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Efficacy of different biological and chemical treatments on control of powdery scab of potato

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ABSTRACT

The study assesses the efficacy of biological and chemical treatments to control potato powdery scab at the farmer's field of Dadeldhura district. The experiment was conducted in a randomized complete block design with 5 treatments and 4 replications. The treatments were Mancozeb, Boric acid, Trichoderma viride, Pseudomonas fluorescens and Non-Treated Control. Cardinal variety of potato was chosen as planting material. The effectiveness of different treatments against potato powdery scab disease was evaluated along with different growth and yield parameters. Significant influences of treatments on disease and yield parameters were observed. Among the treatments, Pseudomonas fluorescens treated tubers showed the least disease incidence (45%) and severity percentage (23.35%). Although, the disease incidence (52.5%) and severity percentage (28.70%) of Trichoderma viride treated plots were found higher but were statistically at par with pseudomonas treated plots while the highest disease incidence (92.5%) and severity percentage (42%) was observed under Non Treated control (NTC). Moreover, Marketable yield (mt ha^{-1}) was observed highest from (34.62mt ha^{-1}) Pseudomonas followed by Trichoderma viride (28.62mt ha^{-1}) and the least yield (15.81mt ha^{-1}) was obtained in boric acid) and Non Treated Control (16.76 mt ha^{-1}). Similarly, higher returns (NRs. 1315910) and B:C ratio (4.79) were obtained in Pseudomonas fluorescens followed by Trichoderma viride (NRs. 1087795 and 3.97 respectively) and least in Boric acid (NRs.600945 and 2.21). From the results, it can be concluded that antagonistic such as Pseudomonas fluorescens and Trichoderma viride are effective and more economical for reducing potato powdery scab severity and increasing the marketable yield of potato tubers under Dadeldhura conditions.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is regarded as fourth important staple crop after rice, maize and wheat in Nepal (Timsina et al. 2019). Potato crop has been playing an important role for food security and reduction of poverty among Nepalese farmers. The adaptability characteristics of potato along with the bumper productivity and adequate demand of the population, farmers are getting interested in its cultivation. Potato contributes about 6.57% in AGDP and 2.17% in GDP of nation. Potato can be easily cultivated from 100 masl to an altitude of 4000 masl in case of Nepal. Dadeldhura, Kailali and Nuwakot districts are major producers of the potato in Nepal (Dahal & Rijal 2019). In the year 2018/19, potato was cultivated in the area of 1154 ha in Dadeldhura district with the production of 16,169 mt and productivity of 14.01 mt ha^{-1} (MoAD, 2018/19) but production and productivity of potato has been found decreasing attributed by the use of the inferior seed, attack of insects, pests and disease, limited application of improved practices for potato production.

PMAMP Project Implementation Unit, Potato Super zone, Dadeldhura, reports that one of the main reason of reduction in productivity is due to infestation of disease and pests of which powdery scab is most prominent one, caused by a fungus namely Spongospora subterranean. The lesions on

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tubers which look like scab are reducing the marketable yield of potato and such tubers when used as seed are carrying infection to the subsequent crops (Merz 2008). The pathogen favors, pH level that is slightly less acidic ranging from 4.7 to 7.6, temperature below 20ºC and soil with a high amount of water content (Secor, 2013). Similar type of environment in the Dadeldhura has promoted the disease incidence in the potato field.

Different interventions have been reported promising ranging from chemical to biological measures. Biological control agent, Trichoderma spp., has potential for reducing activity of S. subterranean, through effects on either resting spore viability or zoospore activity and infectivity (Falloon, 2008). Studies have identified endophytes with the ability to suppress this pathogen which include Bacillus subtilis, Gliocladium catenulatum, Heteroconium chaetospira, Microbispora rosea sp. rosea, Streptomyces griseoruber, S. griseoviridis, S.lydicus, S. olivochromogenes and Trichoderma atroviride, T. harzianum and T. viride (O'Brien & Milroy, 2017). Similarly, Wanner et al. (2014) also has mentioned about the use of the non-pathogenic *Streptomyces* spp., St-Onge et al. (2011) about *Pseudomonas* spp., and Meng et al. (2012) about the use of *Bacillus* spp. to have potential in warding off potato scab disease.

Use of chemicals in soil affects the expression of powdery scab and thus helps in the management of the powdery scab in the soil. In field condition applications of sulphur or salts of zinc in the soil have been found to reduce the disease in the field whereas in laboratory and glasshouse condition, boron as sodium tetra borate has reduced the infection (Falloon 2008). Conventional Methods such as soil amendments/chemistry that includes decreasing soil pH, soil fumigation, pre-sowing treatment of seed tubers and crop rotation hasn't proven effective and also harming the environmental integrity (Dees and Wanner 2012) so the research on biological control as an alternative and eco-friendly approach is being given priority.

Research and studies about the scab in Dadeldhura have not been conducted well. So, the main factor for the disease infestation whether cultural or edaphic or climatic has not been identified yet. Identification of effective treatment to suppress the will help to revive the standard appearance of the tubers increasing the potato's marketability which is the main objective of this research.

MATERIALS AND METHODS

Experimental Location

The experiment was carried out at Bhatkanda, Ganyapdhura rural municipality ward number 1, Dadeldhura district Nepal during 2019/2020. The study site is located at 29º26" N latitude and 80º12" to 80 to 47" longitudes with an elevation of 1745 masl and lies in the subtropical zone of Nepal. The soil texture in the study area is sandy loam with experimental trial conducted from March to June.

Experimental Design

The experimental design details for this experimental trial is included in table 1;

Treatment Details

The treatments used for our experiment along with the amount and application method is included in table 2;

Experiment Detail

Soil and land preparation

To make soil free from large soil clods and weeds, about 3-4 deep ploughing followed by harrowing were done. After sowing the tubers, ridges and furrows were made on the field and complete plantation procedure was done.

Manuring and fertilization

The recommended doses of fertilizers for potato as enlisted under Improved Potato

Table 1. Details of experimental design used in study site at Bhatkanda, Ganyapdhura Rural Municipality-1, Dadeldhura, Nepal, 2020

S.N	Particulars	Trial details
1.	Design	Randomized Complete Block Design (RCBD)
2.	Replication (Blocks)	4
3.	Treatments	5
4.	Plot size	3.6×1 m^2
5	Spacing between replication	0.3m
6	Spacing between plots within replication	0.2m
7	Total number of plots	24
8	Number of plants per plot	24(6 rows and 4 columns)
9	Total number of plants	480
10	Spacing	60×25 cm^2 (row to row and plant to plant respectively)
11	Sample	5 central plants

Table 2. List of treatments, application dose and application method

S.N.	Treatment name	Application dose	Application method
1	Mancozeb	5g L^{-1} of water	Dip treatment of tuber for 30 minutes in manozeb added solution then completely dried in shade and planted.
2	Boric acid	3g L^{-1} of water	Dip treatment of tuber for 30 minutes in boric acid solution then completely dried in shade and planted.
3	*Trichoderma viride*	2ml L^{-1} of water	Dip treatment of tuber for 30 minutes in *Trichoderma* added solution then completely dried in shade and planted.
4	*Pseudomonas fluorescens*	2ml L^{-1} of water	Dip treatment of tuber for 30 minutes in Pseudomonas added solution then completely dried in shade and planted.
5	Non-Treated Control	-	Non-Treated control tubers were only treated with gibberellic acid for better sprouting

Cultivation Methods by PMAMP Potato zone, Dadeldhura was used;

FYM: 30 ton ha^{-1}

Urea: 140 kg ha^{-1}

DAP: 220 kg ha^{-1}

MOP: 100 kg ha^{-1}

Full dosages of all fertilizers were incorporated into the field prior sowing except nitrogen whose split dosage was used one half as basal and another half after 25 days of plantation.

Irrigation

Furrow Irrigation was done after 30 days of planting. Flooded irrigation was avoided and also water level was maintained below $2/4^{th}$ of ridges while irrigating the field.

Harvesting

The maturity day of cardinal variety is around 90-100 days so potatoes were harvested from the experimental field after 100 days of plantation.

The climatic data for the entire duration of the research is in figure 1.

Data collection

For recording the observations on efficacy of different biological and chemical treatments on control of powdery scab of potato, data were collected from the tagged plants at different times according to the requirement.

Growth parameters

A. Germination percentage: Total germination percentage was recorded at 30 days of sowing and 60 days of sowing. For each plot, total number of germinated tuber seed was counted and then germination percentage was calculated using the formula:

Germination percentage = (Total number of germinated tubers/Total number of tubers planted) * 100 %

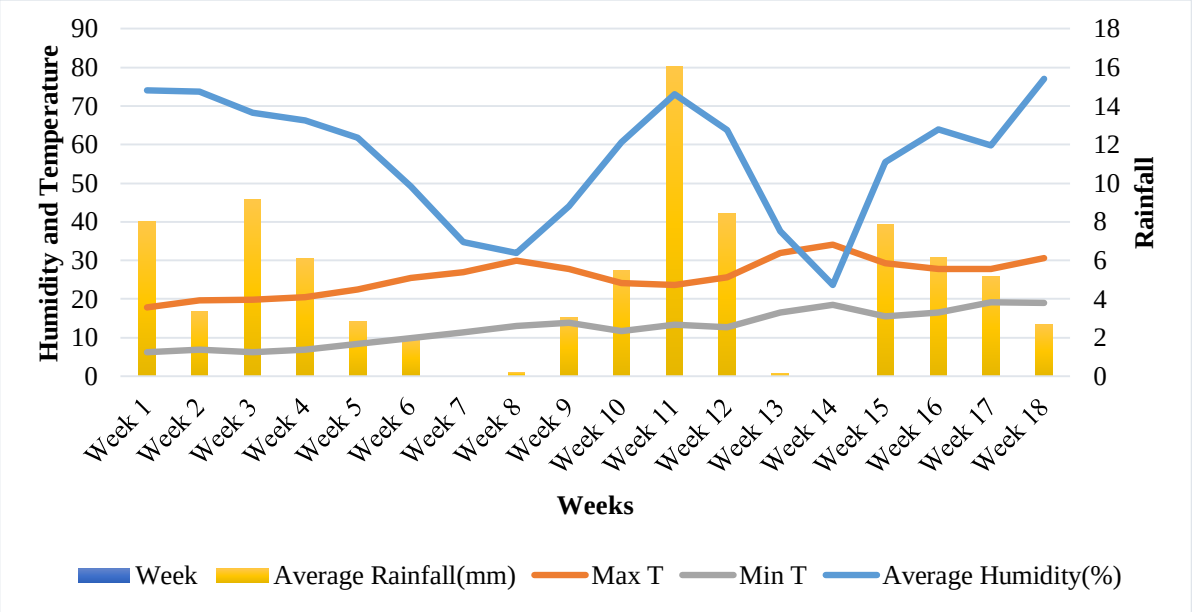

Figure 1. Meteorological data of the study site during the period of study (Source: Regional Department of Hydrology and Meteorological Station, Dadeldhura)

B. Plant height (cm): Plant height record was taken from five tagged plants per plot. The distance from the soil surface to the top most growth point of above ground at full flowering determines the plant height (Zelalem et al. 2009). Plant height data were collected after 45, 60 and 75 days of sowing.

C. Number stems (hill^{-1}): The number of main stems produced per hill were recorded by counting the main stems which came out from the seed tuber from five tagged plants from each plot at full flowering (Zelalem et al. 2009).

D. Diameter of stem (mm): Diameter of the medium sized stem from each hill was recorded from five tagged plants using vernier calipers.

Yield parameters

The number of tubers hill^{-1}, tuber yield hill^{-1}, average tuber weight, average marketable and unmarketable tuber number m^{-2}, total tuber yield, marketable tuber yield and unmarketable tuber yield ton ha^{-1} data were collected at the time of harvesting from the field.

A. Number of tubers (hill^{-1}): It is explained as total number of tubers harvested from each hill.

B. Average tuber yield (g hill^{-1}): Average weight of total tubers harvested from sampled hills/plants was divided by the number of plants. Total yield from five sampled plants was divided by five.

C. Number of tubers (m^{-2}): It included the total number of tubers harvested from the area of 1-meter square.

D. Marketable and Unmarketable number of tubers (m^{-2}): Marketable tubers included non-diseased and slightly infected tuber number whereas unmarketable tubers included severely disease infected tubers harvested from the area of square meter.

E. Total tuber yield (kg m^{-2}): Total tuber yield was recorded as the sum of marketable seed tuber and unmarketable tuber yield harvested from the area of square meter.

F. Marketable and unmarketable seed

tuber yield (kg m^{-2}): It included the yield of marketable and unmarketable tubers harvested from the area of square meter.

Pathological observations

A) Disease incidence

Total number of plants affected by disease in a plot was recorded. For this 10 plants from each of the plots were observed.

Percentage disease incidence = (No. of plants affected/Total number of plants observed) ×100

B) Percentage disease severity

For the evaluation of effect of different treatment against potato powdery scab 5 sample plants were selected and from each sampled plant 3 tubers were choosen then, potato disease severity was determined by using formula:

Disease severity % = (Sum of numerical ratings/ Total number of tubers examined×Max.grade) ×100

Economic analysis

A. Cost of cultivation

Cost of cultivation was calculated on the basis of local charges for different Argo inputs viz. labor, fertilizer, tubers, pesticides and other necessary materials.

B. Gross return

Economic yield was converted into gross returns (NRS. ha^{-1}) on the basis of local market price.

C. Net return

Difference of gross return and total expenditure gave Net return. In formula

Net return = Gross return (NRs. ha^{-1}) – cost of cultivation (NRs. ha^{-1})

D. Benefit cost analysis

The benefit cost analysis of different treatments was carried out by using formula:

B/C *ratio= (Gross return/Variable cost)*

Statistical Analysis

The collected data were systematically arranged and entered in MS Excel. Then the arranged data was analyzed using the software, R studio. The means were compared by using Duncan's multiple Range Test (DMRT) at 5% level

Table 3. Disease scoring scale used to score powdery scab of potato

Score	Severity
0	No symptoms
1	Very small lesion
2	Small superficial lesion
3	Periderm broken
4	Light pitted
5	Deep pitted

Table 4. Influence of treatments on the germination percentage of potato at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatment	Germination percentage	
	Germination 30 DAS	Germination 60 DAS
T_1 (Mancozeb)	34.375	77.08[b]
T_2 (Boric acid)	34.375	89.58[a]
T_3 (*Trichoderma*)	37.50	90.62[a]
T_4 (*Pseudomonas*)	39.58	91.67[a]
T_5 (Non-Treated Control)	33.33	87.50[a]
F value	NS	3.53
Probability	NS	0.04005*
SEM(±)	1.6	3.14
LSD	NS	9.70
CV, %	9.31	7.21
Grand mean	35.83	87.29

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

Table 5. Influence of treatments on the plant height of potato at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatment	Plant height		
	45 DAS	60 DAS	75 DAS
T_1 (Mancozeb)	17.75	27.35[c]	44.08[bc]
T_2 (Boric acid)	16.74	25.55[c]	42.06[c]
T_3 (*Trichoderma*)	18.44	34.90[ab]	48.84[b]
T_4 (*Pseudomonas*)	20.89	40.10[a]	55.83[a]
T_5 (Non-Treated Control)	16.70	29.70[bc]	45.97[bc]
F value	NS	4.46	7.80
Probability	NS	0.01942*	0.002451**
SEM(±)	2.25	2.81	1.91
LSD	NS	8.68	5.91
CV, %	24.92	17.86	8.10
Grand mean	18.11	31.52	47.36

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

of significance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Growth parameters

Germination percentage

The analysis of variance revealed that germination percentage at 30 DAS was found non-significant. At 30 DAS, the highest (39.58%) and lowest (33.33%) germination percentages were observed in the plots treated with *Pseudomonas fluorescens* and Non-Treated Control plots respectively. But at 60 DAS, germination percentage was found to be significant. The highest germination percentage (91.64%) was recorded in the plots treated with *Pseudomonas fluorescens* followed by *Trichoderma viride* (90.62%), Boric acid (89.5%) and Non-Treated Control (87.50 %).

Plant height

The result of analysis of variance showed that there was no any significant difference in the plant height at 45 DAS. The highest (20.89cm) and the lowest (16.70) plant height were observed in *Pseudomonas fluorescens* and Non- Treated Control respectively. However, at 60 DAS and 75 DAS, plant height was found statistically significant. The plant height was found higher (40.10cm at 60 DAS and 55.83cm at 75 DAS) in the plots treated with *Pseudomonas fluorescens*.

Number of main stem

The analysis of variance revealed that the main stem number of potato was not found to be significantly influenced by different treatments applied at different data recordings. At 60 DAS, the highest number of stem (1.55) was found on plots treated with *Pseudomonas fluorescens,* at 75 DAS,

Table 6. Influence of treatments on the Number of main stem of potato at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatment	Number of main stem	
	60DAS	75 DAS
T_1 (Mancozeb)	1.35	1.50
T_2 (Boric acid)	1.25	1.45
T_3 (*Trichoderma*)	1.35	1.60
T_4 (*Pseudomonas*)	1.55	1.80
T_5 (Non-Treated Control)	1.25	1.50
F value	NS	NS
Probability	NS	NS
SEM(±)	0.097	0.124
LSD	NS	NS
CV, %	14.4	15.85
Grand mean	1.36	1.57

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

Table 7. Influence of treatments on stem diameter of potato at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatments	Stem diameter	
	60 DAS	75 DAS
T_1 (Mancozeb)	11.15	12.18^b
T_2 (Boric acid)	11.71	12.69^b
T_3 (*Trichoderma*)	12.19	15.40^a
T_4 (*Pseudomonas*)	12.16	13.70^b
T_5 (Non-Treated Control)	11.66	12.27^b
F value	NS	6.90
Probability	NS	0.004015 **
SEM(±)	0.46	0.51
LSD	NS	1.58
CV, %	7.89	7.73
Grand mean	11.77	13.61

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

Pseudomonas treated plots showed highest number of main stem (1.80) and at 75 DAS, the lowest number of main stem (1.42) was shown by plots treated with Boric acid.

Stem diameter

In case of stem diameter, no significant influence of different treatments on stem diameter was observed at 60DAS. However, at 75 DAS stem diameter was found to be significantly influenced by treatments. The highest stem diameter (15.40mm) was found on the plot treated with *Trichoderma* which was followed by the plot treated with *Pseudomonas* (13.70mm), Boric acid (12.69 mm) and Non-Treated Control plots. The lowest stem diameter (12.18mm) was found on the plots treated with Mancozeb.

Yield parameters

The results obtained in yield parameters such as number of tubers hill^{-1}, number of tubers m^{-2}, marketable tuber number m^{-2}, unmarketable tuber number m^{-2}, tuber yield hill^{-1}, tuber yield m^{-2}, marketable tuber yield m^{-2} , unmarketable tuber yield m^{-2} are presented below.

Average number of tuber per hill and number of tuber per m^2

The analysis of variance revealed that the average number of tuber hill^{-1} and average number of tubers m^{-2} were found statistically significant .Both number of tubers hill^{-1} and tubers m^{-2} were found maximum (11.00 and 73.33 respectively) in the plot treated with *Pseudomonas* which was followed by the plot treated with *Trichoderma* (9.90 and 66.15respectively), Mancozeb (8.90 and 59.55 respectively) and Boric acid (7.95 and 53.00 respectively). The lowest (7.68 and 51.41) number of tubers hill^{-1} and number of tubers m^{-2} (7.68 and 51.41 respectively) were found in the Non-Treated plots.

Marketable and unmarketable tuber number per m^2

Table 8. Influence of treatments on tuber number of potato at Bhatkanda,Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatments	Tuber number			
	Average number of tubers hill^{-1}	Average number of tubers m^{-2}	Marketable tuber number per m^{-2}	Unmarketable tuber number per m^{-2}
T_1 (Mancozeb)	8.90^{ab}	59.55^{abc}	47.67^{bc}	11.67^{c}
T_2 (Boric acid)	7.95^{b}	53.00^{bc}	37.33^{cd}	15.67^{b}
T_3 (*Trichoderma*)	9.90^{ab}	66.15^{ab}	55.00^{ab}	11.00^{cd}
T_4 (*Pseudomonas*)	11.00^{a}	73.33^{a}	65.50^{a}	7.83^{d}
T_5(Non-Treated Control)	7.68^{b}	51.41^{c}	29.50^{d}	21.71^{a}
F value	4.18	4.43	16.58	4.65
Probability	0.02937*	0.01983*	7.859e-05 ***	0.01691 *
SEM(±)	0.68	4.36	3.48	2.47
LSD	2.08	13.42	10.74	3.32
CV,%	14.86	14.35	14.84	15.87
Grand mean	9.09	60.69	47.00	13.57

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

Table 9. Influence of treatments on tuber yield of potato at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatments	Tuber Yield in kg			
	Total yield Plant^{-1}	Total yield m^{-2}	Marketable tuber yield per m^{-2}	Unmarketable tuber yield per m^{-2}
T_1 (Mancozeb)	0.49^{bc}	3.24^{bc}	2.60^{b}	0.64^{b}
T_2 (Boric acid)	0.35^{d}	2.19^{d}	1.58^{c}	0.61^{b}
T_3 (*Trichoderma*)	0.52^{b}	3.43^{b}	2.86^{b}	0.57^{b}
T_4 (*Pseudomonas*)	0.59^{a}	3.87^{a}	3.46^{a}	0.42^{b}
T_5(Non-Treated Control)	0.44^{c}	2.91^{c}	1.68^{c}	1.24^{a}
F value	21.18	20.23	34.12	10.82
Probability	0.00002277**	0.00002887***	0.00000181***	0.0005954***
SEM(±)	0.02	0.14	0.14	0.10
LSD	0.06	0.43	0.42	0.30
CV, %	8.10	8.92	13.45	27.57
Grand mean	0.48	3.13	2.04	0.70

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

Analysis of variance revealed that there was significant difference in the marketable and unmarketable tuber number per m^2 among the plots treated with different treatments. The highest number of marketable tuber m^{-2} (65.50) was found in the plot treated with *Pseudomonas fluorescens* which was followed by *Trichoderma viride* (55.0), Mancozeb (47.67) and Boric acid (37.33) respectively. The lowest marketable tuber number m^{-2} (29.50) was found in Non-Treated Control plots. As marketable tubers were higher in *Pseudomonas* and lower in Non-Treated Control plots, the unmarketable tuber number was lower (7.83) and higher (21.71) respectively.

Average yield of tuber per hill and number of tuber per m^2

The analysis of variance revealed that average yield of tuber hill^{-1} and yield m^{-2} was found statistically significant. Both yield of tubers hill^{-1} and tubers m^{-2} were found maximum (0.59 kg and 3.87 kg respectively) in the plot treated with *Pseudomonasfluorescens* which was followed by the plot treated with *Trichoderma viride* (0.44 kg and 3.43 kg respectively), Mancozeb (0.49 kg and 3.24 kg respectively) and Non-Treated Control (0.347 kg and 2.19 kg respectively). The lowest yield of tubershill^{-1} and number of tubers m^{-2} (0.3470 kg and 2.19 kg respectively) were found in the plots treated with Boric acid.

Marketable and unmarketable tuber yield per m^2

Analysis of variance revealed that there was significant difference in the marketable and unmarketable tuber yield m^{-2} among the plots treated with different treatments. The highest marketable tuber yield m^{-2} (3.47 kg) was found in the plots treated with *Pseudomonas fluorescens*

Table 10. Influence of treatments on Disease incidence of potato powdery scab at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatment	Disease Incidence
T_1 (Mancozeb)	67.50[c]
T_2 (Boric acid)	80.00[b]
T_3 (*Trichoderma*)	52.50[d]
T_4 (*Pseudomonas*)	45.00[d]
T_5 (Non-Treated Control)	92.50 [a]
F value	28.81
Probability	0.0000452***
SEM(±)	3.62
LSD	8.27
CV, %	7.95
Grand mean	67.50

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

which was followed by *Trichoderma viride* treated plots (2.86 kg), Mancozeb (2.60 kg) and Non-Treated Control (1.68 kg). The lowest marketable

tuber number m^{-2} (1.58kg) was found on the plot treated with boric acid Unmarketable tubers yield m^{-2} was higher (1.24 kg) Non-Treated control plots and was lower (0.42 kg) in the plots treated with *Pseudomonas fluorescens.*

Effect of treatments on disease parameters

Disease incidence

The disease incidence of potato powdery scab was found to be significantly influenced by treatments applied as shown in table 10. The highest disease incidence (92.5%) was recorded in the Non-Treated Control plot which was followed by the plots treated with Boric acid (80.00%) and Mancozeb (75.00%). *Pseudomonas* treated plots had the lowest disease incidence (45.00 %) which was at par with *Trichoderma* treated plots (52.50%).

Disease severity

The disease severity of powdery scab disease on potato was found significantly influenced by the application of the treatments. It was calculated using 0-5 disease severity scale based on percent tuber showing scab lesion ,with 0=No disease symptoms, 1=very small lesion, 2=small superficial lesion, 3=periderm broken, 4=light pitted, 5=deep pitted (Wheeler 1969). Comparing all the treatments, the highest disease severity (42.00%) was found on the Non-Treated Control plots which were followed by the plots treated with Boric acid (38.16 %), Mancozeb (31.18%) and *Trichoderma viride* (28.70%). The least disease severity (23.35%) was found in the plots treated with *Pseudomonas fluorescens.*

Economic analysis

The economics was worked out taking into consideration, the cost of production for each treatment, the corresponding marketable yield with prevalent prices per unit output.

Production cost

The cost of production was calculated for one hectare from the cost involved in the experimental plots. Production cost included general cost of cultivation and treatment wise variable cost. The average cost was about NRs. 2, 74,010. Among all

Table 11. Influence of treatments on disease severity of potato powdery scab at Bhatkanda, Ganyapdhura-1 Rural Municipality, Dadeldhura, Nepal, 2020

Treatment	Disease Severity
T_1 (Mancozeb)	31.18[abc]
T_2 (Boric acid)	38.16[ab]
T_3 (*Trichoderma*)	28.70[bc]
T_4 (*Pseudomonas*)	23.35[c]
T_5 (Non-Treated Control)	42.00[a]
F value	3.94
Probability	0.02882*
SEM(±)	3.75
LSD	11.57
CV, %	22.98
Grand mean	32.68

Note: DAS, Days After Sowing, SEM±, Standard Error of Mean; CV, Coefficient of Variation; LSD, Least Significant Difference. Means in the column with same letter (s) in superscript indicate no significant difference between treatments at 0.05 level of significance; '***' Significant at 0.001level of Significance; '**' Significant at 0.01 level of Significance; '*' Significant at 0.05 level of Significance

Table 12. Effect of different types of treatments on economics of potato

Treatments	Total cost of production (NRs. ha^{-1})	Gross return (NRs. ha^{-1})	Net return (NRs. ha^{-1})	B:C ratio
T_1 (Mancozeb)	281440	987280	705840	3.50
T_2 (Boric acid)	271440	600945	319505	2.21
T_3 (*Trichoderma*)	273690	1087795	806355	3.97
T_4 (*Pseudomonas*)	274290	1315910	1034470	4.79
T_5(Non-Treated Control)	269190	636980	355540	2.36

the treatment, the highest production cost (NRs. 281440) occurred in Mancozeb followed by *Pseudomonas fluorescens* (NRs. 274290),

Trichoderma viride (NRs. 273690) and Boric acid (NRs. 271440). The lowest production cost (NRs. 269190) occurred in non-treated control plots.

Gross return

Gross return was influenced by different types of chemical and biological treatments. The average gross return in the experiment was NRs925782.Among different treatments, gross return was found highest (NRs. 1315910) in *Pseudomonas fluorescens* followed by *Trichoderma viride* (NRs. 1087795), (NRs. 987280) and Non-Treated Control (NRs. 636980). Lowest gross return (NRs. 600945) was found in boric acid.

B: C ratio

Among different treatments, highest B:C ratio (4.79) was observed in *Pseudomonas fluorescens* followed by *Trichoderma* (3.97), Mancozeb (3.50), Non-Treated Control (2.36) and lowest B:C ratio (2.21) was found in boric acid.

DISCUSSIONS

Use of biological treatment *Pseudomonas fluorescens* and *Trichoderma viride* had shown some positive effects in suppressing the disease in the field. Low powdery scab incidence and severity percentage was observed in *Pseudomonas fluorescens.* Reduction in the disease incidence by *Pseudomonas fluorescens* has been reported by Duque et al. (2020). Also the *Trichoderma viride* showed lower disease incidence and found effective in controlling the powdery scab. Falloon (2008) also reported that the biological control agent, *Trichoderma* spp. have potential for reducing the activity of S. subterranea, through effects on either resting spore viability or zoospore activity. Falloon et al. (1996) trials had confirmed various chemicals, including, mancozeb reduced the proportion of diseased tubers in the potato.

Pseudomonas fluorescens and *Trichoderma viride* had positively suppressed the disease severity in the field. Duque et al. (2020) experiment showed reduction of severity of powdery scab from 1.3% to minus 0.04 % by *Pseudomonas fluorescens.* Arseneault et al. (2015) demonstrated that a *Pseudomonas* strains have the ability to alter the transcriptional activity of a disease causing gene in a pathogen, resulting in the control of disease. The reduction of the severity and incidence of the powdery scab disease ultimately had increased the number and yield of the marketable tubers and decreased the number and yield of unmarketable tubers in the plots treated with the bio control agent. Arsenault et al. (2016) also reports the effectiveness of Pseudomonas which is attributed to its bio-control mechanism called antibiosis that reduces disease symptoms through the production of antimicrobial compounds, including phenazines. Burr et al. (1978) speculated that the *Pseudomonas*-stimulated yield increase with potatoes is related to the suppression populations of various parasitic and non-parasitic pathogens in the rhizosphere.The antagonistic effect of *Trichoderma* isbecauses of its property of mycoparasitism, antibiosis and competition for resources and spaces (Harman 2006) which helps in inducing systemic or localized resistance.

Rehman et al. (2003) reported promising results of the soaking of potato tubers with 3% boric acid solution for different time interval and all the treatments had lower disease severity in comparison to the untreated plot which corroborates with our findings. Similar, result of superior performance of the boric acid treatment leading to less severe disease incidence was also reported by Hossain et al. (2015).

The yield in the bio agent treated plot (*Pseudomonas fluorescens*) was found comparatively higher than other chemical treatments but the findings of Rampakant et al. (2016) reports otherwise. Similar reports on yield increment by 10% by bacterization process of *Pseudomonas fluorescens* compare to no treated potato tubers had been reported by Weller (2007). Moreover, Burr et al. (1978) reported increment in yield of potato tubers by 33% by a inoculation of seed pieces with *Pseudomonas* spp.

CONCLUSIONS

Biological treatments (*Pseudomonas fluorescens* and *Trichoderma viride*) were found more effective against the powdery scab disease than the chemical treatments (Mancozeb and Boric acid). *Pseudomonas fluorescens* had the most effective

control against the powdery scab among the different treatments. Both disease incidence and disease severity percentage were found least in the biological treatments. Reduction in disease incidence and severity of potato scab by the biological treatments (*Pseudomonas* and *Trichoderma*) had ultimately increased the overall tuber yield and also the marketable yield of tubers and often resulted in a higher B:C ratio and thus can help farmer to earn more economic returns. Results obtained from the experiment under naturally infected field conditions of Dadeldhura, *Pseudomonas fluorescens* bacteria and antagonistic fungi *Trichoderma viride* could be the environment friendly option for powdery scab disease management. Effectiveness of such bacteria and antagonistic fungus may be increased in the succeeding crops because of its multiplication in the soil.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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