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RESEARCH ARTICLE

Bio-inoculants could enhance growth, yield, quality and reduce disease incidence in cabbage

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Abstract

Beneficial microbes are essential to sustainable agricultural production because they help meet population need for food, preserve the environment, and ensure excellent yields at reasonable prices. This experiment focused on the effects of bio-inoculants and fungicides on growth, yield, quality and disease incidence in cabbage grown in the Gangetic plains of West Bengal. The experiment was laid out in a randomized complete block design replicated thrice with seven treatment combinations comprising different bio-inoculants [*Trichoderma asperellum* (IIVR strain); *Trichoderma* (TTV-2-IIVR strain); *Bacillus subtilis* (CRB-7-IIVR strain); *Actinomyces sp*. (IIVR N-1.2strain)] either sole or dual application compared with fungicide application and control. The findings showed that compared to other treatment combinations, cabbage responded better to the dual inoculation of *T. asperellum* (IIVR strain) + *B. subtilis* (CRB-7). The study also showed that the head yield of the crop, as well as its nutritional value, disease control, and the economic return on its cultivation, were influenced by the dual inoculation with *T. asperellum* (IIVR strain) + *B. subtilis* (CRB-7) @ 10 g/kg of seedling and soil drenching with the same bio-inoculant combinations @1% in the root zone at 30 days after transplanting adopted for cabbage production in the Gangetic plains of eastern India.

Keywords: Cabbage, Bio-inoculants, Yield, Quality, Disease incidence, Economics.

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Introduction

Cabbage (*Brassica oleracea* var. *capitata* L.) is one of the most popular vegetables around the world in respect of area, production and availability almost around the year. According to Hasan and Solaiman (2012), cabbage is a great source of calcium, potassium, and vitamin C. The crop has a cooling effect, aids in reducing constipation, increases appetite, speeds up digestion, and is particularly beneficial for diabetic people (Yadav et al., 2000). Cabbage is a heavy-feeder vegetable crop. The overuse of chemical fertilizers has led to a number of issues at the same time, including contamination of the environment, loss of non-renewable energy sources, and deterioration of soil productivity (Bisht and Chauhan, 2020). It has been discovered that applying biofertilizers to vegetable crops is a very effective way to solve this issue. Microorganisms that are useful to agriculture and may mobilize nutritionally significant materials from non-usable to usable form through biological processes are known as bio-fertilizers (Kumar et al., 2001). Many microorganisms like *Azotobacter* sp., *Bacillus* sp., *Pseudomonas* sp., and *Trichoderma* sp. that act together in a complex and synergistic way, have also been exploited as bio-control agents for the management of soil-borne pathogens and a number of them have been registered and are commercially available for use against pathogens (Baker, 1987; Bennett, 1997). PGPR's microorganisms are being used in a new way in sustainable production systems to maximize plant development while reducing the need for mineral fertilizers. Applying blends of various microbial inocula enhances the beneficial impact of a single microbial species on plant growth in low-fertility soils. Biological control of plant diseases has been considered a viable alternative method to chemical control. Cabbage diseases [black rot, club root, black spot (dark spot), downy mildew, watery soft rot (white mold), and wire stem] are the chief limiting factors in profitable commercial cabbage growing in India. There are various naturally occurring bio-control agents that aggressively attack plant pathogens and suppress plant diseases by different modes of action. Bio-control agents comprise multiple beneficial characteristics such as rhizosphere competence, antagonistic potential, and ability to produce antibiotics, lytic enzymes, computation for nutrients and niche (Tsegaye et al., 2018). Keeping in view the importance of the study, the present investigation was carried out to study the effect of bio-inoculants on growth, yield, quality and disease incidence of cabbage and to assess the economic feasibility of the system.

Materials and Methods

Field experiments of the present investigation were carried out under the research field of All India Coordinated Research project on Vegetable Crops, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal for two consecutive years 2021-2022 and 2022-23). The farm is situated at 23.5 ^{0}N latitude and 89 ^{0} E longitude at an elevation of 9.75 m above the mean sea level. A cabbage hybrid 'Mohor' (Bharat Nursery PVT. Ltd., Kolkata, W.B.) was employed in the present investigation. About 30-day-old seedlings were transplanted at a spacing of 60 cm in both ways. Cow dung manure @ 5 t/ha and inorganic fertilizers @ 180 N: 90 P:90 K kg/ha were applied. In T_1 treatment seedlings, root dipping was done by talc-based *Trichoderma asperellum* (IIVR strain) @ 10 g/kg of seedling and soil drenching was done @1% in the root zone at 30 DAT. In T_2 treatment, seedling root dipping was done by talc-based *Trichoderma* (TTV-2-IIVR strain) @ 10 g/kg of seedling and soil drenching was done @1% in the root zone at 30 DAT. In T_3 treatment, seedling root dipping was done by talc-based *Bacillus subtilis* (CRB-7-IIVR strain) @ 5 g/kg of seedling and soil drenching was done @0.5% in the root zone at 30 DAT. In case of T_4 treatment, seedling root dipping by talc-based *Actinomyces sp*. (IIVR N-1.2 strain) @ 10 g/kg of seedling and soil drenching @1% in the root zone at 30 DAT was done. In T_5 treatment, seedling root dipping was done by consortia of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) @ 10 g/kg of seedling and soil drenching @1% in the root zone at 30 DAT was done. In the case of T_6 treatment, seedling root dipping was done by mancozeb + carbendazim (SAAF) @ 2.5g/kg seedling and spraying of SAAF @ 0.25% in the leaf and root zone at the time of first appearance of diseases. In T_7 treatment, seedling root dipping was done with water (control). The experiments were conducted following a randomized complete block design (RCBD) with three replications.

Ten randomly selected plants in each replication and treatment were considered to record the observations on plant height (cm); the number of leaves per plant, length (cm) and width (cm) of leaves at 30 days after transplanting (DAT), 45 DAT and 65 DAT; days taken from transplanting to reach 1st head formation; days taken from transplanting to reach 50% plant forming heads; polar diameter of head (cm); equatorial diameter of head(cm) at marketable maturity stage, weight of total biomass (kg) (marketable head with all leaves and stem excluding root) and the weight of head (kg) excluding stalk, net head yield/plot (kg/plot) and net head yield/ha (q/ha) at harvesting stage. Ascorbic acid was estimated by 2, 6 dichlorophenol indophenol method (Sadasivam and Manickam, 1996) at marketable maturity. Incidence of *Alternaria* leaf spot and *Sclerotinia* root rot disease was recorded from each treatment and replication. A number of plants showing disease symptoms were counted and recorded from each plot of all replications. The economic analysis was calculated by considering the cost of variable as well as fixed inputs and prevailing whole sale market rates, the expenditure incurred on various inputs and operations. Simultaneously, gross returns were worked out for each treatment based on wholesale market price of the produce. The income per rupee investment was worked out by dividing the total cost of production incurred from the gross returns of the particular treatment. All data were subjected to ANOVA for a RCBD. Treatment means were separated using the least significant differences with Tukey's post hoc test. Statistical analysis was with SAS (ver. 9.3 Professional Version, SAS Institute, Cary, NC.

Results and Discussion

Plant Height

The results revealed that cabbage showed variable responses to different bio-inoculants and fungicide applications with regard to plant height in both years. There was significant variation in plant height observed at 65 DAT in both years (Table 1). The maximum plant height was recorded in T_5 (32.47 cm in 1st year and 32.80 cm in 2nd year) followed by T_6 (31.61 cm in 1st year and 31.94 cm in 2nd year), but the mean of two years plant height in T_5 and T_1 were statistically different and T_5 and T_6 were statistically at par. Microbial consortia are much more efficient than single strains of organisms with diverse metabolic capabilities. Many of these bio-control agents and PGPRs are known to produce amino acids, vitamins and growth-promoting substances like IAA, GA and cytokines, which help in better growth of crop plants (Ponmuruganan, 2006).

Table 1: Effect of bio-inoculants on growth parameters in cabbage

Treatment	*Plant height (cm) at 65 DAT*			*Number of non-wrapper leaf At 65 DAT*			*Non-wrapper leaf length (cm) at 65 DAT*			*Non-wrapper leaf width (cm) at 65 DAT*		
	1st year	*2nd year*	*Mean**	*1st year*	*2nd year*	*Mean*	*1st year*	*2nd year*	*Mean*	*1st year*	*2nd year*	*Mean*
T_1	30.67	31.00	30.84^{ba}	13.72	14.06	13.89^{ba}	27.55	27.89	27.72^{bac}	29.00	29.33	29.17^{ba}
T_2	29.95	30.29	30.12^{ba}	13.30	13.63	13.47^{ba}	26.90	27.23	27.07^{bac}	27.58	27.92	27.75^{bac}
T_3	28.64	28.97	28.81^{bc}	12.89	13.22	13.06^{ba}	25.46	25.79	25.63^{bdc}	26.61	26.94	26.78^{bdc}
T_4	27.89	28.23	28.06^{bc}	12.42	12.75	12.59^{b}	23.87	24.20	24.04^{dc}	25.73	26.06	25.90^{dc}
T_5	32.47	32.80	32.64^{a}	15.70	16.03	15.87^{a}	29.72	30.05	29.89^{a}	30.62	30.96	30.79^{a}
T_6	31.61	31.94	31.78^{a}	14.60	14.94	14.77^{ba}	28.50	28.83	28.67^{ba}	29.71	30.04	29.88^{a}
T_7	26.70	27.03	26.87^{c}	11.79	12.12	11.96^{b}	22.99	22.99	22.99^{d}	24.42	24.75	24.59^{d}
df			15			15			15			15
F_{cal} value			4.86			1.78			3.71			4.85
p value			0.0002			0.0952			0.0017			0.0002
CV			5.14			12.36			7.67			6.04
MSD			2.8295^{**}						3.7546^{**}			3.0956^{**}

*Means with different superscripts differ significantly (Tukey post-hoc test) ** means $p<0.01$, * means $p<0.05$ df: degrees of freedom, CV: Coefficient of variation (%), MSD: Minimum Significant Differences

Number of Non-wrapper Leaf

Cabbage showed variable responses to different bio-inoculants and fungicide applications with regard to the number of non-wrapper leaves in both years. Significant variation was observed at different crop growth stages. At 65 DAT, the number of non-wrapper leaf varied from 11.79 to 15.70 in 1st year and 12.12 to 16.03 in 2nd year (Table 1). The maximum number of non-wrapper leaf was recorded in dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5) treatment (15.70 in 1st year and 16.03 in 2nd year) followed by fungicide (T_6) application (14.60 in 1st year and 14.94 in 2nd year). The mean of the number of non-wrapper leaf in both years in T_5, T_6 and T_7 treatment was statistically different from each other. Higher vegetative growth of plant in case of microbe's application might be due to better growth and elongation of leaves. These results are closely in consonance with the findings of Devi et al. (2003) in cabbage and Chaudhary et al. (2004) in cauliflower. More leaf number in plots receiving dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) might be due to the fact that they increase the availability of major and micronutrients present in the soil because of the action of added bio-fertilizers which acts as an important constituent of chlorophyll and protein, which ultimately resulted in early growth and development of leaf. These results are in close conformity with the findings of Singh et al. (2009) and Yadav et al. (2012).

Length of Non-wrapper Leaf

In both years the maximum length of the non-wrapper leaf was recorded in dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (29.72 cm in 1st year and 30.05 cm in 2nd year) followed by T_6 treatment (28.50 cm in 1st year and 28.83 cm in 2nd year) (Table 1). The mean of the length of the non-wrapper leaf in both years in T_5 treatment was statistically different from the mean of the length of the non-wrapper leaf in both years in T_6 treatment but the mean of T_1 treatment was statistically at par with T_2 treatment. The increased leaf number in cabbage is believed to result from the joint action of *Trichoderma* and *Bacillus* to better nutrient uptake of plants (Doni et al., 2017) or its secretion of phytohormones to stimulate plant growth, including IAA and its derivatives (Pelagio-Flores et al., 2017).

Width of Non-wrapper Leaf

The width of non-wrapper leaf differed significantly in response to different bio-inoculants and fungicide applications at different crop growth stages (Table 1). The width of the non-wrapper leaf varied from 24.42 cm to 30.62 cm in 1st year and 24.75 cm to 30.96 cm in 2nd year at 65 DAT. The maximum width of the non-wrapper leaf was recorded in T_5 treatment (30.62 cm in 1st year and 30.96 cm in 2nd year) followed by T_6 treatment (29.71 cm in 1st year and 30.04 cm in 2nd year), but they were statistically at par. The dual inoculation of bio-fertilizers helped in increasing net photosynthetic rates and in turn, increased the supply of carbohydrates to plants, resulting in better plant growth. The present findings are in agreement to the earlier works done by Sable and Bhamare (2007) on cauliflower.

Days to 1st Head Formation

Days to head maturity is an important character as it indicates the earliness of the crop. Early maturity is desirable

Table 2: Effect of bio-inoculants on head parameters in cabbage.

Treatment	Days to 1st head formation			Days to 50% head formation			Polar diameter of head (cm)			Equatorial diameter of head (cm)			Weight of head (kg)			Ascorbic acid content (mg/100 g)		
	1st year	2nd year	Mean*	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
T_1	37.33	37.00	37.17^{de}	40.00	39.67	39.83^{d}	54.09	54.42	54.25^{bac}	57.49	57.82	57.65^{ba}	1.49	1.53	1.51^{bac}	25.68	27.40	26.54^{b}
T_2	38.00	37.67	37.84^{dc}	41.33	41.00	41.17^{c}	53.24	53.58	53.41^{bdac}	56.22	56.55	56.39^{bc}	1.39	1.42	1.40^{bdc}	23.68	25.82	24.75^{cb}
T_3	39.00	38.67	38.84^{c}	42.33	42.00	42.17^{cb}	52.21	52.54	52.38^{bdc}	55.46	55.79	55.63^{c}	1.33	1.36	1.35^{bdc}	28.12	28.48	28.30^{b}
T_4	40.67	40.33	40.50^{b}	43.33	43.00	43.17^{b}	50.81	51.14	50.98^{dc}	54.91	55.24	55.07^{dc}	1.29	1.33	1.31^{dc}	24.78	24.94	24.86^{cb}
T_5	34.33	34.67	34.50^{f}	36.33	36.00	36.17^{f}	57.26	57.60	57.43^{a}	59.26	59.59	59.42^{a}	1.66	1.69	1.68^{a}	33.08	33.42	33.25^{a}
T_6	36.33	36.00	36.17^{e}	38.00	37.67	37.83^{e}	55.15	55.48	55.32^{ba}	58.66	58.99	58.83^{a}	1.54	1.58	1.56^{ba}	21.34	21.59	21.47^{c}
T_7	42.67	42.00	42.34^{a}	46.00	45.67	45.83^{a}	49.70	50.03	49.87^{d}	53.18	53.51	53.34^{d}	1.21	1.25	1.23^{d}	21.10	21.43	21.27^{c}
df			15			15			15			15			15			15
F_{cal} value			62.89			75.76			3.76			11.61			5.55			6.22
p value			0.0001			0.0001			0.0015			0.0001			0.0001			0.0001
CV			1.49			1.499			4.16			1.899			8.53			10.17
MSD			1.0457^{**}			1.1286^{**}			4.0937^{**}			1.9805^{**}			0.2252^{**}			4.8297^{**}

*Means with different superscripts differ significantly (Tukey's post-hoc test). ** means $p<0.01$, * means $p<0.05$ df: degrees of freedom, CV: Coefficient of variation (%), MSD: Minimum Significant Differences

since it fetches good returns to the vegetable growers. In case of both years, the minimum days taken to 1st head formation was recorded in T_5 (34.33 days in 1st year and 34.67 in 2nd year), followed by T_6 (36.33 days in 1st year and 36.00 in 2nd year) (Table 2). The maximum days taken to 1st head formation was recorded in control in both years.

Days to 50% Head Formation

Significant differences were observed in response to different bio-inoculants and fungicide applications with regard to days to 50% head formation in both years (Table 2). Days to 50% head formation varied from 36.33 to 46.00 in 1st year and 36.00 to 45.67 in 2nd year. The minimum days taken to 50% head formation was recorded in the dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5) treatment (36.33 days in 1st year and 36.00 days in 2nd year) followed by fungicide (T_6) application in both years.

Polar Diameter of Head

The size of heads formed and their shape are an important cultivar trait in cabbage determined by genetics, but cultivation practices can influence these traits. The results revealed that cabbage showed variable responses to different bio-inoculants and fungicide applications with regard to polar diameter of the head (Table 2). Significant differences were recorded in the polar diameter of the head among the treatments at the time of harvesting in both years. The maximum polar diameter of the head was recorded in T_5 (57.26 cm in 1st year and 57.60 cm in 2nd year) in both years. The mean of the polar diameter of the head in both years of all seven treatments was significantly different from each other.

Equatorial Diameter of Head

Cabbage exhibited variable responses to different bio-inoculants and fungicide applications with regard to the equatorial diameter of the head (Table 2). At the time of harvest, the equatorial diameter of the head varied from 53.18 cm to 59.26 cm in 1st year and 53.51 cm to 59.59 cm in 2nd year. The maximum equatorial diameter of the head was recorded in the dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) in T_5 treatment (59.26 cm in 1st year and 59.59 cm in 2nd year), which was statistically at par with T_6 treatment (58.66 cm in 1st year and 58.99 cm in 2nd year)

Weight of Head

The adoption of different bio-inoculants and fungicide applications significantly influenced head weight of cabbage (Table 2). The maximum head weight was obtained from the dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5) treatment (1.66 kg in 1st

Table 3: Effect of bio-inoculants on total biomass production and yield in cabbage

Treatment	*Total biomass production (kg/plot)*			*Head yield (q/ha)*		
	1st year	*2nd year*	*Mean**	*1st year*	*2nd year*	*Mean*
T_1	2.30	2.33	2.32^{bac}	331.85	353.44	342.65^{bac}
T_2	2.08	2.12	2.10^{bc}	308.15	342.01	325.08^{bdc}
T_3	1.95	1.98	1.97^{bc}	295.56	320.95	308.25^{edc}
T_4	1.80	1.84	1.82^{c}	287.41	306.47	296.94^{ed}
T_5	2.71	2.74	2.72^{a}	368.89	387.94	378.41^{a}
T_6	2.55	2.58	2.56^{ba}	342.96	372.38	357.67^{ba}
T_7	1.71	1.74	1.72^{c}	269.63	280.21	274.92^{e}
df			15			15
F_{cal} value			3.12			9.36
p value			0.0053			0.0001
CV			15.44			6.86
MSD			0.6182^{NS}			41.206^{**}

Table 4: Effect of bio-inoculants on disease parameters in cabbage

Treatment	*Incidence of Alternaria leaf spot (%)*			*Incidence of Sclerotinia root rot (%)*		
	1st year	*2nd year*	*Mean***	*1st year*	*2nd year*	*Mean*
T_1	6.02 (2.45)*	6.53 (2.55)	2.49^{cd}	6.42 (2.53)	7.03(2.65)	2.59^{e}
T_2	7.62 (2.76)	7.18 (2.68)	2.72^{cb}	8.34 (2.88)	8.92(2.98)	2.93^{de}
T_3	5.03 (2.24)	4.18 (2.03)	2.14^{d}	12.20 (3.49)	12.86(3.58)	3.54^{bc}
T_4	9.10 (3.01)	9.76 (3.12)	3.07^{b}	14.62 (3.82)	15.21(3.90)	3.86^{ba}
T_5	2.98 (1.72)	2.01 (1.40)	1.56^{e}	4.32 (2.07)	3.12(1.76)	1.90^{f}
T_6	8.83 (2.97)	8.39 (2.88)	2.93^{b}	10.23 (3.19)	11.30(3.36)	3.28^{dc}
T_7	12.98 (3.60)	12.27 (3.49)	3.55^{a}	17.30 (4.16)	17.81(4.22)	4.19^{a}
df			15			15
F_{cal} value			24.60			31.43
p value			0.0001			0.0001
CV			7.96			6.91
MSD			0.3862^{**}			0.4051**

*Figures in parentheses indicate square root transformed values.
**Means with different superscripts differ significantly (Tukey's post-hoc test)
** means $p < 0.01$, * means $p < 0.05$ df: degrees of freedom, CV: Coefficient of variation (%), MSD: Minimum Significant Differences

year and 1.69 kg in 2nd year) in both years. The minimum weight of the head was observed in T_7 treatment (1.21 kg in 1st year and 1.25 kg in 2nd year) in both years.

Ascorbic acid content

Ascorbic acid content (vitamin C) is one of the major quality components in cabbage as it improves the nutritional quality of head. The results from the experiment revealed that cabbage showed variable responses to different bio-inoculants and fungicide applications with regard to vitamin C content of head (Table 2). Significant differences were observed between the mean of the two years ascorbic acid content in dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (33.08 mg/100 g in 1st year and 33.42 mg/100g in 2nd year), T_3 treatment [application of *B. subtilis* (CRB-7-IIVR strain)] and T_4 treatment in both years. No significant differences observed between the mean of the two years ascorbic acid content in T_6 and T_7 treatment. The present study corroborates the findings of Kumar et al. (2015) in cabbage, Bahadur et al. (2003) and Singh and Singh (2019) in cauliflower. They observed more vitamin C content in cole crops receiving treatments with bio-fertilizers and

Table 5: Cost-return analysis per hectare cultivation of cabbage in experimental plot

Treatment	*Total operational cost (Rs.)*	*Interest on working capital @12.5% of operational cost (Rs.)*	*Total cost of production (Rs.) (Cost A_1)*	*Wholesale market price (Rs/t)*	*Yield (t/ha)*		*Gross return (Rs.)*		*Income per rupee investment (Rs.)*	
					1st year	*2nd year*	*1st year*	*2nd year*	*1st year*	*2nd year*
T_1	73900	9237.50	83137.50	5000	33.185	35.344	165925	176720	1.99	2.13
T_2	74135	9141.87	83276.87	5000	30.815	34.201	154075	171005	1.85	2.05
T_3	74095	9261.87	83356.87	5000	29.556	32.095	147780	160475	1.77	1.93
T_4	74095	9261.87	83356.87	5000	28.741	30.647	143705	153235	1.72	1.84
T_5	73995	9249.37	83244.37	5000	36.889	38.794	184445	193970	2.21	2.33
T_6	73900	9237.50	83137.50	5000	34.296	37.238	171480	186190	2.06	2.24
T_7	72535	9066.87	81601.87	5000	26.963	28.021	134815	140105	1.65	1.72

Operational cost includes: a) cost of seeds, b) cost of land preparation, c) cost of manure and fertilizer, d) cost of plant protection chemicals, e) irrigation cost, and f) human labour cost @ 300/- per man days. Total cost of production (Cost A1) = Operational cost + interest on working capital @12.5% per annum.

other organic amendments than the recommended dose of inorganic fertilizers.

Total Biomass Production

The results from the experiment indicated that cabbage showed variable response to different fungicide and bio-inoculant applications with regard to total biomass production (Table 3). The maximum total biomass weight was recorded in T_5 treatment (2.71 kg/plot in 1st year and 2.74 kg/plot in 2nd year) followed by fungicide (T_6) application (2.55 kg/plot in 1st year and 2.58 kg/plot in 2nd year). The mean of the total biomass production in both years in T_5, T_1, T_2, T_7 treatment was statistically different from each other.

Head Yield

The application of bio-inoculants and fungicides significantly influenced the head yield of cabbage per hectare (Table 3). The maximum head yield was obtained from dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5 treatment) (368.89 q/ha in 1st year and 387.94 q/ha in 2nd year) and the mean of the head yield (q/ha) in both years in T_5 treatment was statistically different from *T. asperellum* (IIVR strain) (T_1) treatment (331.85 q/ha in 1st year and 353.44 q/ha in 2nd year), T_2 treatment [*Trichoderma* (TTV-2-IIVR strain)] (308.15 q/ha in 1st year and 342.01 q/ha in 2nd year) and fungicide (T_6) application (342.96 q/ha in 1st year and 372.38 q/ha in 2nd year) in both years. The mean of the head yield (q/ha) in both years in all the treatments were statistically different from each other. Our results agreed well with the findings of Sood and Vidyasagar (2007) who obtained higher yield in cabbage by application of bioinoculants. Sharma (2002) also found better performance and increased yield of cabbage under nitrogenous fertilizer and microbial inoculants.

Incidence of Alternaria Leaf Spot

Alternaria leaf spot disease was noticed in all the treatments under study. The incidence of disease significantly differed among treatments (Table 4). Results revealed that dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5 treatment) was the most effective in percent reduction (2.98% in 1st year and 2.01% in 2nd year) of *Alternaria* leaf spot disease incidence followed by the application of *B. subtilis* (CRB-7-IIVR strain) (T_3) (5.03% in 1st year and 4.18% in 2nd year).Significant differences were observed between the mean of the two years of disease incidence in T_1, T_2, T_3 and T_5 treatment. No significant differences were observed between the mean of the two years of disease incidence in T_4 and T_6 treatment. Higher disease incidence (12.98% in 1st year and 12.27% in 2nd year) in control plot (T_7) was observed.

Incidence of Sclerotinia Root Rot

Sclerotinia root rot disease was noticed more or less in all the treatments under study. The incidence of disease varied significantly among the treatments (Table 4). Results revealed that dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5 treatment) was the most effective in percent reduction (4.32% in 1st year and 3.12% in 2nd year) in *Sclerotinia* root rot disease incidence. This treatment was statistically different from others during both years. However, the control plot (T_7) exhibited higher disease incidence (17.30% in 1st year and 17.81% in 2nd year) than the treated plots.

The increased concern for environmental awareness of chemical hazards has evoked a worldwide interest in microbial control of pathogens. In this context, many microorganisms like *Azotobacter* sp., *Bacillus* sp., and *Pseudomonas* sp., *Trichoderma* sp. have been exploited as bio-control agents for the management of soil-borne pathogens, foliar diseases and a number of them have been registered and are commercially available for use against pathogens (Baker, 1987; Bennett, 1997; Tewari and Mukhopadhyay, 2001). The majority of *Trichoderma*-containing products on the market make claims to be fungicidal, to be used mainly for the biological control of root diseases for preventative and/or curative control of soil-borne pathogens such as *Rhizoctonia, Pythium, Fusarium, Verticillium, Sclerotinia, Phytophthora,* etc. Additionally, the fungicidal characteristics are used for the control of foliar diseases, protection of pruning wounds, wood and root decay caused by *Botrytis, Chondrostereum, Heterobasidon, Armillaria, Eutypa* etc (Woo et al., 2014). Many of these crop protection products are approved for use in organic farming in diverse countries. Trichoderma spp. is well well-documented and effective biological control agent of soil-borne diseases by secreting several cell wall degrading enzymes and antibiotics (Coley-Smith et al., 1991; Sivan et al., 1984). It is found that *T. harzianum* LTR-2 is an effective biological control agent for cabbage clubroot, which acts through modulation of the soil and rhizosphere microbial community (Li et al., 2020). Combined with the previous research on *Trichoderma* as biological control (Peng et al., 2011) , we observed that the control effect is related to the colonization of *Trichoderma* in the rhizosphere of cabbage and the subsequent change of fungal microbial community in the roots. Bacillus is a known biological control agent that can effectively inhibit clubroot disease (Munir et al., 2018), and the increase in relative abundance may have contributed to a lower incidence of disease in this study. The potential for a mutually beneficial interaction of *T. asperellum* and *B. subtilis* in the rhizosphere of cabbage warrants further investigation

Economic Analysis of Cabbage Production

An attempt has been made on the economics of different bio-inoculants and fungicide applications in cabbage production with their respective cost component analysis and economic return on the basis of the information gathered from 10 progressive cabbage growers from Nadia districts of West Bengal (Table 5). Through detailed survey and questionnaire break up of cost components for cabbage along with their operational costs and wholesale price have been collected in both years. An extra cost for bio-inoculants and fungicide application required in one hectare of land was added in operational cost. The maximum economic return (Rs 2.21, income per rupee investment in 1st year and Rs 2.33, income per rupee investment in 2nd year) was recorded in the dual application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) (T_5 treatment) followed by fungicide (T_6) application. The minimum economic return was recorded in the control (T_7) treatment.

Conclusion

From the present study, it can be concluded that conjoint application of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) increased the growth, yield, and nutritional quality attributes as well as reduced the incidences of *Alternaria* leaf spot and *Sclerotinia* root rot and also proved remunerative from the economic point of view. Therefore, seedling root dipping by consortia of *T. asperellum* (IIVR) + *B. subtilis* (CRB-7) @ 10 g/kg of seedling and soil drenching with the same bio-inoculant combinations @1% in the root zone at 30 days after transplanting can be recommended for commercial cabbage cultivation in West Bengal.

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सारांश

लाभकारी सूक्ष्मजीव स्थायी कृषि उत्पादन के लिए आवश्यक हैं क्योंकि वे जनसंख्या की भोजन की आवश्यकता को पूरा करने, पर्यावरण को संरक्षित करने और उचित कीमतों पर उत्कृष्ट पैदावार सुनिश्चित करने में मदद करते हैं। यह प्रयोग पश्चिम बंगाल के गंगा के मैदानी इलाकों में उगाई जाने वाली गोभी की वृद्धि, उपज, गुणवत्ता और रोग की घटनाओं पर जैव-इनोकुलेंट्स और कवकनाशी के प्रभाव पर केंद्रित था। प्रयोग को एक यादृच्छिक पूर्ण ब्लॉक डिज़ाइन में रखा गया था जिसे विभिन्न जैव-इनोकुलेंट्स [ट्राइकोडर्मा एस्पेरेलम (आईआईवीआर स्ट्रेन) सहित सात उपचार संयोजनों के साथ तीन बार दोहराया गया था; ट्राइकोडर्मा (TTV-2-IIVR स्ट्रेन); बैसिलस सबटिलिस (CRB-7-IIVR स्ट्रेन); एक्टिनोमाइसेस एसपी. (आईआईवीआर एन-1.2स्ट्रेन)] कवकनाशी अनुप्रयोग और नियंत्रण की तुलना में या तो एकमात्र या दोहरा अनुप्रयोग। निष्कर्षों से पता चला कि अन्य उपचार संयोजनों की तुलना में, गोभी ने ट्राइकोडर्मा एस्पेरेलम (आईआईवीआर स्ट्रेन) + बैसिलस सबटिलिस (सीआरबी-7) के दोहरे टीकाकरण पर बेहतर प्रतिक्रिया दी। अध्ययन से यह भी पता चला कि फसल की मुख्य उपज, साथ ही इसके पोषण मूल्य, रोग नियंत्रण और इसकी खेती पर आर्थिक रिटर्न, ट्राइकोडर्मा एस्पेरेलम (आईआईवीआर स्ट्रेन) + बैसिलस सबटिलिस (सीआरबी -7) के दोहरे टीकाकरण से प्रभावित थे।) पूर्वी भारत के गंगा के मैदानी इलाकों में गोभी उत्पादन के लिए अपनाई जाने वाली रोपाई के 30 दिन बाद जड़ क्षेत्र में 10 ग्राम/किग्रा अंकुर और मिट्टी को 1% की दर से समान जैव-इनोकुलेंट संयोजन के साथ भिगोना।