26^{ab}	8.96^{bc}	3.76^{ab}	3.3^{c}	9.63^{bc}
Palmarosa	4.23^{ab}	9.93^{ab}	4.18^{a}	5.3^{b}	10.4^{b}
Mint	3.63^{b}	7.96^{c}	3.41^{ab}	2.7^{c}	8.96^{c}
Lemongrass	4.8^{a}	11.21^{a}	4.11^{ab}	6.3^{a}	13.43^{a}
Chinese chive	3.6^{b}	$8.6b^{c}$	3.30^{ab}	5.2^{b}	12.36^{a}
Control	2.83^{c}	7.66^{c}	2.88^{b}	2.53^{c}	7.06^{d}
LSD (5%)	0.72	1.86	1.23	0.78	1.31
CV (%)	10.28	11.29	18.78	10.19	7.01

*NTPP: number of tillers per plant; RL: rhizome length (cm); RW: rhizome width (cm); NFPR: number of fingers per rhizome; Means followed by the same letter(s) columnwise and in adjacent columns are not significantly different at 5% level of significance.

It is well documented that soil amendments that enhance host plant growth and resistance have significant effects in reducing disease incidence (Datnoff et al., 2007), improving tolerance to environmental and pest stress, and enhancing crop growth, yield and quality parameters (Sahebi et al., 2016). For instance, application of potassium fertilizer with lemongrass soil supplement increased ginger growth and yield (Jibat et al., 2018), and the same was shown in this study. Analysis of variance also revealed highly significant ($P < 0.001$) variation between different botanical soil amendments in rhizome yield. The highest (13.43 t ha^{-1}) rhizome yield was obtained from plots treated with lemongrass, followed by plots treated with Chinese chive (12.36). The lowest rhizome yield was harvested from untreated plots, which was about 7.06 t ha^{-1}.

Cultural practices that include soil biofumigation are the most popular approach to manage bacterial wilt by reducing the incidence and severity of wilt, and consequently sustaining productivity of crops. Several studies have also described the effects of cultural practices in reducing bacterial wilt incidence and increasing yield of various crops (Anith et al., 2000; Ji et al., 2005; Yadessa et al., 2010; Ayana et al., 2011; Lee et al., 2012; Sahebi et al., 2016). The mechanisms of disease suppression and increase in rhizome yield was supposed to be based on increase in soil nutrients, changes in physical and chemical properties of the experimental soil due to fertilizer and lemongrass incorporation. In this regard, lemongrass might release essential oils into soil and so reduce bacterial population. Moreover, soil fumigation with botanicals could enhance the capabilities of beneficial microbes against target pathogens.

In line with this finding, Yadessa et al. (2010) found that soil amendments with cocoa peat, farmyard manure, compost and green manure significantly reduced bacterial wilt incidence by 81% and enhanced tomato yield in amended over unamended soil. Some other studies have also noted that lemongrass oil provided protection from tomato wilt by reducing pathogen population and increasing yield under controlled conditions; and disease suppression reached 45-60% under field conditions (Ji et al., 2005). However, the efficacy of lemongrass excelled when integrated with other soil amendment tactics under field conditions (Hong et al., 2011). Furthermore, other related findings demonstrated that soil solarization, combined with fumigation (Yamada et al., 1997) and biological control agents (Kumar & Sood, 2002), reduced the incidence of tomato bacterial wilt and increased fruit yield.

The relative yield loss due to bacterial wilt, calculated against untreated plots, was 47.4% (Table 3). Relative yield loss was reduced by soil amendments with lemongrass. The lemongrass-amended plots recorded 8.97-33.29% higher yields in comparison with other treatments, excluding the control. Soil amendments with Chinese chive caused the next lowest (8.97%) mean relative yield loss. Yield gains of 90.2% were obtained due to soil biofumigation with lemongrass. Theoretically, integrated disease management is intended to eliminate or reduce initial inocula, reduce the effectiveness of initial inocula, increase resistance of hosts, delay disease onset and slow down secondary cycles of infections (Agrios, 2005). This might imply that lemongrass biofumigation along with soil solarization and fertilization highly reduced *R. solanacearum* population and subsequent damage of ginger by mechanisms discribed above. Previous research results have also shown that the application of *Brassica* spp. as green manure is effective in reducing soilborne pathogens through the release of toxic and volatile chemicals after decomposition (Brown & Morra, 2005). Application of plastic mulch, followed by green manure incorporation, would enhance the decomposition process, minimize the escape of volatile gases into the atmosphere and raise soil temperature to kill soilborne pathogen propagules and, as a result, reduce plant yield losses due to disease (Katan et al., 1980).

Association of disease, growth and yield parameters

Computing correlation between final mean disease incidence, and growth and yield parameters was important since change of wilt incidence influenced the response of growth and yield parameters during the experiment. The average bacterial wilt incidence (120 DAP) had a negative and highly significantly ($P \leq 0.01$) association ($r = -0.90^{**}$) to rhizome yield (Table 4). Moreover, the final mean disease incidence (120 DAP) and number of fingers per rhizome were observed to correlate ($r = -0.73^{**}$) negatively and highly significantly ($P \leq 0.01$) over the cropping season. More or less similar phenomena were noted for the correlation between mean wilt incidence and growth and yield parameters. Such findings confirm negative effects of bacterial wilt on the growth, rhizome yield and components of ginger. This complies with the findings of Bekele and Gebremedhin (2000) who found that late blight disease parameters strongly and negatively correlated with final tuber yields. Research reports of Fekede (2011) also confirmed that disease parameter is associated with yield components. Inverse relations were found between chocolate spot disease and grain yield and components of faba bean in sole and mixed cropping systems (Sahile et al., 2010).

Table 3. Effects of biofumigation soil amendment on ginger rhizome yield (t ha^{-1}) and rhizome yield losses at Tepi, Ethiopia, during the 2019 and 2020 main cropping seasons

	Yield (t ha^{-1})	Relative yield (%)	Relative yield loss (%)
Citronella	9.63	71.70	–28.3
Palmarosa	10.4	77.43	–22.57
Mint	8.96	66.71	–33.29
Lemongrass	13.43	100	0.00
Chinese chive	12.36	92.03	–8.97
Control	7.06	52.6	–47.4

Table 4. Coefficients of correlation (r) between growth, yield and disease incidence in ginger at Tepi during the 2019 and 2020 main cropping seasons

Parameter	Yield (t ha^{-1})	Finger per rhizome	Rhizome length height	Tiller per plant	FDI (120 DAP)	AUDPC (% days)
Yield (t ha^{-1})	1					
Finger per rhizome	0.71**	1				
Rhizome length	0.94**	0.75**	1			
Tiller per plant	0.78**	0.65**	0.89**	1		
FDI (120 DAP)	–0.90**	–0.73**	–0.84**	–0.61**	1	
AUDPC (% days)	–0.91**	–0.75**	–0.86**	–0.64**	0.98**	1

** Describes level of statistical significance at $P \leq 0.01$

CONCLUSIONS

The present field data provided empirical evidence that soil amendment with plant biofumigants as green manure before planting reduced yield loss due to ginger bacterial wilt. Soil amendment with plant biofumigants improved rhizome yield, yield components and growth of ginger, compared to untreated control plots. The results demonstrated that, considering all biofumigants used, soil amendment with lemongrass as green manure before planting ginger enhanced ginger rhizome yield, yield components and growth parameters, and highly reduced associated damage due to bacterial wilt incidence, compared to the untreated control and other treatments. These present findings can benefit farmers through increased productivity and income by way of reducing inputs into non-chemical means of control of bacterial wilt epidemics. Additionally, much more research work can be done with biofumigant effects on soil physico-chemical properties and mechanisms by which green manure soil amendment reduces the incidence of ginger bacterial wilt.

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Suzbijaje epidemija bakterijskog uvenuća đumbira (*Ralstonia solanacearum*) biofumigacijom u Tepi, jugozapadna Etiopija

REZIME

Bakterijsko uvenuće đumbira, izazvano bakterijom *Ralstonia solanacearum*, je bolest koja prouzrokuje najveće štete u Etiopiji, dovodeći do ubrzanog i raširenog uvenuća, odnosno umanjenja prinosa i kvaliteta rizoma đumbira. Eksperiment je izveden kako bi se procenio uticaj različitih biofumiganata na bakterijsko uvenuće u Etiopiji tokom perioda vegetacije u godinama 2019-2020. Eksperiment je izveden u Agricultural Research Center u Tepi. Pre sadnje, primenjeni su različiti biofumiganti za obogaćivanje zemljišta (citronela, palmarosa, nana, limunova trava i kineski vlašac). Ogledi su izvedeni u potpuno slučajnom blok sistemu sa tri ponavljanja. Ocena varijanse pokazala je da je dodavanje biofumiganata zemljištu u velikoj meri umanjilo delovanje bakterijskog uvenuća i poboljšalo razvoj rizoma i njegovih komponenti. Poboljšanje prinosa rizoma od oko 90.2%, u poređenju sa netretiranom kontrolom, postugnuto je upotrebom biofumiganta sa limunskom travom. Relativna šteta u prinosu rizoma kao posledica bakterijskog uvenuća na kontrolnoj parceli bila je 47.4%. Smanjenje prinosa bilo je manje na parcelama gde je primenjena limunska trava. Delovanje uvenuća bilo je značajno ($p \leq 0.01$) i obrnuto proporcionalno ($r = -0.90^{**}$) prinosu rizoma. Rezultati istraživanja pokazuju da se limunska trava može koristiti za tretman zemljišta pre sadnje u eksperimentalnim zonama u budućim agro-ekološkim istraživanjima.

Ključne reči: đumbir, bakterijsko uvenuće, biofumiganti, prinos, Etiopija