J.Mycopathol.Res. 62(4) : 769-776, 2024, ISSN : 0971-3719 (Print), 2583-6315 (Online) 10.57023/JMycR.62.4.2024.769

Incremental cost-benefit ratio of biocontrol agents and fungicides against *Aspergillus niger* in groundnut in western undulating agroclimatic zones of Odisha

SRUJANI BEHERA[1*], SUNITA BEHERA[2] AND B.S. NAYAK[3]

[1]*Plant Pathology, College of Agriculture, Odisha University of Agriculture and Technology, Bhawanipatna-766001, Odisha*

[2]*Plant Pathology, Nutri Crops Research Station, OUAT, Berhampur-751003, Odisha*

[3]*RRTTS, OUAT, Bhawanipatna-766001, Odisha*

Received : 14.07.2024 Accepted : 04.11.24 Published : 30.12.2024

Groundnut is an economically important edible oilseed crop. Of the diseases that affect groundnuts, collar rot is one of the most commercially significant and is seen in practically every state that grows groundnuts. This disease is extensive in the *Kharif* season rather than *Rabi* season. In *kharif* 2022 and 2023, an experiment was carried out to calculate the Incremental Cost-Benefit Ratio (ICBR) of biocontrol agents and fungicides against *Aspergillus niger* in groundnut. It is important to investigate the results of treating seeds, applying FYM to the soil, and drenching the soil in fungicides. Total grain yield, additional yield, increased income, and net income were acquired for each treatment upon crop maturity in order to calculate its ICBR. The research findings indicate that the highest ICBR of 1:5.48 was attained in the plot treated with a combination of Carboxin+Thiram at 2 g /kg seed, followed by soil treatment using *Trichoderma viride* and *Pseudomonas fluorescens* @ 4kg each along with 10q/ha enriched FYM at sowing time, and subsequent soil drenching with the same beneficial fungi in comparison to control. The effectiveness of treatment and cost-effectiveness were considered in evaluating these approaches. Soil drenching with beneficial fungi can effectively manage diseases while maintaining healthy soil.

Keywords : Additional income, Additional yield, ICBR, *Pseudomonas fluorescens*, *Trichoderma viride*

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oil, food and feed legume crop grown in over 100 countries. It is the world's third-most significant source of vegetable protein and the fourth-most significant source of edible oil. With a total acerage of 54.2 lakh hectares under cultivation, India leads the globe in groundnut production with 101 lakh tons and an average productivity of 1863 kg per hectare in 2021–2022. Over 45.53 lakh hectares, groundnut production reached 83.69 lakh tonnes in *Kharif*, 2022–2023 (Haseena Banu *et al*. 2022).

Although groundnuts are grown in all three seasons (*Kharif, Rabi*, and Summer), *Kharif* crops account for around 90% of the crop's acreage and yield (June to October).

In India, the crop is mostly grown in the states of Gujarat, Andhra Pradesh, Telangana, Tamil Nadu, Karnataka, Rajasthan, Maharashtra and Odisha constituting about 80% of the total area and production of groundnut. According to Odisha Agriculture Statistics 2021-22 for the year 2021–22, kharif groundnut is grown on 69.04 thousand hectares in Odisha and produces 103.06 thousand metric tonnes. In Kalahandi district, on the other hand, kharif groundnut is grown on 4.81 thousand hectares and produces 8.1 thousand metric tonnes. Due to biotic and abiotic stresses, groundnut production frequently has large yield losses each year, which is one of the major limiting factors to achieving high productivity in India. Reduced pod yields can be attributed to a various biotic stress, including foliar and soilborne diseases (Vineela *et al*. 2018). All crop growing areas are experiencing severe damage from fungal diseases such collar rot (*Aspergillus niger*), stem rot (*Sclerotium rolfsii*), and root rot (*Rhizoctonia solani*) (Jadon *et al*. 2015). Among

*Correspondence : srujani@ouat.ac.in

these, collar rot disease is the major soil borne disease with significant yield losses annually. The disease known as collar rot is typically observed in the early phases of crop growth. It frequently causes increased rates of seedling mortality and presents as a pre- and post-emergence damping-off of the affected seedlings. This pathogen is polyphagous, ubiquitous, nontargeting, and extremely damaging in soil and seeds (, Kumar and Saifulla 2017). It is important to note that this disease affects practically every area in the world where groundnuts are grown. According to Suman and Tahira (2019), collar rot is prevalent in almost every Indian state that grows groundnuts, including Punjab, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Gujarat, Maharashtra, Rajasthan, Karnataka, and Odisha. Debata and Das (2018) reported that the incidence of the disease in Odisha is 12–31%. Medium black and sandy loam soils are seeing an increase in the prevalence of collar rot. This disease can affect most varieties of groundnuts. The pathogen produces significant yield losses in groundnut crops and is adaptable even at higher temperatures (Kumari and Singh 2016).

It is extremely difficult to manage soil-borne diseases in groundnuts (Standish et al., 2019). The combined application of all possible management techniques, including chemical, biological, physical, and host plant resistance, is known as integrated disease management (IDM). When these bio agents are utilized in IDM, the harmful effects of fungicides and herbicides may cause their efficacy to be reduced (Wang *et al*. 2018; Liu *et al.* 2018). According to multiple reports (Adhilakshmi *et al*. 2014; John *et al*. 2015; Ekundayo *et al*. 2016; Sharma *et al*. 2016), groundnut collar rot can be controlled by bioagents like *Trichodema harzianum* and *Pseudomonas fluorescens*.Collarrot can be also be managed by seed treatment with fungicides like thiram, carbendazim (Divya *et al*. 2012).

Numerous studies on the antagonistic properties of several bacterial and fungal biocontrol agents have been conducted over the past three decades (Howell, 2003; Kishore *et al.* 2005; Couillerot*et al*. 2008) They are well-known antagonists, especially in the soil, and they participate in competition, antibiosis, and hyperparasitic interactions. It has been observed that *Trichoderma* spp. (Rao and Sitaraiah, 2000; Gajera et al., 2011; Sharma et al., 2012) and *Pseudomonas fluorescens* (Parakhia and Akbari, 2004; Latha, 2013) are effective against *A. niger*. Therefore, the current experiment was carried out utilizing various combinations of biocontrol agents and fungicides to know the influence against *Aspergillus niger* on groundnut crop in order to create a superior disease management module for the crop in this location. In order to determine the most cost-effective application, the incremental cost-benefit ratio (ICBR) of several treatment combinations was then calculated for the *kharif* 2022 and 2023.

MATERIALS AND METHODS

During the kharif seasons of 2022 and 2023, an experiment was carried out at the Regional Research and Transfer Technology Station, OUAT, Bhawanipatna, Kalahandi, Odisha, with the aim of identifying a low-cost and acceptable alternative for managing *Aspergillus niger* in groundnut. Throughout both of the experimental years, the same plots were employed. Bhawanipatna is situated 248 meters above mean sea level and is located in latitudes 19 54'36" N and longitudes 83 7'40.8" E, respectively. The Kalahandi district is located in Odisha's Western Undulating Agroclimatic Zone. The three different seasons are wet (mid-June to September), winter (October to February), and summer (March to mid-June). The climate is hot and humid sub-humid. It receives 1352 mm of mean annual rainfall, of which the rainy season accounts for about 90%. The mean maximum summer temperature is 37.8°C and the mean minimum winter temperature is 11.9°C. In nature, the soils are clay loam to sandy clay loam. The nature of the soil is non-saline. The soil's reaction might range from being quite alkaline to being somewhat acidic. Soil's organic carbon content ranges from 3.97 to 12.90 g /kg, with low to high values. The soil at such locations has a low available nitrogen status, ranging from 25.27 to 248.21 kg/ ha. The soil's available potassium and phosphorus levels range from medium to high (Sinha and Dash, 2021).The experiment was laid out in a randomized block design with three replications using the cultivar Dharani (TCGS-1043) in 3 × 3 m sized plots with row to row spacing at 30 cm and plant to plant spacing at 15 cm. The following are the treatments.

Details of the treatments used in field studies

T_1: Seed treatment with Carbendazim 50% WP @2g/kg of seeds and soil drenching with Carbendazim (12%) +Mancozeb (63%) @2g/l at the time of sowing and twice @10days interval.

T_2: Seed treatment with Carboxin +Thiram @ 2g/ kg and soil drenching with Validamycin 3%L@2ml/lat the time of sowing and twice @10days interval.

T_3: Seed treatment with Tebuconazole 2% DS @ 1.5g/kg seeds and soil drenching with Tebuconazole 25.9% EC @2ml/l at the time of sowing and twice @10days interval.

T_4: Seed treatment with Metalaxyl 35%WS @ 1.5g/kg seeds and soil drenching with Metalaxyl (8%) +Mancozeb (64%) @ 2g/l at the time of sowing and twice @10days interval.

T_5: Seed treatment with *Trichoderma viride* @ 10g/kg seeds and soil application of *T.viride* @ 4kg along with 10q/ha enriched FYM at time of sowing and soil drenching with *T.viride* @ 10g/l twice @ 15 days interval.

T_6: Seed treatment with *Trichodermaviride* + *Pseudomonas fluorescens* @ 5g each/kg of seeds and soil application of *T. viride* + *P. fluorescens* @ 4kg each along with 10q/ha enriched FYM at time of sowing and soil drenching with *T. viride* + *P. fluorescens* @ 10g each/ltwice @ 15 days interval.

T_7: Seed treatment with Carboxin+Thiram@ 2g/ kg and soil application of *T. viride* + *P. fluorescens* @ 4kg each along with 10q/ha enriched FYM at time of sowing and soil drenching with *T. viride* + *P. fluorescens* @ 10g each/l twice @ 15 days interval.

T_8: Untreated Control

The groundnut cultivar Dharani (TCGS-1043) was used for field studies and is susceptible to collar rot. For soil application, *T. viride* + *P. fluorescens* @ 4 kg each was combined with farm yard manure (10q/ha) and applied to the soil at the time of sowing. For seed treatment, *T.viride* @ 10g and *T. viride* + *P. fluorescens* @ 5g each were applied per kg of seed.The following treatments were applied to the soil: Tebuconazole 25.9% EC @2ml/l, Metalaxyl (8%) + Mancozeb (64%) @ 2g/ l, Validamycin 3%L@2ml/l, Carbendazim (12%) + Mancozeb (63%) @2g/l, and twice at intervals of 10 days. However, twice at a 15-day interval, soil was drenched with 10g/l of *T.viride* or 10g/l of *T. viride* + *P. fluorescens*@ 15 days interval. Before seeding, the seeds were treated with the fungicides Carbendazim 50% WP and Carboxin + Thiram at a rate of 2 g / kgseed. Before seeding, 1.5 g / kg of other fungicides, Tebuconazole 2% DS and Metalaxyl 35% WS, were applied to the seed.

Experimental details

Before the experimental plots were prepared, a basal dose of 20:40:40 kg ha^{-1} of NPK was applied. Insect pests were managed during the crop growing period by applying insecticides based on the need. Fungicidal treatments involved soaking seeds for 30 meters, followed by shade drying them before sowing, in accordance with the amount of fungicide used per kilogram of seed. The seeds were first soaked, treated with bioagents for 30 m, and then shade dried in order to treat them simultaneously with *T.viride* and *P. fluorescens* at a rate of 10 g each per kg of seed. In the first week of July, the crop was sowed. At various phases of development, it received three irrigations, and weeding was done as needed.

Method of recording observations

Up to 50 days after sowing, observations on the percentage disease incidence of collar rot were recorded on a plot basis. After that point, the incidence of collar rot is negligibledue to hardening of stem. After selecting from each plot in each treatment, the yield by plot was noted and weighed individually. For each treatment, the average yield was extrapolated and expressed as kg/plot and kg/ha before being statistically examined. The cost of labor, sprayer fees, and fungicides per hectare were factored into the total cost of plant protection. Net monetary return of a treatment was comprised of increase in yield as a function of treatment over control and prevailing market price of groundnut seed. The net profit of treatment was worked out by deducting the total cost of plant protection from total monetary return Nemade*et al*. (2017).

Cost-Benefit analysis of fungicidetreatments: Fungicides were purchased from local market of Bhawanipatna and the cost of fungicides was obtained by multiplying total quantity (kg or litre) of respective fungicides required for per hectare application with the prevalent market price (Rs.) for per litter/kg of respective fungicide. Various parameters used for working out the incremental cost benefit ratio are given below.

Labour wages (Rs./ha): Two labourers were considered sufficient for spraying in a day over one hectare crop @ prevailing local market rate of Rs. 333 or 345.00/day/labour.

Sprayer hiring charges (Rs./ha): The rent charge of power sprayer was considered as Rs.50.00 per hectare for each treatments.

Total cost of plant protection/ treatment (Rs./ha): Cost of fungicide, Labourer wages and sprayer hiring charges were summed up to work out the cost of respective treatment.

Additional yield (q/ha): This was obtained by subtracting the values of control yield from yield of a respective treatment.
Additional yield = T – C

Where, T = Yield in respective treatment
C = Yield in untreated control treatment

Additional income (Rs./ha): It was calculated by multiplying the additional yield over the untreated control with prevailing minimum support price of groundnut seed.

Net return (Rs./ha): This was calculated separately by subtracting the cost of treatment from additional income of respective treatment.
Incremental Cost-Benefit Ratio: Incremental cost benefit ratio (ICBR) was worked out as a ratio of net profit to the cost of plant protection of treatment which exhibits the economic viability of the treatment. This was calculated separately for each treatment as per following formulae suggested by Ojha (2017).

Incremental Cost Benefit Ratio =

$$\frac{\text{Net Profit}}{\text{Total cost of plant protection or Treatment}}$$

RESULTS AND DISCUSSION

Grain yield (q/ha)

Based on yield data from both years, all fungicides were found to be more superiorin increasing yield over control. The combination of treatments that produced the highest grain yield was seed treatment with Carboxin + Thiram @ 2g/kg followed by soil application of *T. viride* + *P. fluorescens* @ 4 kg along with 10q/ha FYM at planting and soil drenching with *T. viride* + *P. fluorescens* @ 10g each/l twice @15 days interval treated plot (21.11 q/ha during 2022 and 18.70 q/ha during 2019). The untreated control plot yielded the lowest yield at 14.25 q/ha and 12.26 q/ha in 2022 and 2023, respectively.

Additional yield (q/ha)

The combination of seed treatment with carboxin+thiram at 2g/kg, soil application of *T. viride* + *P. fluorescens* at 4kg + 10q/ha FYM at planting, and soil drenching with *T. viride* + *P. fluorescens* at 10g each/l twice at 15 days interval treated plot yielded the highest additional yield 6.86 q/ha and 6.44 q/ha in 2022 and 2023, respectively. Grain yield increased with other treatments, rising from 1.19 to 3.90 q/ha in 2022 and 2.18 to 4.96 q/ha in 2023.

Total Cost of treatments (Rs./ha):

The seed treatment with carbendazim @ 2g/kg, soil drenching with carbendazim+Mancozeb @ 2g/lt at planting and twice@10days interval treated plot had the lowest total cost of treatment(Rs. 4454.00); the highest (Rs. 6208) was the soil application with *T.viride* @ 4kg + 10q/ha FYM at planting and soil drenching with *T. viride* 10g/l twice@15 days intervaltreated plot in 2022. But in 2023, the total cost of treatment was highest for seed treatment with Carboxin+Thiram@ 2g/kg, soil application with *T. viride + P. fluorescens* @ 4kg + 10q/ha FYM at plantingand soil drenching with *T. viride + P. fluorescens*@ 10g each/l twice @15 days intervaltreated plot i.e Rs.6770 and lowest for seed treatment with Carbendazim @ 2g/kg, soil drenching with Carbendazim+Mancozeb@ 2g/l at planting and twice@10 days interval treated plot i.e Rs. 4735.

Additional income (Rs./ha)

The highest additional income (Rs. 40150.5/ha) was obtained with treatment combination of seed treatment with Carboxin+Thiram@ 2g/kg, soil application of *T.viride + P.fluorescens* @ 4kg along with 10q/ha FYM at time of planting and soil drenching with *T.viride + P.fluorescens*@ 10g each/l twice @15 days intervalduring 2022 and Rs. 41091.5/ha during 2023 followed by seed treatment with Carbendazim @2g/kg,soil drenching with Carbendazim+Mancozeb@2g/l at planting and twice@10daysinterval treated plot i.eRs.22804.17/ha and Rs. 31644.09 /ha during 2022 and 2023 respectively.

Net income (Rs./ha)

The combination of treatments that produced the highest net income (Rs. 33952.50/ha) was the following: seed treatment with Carboxin+ Thiram@ 2g/kg; soil application of *T. viride + P. fluorescens* @ 4kg along with 10q/ha FYM at time of planting; and soil drenching with *T. viride + P. fluorescens* @ 10g each/l twice @15 days interval in 2022 and Rs. 34321.50/ha in 2023. These treatments were followed by the treatments of seed treatment with Carbendazim @ 2g/kg and soil drenching with Carbendazim+Mancozeb@ 2g/l at planting and twice @10days interval treated plot i.e. Rs. 18350.17/ ha in 2022 and Rs. 26909.09/ha in 2023.

Incremental Cost-benefit ratio (ICBR)

Based on two consecutive years findings, In 2022,the highest ICBR was registered with a plot treated with combination of seed treatment with Carboxin+Thiram@ 2g/kg, soil application of *T.viride + P.fluorescens* @ 4kg along with 10q/ha FYM at time of planting and soil drenching with *T.viride + P.fluorescens* @ 10g each/l twice @15 days interval as 1:5.48 followed by the plot seed treated with Carbendazim @2g/kg, soil drenching with Carbendazim+Mancozeb@2g/lt at planting and twice@10daysinterval as 1:4.12. Other treatments had ICBR from 1:0.53 to 1:1.42. Similarly in 2023, the highest ICBR was calculated with seed treatment with Carbendazim @2g/kg, soil drenching with Carbendazim +Mancozeb @ 2g / l at planting and twice @10 days interval treated plot as 1:5.68 followed by seed treatment with Carboxin+Thiram@ 2g/kg, soil application with *T. viride + P.fluorescens* @ 4kg +10q/ha FYM at planting and soil drenching with*T. viride + P.fluorescens* @ 10g each/l twice @15 days intervaltreated plot as 1:5.07.

Therefore,the research findings indicate that, the plot treated with a combination of Carboxin+Thiram at 2g/kg seed had the highest Incremental Cost-Benefit Ratio (ICBR) of 1:5.48. This was followed by soil treatment with *T.viride* and *P. fluorescens* at 4kg each along with 10q/ha enriched FYM at the time of sowing, and then soil drenching with the same beneficial fungi. When assessing these strategies, the efficacy of the treatment and cost-effectiveness were taken into account. Beneficial fungus drenched into the soil can efficiently manage diseases while preserving the health of the soil.

The most effective treatment for controlling the incidence of collar rot disease was found to be the integration of bioagents and fungicides module (T7), which involves treating seeds with Carboxin+Thiram at 2g/kg, applying *T. viride + P. fluorescens* at 4kg in the soil along with 10q/ha FYM at planting, and drenching the soil twice at 15-day intervals with *T. viride + P. fluorescens* at 10g each/l. This is consistent with studies by Debele and Ayalew (2015), Divya Rani *et al.* (2022), and Hagan *et al.* (2010) which have shownthe efficacy of utilizing fungicides, biological controls, and cultural methods to manage collar rot disease in groundnuts. In the current study, the incremental cost-benefit ratio (ICBR) was also assessed.The treatments with the highest ICBR (1:5.48) and positive return are those shown in Tables 1 and 2. These treatments include soil application of *T. viride + P. fluorescens* @ 4 kg along with 10q/ha FYM at planting time, and twice at 15-day intervals, soil drenching with *T. viride* + *P. fluorescens* @ 10g each/l. Smith *et al*. (2000) also observed a higher net return by fungicidal spray and seed treatment in groundnut as compared to the untreated control. The application of *T. harzianum* in groundnut crops was shown to result in comparable increased economic returns and benefit-cost ratios in farmers' fields (Sharma *et al*. 2012). In order to benefit farmers with limited resources, an integrated disease management strategy should be developed that combines various readily available, environmentally sound control components with locally generated techniques and solutions that are appropriate for their specific farming systems. Therefore, based on the findings of this study, it can be said that the most efficient and cost-effective methods for controlling the groundnut collar rot disease were to treat the seeds with Carboxin + thiram at a rate of 2 g per kg, apply 4 kg of *T. viride* + *P. fluorescens* to the soil along with 10 q/ha FYM at planting, and drench the soil twice at a 15-day interval with 10 g of each agent.

CONCLUSION

Based on the findings of two consecutive years, it can be concluded from the above results that in 2022, when taking into account the current cost of inputs, the highest incremental cost benefit ratio (ICBR) was recorded with the following treatments: soil application of *T. viride* + *P. fluorescens* @ 4 kg along with 10q/ha FYM at the time of planting, and soil drenching with *T. viride* + *P. fluorescens* @ 10g each/l twice @15 days interval as 1:5.48. The next treatment in descending order in respect of ICBR i.e seed treatment with Carbendazim @2g/kg, soil drenching with Carbendazim+Mancozeb @ 2g/l at planting and twice@10days interval as 1:4.12. The ICBR for other treatments ranged from 1:0.53 to 1:1.42. Similar calculations were made in 2023 to determine the highest ICBR, which included seed treatment with carbendazim @ 2g/kg, soil drenching with carbendazim+Mancozeb @ 2g/l at planting and twice @10days interval as 1:5.68 followed by seed treatment with carbozin+thiram @ 2g/kg, soil application with *T. viride* + *P. fluorescens* @ 4kg + 10q/ha FYM at planting and

Table 1 : Incremental cost benefit ratio (economics) of various treatments in 2022-23

Treatment	Yield (q/ha)	Increase in yield over control (q/ha)	Cost of treatments (Rs/ha)	Labour charge (Rs/ha)	Sprayer hire charge (Rs/ha)	Total cost of treatment (A)	Cost of increased yield (Rs/ha) (B)	Net Profit C (B-A)	ICBR (C/A)
T1	18.15	3.90	2156.00	1998	300.00	4454.00	22804.17	18350.17	1:4.12
T2	15.44	1.19	2240.00	1998	300.00	4538.00	6944.167	2406.17	1:0.53
T3	15.59	1.34	2500.00	1998	300.00	4798.00	7841.167	3043.17	1:0.63
T4	16.67	2.42	3549.00	1998	300.00	5847.00	14137.5	8290.50	1:1.42
T5	16.37	2.12	4010.00	1998	200.00	6208.00	12404.17	6196.17	1:1.00
T6	15.65	1.40	2600.00	1998	200.00	4798.00	8170.5	3372.50	1:0.70
T7	21.11	6.86	4000.00	1998	200.00	6198.00	40150.5	33952.50	1:5.48
T8	14.25	0.00							

Labour charges for one spray/ha@Rs 333/labour/day, two labours required for each treatment/ha.
Sprayer pump hiring charge/ha @ Rs. 50 for each treatment.
Minimum support price of groundnut seed@ Rs 5850/q in 202

Table 2 : Incremental cost benefit ratio (economics) of various treatments in 2023-24

Treatment	Yield in q/ha	Increase in yield over control (q/ha)	Cost of treatments (Rs/ha)	Labour charge (Rs/ha)	Sprayer hire charge (Rs/ha)	Total cost of treatment (A)	Cost of increased yield (Rs/ha) (B)	Net Profit C (B-A)	ICBR (C/A)
T1	17.22	4.96	2365.00	2070	300.00	4735.00	31644.09	26909.09	1:5.68
T2	14.44	2.18	2310.00	2070	300.00	4680.00	13930.2	9250.20	1:1.98
T3	15.04	2.78	2620.00	2070	300.00	4990.00	17709.17	12719.17	1:2.55
T4	16.19	3.93	3652.00	2070	300.00	6022.00	25030.91	19008.91	1:3.16
T5	16.00	3.74	4090.00	2070	200.00	6360.00	23849.98	17489.98	1:2.75
T6	14.55	2.29	4064.00	2070	200.00	6334.00	14603.33	8269.33	1:1.31
T7	18.70	6.44	4500.00	2070	200.00	6770.00	41091.5	34321.50	1:5.07
T8	12.26	0.00							

Labour charges for one spray/ha@Rs 345/labour/day, two labours required for each treatment/ha.
Sprayer pump hiring charge/ha @ Rs. 50 for each treatment.
Minimum support price of groundnut seed@ Rs 6377/q in 2023-24.

soil drenching with *T. viride + P. fluorescens* @ 10g each/l twice @15 days interval as 1:5.07.

The ICBR of various treatment combinations in two consecutive years, 2022 and 2023 in decreasing order is as follows: During 2022, T_7 (1:5.48)>T_1 (1:4.12)>T_4 (1:1.42)>T_5 (1:1.00)>T_6 (1:0.70)>T_3 (1:0.63)>T_2 (1:0.53) whereas during 2023, T_1 (1:5.68)>T_7 (1:5.07)>T_4 (1:3.16)>T_5 (1:2.75)>T_3 (1:2.55)>T2 (1:1.98)>T_6 (1:1.31).Use of various combinations of biocontrol agents and fungicides shall be the most affordable and effective against groundnut soil borne pathogen under Odisha conditions, taking into account the hazards of chemical fungicides which can pollute the ecosystem.

ACKNOWLEDGMENT

The authors are grateful to the Associate Director of Research, Regional Research and Transfer Technology Station, Bhawanipatna, Odisha University of Agriculture and Technology for providing necessary facilities during the course of these investigations.

DECLARATION

Conflict of interest. Authors declare no conflict of interest.

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