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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(8): 1230-1232

www.thepharmajournal.com
Received: 07-05-2023
Accepted: 15-07-2023

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Yield maximization in ginger through management of ginger (*Zingiber officinale* Roscoe) rhizome rot

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Abstract
Ginger (*Zingiber officinale* Roscoe) is facing a serious issue with rhizome rot, which is caused by the fungal genus *Fusarium oxysporum* f. sp *zingiberi*. This problem is affecting the production and cultivation of ginger not only in the state of Bihar, but throughout the entire country. To investigate the effect of on-farm testing on the adoption of ginger production technologies among smallholder farmers in the Kishanganj district of the Koshi region of the state Bihar, we studied through adopting a pragmatic paradigm and a cross-sectional survey design, sampling farmers in two consecutive years (2021and 2022). A study was conducted by Krishi Vigyan Kendra in Kishanganj, Bihar, to develop alternative control strategies for reducing the dependence on synthetic fungicides. The focus was on managing rhizome rot disease in ginger using eco-friendly methods such as bio-control agents. The study was conducted using a randomized complete block design. Results revealed that the maximum average yield of ginger was 182.7 and 189.78 q/ha with pooled 186.24 q/ha was recorded with maximum rhizome germination 83.21% and 85.65% with pooled 84.43% and minimum plant infected 17.68% and 16.59 with pooled 17.13%, with application of *T. harzianum* 2.5 kg mixed with 50 kg FYM + Metalaxil MZ 1gm/l of water 3 drenching at 20 days of interval and BC ratio 2.75.

Keywords: Ginger, rhizome rot, *T. harzianum.* germination, yield, fungicides

Introduction
Ginger is a valuable crop that is primarily grown for its aromatic rhizomes, which are utilized as a spice and for medicinal purposes. Ginger is said to have originated in southern China, Southeast Asia, and India. It was brought to the Mediterranean in the 1st century, Japan in the 3rd century, England in the 11th century, and America in 1585, according to Langner *et al.* (1998) [8]. Ginger has potential benefits in traditional medicine due to its nutritional value, taste properties, and therapeutic advantages, as noted by Le *et al.* (2014) [9]. The major ginger-producing countries are India, China, Nigeria, Indonesia, Bangladesh, Thailand, Philippines, Jamaica, etc. India ranks first with respect to ginger production contributing about 32.75% of the world's production followed by China (21.41%). Ginger is typically utilized as a spice and flavor enhancer in food. However, the crop is vulnerable to insect pests, as well as pathogenic and non-pathogenic diseases (Yuan and Gao, 2016) [17]. Furthermore, it is significantly affected by a variety of pathogenic diseases that originate from viruses, bacteria, fungi, and nematodes, resulting in a sharp decrease in potential yields (Dohroo, 2016) [5]. Rhizome rot in ginger is a major disease that affects the yield and quality of ginger crops globally. The disease is often caused by a complex of pathogens such as *Pythium spp.*, *Fusarium spp.*, and *Ralstonia solanacearum*, amongst others, which are soil-borne fungi and bacteria that cause decay in the rhizomes, the underground stems of the ginger plant. The rhizomes become soft, water-soaked, and discoloured, often exhibiting a foul smell due to the rot. Unfortunately, the cultivation of this crop is severely impacted by rhizome rot caused by *Fusarium oxysporum* f. sp *zingiberi*, which is a persistent issue in the state's production. The disease has been observed to appear as pre- or post-emergence rhizome rotting, resulting in significant losses of up to 92 percent in some local cultivars (Daiho and Upadhyay, 2004) [2]. The pathogen is both seed and soilborne. Several workers have worked to prevent this disease, and the efficiency of several treatments against it is well established (Das *et al*, 1990, Haware and Joshi, 1974., Sharma and Rana, 2000., Singh *et al*, 2004., Sterling, 2004) [3, 6, 13, 14, 16].

Managing rhizome rot in ginger can be challenging due to the soil-borne nature of the pathogens. It often involves a combination of strategies, including the use of resistant varieties, proper field sanitation, good water management, crop rotation, and in some cases, the application of fungicides and biocontrol agents. The disease comes on by microorganisms that attack the rhizome's root, collars, and juicy regions. Soft rot is the most serious and destructive ginger disease known to science. Although it is difficult to find precise information, it has been suggested that ginger soft rot reduces yields by between 50 and 90%. (N P Dohroo, 2005) [10]. Application of a mixture of biological bacteria could be very promising to increase rhizome production (Debata *et al*., 2019) [4]. Rhizome rot poses a significant economic threat to ginger producers around the world, given that the disease can cause substantial losses in yield. It is therefore essential for further research and development efforts to be made to manage this disease effectively. Trichoderma may be applied at the time of planting and subsequently if necessary.

Methods and Materials

Selecting and conducting on-farm experiments

The farmers were selected by organizing group meeting prior to conduction of demonstrations on farm testing on yield maximization in ginger through management of Ginger rhizome rot and specific comprehensive training was also conducted for the selected farmers regarding detail package of practices of Ginger. A base line survey was carried out to find out the problems under ginger cultivation in the demonstration area and it was observed that lower average yield with rhizome rot was mainly due to use of only unknown fungicides, no rhizome treatment, no soil testing and imbalance use of inorganic fertilizers and plant protection chemicals resulting in poor plant population, growth, and yield.

Imposition of treatments

During the summer seasons of 2021 and 2022, an experiment was conducted on several farmers' fields in the Kishanganj district of Bihar, India. The experiment was supervised by the Farm Science Centre in Kishanganj and followed a Complete Randomized Block Design with eight replications. Centre ware facilitated the farmers to conduct effective demonstrations and monitored the on-farm testing with time-to-time visits on the fields. The several treatments included were i) Farmer's practice: unknown fungicides (T_1) ii) Seed Treatment + Soil drenching with Metalaxil MZ 1gm/L. (T_2) iii) Application of *Trichoderma harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/L of water in 3 drenching at 20 days (T_3). All the technological interventions were taken as per the prescribed package and practices for improved Nadia variety.

Planting of rhizomes

The experimental site of the land, it's crucial to ensure the soil is friable; thus, the field is ploughed and harrowed. Raised beds, typically 15 cm in height and 100 cm in width, are structured to facilitate proper drainage. Healthy, disease-free rhizome pieces, weighing around 20-25 grams and often referred to as "sets", are ideal for planting. Planting is generally done as the monsoon begins, around May to June. It's imperative to maintain moderate irrigation without letting water stagnate.

Observations recorded

For each treatment and replication, five competitive plants were chosen to observe four economically important traits. *viz*., Rhizome germination %, Infected plant %, Disease severity %, Rhizome Yield (q/ha.) as well as economic study (benefit-cost ratio) of experimental plots. The data from the two years (2021 and 2022) is pooled and the analysis of variance (ANOVA) for the experiment was carried out according to SPAR 2.0.

Results and Discussion

In 2021 and 2022, the antagonistic ability of certain biological control agents was tested against *Fusarium oxysporum* f. sp. *zingiberi*. In 2021 and 2022, the antagonistic ability of certain biological control agents was tested against *Fusarium oxysporum* f. sp. zingiberi. There was significant difference in rhizome yield of ginger due to application of *T. harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/l of water 3 drenching at 20 days in both years. Under field condition, application of *T. harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/l of water 3 drenching at 20 days of resulted in maximum reduction of plant infection 17.68% and 16. 59% with pooled 17.13% and germination of rhizome maximized 83.21% and 85. 65% with pooled 84.43% with consequent disease control severity (0-5) in 4 and 5 with pooled 4.5, crop stand over the farmers practice rhizome yield (q/ha) 182.70 and189.78 with pooled 186.24, respectively in similar observation made by Khatso and Tiameren, 2013) [7]. In Table 1, it was found that all treatments had a significant decrease in disease incidence compared to the control group and showed similar results. The effectiveness of *Trichoderma spp* in controlling Several researchers, such as Bhardwaj *et al*. (1988) [1], Srivastava (1994) [15], Rajan *et al*. (2002) [11], Daiho and Upadhyay (2004) [2], have reported on the impact of Fusarium-induced diseases on growth and yield improvement. In 2000, Ram *et al*. found that *T. harzianum* was able to thrive in the rhizosphere of ginger plants and effectively lower the occurrence of *Fusarium* sp., leading to a notable boost in crop yield. The findings of the current study indicate that *T. harzianum* has a strong ability to combat plant diseases through its effective antagonistic and mycoparasitic activity. These results align with those of previous researchers. A statement was reported that fungal biocontrol agents, such as *T. harzianum* and Trichoderma virens, are effective in controlling pathogens in other crops like black pepper, cardamom, and ginger. Considering the economics of study, particularly net return, benefit: cost ratio, and the rhizome yield of recorded. The economic parameters were obtained under application of *T. harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/l of water 3 drenching at 20 days net return Rs. 2,90,750 and Rs. 3,07,250 with B: C ratio 2.75 and 2.84 in 2021 and 2022, respectively (Table 2).

Table 1: Agro-morphological parameters and disease infestation of rhizome under different treatment combinations on Ginger crops. (2021 and 2022)

Technology options	Rhizome germination (%)			Infected plant (%)			Disease severity (0-5)			Rhizome yield (q/ha)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1: Farmer Practice (unknown fungicides)	66.55	67.22	66.88	41.66	43.54	42.60	1.00	1.00	1.00	126.60	122.85	124.72
T_2: Seed treatment + soil drenching with Metalaxil MZ 1gm/l	72.85	70.50	71.67	27.22	29.41	28.32	2.00	3.00	2.50	160.40	161.76	161.08
T_3: Application of *T. harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/l of water 3 drenching at 20 days.	83.21	85.65	84.43	17.68	16.59	17.13	4.00	5.00	4.50	182.70	189.78	186.24
S.Em ±	4.46	5.10	4.97	2.14	2.42	2.37	-	-	-	10.33	12.74	11.88
CD @ 5%	8.86	10.14	9.89	4.25	4.82	4.71	-	-	-	20.54	25.33	23.61

Table 2: Effect of different application of treatments on Economics of Ginger crops. 2021 and 2022)

Technology options	Cost of cultivation (Rs/ha)		Grass return (Rs/ha)		Net return (Rs/ha)		BC ratio	
T_1: Farmer Practice (unknown fungicides)	160000	161500	316500	307125	156500	145625	1.98	1.90
T_2: Seed treatment + soil drenching with Metalaxil MZ 1gm/l	164200	164800	401000	404400	236800	239600	2.44	2.45
T_3: Application of *T. harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/l of water 3 drenching at 20 days.	166000	167200	456750	474450	290750	307250	2.75	2.84

Conclusion
From the overall results, we came to the conclusion that different treatments of biochemical and systematic fungicides under the application of *T. harzianum* (2.5 kg mixed with 50 kg FYM) + Metalaxil MZ 1gm/l of water 3 drenching at 20 days performed well under both season of Ginger production against the rhizome rot in Kishanganj district of Bihar. It is recommended to involve extension workers and farmers in a participatory approach to demonstrate proven technologies and evaluate the potential to reduce losses caused by disease incidences.

Acknowledgment
This study was financially supported by Krishi Vigyan Kendra, Kishanganj from ATMA, Kishanganj and the authors of grateful to ICAR- ATARI, Zone-IV, Patna and BAU, Sabour for necessary support and guidance to complete this work successfully.

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