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RESEARCH PAPER

Agrientreprenuiral Feasibility of High-value Vegetable Crops for Small-holder Farmers for Supplementing Inorganic Fertilizer with Bioinoculants

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ABSTRACT

The study conducted at the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, during the Rabi season of 2022-2023, focuses on assessing the economic feasibility and sustainable productivity of seedling bio-priming coupled with reduced inorganic fertilizer doses for high-value vegetable crops. Utilizing *Trichoderma harzianum* (TH) and *Bacillus subtilis* (BS) in seedling bio-priming, the experiment examined three crops under varied mineral fertilizer conditions. Results indicate that employing microbial consortia in high-value vegetable cultivation is economically viable for smallholder farmers, with a high cost-benefit ratio. The combination of *T. harzianum* + *B. subtilis* along with 75% recommended dose of NPK fertilizer emerged as the most effective treatment for enhancing productivity. In conclusion, incorporating efficient microbes will reduce the dependence on chemical fertilizers, promoting sustainable production, and ensuring the technical and economic viability of high-value vegetable cultivation for smallholder farmers.

HIGHLIGHTS

- Evaluation of gross return, net return, and the B: C ratio is presented for three high-value vegetables crops.
- Assessment of the effect of biopriming intervention on the cultivation of high-value vegetable crops, emphasizing its potential influence on farm profitability.
- Diversification by small farmers toward high-value vegetable crops, viz., broccoli, cherry tomatoes, and capsicum that can raise farm incomes.

Keywords: High- value, bioinoculants, inorganic fertilizer, grosses return, net return &B: C ratio

Rice–wheat cropping system (RWCS) of the South Asia is labour-, water-, capital- and energy-exhaustive, and become barely profitable as the availability of these resources decline. This could be further aggravated with degradation of soil structure, declining underground water and reduce land and water productivity which ultimately are threat in front of sustainable and profitable RWCS in the region. RWS (rice–wheat system), leave behind large quantities of straw in the field for open burning of residue (Bhat *et al.* 2016). Resource exhausting practices engage non renewable energy sources are raising significant questions about the stability and resilience of the natural ecosystem. The United Nations (UN) proposed 17 Sustainable Development Goals (SDGs) after critically evaluates

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the situation and potential threats of climate change. These goals aim at collaborative efforts towards the upliftment of social and economic standards without compromising the environment and future generations (Akinsemolu, 2018; Dubey *et al.* 2021). A paradigm change is necessary to increase this sequence's profitability, productivity, and sustainability. Thus, policymakers' primary focus is replacing the rice-wheat cropping system in the cropping pattern.

High-value vegetable crops have the potential to significantly improve the living standards of marginal farmers, as well as their consumption of high-quality foods, the sustainability of the food supply chain, and the economies of entire nations. This is because they can help meet the world's changing nutritional demands and the changing global economy (Singh and Rakshit, 2024). Smallholder farmers play larger role in vegetable production. Indian agriculture is dominated by smallholders (contextually defined as farmers with land sizes 2 ha) (GOI, 2005). These farmers have low endowments of land as well as other factors such as capital but tend to be well abundant with labour. As Indian economy has grown constantly for some time, it offers opportunities with increased demand for agricultural products. The food demand growth has however been dominated by high-value (Birthal *et al.* 2012).Vegetable production has great importance in delivering three to four times more calories of energy and per hectare cash income compared to cereals, pulses and oilseed crops. Importance of vegetables in human diet is also enormous as these provide the balanced diet and also add palatability to food. Vegetables also have a greater digestibility coefficient due to the existence of exceptional roughage quality in them (Kala *et al.* 2020).

The results of the study revealed that crops diversification with high value vegetable crop viz., broccoli, cherry tomatoes, and capsicum improved the system productivity, profitability and sustainability; which lead to improve the food security of the increasing population and also reduce the effect on the environment. Increased production of high value vegetable crops especially cherry tomatoes, capsicum and broccoli assume multidimensional significance for small holder farmers, where the rice-based cropping system is increasingly proven nonsustainable; economically and environmentally. Increased production and productivity achieved through high resource use efficiency makes farming of these crops profitable and enhances food and nutritional security. To revamp the production and productivity of these three major non-paddy crops, a systematic and well-coherent measure to be promoted targeting consistent and decent growth in area and productivity. The dissemination of technical expertise and targeted capacity development program can support the efforts to make the production profitable and cost effectiveness. Therefore, on the basis of technical feasibility and economic viability, high value vegetable crop cultivation must be benefited for small holder farmers.

MATERIALS AND METHODS

Three high-value vegetables, viz., cherry tomatoes, broccoli, and capsicum, will be taken as test crops. Experiments will be conducted at the Farm of the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (25° 26N, 82° 99′ E, and 80.7 m above mean sea level), Uttar Pradesh, India, during the winter (*Rabi*) seasons of 2022–23. The experimental site falls under the Indo-Gangetic Plains (agro-ecological region) of eastern India. The experimental soil, Gangetic alluvial in nature, is classified in Typic Ustochrept of the order Inceptisol. Pre-cropping soil analysis revealed that the soil is slightly alkaline in reaction (7.58); low in organic carbon (4.04 g kg^{-1}) and available N (203.21 kg ha^{-1}) content; medium in available P (20.86 kg ha^{-1}) and available K (217.73 kg ha^{-1}) content; and sandy loam in texture (Sarkar *et al.* 2022).

There were total 6 treatment combinations of single strains and microbial consortia with mineral fertilizer, in these two bioinoculants (*Trichoderma harzianum* and *Bacillus subtilis*) are used, which were replicated thrice. For seedling biopriming, seedlings of cherry tomatoes, broccoli, and capsicum were picked when there were 4-5 leaves. The soil attached to the roots was washed carefully, followed by root dipping in liquid culture containing 2% carboxymethyl cellulose (CMC) as an adhesive agent. The bio-priming treatment or microbial consortium inoculation process was conducted in incubated conditions (28 ± 2 ◦C; >90 % relative humidity) for 5 h. The experimental design includes two (2) varied levels of recommended dose of fertilizer (RDF) were applied @ 40:60:30 and 30:45:22.5 (N: P2O5:K_2O) kg ha^{-1} through urea, DAP, and MOP, respectively. The fertilizer dose was reduced to 25% when the microbial consortium was used. Treatments combination applied during the investigation: T_1: Absolute control; T_2: 100% recommended dose of fertilizers (RDF); T_3: 75% RDF; T_4: 75% RDF + seedling bio-priming with *Trichoderma harzianum*; T_5: 75% RDF + seedling bio-priming with *Bacillus subtilis*; T_6: 75% RDF + seedling bio-priming with *Trichoderma harzianum* + *Bacillus subtilis*.

Economic analysis

The cost of production was calculated considering the prevailing market price of variable inputs and output (unit cost). Net return is calculated by subtracting total expenditure during crop production from gross income.

$$\text{Net return} = \text{Gross return} - \text{Cost of cultivation}$$

Where,

Gross return = Market price × Total quantity of marketed product

Cost of cultivation = Total variable cost + Total fixed cost

Benefit: cost (B: C) ratio was estimated using the following formula:

$$\textbf{B: C ratio} = \frac{\text{Net return Rs./ ha}}{\text{Total expenditure Rs./ ha}}$$

Statistical analysis

Experimental data were tested for analysis of variance (ANOVA) and mean value of all the treatments compared through Duncan's multiple range test (DMRT) ($P \leq 0.05$ significance level). Computer Statistical Package for Social Science (SPSS) software was used for homogeneity test of all the collected data.

RESULTS AND DISCUSSION

Conventional agricultural practices and ascent energy crisis create a question about the sustainability of the present-day food production system. Nutrient exhaustive crops can have a drastic influence on native soil fertility by causing nutrient mining. The formulations of novel biofertilizers will have a significant impact for the production of exotic crops under sustainable agriculture. Furthermore, improving nutrient use efficiency in crops by using realistic solutions such as bio-priming lessen fossil fuel utilization (fertilizers, pesticides, etc.) and encourage the fundamental goals of sustainable agriculture. Future studies should also target to determine the root colonization pattern of bio-agents under the rhizosphere engineering of exotic crops (Sarkar *et al.* 2022).

In this backdrop, we conducted a comprehensive assessment of bioinoculants intervention in three high value vegetables crops viz., cherry tomatoes, broccoli and capsicum production considering economic benefits for its sustainable intensification, among resource-small holder farmers. Farmers will embrace any technology when it is economically feasible. Different economic indicators, such as gross return, the net return, and benefit-cost (B: C) ratio showed wide variations among the treatments (Table 1, 2 and 3). Relevance of agriculture technology for farmers is determined by their economic feasibility in terms of gross return, net return and B: C ratio.

The economic data provided in table 1 for cherry tomato shows that application of seed biopriming and reduced doses of fertilization have significantly influence on gross return, net return and B: C ratio. Highest gross return (561093.133 and 530859.300 INR ha^{-1}) was registered in T_2 (100 % RDF) which is followed by the T_6 (75% RDF + *Bacillus subtilis* + *Trichoderma harzianum*). In term of net return, T_2 was merely 7.00 % increased than T_6. Control treatment was lowest net return and B:C ratio. Table 2 represents B: C ratio analysis of broccoli. The table revealed that maximum gross return (404800.433 and 363275.400 INR ha^{-1}) and net return (282417.367 and 237482.133 INR ha^{-1}) were recorded with the application of (T2) 100 % RDF and T_6 (75% RDF + *T. harzianum* + *B. subtilis*), respectively. The treatment also achieved the highest B: C ratio of 2.300 and 1.880. Lowest returns and B: C ratio was observed in control. According to data provided in Table 3 for green capsicum, application of T6 (75% RDF + *Trichoderma harzianum* + *Bacillus subtilis*) increase the net return by 49.07 % compared to control (T_1). However, maximum gross return (1085646.600 and

Table 1: Economics of cherry tomato production as influenced by bio-priming and mineral fertilization. Different letters indicate significant differences at P ≤ 0.05 among the treatments as per DMRT at each column

Treatments	Gross return (INR ha^{-1})	Net return (INR ha^{-1})	B:C ratio
T_1: Absolute control $N:P_2O_5:K_2O$ @ 0:0:0 kg ha^{-1}	222890.933^{f}	94732.800^{f}	0.730^{f}
T_2: 100% RDF of $N:P_2O_5$: K_2O @ 40:60:30 kg ha^{-1}	561093.133^{a}	428986.067^{a}	3.240^{a}
T_3: 75 % RDF of N:P2O5:K2O @30:45:22.5	374766.933^{e}	243645.100^{e}	1.850^{e}
T_4: 75 % RDF + *Trichoderma harzianum*	452813.533^{d}	320892.467^{d}	2.430^{d}
T_5: 75 % + *Bacillus subtilis*	503438.900^{c}	371516.967^{c}	2.810^{c}
T_6: 75 % + *Bacillus subtilis* + *Trichoderma harzianum*	530859.300^{b}	398939.800^{b}	3.027^{b}
CD (P ≤ 0.05)	8.704	6.001	0.065

Table 2: Economics of broccoli production as influenced by bio-priming and mineral fertilization. Different letters indicate significant differences at P ≤ 0.05 among the treatments as per DMRT at each column

Treatments	Gross return (INR ha^{-1})	Net return (INR ha^{-1})	B:C ratio
T_1: Absolute control $N:P_2O_5:K_2O$ @ 0:0:0 kg ha^{-1}	129525.500^{f}	7142.500^{f}	0.050^{f}
T_2: 100% RDF of $N:P_2O_5:K_2O$ @ 40:60:30 kg ha^{-1}	404800.433^{a}	282417.367^{a}	2.300^{a}
T_3: 75 % RDF of $N:P_2O_5:K_2O$ @30:45:22.5	261800.600^{e}	136807.000^{e}	1.090^{e}
T_4: 75% RDF + *Trichoderma harzianum*	334895.100^{c}	209101.967^{c}	1.660^{c}
T_5: 75% + *Bacillus subtilis*	305580.067^{d}	179788.433^{d}	1.420^{d}
T_6: 75% + *Bacillus subtilis* + *Trichoderma harzianum*	363275.400^{b}	237482.133^{b}	1.880^{b}
CD (P ≤ 0.05)	8.615	30.015	0.072

Table 3: Economics of green capsicum production as influenced by bio-priming and mineral fertilization. Different letters indicate significant differences at P ≤ 0.05 among the treatments as per DMRT at each column

Treatments	Gross return (INR ha^{-1})	Net return (INR ha^{-1})	B:C ratio
T_1: Absolute control $N:P_2O_5:K_2O$ @ 0:0:0 kg ha^{-1}	608796.267^{f}	403497.233^{f}	1.960^{f}
T_2: 100% RDF of $N:P_2O_5:K_2O$ @ 40:60:30 kg ha^{-1}	1085646.600^{a}	880348.367^{a}	4.280^{a}
T_3: 75 % RDF of $N:P_2O_5:K_2O$ @30:45:22.5	703896.267^{e}	498597.400^{e}	2.420^{e}
T_4: 75% RDF + *Trichoderma harzianum*	780092.000^{d}	574793.667^{d}	2.790^{d}
T_5: 75% + *Bacillus subtilis*	879628.667^{c}	674329.333^{c}	3.280^{c}
T_6: 75% + *Bacillus subtilis* + *Trichoderma harzianum*	997660.233^{b}	792360.467^{b}	3.850^{a}
CD (P ≤ 0.05)	7.335	2.912	0.022

997660.233 INR ha^{-1}) and net return (880348.367 and 792360.467 INR ha^{-1}) were recorded with the application of (T_2) 100 % RDF and T_6 (75% RDF + *T. harzianum* + *B. subtilis*) respectively.

The present findings are in line with findings of Mookherjee *et al.* (2014) who reported that application of chemical fertilizer with Azotobacter and PSB in yellow sarson provide highest return rupee^{-1} compared to solo application of fertilizers. Similarly, Singh and Singh (2014) reported that inoculation of Indian mustard with PSM and Azospirillum increased the gross return, net return and B: C ratio. Thakur *et al.* (2018) noted the highest net return and B:C ratio with the combine application of 75% NPK and organics (organic manures + biofertilizers) in cauliflower. Another study by Kamal *et al.* (2016) reported a significant effect on B: C ratio of cabbage production due to the conjoint application of bio-inoculants and chemical fertilizers. Application of bio-inoculants as a primer is a well-demonstrated process in synergizing a stimulus in the rhizosphere, which facilitates biochemical nutrient cycling, enzymology, and partitioning/translocating, which, in turn, improves crop performance under a changing climate plan (Sarkar *et al.* 2021).

Table 1, 2 and 3 clearly represent the positive effect of the application of microbial consortium and 75% RDF could be profitable than 100% RDF by providing higher net return on a hectare basis. The integrated approach's performance was better in a dual consortium in most cases, while in single-species bio-priming, application of B. subtilis in cherry tomato and capsicum performed better than control treatment. 75% RDF + *Trichoderma harzianum* + *Bacillus subtilis* with highest gross return, net returns and B:C ration in all the experiments was found to be most effective type of treatment combination in high value vegetables crop. It is suggested, based on the current data, that inoculation agents might be used in place of a full fertilizer dosage for high-value vegetable crop.

CONCLUSION

From the present study, it can be concluded that inoculation of cherry tomato, broccoli, and capsicum seedling with *Trichoderma harzianum* and *Bacillus subtilis* along with 75% RDF ($N:P_2O_5:K_2O$ @ 30:45:22.5) can increase gross return, net return, and a high B:C ratio for enhancing the productivity and economic feasibility of high-value vegetable crops for small-holder farmers. The benefit-cost ratio is positive at all bio-inoculants interventions compared to sole application of N: P_2O_5: K_2O only. The best returns would be achieved at an application rate of N: P_2O_5: K_2O at 30:45:22.5 kg ha^{-1} along with seed biopriming with *Bacillus subtilis* and *Trichoderma harzianum*. Overall, our conclusions enlighten the use of microbes in combination with a reduced fertilizer dose (75% RDF) to increase the growth and productivity of high-value vegetable crops for sustainable agriculture while reducing the cost of mineral fertilizer.

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