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Management strategies under chemicals, liquid organic amendments and plant extracts against black scurf of potato caused by *Rhizoctonia solani* Kühn in *tarai* regions of Uttarakhand

SURAJ ADHIKARI[1], SHAILBALA SHARMA[1], R. P. SINGH[1], SUNITA T. PANDEY[2] and VIVEK SINGH[1]

[1]Department of Plant Pathology, [2] Department of Agronomy, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar-263145 (U.S. Nagar, Uttarakhand)

ABSTRACT: Black scurf is an important disease of potato caused by *Rhizoctonia solani* Kühn, which affects the quantitative and qualitative attributes of the crop. Chemicals are the quickest and most effective way providing varying degree of effectiveness to control this disease. Rising concerns over the ill effects of chemicals and increasing demand for organic potatoes have spurred researchers to look for organic alternatives. In this regard, various chemicals, plant extracts and organic amendments were tested under laboratory conditions. *Urtica diocia* at 25 per cent concentration was found to be the best among the five plant extracts tested under *In vitro* conditions inhibiting 83.54 per cent mycelial growth of the test pathogen followed by *Pinus roxiburgii* @ 25 per cent. *In vitro* evaluation of liquid organic amendments revealed that kunapajala (KJ) treatments were found to be better than jeevamrut and duspharni ark as KJ2 inhibited 100 per cent followed by KJ1 inhibiting 99.60 per cent mycelial growth of *R. solani* at 10 per cent concentration. Among the nine chemicals, the best results were depicted by penflufen as systemic fungicide and pencycuron as contact fungicide recording 94.11 and 91.02 per cent inhibition of *R. solani* mycelial growth at 10 and 100 µg ml^{-1} concentration, respectively. The chemicals were further tested in the field on the crop variety Kufri Bahar during the *rabi* season of 2020-21 at Vegetable Research Centre, Pantnagar. Among them tuber treatment with penflufen @ 0.082 per cent was found best as it recorded 89.97 and 93.23 per cent reduction in disease incidence and disease index over control, highest yield (36.65 t/ha) and best B: C ratio (17.45). Although the chemicals were found better but *U. diocia* and Vrikshayurveda based kunapajala exhibited immense potential against *Rhizoctonia solani* the incitant of black scurf of potato which can be exploited to minimize our dependence on chemicals for its management.

Key words: Black scurf of potato, chemical control, economics, organic alternatives, *Rhizoctonia solani*

Potato (*Solanum tuberosum*) is the most important non cereal food crop with India being the second largest producer after China. In Uttarakhand, potato is grown both in *rabi* and summer season in all the thirteen districts, with the highest production in Udham Singh Nagar, Almora and Tehri Garhwal districts, respectively. However, potato is susceptible to a number of biotic and abiotic stresses among which black scurf of potato caused by *Rhizoctonia solani* Kühn is of utter significance among the potato farmers of the world (Tsror, 2010). The disease was first reported by Kühn in 1858 and accounts for quantitative losses 10 to 25 per cent in India (Sharma, 2015). The disease not only reduces the quantity but also the quality of potatoes by making them deformed and ugly thus causing severe economic losses (Atkinson *et al.,* 2010). The most popular management of the disease is seed treatment by chemical fungicides providing varied degree of effectiveness for this disease (Arora *et al.,* 2013; Lal *et al.*, 2014). However, due to growing concerns regarding the ill-effects of chemicals, exigency for sustainable agriculture and great demand for organically produced products various eco-friendly alternatives are being explored. Hence, efficacy of various recommended as well as some new chemicals, plant extracts and liquid organic amendments were tested against the test fungus *Rhizoctonia solani* under *In vitro* conditions, while the economics of potato production along with efficacy of various chemicals was evaluated under the field conditions.

MATERIALS AND METHODS

Laboratory experiment

Isolation, Purification, Identification and Maintenance of the pathogen

Isolation of the test pathogen was made from the sclerotia present on the surface of potato tuber on

Potato Dextrose Agar media. The purification of pathogen was done by hyphal tip isolation method (Zhang *et al.,* 2013) and the culture obtained was maintained on PDA slants and Petri plates. The identification was done on the basis of morphological and cultural characteristics of the pathogen (Parmeter and Whitney, 1970). The subculturing of the axenic culture was done at every 15 days interval on fresh PDA media and stored in refrigerator for future use.

Preparation of plant extracts

Seven plants *viz. Catharanthus roseus* (Periwinkle), *Pinus roxburghii* (Pine), *Sapindus mukorossi* (Indian soapberry), *Urtica dioica* (Stinging nettle) and *Zingiber officinale* (Ginger) were evaluated under *In vitro* condition against the pathogen *R. solani* causing black scurf of potato. The extract was taken from leaves (*Catharanthus roseus, Catharanthus roseus* and *Urtica dioica*), rhizome (*Zingiber officinale*) and leaves as well as bark (*Pinus roxburghii*).

Cold water extraction technique was used to prepare extracts from respective plant parts (Shekhawat and Prasad, 1971; Ansari, 1995). The fresh leaves, rhizome and bark were thoroughly washed with tap water followed by washing them thrice in distilled water. These were surface sterilized in 2 per cent sodium hypochlorite for 1-2 minutes and then thoroughly rinsed in sterile distilled water. The plant parts were crushed by adding equal amount of sterilized distilled water with equal amount of fresh weight of plant parts in mortar pestle (1:1 w/v). The plant extracts were then passed through four layered muslin cloth and finally through Whatman No. 1 filter paper and bacteria proof filter, respectively. The final extract collected was used as 100 per cent concentration stock.

Sterilized distilled water was mixed to obtain double concentration of 10, 20, 30, 40 and 50 per cent for each plant extracts and combined with the double strength media (PDA) so that the final volume had the required concentration of 5, 10, 15, 20 and 25 per cent.

Preparation of liquid organic formulation

Three types of Vrikshayurveda based herbal kunapajala (KJ1, KJ2, KJ3) along with Jeevamrut and Duspharni ark were tested under *In vitro* conditions at 5, 10, 15, 20 and 25 per cent concentration. For preparing herbal kunapajala the preparation methodology was inspired from the works of Nene (2007) with little modification. Although some ingredients like 20 kg fresh cow dung, 10 l cow urine (as old as possible), 2 kg *Vigna mungo* germinated seeds, 2 kg mustard oilcake, 2 kg jaggery, 1 l raw milk, 3 kg rice husk water, 2 l sour butter milk, water extract of 4 cow dung cake and 10 l water were common in all the kunapajala (KJ1, KJ2 and KJ3) but the main difference was in the key ingredients, which were as follows: 20 kg finely chopped leaves of *Urtica dioica* (stinging nettle) was main ingredient in KJ1; 10 kg finely chopped leaves of *U. dioica* along with chopped leaves of *Azadirachta indica* (2 kg), *Clerodendron phlomidis* (1 kg), *Calotropis gigantea* (1 kg), *Datura stramonium* (1 kg), *Aegle marmelos* (1 kg), *Ricinus communis* (1 kg), *Cascabela thevetia* (1 kg), *Annona squamosa* (1 kg) and seasonal local weeds around the field (1 kg) were the key ingredients for KJ2; while *Azadirachta indica* (3 kg), *Clerodendron phlomidis* (2 kg), *Calotropis gigantea* (2 kg), *Datura stramonium* (2 kg), *Aegle marmelos* (2 kg), *Ricinus communis* (2 kg), *Cascabela thevetia* (2 kg), *Annona squamosa* (2 kg) and local seasonal weeds 3 kg) were used as key ingredients for preparing KJ3. These were all mixed thoroughly in a 200 l non transparent drum with a lid. The volume was made up to 200 l by adding more water followed by stirring and closing of the lid (anaerobic condition). The mixture was stirred thoroughly for 20 days once in morning and once in evening, while the bubbles were formed throughout the process. After 20 days the bubbles formation stopped, marking the completion of fermentation process. The mixture was filtered and stored at a shady place for future use as 100 per cent concentration stock.

To prepare Jeevamrut, cow dung (5 kg), cow urine (5 l), jaggery (1 kg), chickpea flour (1 kg) and field soil (0.5 kg) was mixed in 50 l water with a help of a wooden stick and kept for 7 days while stirring it

thoroughly once in morning and once in evening, respectively after which it was filtered and was ready to be used as 100 per cent concentration stock (Palekar, 2006). Duspharni ark was prepared by using 2 kg finely chopped leaves of ten plants as key ingredient *viz*., *Azadirachta indica*, *Ricinus communis*, *Annona squamosa, Aegle marmelos*, *Datura stramonium*, *Psidium guajava*, *Cucurma longa*, *Tagetes erecta* Linn, *Calotropis gigantea* and *Mangifera indica* as key ingredient combined with cow urine (10 l), cow dung (2 kg), turmeric powder (0.5 kg), ginger paste (0.5 kg), asafoetida powder (0.2 kg), tobacco powder (1 kg) and green chili powder (1 kg) in 200 l water. Solution was kept for about a month for the process of fermentation (aerobic) after which it was filtered and then was ready to be used as 100 per cent concentration stock (Palekar, 2006).

Each liquid organic formulation was mixed with sterilized distilled water to obtain double concentration of 10, 20, 30, 40 and 50 per cent and combined with the double strength media (PDA) so that the final volume of the resulting mixture had the required concentration of 5, 10, 15, 20 and 25 per cent.

Preparation of chemicals

For *In vitro* studies, total ten fungicide were evaluated which are presented in Table 5. Based on active ingredient, stock solution of 1000 µg ml^{-1} was prepared for various chemical. Double concentrations of chemicals were prepared by adding sterile distilled water and combined with double concentration of media (PDA) to obtain required concentrations for the experiment. Pencycuron being a contact fungicide was tested at 50, 100, 150, 200 and 250 µg ml^{-1} concentration while azoxystrobin, hexaconazole, penflufen, propiconazole, thifluzamide, carboxin + thiram, tebuconazole + trifloxystrobin, thiophanate methyl + kasugamycin and thiophanate methyl + pyraclostrobin being systemic chemicals were tested at 1.25, 2.5, 5, 10 and 20 µg ml^{-1} concentration against the test pathogen *R. solani.*

Poisoned food technique

Poisoned food technique (Grover and Moore, 1962) was used to evaluate the efficacy of different chemicals against the test fungus *R. solani*. Mycelial discs from a 4-day old pure culture of *R. solani* were placed at the centre of the poured PDA plate containing different concentration of various test chemicals. Three replications were maintained of each treatment and these plates were kept in incubator at 28±2^0 C until the control plates were covered completely with *R. solani* mycelial growth. The readings of radial mycelial growth were taken and per cent inhibition of mycelial growth was calculated by using the formula of Vincent (1927).

$$\% I = \frac{C-T}{C} \times 100$$

Where:

I = Per cent inhibition of mycelial growth

C = Average colony diameter in control plates (mm)

T = Average colony diameter in treated plates (mm)

Field experiment

Two field experiments were conducted on crop variety Kufri Bahar in Vegetable Research Centre, Pantnagar (Uttarakhand) which is situated at an altitude of 243.84 m above sea level with longitude 79.3°E and latitude 29°N during the *rabi* season of 2020-2021. Experiment was laid out in Randomised Block Design with 10 treatments in 3 replications. The spacing was 60 cm between rows and 20 cm between the tubers while the plots size was of 3m × 3m. The crop was sown on 25.10.2020 and harvested on 15.03.2021. All the recommended package of practices from field preparation to harvesting were followed for the potato cultivation. The chemicals were applied by tuber dip treatment prior to sowing by dipping the tubers as per the recommended doses for 15 minutes while the check treatment tubers were dipped in normal water (Table 5). All the tubers were shade dried and then sowed as per the layout.

Observation recorded

Germination count was taken at 35 days after sowing. After the harvesting, the tubers were washed and shade dried and then rated according to 0-3 rating scale (0 for healthy tubers, 1 for up to 25 % disease severity, 2 for 25-50 % disease severity and 3 for >50 % disease severity) recommended for black

scurf of potato (Boer, 1996).

Per cent disease incidence (DI) (Cooke, 2006) and per cent disease index (PDI) (Wheeler, 1969) were calculated by the following formula:

$$DI = \frac{\text{Number of infected tuber}}{\text{Total number of tuber}} \times 100$$

All the data were statistically analysed by ANOVA using Completely Randomised Design for laboratory trials and RBD for field trial through OPSTAT. The treatments were compared by mean of critical difference at 5 per cent level of significance (Sheoran, 1998).

RESULTS AND DISCUSSION

In vitro studies

Effect of chemicals against R. solani at different concentration

The data on mycelial growth and per cent inhibition (Table 1) revealed that the contact fungicide pencycuron was better than the control inhibiting 84.89 and 91.02 per cent *R. solani* mycelium at 25 and 50 µg ml^{-1}, respectively while completely inhibiting the mycelial growth at 150 and 200 µg ml^{-1}.

Further studies of systemic fungicides against test pathogen (Table 2) revealed that all the systemic chemicals were significantly better than control at all the concentrations. Among the chemicals tested at 10 µg ml^{-1} more than 90 per cent inhibition was shown only by penflufen (94.11%) followed by azoxystrobin (90.39%). However, at 20 µg ml^{-1}, all the chemicals completely inhibited the mycelium growth of *R. solani* except thifluzamide which recorded only 74.75 per cent inhibition of mycelial growth of the pathogen.

The results were in accordance with the work of Sirari (2012) who reported that pencycuron completely inhibited *R. solani* mycelial growth at 100 µg ml^{-1} under which may be due to increase in resistance by the pathogen against the chemical and Hemlatha (2020) also reported that the penflufen completely inhibited the mycelial growth of *R. solani* causing banded leaf and sheath blight of maize at 10 µg ml^{-1} under *In vitro* conditions.

Effect of plant extracts against R. solani at different concentration

Five plant extracts *Urtica dioica, Pinus roxburghii, Sapindus mukorossi, Zingiber officinale* and *Catharanthus roseus* were evaluated against *R. solani* under *In vitro* conditions. The data for the per cent inhibition of mycelial growth presented in the Table 3 revealed that the minimum concentration at which inhibition of mycelial growth was noticed varied among plant extracts. *Urtica dioica* was found inhibitory at 5 per cent, *Pinus roxburghii* and *Sapindus mukorossi* at 10 per cent, *Zingiber officinale* at 20 per cent while *Catharanthus roseus* at 25 per cent.

Urtica dioica was found best as it was significantly better than control in inhibiting the test pathogen mycelial growth at all the concentration. *U. dioica* recorded 16.47, 23.75, 29.79, 46.41 and 83.54 per cent inhibition of *R. solani* mycelial growth at 5, 10, 15, 20 and 25 per cent concentration, respectively. The results were in accordance of with work of Hadizadeh *et al.* (2009) who also reported that *U. dioica* was found effective in inhibiting mycelial growth of *R. solani* by 15.3, 27.2 and 42 per cent at 0.3, 0.5, 0.7 per cent, respectively using agar dilution bioassay. Meanwhile, Tapwal *et al.* (2011) also reported that *U. dioica* recorded 18.80 per cent inhibition of *R. solani* mycelium at 20 per cent concentration.

Further the *P. roxburghii* extract was found to be the second best after *U. dioica. P. roxburghii* inhibited 27.92, 33.96 and 63.13 per cent mycelial growth of *R. solani* at 15, 20 and 25 per cent concentration respectively. Meanwhile *S. mukorossi*

$$PDI = \frac{\Sigma \text{ sum of all numerical rating}}{\text{Total number of tubers observed x highest rating number of the class}} \times 100$$

Table 1: Efficacy of pencycuron against *Rhizoctonia solani* causing black scurf of potato under *In vitro* conditions

	Mycelial growth(mm)					Inhibition of mycelial growth (%)				
Concentration (µg ml^{-1})	**25**	**50**	**100**	**150**	**200**	**25**	**50**	**100**	**150**	**200**
Pencycuron 22.9% SC	13.6	12.5	8.08	0.00	0.00	84.89	86.11	91.02	100	100
Control	90.00	90.00	90.00	90.00	90.00	0.00	0.00	0.00	0.00	0.00
	Fungicide (A)		**Concentration (B)**			**Fungicide × Concentration (A × B)**				
CD (0.05)	0.319		0.504			0.713				

Table 2: Efficacy of different systemic fungicides against *Rhizoctonia solani* causing black scurf of potato under *In vitro* conditions

	Mycelial growth (mm)					**Inhibition of mycelial growth (%)**				
Concentration (µg ml^{-1})	**1.25**	**2.5**	**5**	**10**	**20**	**1.25**	**2.5**	**5**	**10**	**20**
Azoxystrobin	25.26	17.61	13.67	8.65	0.00	71.93	80.43	84.81	90.39	100
Hexaconazole	25.94	16.88	11.34	9.55	0.00	71.18	81.25	87.40	89.39	100
Penflufen	28.92	15.45	11.28	5.30	0.00	67.86	82.82	87.47	94.11	100
Thifluzamide	46.78	35.95	32.74	25.39	22.73	48.03	60.05	63.62	71.79	74.75
Carboxin + Thiram	66.17	36.45	17.65	14.63	0.00	26.48	59.47	80.39	83.74	100
Tebuconazole + Trifloxytrobin	45.13	36.63	25.16	10.49	0.00	49.85	59.30	72.04	88.34	100
Thiophanate methyl + Kasugamycin	68.08	32.87	16.92	11.24	0.00	24.35	63.48	81.20	87.51	100
Thiophanate methyl + Pyraclostrobin	51.23	26.48	15.18	9.01	0.00	43.08	70.58	83.13	89.99	100
Control	90.00	90.00	90.00	90.00	90.00	0.00	0.00	0.00	0.00	0.00
	Fungicide (A)		**Concentration (B)**			**Fungicide × Concentration (A × B)**				
CD (0.05)	0.500		0.354			1.119				

Table 3: Efficacy of different plant extracts against *Rhizoctonia solani* causing black scurf of potato under *In vitro* conditions

Treatment	**Mycelial growth (mm)**					**Inhibition of mycelial growth (%)**				
Concentration (%)	**5**	**10**	**15**	**20**	**25**	**5**	**10**	**15**	**20**	**25**
Catharanthus roseus	90.00	90.00	90.00	90.00	66.56	0.00	0.00	0.00	0.00	26.04
Pinus roxburghii	90.00	85.13	64.88	59.44	33.19	0.00	5.42	27.92	33.96	63.13
Sapindus mukorossi	90.00	87.90	87.35	84.90	81.92	0.00	2.34	2.94	5.67	8.98
Urtica dioica	75.18	68.63	63.19	48.23	14.81	16.47	23.75	29.79	46.41	83.54
Zingiber officinale	90.00	90.00	90.00	76.31	36.33	0.00	0.00	0.00	15.21	59.63
Control	90.00	90.00	90.00	90.00	90.00	0.00	0.00	0.00	0.00	0.00
	Plant extracts (A)		Concentration (B)			Plant extracts × Concentration (A × B)				
CD (0.05)	0.790		0.625			1.767				

Table 4: Efficacy of different liquid organic amendments against *Rhizoctonia solani* causing black scurf of potato under *In vitro* conditions

Treatment	**Mycelial growth (mm)**					**Inhibition of mycelial growth (%)**				
Concentration (%)	**5**	**10**	**15**	**20**	**25**	**5**	**10**	**15**	**20**	**25**
Jeevamrut	90.00	90.00	90.00	90.00	55.74	0.00	0.00	0.00	0.00	38.06
Duspharni	90.00	90.00	90.00	90.00	71.44	0.00	0.00	0.00	0.00	20.63
KJ1	41.42	0.36	0.00	0.00	0.00	53.98	99.60	100	100	100
KJ2	41.16	0.00	0.00	0.00	0.00	54.27	100	100	100	100
KJ3	55.41	37.23	0.00	0.00	0.00	38.44	58.64	100	100	100
Control	90.00	90.00	90.00	90.00	90.00	0.00	0.00	0.00	0.00	0.00
	Treatments (A)		**Concentration (B)**			**Treatments × Concentration (A × B)**				
CD at 5%	1.166		1.065			2.608				

inhibited 2.34, 2.94, 5.67 and 8.98 per cent mycelial growth of *R. solani* at 10, 15, 20 and 25 per cent concentration, respectively which were significantly better than the control. *Z. officinale* extract inhibited

Table 5: Effect of different chemicals on germination, disease incidence, disease index and yield against black scurf of potato

Treatments	Trade name + active ingredient	Dose (%)	Germ-ination (%)	Disease incidence (%)	Reduction (%) in DI over control	PDI	Reduction (%) in PDI	Tuber Yield (t/ha)
Pencycuron	Monceren (22.9% SC)	0.40	86.67	8.31	88.83	2.82	92.34	36.53
Azoxystrobin	Amistar (23% SC)	0.25	82.22	10.17	86.33	3.71	89.92	35.68
Hexaconazole	Sitara plus (5% SC)	2.00	33.33	36.25	51.28	16.97	53.89	21.42
Penflufen	Emesto(22.43% FS)	0.08	83.11	7.46	89.97	2.49	93.23	36.65
Thifluzamide	Pulsor(24% SC)	0.25	81.78	10.73	85.58	3.58	90.27	35.28
Carboxin + Thiram	Vitavax(37.5% WS + 37.5% WS)	0.25	84.00	10.63	85.71	4.01	89.10	36.31
Tebuconazole + Trifloxytrobin	Nativo(50% WG + 25% WG)	0.50	64.44	26.69	64.13	12.73	65.41	27.42
Thiophanate methyl + Kasugamycin	-(44.8% SC + 2.6% SC)	0.35	66.67	20.94	71.85	8.64	76.52	29.36
Thiophanate methyl + Pyraclostrobin	Xelora (450g/L FS + 50g/L FS)	0.20	84.89	12.22	83.58	4.13	88.78	35.28
Control		-	79.11	74.40	0.00	36.8	0.00	29.87
	CD (0.05)		9.461	4.979		2.638		2.673

Table 6: Economics of various chemicals under *in vivo* conditions against black scurf of potato

Sl. No	Treatment	Cost of treatment (Rs/ha)	Mean tuber yield (t/ha)	Extra yield over control (t/ha)	Gross return (Rs/ha)*	Net return (Rs/ha)	B:C Ratio
1	Pencycuron	2000	36.53	6.66	33300	31300	16.65
2	Azoxystrobin	5005	35.68	5.81	29050	24045	5.80
3	Hexaconazole	2560	21.42	-8.45	-42250	-44810	-16.50
4	Penflufen	1942.4	36.65	6.78	33900	31957.6	17.45
5	Propiconazole	3204	6.95	-22.92	-114600	-117804	-35.76
6	Thifluzamide	4200	35.28	5.41	27050	22850	6.44
7	Carboxin + Thiram	20050	36.31	6.44	32200	12150	1.60
8	Tebuconazole + Trifloxytrobin	3680	27.42	-2.45	-12250	-15930	-3.32
9	Thiophanate methyl + Kasugamycin	2100	29.36	-0.51	-2550	-4650	-1.21
10	Thiophanate methyl + Pyraclostrobin	3150	35.28	5.41	27050	23900	8.58
11	Control	-	29.87	0	0	0	-

*Sale price of potato tuber @ Rs 5/kg

15.21 and 59.63 per cent mycelial growth of the test fungus at 20 and 25 per cent concentration, respectively. *C. roseus* also recorded 26.04 per cent inhibition of *R. solani* mycelium at 25 per cent concentration.

Among all the plant extract tested at highest concentration (25 per cent), *U. dioica* was found highly effective reducing the radial growth of *R. solani* (83.54%) followed by *P. roxburghii* (63.13%) and *Z. officinale* (59.63%), respectively while minimum inhibition was recorded in *S. mukorossi* (8.98%) followed by *C. roseus* (26.04 %).

Effect of liquid organic formulations against R. solani at different concentration

Antifungal activity of five liquid organic amendments *viz.*, KJ1, KJ2, KJ3, jeevamrut and duspharni ark was assayed on *R. solani* mycelial growth and is presented in Table 4. Best result was recorded by KJ2 followed by KJ1 and KJ3 with 100, 99.60 and 58.64 per cent inhibition of mycelial growth of the test fungus at 10 per cent concentration. The results of kunapajala treatments (KJ1, KJ2 and KJ3) were significantly better than control at all the concentration. Jeevamrut and Duspharni ark did not exhibited any inhibitory effect at lower concentration of 5, 10, 15 and 20 per cent

but recorded 38.06 and 20.63 per cent mycelial inhibition, respectively at 25 per cent concentration. However, it was interesting to observe that extensive sclerotia formation was observed at initial concentrations in both Jeevamrut and Duspharni ark treatments which pointed that the formulations rather encouraged the *R. solani* mycelial growth instead of inhibiting it at lower concentrations. It may be due to the preparation methodology difference i.e., kunapajala being the product of anaerobic fermentation while jeevamrut and dushpharni ark being aerobically fermented products but search for literature regarding this phenomenon revealed that not much literature was present. However, Scheuerell *et al.* (2007) while working on geranium reported that suppression of gray mold caused by *Botrytis cinerea* was significantly higher in non-aerated compost teas compared to aerated compost teas. But further research and experimentation are suggested to identify the reason behind it.

Field evaluation of fungicides

Effect on germination per cent

Data on germination Per cent (Table 5) revealed that all the treatments were statistically at par with the control (79.11 %). However, hexaconazole, tebuconazole + trifloxystrobin and thiophanate methyl + kasugamycin treatments recorded significantly lower germination with 33.33, 64.44 and 66.67 per cent germination respectively. Similar results were also observed by Lal *et al.* (2014) who in an experiment found out that pencycuron and penflufen as tuber dip treatment recorded 96.44 and 94.67 per cent germination, respectively against the control with 92.44 per cent germination.

Meanwhile, it was interesting to observe that most of the treatments under which low germination was observed belonged to triazole group of fungicide, although search for the literature revealed that not much information is available with regard to the connection between low germination of potato seed tubers and the triazoles chemicals. However, Yang *et al.* (2014) revealed that germination per cent of maize was reduced when encapsulated by tebuconazole. Likewise, Gōrtz *et al.* (2008) reported a significant reduction in the germination of barley when seed treatment was done with triazole fungicides like triadimenol, flutriafol, prothioconazole and tebuconazole.

Effect on disease incidence and disease severity

All the chemicals significantly reduced the disease incidence over control (Table 5). The highest disease incidence was found in control treatment (74.40 %) while the lowest was recorded in penflufen (7.46 %) followed by pencycuron (8.31%), azoxystrobin (10.17%), carboxin + thiram (10.63%), thifluzamide (10.73%) and thiophanate methyl + pyraclostrobin (12.22%) were significantly effective showing 89.97, 88.83, 86.33, 85.71, 85.58 and 83.58 per cent reduction in disease incidence over the control, respectively.

Highest disease index (36.8%) was found in control treatment. Meanwhile the best results were seen in penflufen followed by pencycuron, thifluzamide, azoxystrobin, carboxin + thiram and thiophanate methyl + pyraclostrobin with 2.49, 2.82, 3.58, 3.71, 4.01 and 4.13 per cent disease index, respectively and 93.23, 92.34, 89.92, 90.27, 89.10 and 88.78 per cent reduction in disease index over the check, respectively (Table 5).

Overall, it was found that seed treatments with all the chemical were found to be significantly better in reducing disease incidence and disease index over the control treatment. Penflufen treatment being the best followed by pencycuron against the black scurf disease of potato. Similar results were also recorded by Lal *et al.* (2014), Bagri *et al.* (2017), Kulkarni and Chavhan (2017) who also found penflufen to be most effective against black scurf of potato among various chemical tested.

Effect on total tuber yield of potato

Highest tuber yield was recorded in penflufen followed by treatment pencycuron, carboxin + thiram, azoxystrobin, thifluzamide and thiophanate methyl + pyraclostrobin with tuber yield of 36.65, 36.53, 36.31, 35.68, 35.28 and 35.28 t / ha, respectively while the lowest yield was recorded in hexaconazole, tebuconazole + trifloxystrobin, thiophanate methyl + kasugamycin and control which was 21.42, 27.42, 29.36 and 29.87 t/ha

respectively (Table 5). This is in accordance with findings of studies by Arora (2013), Lal *et al.* (2014), Bagri *et al.* (2017) and Lal *et al.* (2017).

Effect on benefit-cost ratio

Benefit-cost ratio over control for different chemicals (Table 6) revealed that the highest B: C ratio was in treatments penflufen (17.45) followed by pencycuron (16.65), thiophanate methyl + pyraclostrobin, thifluzamide, azoxystrobin and carboxin + thiram with B:C ratio of 8.587, 6.440, 5.804 and 1.606, respectively.

CONCLUSION

The present investigation revealed that seed treatment with penflufen was the best management strategy against the black scurf disease of potato providing highest reduction in disease incidence and disease index over control, producing highest yield and exhibiting the best B: C ratio among all the treatments. Therefore, can be recommended to potato growers in *tarai* regions of Uttarakhand. However, *U. dioica* extract and herbal kunapajala formulations under *In vitro* conditions were also found very effective and exhibited promising results against *R. solani* the incitant of black scurf of potato. These can be exploited to reduce our dependence on harmful chemicals. However, detail studies and experimentation are required in this regard.

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