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Evaluation of Different Integrated Disease Management Approaches for Rhizome Rot of Ginger (*Zingiber officinale* Roscoe.) Caused by *Ralstonia solanacearum* (Smith.) under Field Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Ginger (*Zingiber officinale* Roscoe.,) is a slender herbaceous perennial plant belonging to the family Zingiberaceae, medicinally important and commercial spice crop. India is the largest producer of ginger and accounts for about 1/3rd of the total world output. Ginger is grown in Kerala, Karnataka,

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West Bengal, Andhra Pradesh, Orissa, Arunachal Pradesh, Sikkim and other parts of India. The production of ginger is greatly influenced by diseases caused by bacteria, fungi, viruses, mycoplasma and nematodes. One of the diseases of ginger is bacterial wilt caused by *Ralstonia solanacearum*, which causes yield loss of up to 80 percent. A field experiment was conducted with integrated approaches to manage the ginger rhizome rot caused by *R. solanacearum* (Smith). The experiment was laid out with a Randomized Completely Block Design (RCBD) including nine treatments and four replications. The experiment results revealed that, rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/l + Metalaxyl MZ @ 1.0 g/lit for water three times at 20 days intervals + Ginger special spray 45 DAS, starting with the initiation of the disease was significantly most effective and recorded a higher yield of 110.27 q/ha with least disease incidence of disease (14.23 %). Integrated management of rhizome rot of ginger through soil solarization revealed that, among the different treatments, the treatment treated with soil solarization + rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/lit of water + Soil application of *Pseudomonas fluorescens* @ 10 kg along with 25t FYM /ha recorded higher yield of 115.23 q/ha with less percent disease incidence (8.20 %).

Keywords: Disease management; Ralstonia solanacearum; ginger; rhizome rot; soil solarization.

1. INTRODUCTION

Ginger (*Zingiber officinale* Roscoe.) is an economically important spice and medicinal crop of India. The production of ginger is influenced largely by a number of diseases caused by bacteria, fungi, viruses, mycoplasma and nematodes. Main diseases of ginger are bacterial wilt (*Ralstonia solanacearum*), rhizome rot (Pythium sp., Fusarium sp., Sclerotium sp., Pseudomonas sp.) [1,2,3,4,5,].

Bacterial rhizome rot is a serious disease that has drastic effects on crops and eventually leads to yield loss of up to 80 percent [6,7]. It is a soil-borne bacterium, that belongs to the beta-proteobacteria and is responsible for bacterial wilt of more than 200 plant species from 50 botanical families, including important crops such as potato, tomato, eggplant, pepper, tobacco and banana. In fact, bacterial wilt is considered the single most destructive bacterial plant disease because of its extreme aggressiveness, wide geographic distribution, and unusually broad host range [8]. It is manifested initially by foliar yellowing and later water-soaked lesions appear on the collar of the pseudostem which extend to rhizomes and leaves resulting in the rotting of the rhizome and drying of the entire plant. The disease is both seed and soil-borne [9].

Bacterial rhizome rot of ginger was reported by Orian [10] for the first time in Mauritius. Later, the disease was reported in Hawaii [11,12] and Australia Hayward *et al.,* [13] although the disease occurred in India since in the middle of the 20th century, but Mathew *et al.,* reported it from Kerala in 1979. Supriadi [14] reported that bacterial wilt causes losses of up to 75 billion rupees per year. Therefore, the present study was undertaken to manage the rhizome rot with special emphasis on *R. solanacearum* through different integrated disease management approaches.

Soil solarization is a soil disinfestation practice and main the benefits of solarization are pathogen and disease control and yield increase [15]. It is essentially a hydro-thermal disinfestation accomplished by covering moist soil with transparent polyethylene film during the periods of high temperature and intense solar radiation. It aims to eradicate or reduce soil-borne inoculum, prior to planting. The final goal is to achieve an economic reduction in disease incidence for at least one season [15]. Solarization is non-hazardous, more economical and leaves no residue [16]. In this connection the present experiment was undertaken to evaluate the different integrated disease management approaches for rhizome rot disease management under field conditions with cost effective practices.

2. MATERIALS AND METHODS

A field experiment was conducted in farmers' ginger filed at Bikonahalli village of Shivamogga, where the highest disease incidence was observed. Integrated approaches were made under field conditions in relation to managing the rhizome rot of ginger. The trial was laid out in a Randomized completely block design (RCBD) with four replications with a plot size of 14.2

x14.2 m. The variety Himachal was used (Plate 1a). All the recommended packages and practices of Ginger production were followed for all treatments except the control treatment. The details of the treatments are given in the Table 1.

Plate 1a. IDM activities in farmers filed

Table 1. Treatment details of the integrated disease management of rhizome rot of ginger caused by *R. solanacearum*

Plot size	: 8m x 8m
Design	: RCBD
Treatments	: 7
Replications	: 4
Variety	: Himachal
Location	: Bikonahalli village, Shivamogga.

Treatment No.	Treatment details
T_1	Rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/l + Metalaxyl MZ @ 1.0 g/l for water three time at 20 days intervals + Ginger special spray 45 DAS.
T_2	Rhizome treatment with Kasugamycin @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/lit + Metalaxyl MZ @ 1.0 g/l for water three time at 20 days intervals + Ginger special spray 45 DAS.
T_3	Rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with Copper oxychloride @ 3.0 g/l + Metalaxyl MZ @ 1.0 g/l for water three time at 20 days intervals + Ginger special spray 45 DAS.
T_4	Rhizome treatment with Kasugamycin @ 0.5 g + COC @ 3.0 g/lit of water + soil application with neem cake 3q/ha followed by drenching with Copper oxychloride @ 3.0 g/l + Metalaxyl MZ @ 1.0 g/l of water three time at 20 days intervals + Ginger special spray 45 DAS.
T_5	Rhizome treatment with *Trichodermaharzianum* @ 8 g/Kg + Soil application of Trichoderma harzianum @ 10 Kg talc powder mixed with 25t FYM /ha + Ginger special spray 45 DAS.
T_6	Neem cake 3q/ha + Metalaxyl MZ @ 1.0 g/lit. of water three time at 20 days intervals + Ginger special spray 45 DAS.
T_7	Rhizome treatment with *Pseudomonasfluorescens* @ 8 g /Kg + Soil application of *P. fluorescens* @ 10 Kg talc powder mixed with FYM /ha + Ginger special spray 45 DAS.
T_8	Ginger special spray 45 DAS
T_9	Untreated (Control)

2.1 Soil Solarization as a Component in Integrated Disease Management with Special Reference to *R. solanacearum*

Soil solarization is a method of soil disinfection based on its solar heating by mulching soil with a transparent polyethylene during the hot season, thereby controlling soil-borne pathogen and disease control are attributed to microbial, chemical, and physical processes in addition to the thermal killing. Soil solarization was achieved by mulching with a transparent polythene sheet for around 45 days during the summer season to the specific treatment. The experiment was conducted in the sick plots of rhizome rot at ZARS, College of Agriculture, Shivamogga and healthy rhizomes of variety Himachal were used. The details of the treatments are given in the Table 2.

Plots were prepared after pre-monsoon shower in the first week of April. The beds in the plot meant for solarization were immediately covered with transparent polythene sheets of thickness 150µm and the sides were sealed. The non-solarized plots were also maintained without polythene tarping. After solarization the beds were imposed with the treatments with best components of all bactericides *i.e.,* rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water, soil application bioagents *i.e. P. fluorescens* and FYM.

The land to be used for solarized was thoroughly cultivated and then levelled so as to minimize protrusions as clods, stubble and stones to prevent tearing of the sheet. 40-50 mm irrigation was given before mulching. The Clear, transparent polythene sheet of 150µm thickness was used for this purpose. The polythene sheet was applied immediately after irrigation and when it was least windy. Solarization was conducted for six weeks during April to May. All free edges were buried and the soil around them compacted so as to prevent escape of heated air or moisture.

2.2 Observations

The observations about the incidence and severity of the disease were recorded using the percent disease incidence formula and PDI was worked out in each treatment Soil temperature in each plot was recorded daily at three different depths viz., 5, 15 and 30cm using permanently fixed soil thermometers. The bacterial population in both the plots was analyzed before the commencement of soil solarization, subsequently it was recorded once in every in 15 days. *R. solanacearum* population was estimated by using the serial dilution method on TZC media.

The yield observations were recorded based on the weight of rhizomes collected from each bed were separated and the weight of the rhizomes was recorded and the average was computed and later it was converted to per hectare. The cost of cultivation was calculated based on the price of input that prevailed at the time of their use and was considered to work out the cost of cultivation. The cost of cultivation was worked out considering the material input cost like the rhizome, manure, fertilizer, etc. and labor for all the operations except the price of the treated chemicals/bio-agents. Treatment wise cost of cultivation based on the price of the treated chemicals/bio-agents was worked out and expressed as ha^{-1}. . The data obtained were analyzed statistically. The data on yield of rhizome in treated and control plots were also recorded and analyzed as per the statistical procedures [17].

3. RESULTS AND DISCUSSION

As a part of experiment the roving survey was also conducted in different Ginger growing areas of Karnataka to know the incidence and severity of bacterial rhizome rot of Ginger and collection of isolates from different geographical locations. The bacterial rhizome rot incidence was observed in all the surveyed locations of Karnataka state *viz*., Shivamogga, Hassan, Uttara Kannada and Bidar districts and the disease incidence varies from 11.25 to 46.25 percent. In the evaluation of bactericides new generation of systemic molecules were tested both in laboratory and field conditions along with recommended bactericides to know their relative efficacy against pathogen. The disease could be managed effectively by incorporating fungicides, bactericides, bioagents and organic amendments.

Table 2. Treatment details of soil solarization treatments as a component of integrated disease management

Plot size : 8m x 8m
Design : RCBD
Treatments : 7
Replications : 4
Variety : Himachal
Location : Bikonahalli village, Shivamogga.

Sl. No.	Treatment details
T_1	soil solarization alone
T_1	T_1 + Rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water + soil application of 25t FYM /ha
T_2	T_1 + Rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water + Soil application of *Trichoderma harzianum* @ 10 kg along with 25t FYM /ha
T_3	T_1+ Rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water + Soil application of *Pseudomonas fluorescens* @ 10 kg along with 25t FYM /ha
T_4	T_1+ Rhizome treatment with *P. fluorescens* @ 10 g /kg rhizomes
T_5	T_1+ Rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/l of water + Soil application of *P. fluorescens* @ 10 kg along with 25t FYM /ha + Metalaxyl MZ @ 1.0 g/ldrenching (45 DAP immediately after the onset of the diseases)
T_7	Control (Without soil solarization)

Overall view of field

T1 = Rhizome treatment with streptocycline @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/l + Metalaxyl MZ @1.0 g/l of water three time at 20 days intervals + Ginger special spray 45 DAS.

Control

Plate 1b. Effect of integrated approaches on ralstonia solanacearum at different treatments

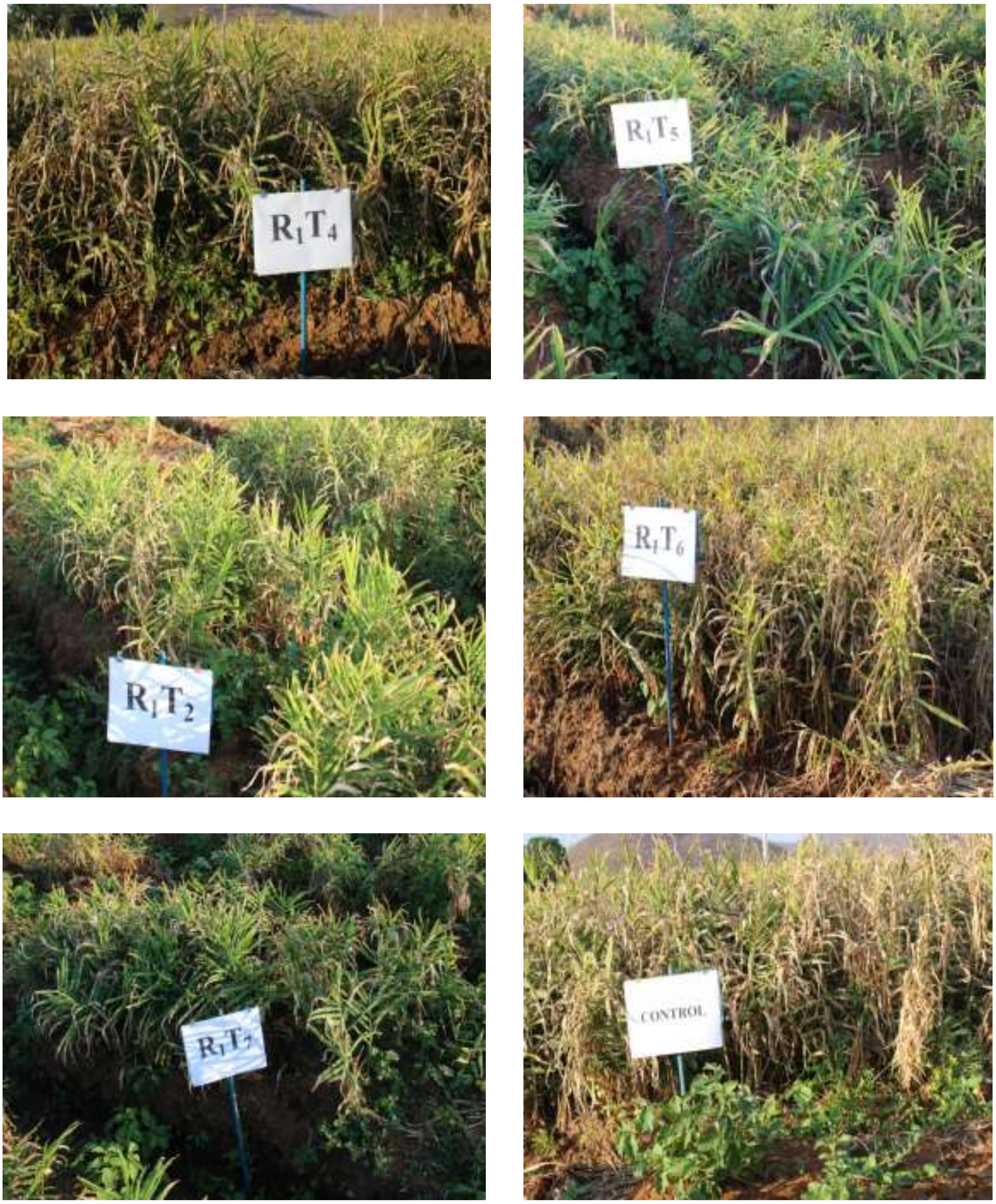

Plate 1c. Effect of integrated approaches on *Ralstonia solanacearum* at different treatments

The results of integrated disease management of bacterial rhizome rot of Ginger were indicated in Table 3, plates 1a, 1b and 1c. The result revealed that, among the nine different integrated treatments, rhizomes of ginger treated with Streptocycline @ 0.5 g + COC @ 3.0 g/lit of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/lit + Metalaxyl MZ @ 1.0 g/lit for three time at 20 days intervals + Ginger special spray 45 DAS (T_1) for three time at 20 days interval starting with initiation of the disease recorded very less disease incidence of 14.23 percent and which was found significantly superior over control (48.50 %), followed by T_7 (rhizome treatment with *Pseudomonas* *fluorescens* @ 8 g /Kg + Soil application of *P.fluorescens* @ 10 Kg talc powder mixed with FYM /ha + Ginger special spray 45 DAS three time at 20 days interval starting with the disease initiation) recorded a disease incidence of 16.05 per cent. Apart from above, better drainage was maintained in the field as a good cultural practice, other cultural practices like proper land preparation, healthy planting materials, application of FYM and other nutrients have resulted in good germination in treated plots.

Present findings confirm the findings of previous research showed, rhizomes of ginger treated with streptocycline @ 0.5 g/l + COC @ 2.0 g/l + soil application of carbofuron + drenching with metalaxyl MZ @ 1.0 g/l and drenching the streptocycline at 0.5 g per lit twice at 20 days interval starting from the initiation of disease recorded very less (11.75 percent) disease incidence [18]. Similar findings have also been by Anand [19] who reported that, rhizomes treated with Streptocycline @ 0.5 g + COC @ 3.0 g/lit of water + soil application with neem cake followed by drenching with bleaching powder (33%) @ 2.0 g/lit + Metalaxyl MZ @1.0 g/lit for water three times at 20 days interval starting with initiation of the disease recorded less incidence of rhizome rot (15.50 %) over control (47.42 %).

3.1 Yield

The yield was significantly higher in treatments like rhizomes of ginger treated with Streptocycline @ 0.5 g + COC @ 3.0 g/lit of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/lit + Metalaxyl MZ @ 1.0 g/lit for water three time at 20 days intervals + ginger special spray 45 DAS three time at 20 days interval starting with initiation of the disease, which recorded a yield of 110.27q/ha, followed by T_7(106.05 q/ha) and T_5 (105.50 q/ha). Whereas in control plot, yielded the minimum rhizome yield of 65.51q/ha.

3.2 Benefit Cost Ratio

The benefit cost ratio has been worked out for different treatments and presented in table 15. The highest B: C ratio was obtained in treatment T_1 (2.53) followed byT_7 (2.28). Most of the remaining treatments, T_5 recorded 2.26 and 2.10 in T_2 respectively. Ojha *et al.* (1986) observed that, rhizome treatment with Emisan 6 +plantomycine followed by three sprayings in 30 days interval after planting gives good control of the rhizome rot disease with highest benefit cost ration (1.980) compared to untreated control (0.78) treatment. Singh *et al.* [20] stated that streptomycin + Streptopenicilline was effective against the *R. solanacearum* both under *in vitro* and *in vivo* conditions.

3.2.1 Soil solarization component in the integrated disease management with special reference to *R. solanacearum*

Integrated management of rhizome rot of ginger through soil solarization (Table 4 and Plate 2) revealed that, among the different treatments, the treatment treated with soil solarization + rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/lit of water + Soil application of *Pseudomonas fluorescens* @ 10 kg along with 25t FYM /ha recorded higher yield of 115.23 q/ha with less percent disease incidence (8.20 %).

These findings are in agreement with Anith *et al.,* [21] found that the maximum mean difference in temperature taken at 14 h. was 12.2°C in plots mulched after irrigation which significantly reduced the soil microbial population, solarization and seed treatment with *P. fluorescens* strain EM 85 decreased the wilt incidence to 7.42 per cent and increased the yield to 29.42 t/ha over control. They also showed the incorporation of neem cake before solarization provides no additional advantage in controlling the disease. Interaction between solarization and bactericides leading to synergistic effect on suppression of soil-borne pathogens were demonstrated by Aharonson and Katan [22]. Hence, soil solarization concept helps the farming community to manage the disease effectively and also enhance the yield levels.

Increase in soil temperature in solarized plot was observed at 5, 15 and 30 cm depth. Soil temperature in solarized plot at 5 cm depth was increased by 10.70^{O}C over nonsolarized plot. In deeper depth also temperature was increased by 3 to 8^{O}C. In the month of April, highest temperature was recorded (56.60) during 2nd week of April at 5 cm depth. Similar results are obtained by Katan [23] rise in soil temperature to the tune of 10^{o}C in solarized field. Maximum temperature attained decrease with increasing soil depths. Balakrishnan *et al*. [24] reported that, there was increase in temperature in solarized plot by 8^{O}C at 5 cm depth over non-solarized plot.

Soil solarization plots

T3 = Soil solarization + Rhizome treatment with streptocycline @ 0.5 g + COC @ 3.0 g/l of water + soil application of *Pseudomonas fluorescens* @ 10 kg along with 25t FYM/ha

Control

Plate 2. Integration of soil solarization for the management of rhizome rot of ginger

Conclusion

Table 3. Integrated management of rhizome rot of ginger caused by *Ralstonia solanacearum* under field condition

Treatment details		Per cent disease incidence	Yield (Q/ha)	Benefit cost ratio
T_1	Rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/l + Metalaxyl MZ @ 1.0 g/lit for water three time at 20 days intervals + Ginger special spray 45 DAS.	14.23 (22.16)*	110.27	2.53
T_2	Rhizome treatment with Kasugamycin @ 0.5 g + COC @ 3.0 g/l of water + soil application with neem cake 3q/ha followed by drenching with bleaching powder (33%) @ 2.0 g/l + Metalaxyl MZ @ 1.0 g/lit for water three time at 20 days intervals + Ginger special spray 45 DAS.	17.15 (24.46)	98.38	2.10
T_3	Rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/lit of water + soil application with neem cake 3q/ha followed by drenching with Copper oxychloride @ 3.0 g/lit + Metalaxyl MZ @ 1.0 g/lit for water three time at 20 days intervals + Ginger special spray 45 DAS.	17.80 (24.95)	95.63	1.96
T_4	Rhizome treatment with Kasugamycin @ 0.5 g + COC @ 3.0 g/lit of water + soil application with neem cake 3q/ha followed by drenching with Copper oxychloride @ 3.0 g/lit + Metalaxyl MZ @ 1.0 g/lit of water three time at 20 days intervals + Ginger special spray 45 DAS.	18.20 (25.25)	90.20	1.61
T_5	Rhizome treatment with *Trichoderma harzianum* @ 8 g/Kg + Soil application of*T. harzianum* @ 10 Kg talc powder mixed with 25t FYM /ha + Ginger special spray 45 DAS.	16.75 (24.16)	105.50	2.26
T_6	Neem cake 3q/ha + Metalaxyl MZ @ 1.0 g/lit. of water three time at 20 days intervals + Ginger special spray 45 DAS.	30.45 (33.49)	80.08	1.31
T_7	Rhizome treatment with *Pseudomonas fluorescens* @ 8 g /Kg + Soil application of *P. fluorescens* @ 10 Kg talc powder mixed with FYM /ha + Ginger special spray 45 DAS.	16..05 (23.62	106.05	2.28
T_8	Ginger special spray 45 DAS	37.33 (37.66)	73.24	0.97
T_9	Control	48.50 (44.14)	65.51	0.78
S.Em ±		0.58	0.624	
CD at 5 %		1.84	4.02	

** Figures in the parenthesis are corresponding arcsine transformed values.*

Table 4. Effect of soil solarization and rhizome treatment and drenching of bactericides/ biocontrol agents/ organic manure on *Ralstonia solanacearum* under field condition

Treatment details		Per cent disease incidence	Yield (Q/ha)	Benefit cost ratio
T_1	Soil solarization alone	10.60 (19.00) *	112.43	2.30
T_2	T_1 + Rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water + soil application of 25t FYM /ha	15.30 (23.03)	98.18	2.15
T_3	T_1 + Rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water + Soil application of *Trichoderma harzianum* @ 10 kg along with 25t FYM /ha	8.20 (16.64)	115.23	3.80
T_4	T_1+ Rhizome treatment with Streptocycline @ 0.5 g + Copper Oxy Chloride @ 3.0 g/l of water + Soil application of *Pseudomonas fluorescens* @ 10 kg along with 25t FYM /ha	13.15 (21.26)	108.48	2.78
T_5	T_1 + Rhizome treatment with *P. fluorescens* @ 10 g /kg rhizomes	17.33 (24.60)	91.68	1.80
T_6	T_1 + Rhizome treatment with Streptocycline @ 0.5 g + COC @ 3.0 g/l of water + Soil application of *P. fluorescens* @ 10 kg along with 25t FYM /ha + Metalaxyl MZ @ 1.0 g/l drenching (45 DAP immediately after the onset of the diseases)	20.65 (27.03)	86.63	1.20
T_7	Control (Without soil solarization)	48.20 (43.97)	70.38	0.97
S.Em ±		0.970	1.452	
CD at 5 %		2.97	4.361	

** - Figures in the parenthesis are corresponding arcsine transformed values.*

Soil solarization was an effective method for managing rhizome rot has been reported by many workers (Katan et al., [16] Grinstein *et al.,* [25] Stapleton and DeVay, [26]. The temperature range of 37-52o C is sufficient to kill or inhibit most of the major pathogens provided sufficiently long exposure time for sunlight is allowed (Katan, 1981).[15] Significant reduction of *R. solanacearum* population could be noticed in solarized plots. *R. solanacearum* populations were almost same before solarization and non-solarized control plots [27].

4. CONCLUSION

Bacterial rhizome rot is the major constraint of Ginger production throughout the world. Since the pathogen is soil and seed born once it enters the soil, it can multiply and transmit in a short period of time, which leads to difficulty to managing. As of now, a single control measure has not found effective against the pathogen. However, some levels of bacterial rot diseases can be managed through the possible use of a combination of diverse methods, like disease resistance, quarantine methods, agronomic practices, biological control and chemical control with integrated disease management approaches. Even though these different approaches have been developed to control this disease, we still lack an efficient and environmentally friendly control measure for most of the host crops, especially for Ginger. Special focus should be given to this pathogen in the future to avoid crop loss.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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