EFFICACY OF ECO-COMPATIBLE INPUTS FOR MANAGING BLACK SCURF DISEASE OF POTATO INCITED BY *Rhizoctonia solani* (kühn)

THESIS

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PARTIAL FULFILLMENT OF THE
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SUBMITTED BY
Dasari Devi Indrani
Id. No. CA-12980/2023

UNDER THE GUIDANCE OF
Prof. S. K. Biswas

Department of Plant Pathology

Chandra Shekhar Azad University of Agriculture and Technology, Kanpur-208002 (U.P.) India

Dedicated to my beloved grandmother, Mrs. Pajjuru Sriravamma for her constant inspiration, support, love and blessings

……Dasari Devi Indrani

Prof. S. K. Biswas
M. Sc. & Ph.D. (I.A.R.I.)
DSMM, Chennai
AKI (OSU, USA)
Deptt. of Plant Pathology

C.S.A. University of Agriculture & Technology,
Kanpur 208002(Uttar Pradesh)
Email: *biswas.plpath@gmail.com*

Certificate

This is to certify that the thesis entitled **" Efficacy of eco-compatible inputs for managing Black Scurf Disease of Potato (*Solanum tuberosum L.*) incited by *Rhizoctonia solani kuhn* "** submitted in partial fulfillment of the requirement for the degree of **Master of Science (Agriculture) in Plant Pathology at the College of Agriculture, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur is record of bonafide research work carried out by Dasari Devi Indrani, Id. No. CA-12980/2023** under my guidance and supervision.

Date: /   /2025
Place: Kanpur

(S. K. Biswas)

Chairman

Department of Plant Pathology

Chandra Shekhar Azad University of Agriculture and Technology,

Kanpur-208002 (U.P.) India

Certificate

We, the undersigned, members of the Advisory Committee of Miss. Dasari Devi Indrani , Id. No. CA-12980/2023 , a candidate for the degree of Master of Science in Agriculture with major in Plant Pathology, We agree that the thesis entitled "Efficacy of eco-compatible inputs for managing Black Scurf Disease of Potato (*Solanum tuberosum L.*) incited by *Rhizoctonia solani kuhn* " may be submitted by her in partial fulfillment of the requirements for the degree.

(S. K. Biswas)
(Chairman)
Professor
Department of Plant Pathology

(Mukesh Srivastava)
(Member)
Professor and Head
Department of Pathology

(V.K Tripathi)
(Member)
Professor and Head
Department of Fruit Science

(Shweta)
(Member)
Asst. Professor
Department of Genetics and Plant Breeding

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Place: Kanpur ***(Dasari Devi Indrani)***

Date: / /2025 ***Author***

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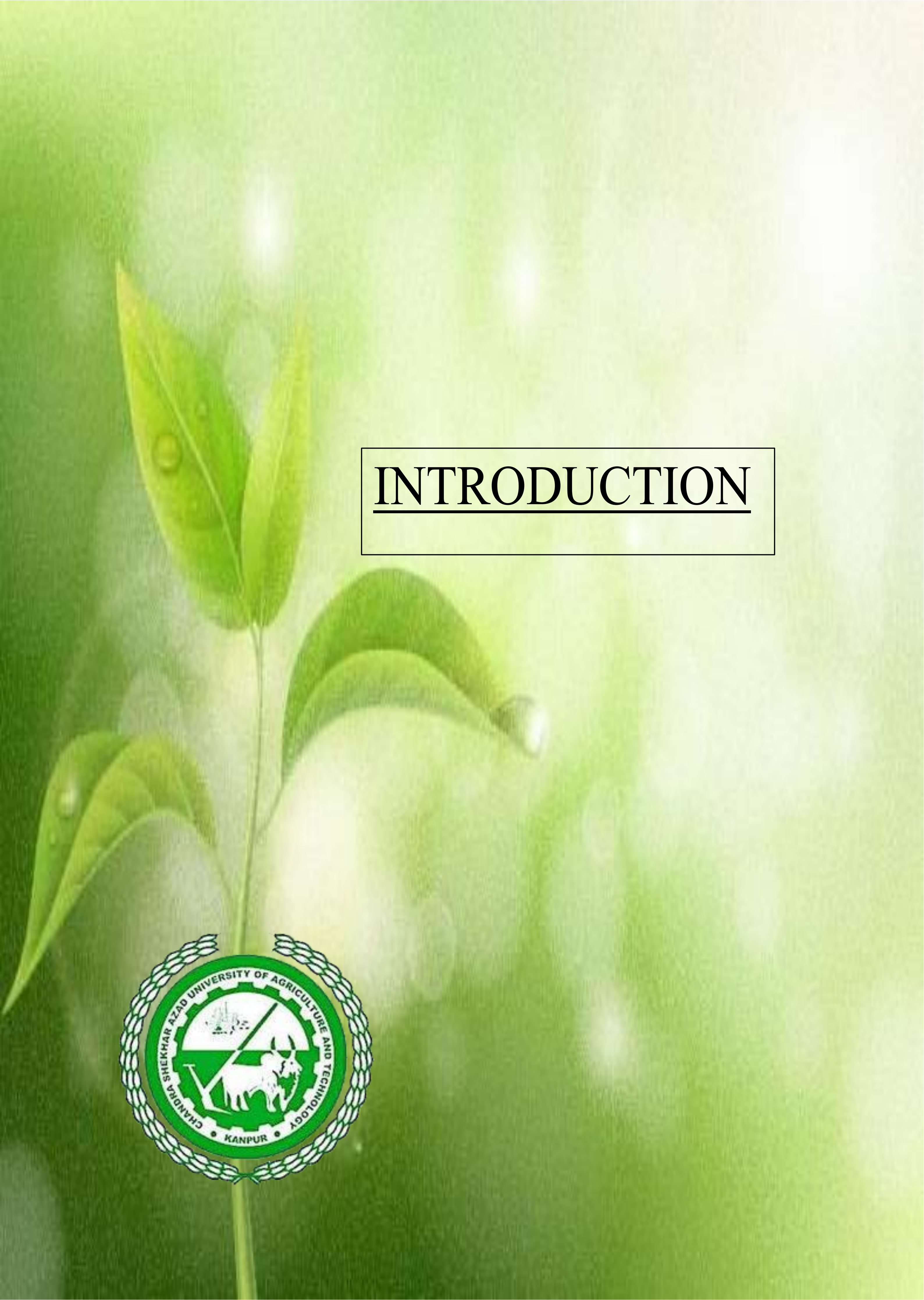
List of Abbreviations

Symbol / Abbreviation	**Word Stands For**
%	Per cent
@	At the rate of
<	Less than
>	Greater than
±	Plus or Minus
µm	Micrometer
BOD	Biological Oxygen Demand
CD	Critical Difference
cm	Centimetre
d.f.	Degree of Freedom
DOI	Days after Inoculation
DOP	Days after Planting
DOS	Days after Spraying
e.g.	For example
et al.	And others
etc.	Etcetera (and others)
Fig.	Figure
g	Gram
h	Hour
ha	Hectare
i.e.	That is
In vitro	In Plates
kg	Kilogram
Max.	Maximum
m	Meter
Min.	Minimum
ml	Millilitre
mm	Millimetre
NS	Non significant
°C	Celsius
PDA	Potato Dextrose Agar
PDI	Per cent Disease Index
Q	Quintal
q/ha	Quintal per hectare
S	Significant
SEm(+)	Standard Error of Mean
SI.No.	Serial Number
Sp.	Species (singular)
Spp.	Species (plural)

INTRODUCTION



Potato (*Solanum tuberosum L.*) has emerged as an important crop in global food security systems, ranking third in worldwide consumption after rice and wheat, often called the "**KING OF VEGETABLES**," (Amarananjundeswara *et al.,* 2020) it covers the largest area under any single vegetable crop globally.The name "Potato" likely comes from the Latin word “papa” . Potato is believed to be originated in the South American Andes, specifically in the region of present-day Southern Peru and North western Bolivia (*Latin America Potato Production*, 2022). Spanish explorers brought potatoes from Peru (South America) to Spain around 1570 AD and within a century, they were widely grown across Europe. Spanish settlers introduced potatoes to Ireland as a garden crop, where by the 18th century, they had become the staple food for many ordinary people. Potatoes reached India in 1610, Japan in 1766 and China in 1770 from Europe. Though there are about 1,500 Solanum species, only 90 produce tubers and very few are cultivated across the world. The early potatoes introduced to India weren't *Solanum tuberosum spp. tuberosum* but *Solanum tuberosum spp. andigena* (Sukhotu & Hosaka, 2006). These initial varieties became established in India and through farmer selection, developed into indigenous "desi" varieties. Though desi varieties could grow in the Indian plains, they produced less yield and were affected by many viruses. Potato production in India significantly improved after the establishment of Central Potato Research Institute in 1949.

The global potato production reached approximately 383 million tonnes in 2023, cultivated across nearly 16.8 million hectares of farmland. The geographical distribution of production shows China maintaining its position as the leading producer, followed by India, Russia, Ukraine and the United States. Notably, developing nations have witnessed a significant shift toward potato cultivation, recognizing its dual value as both a nutritional staple and an income-generating crop for smallholder farming communities (FAOSTAT-2023) .

India has established itself as a pivotal contributor to the global potato market, currently holding the position of second-largest producer worldwide. In India's potato production landscape, Uttar Pradesh leads with 19,173,000 metric tonnes, followed by West Bengal with 13,000,000 metric tonnes in 2023-24. During this period, India's total potato production reached 57,053,000 metric tonnes (Horticulture Statistics Division, Ministry of Agriculture and Farmers Welfare, 2023-24) .

Worldwide , over one billion people consume potatoes, with half a billion consumers living in developing nations. According to FAO statistics, worldwide potato utilization breaks down approximately as: 45% for human consumption, 30% for animal feed, 15% for seed purposes, 2% for starch productionand approximately 8% lost as waste. The remarkable adaptability of potato across diverse agroclimatic zones has further cemented its position as a crucial component in addressing nutritional needs worldwide. According to USDA (2020), 100 g of potato contains approximately 79.25 g water, 77 kcal energy, 17.49 g Carbohydrate, 2.05 g protein and also other contents like Sugars, Starch, Calcium, Iron, Magnesium, Sodium, Manganese, Vitamin-C in minor quantities.

The potato cultivation landscape in India faces numerous challenges, including climate variability, inconsistent irrigation infrastructure, limited availability of quality seed tubersand most significantly, the persistent pressure from various pathogens. These factors collectively contribute to a considerable yield gap that represents a substantial opportunity for improvement through targeted research and intervention strategies.

Potato crops are susceptible to a variety of soil- and tuber-borne diseases, including common scab (*Streptomyces scabies*), powdery scab (*Spongospora subterranea*), brown rot (*Ralstonia solanacearum*), black leg (*Erwinia carotovora*), sclerotium wilt (*Sclerotium rolfsii*), Verticillium wilt (*Verticillium albo-atrum*), black scurf (*Rhizoctonia solani*) and stem rot caused by (*Sclerotinia sclerotiorum*). Moreover, nematode infestations, including root-knot nematode (*Meloidogyne incognita*) and potato cyst nematodes (*Globodera rostochiensis* and *G. pallida*), along with viral infections such as Potato virus Y (PVY), Potato virus X (PVX)and Potato leafroll virus (PLRV), pose significant threats.

Black scurf caused by *Rhizoctonia solani* is particularly widespread in the state and leads to major crop losses. Its incidence has been recorded as high as 37% in various regions (Khanna and Sharma, 1993). Conservative estimates indicate that these pathogens collectively contribute to global potato yield reductions of 16-28%, with associated economic losses exceeding $14 billion annually. In India specifically, disease-related losses in potato production are estimated at ₹3,500-5,000 crore annually, highlighting the urgent need for improved disease management strategies (Civitarese, 2023).

Black Scurf Disease: An Underestimated Threat

Among the various diseases affecting potato, black scurf caused by *Rhizoctonia solani Kühn* (Teleomorph: *Thanatephorus cucumeris*) represents one of the widely spread yet frequently underestimated threats to sustainable production. This soil-borne fungal pathogen manifests in two primary symptom complexes: (1) black, irregular sclerotia adhering to tuber surfaces (black scurf) and (2) necrotic lesions on underground stems, stolons and roots (stem canker) Brewer & Larkin (2005). While the visible tuber symptoms often receive greater attention, the below-ground damage frequently causes more significant economic impact by disrupting plant development and productivity. The multifaceted impact of *Rhizoctonia solani* on potato production systems includes reduced emergence rates and non-uniform stand establishment, delayed vegetative development and diminished photosynthetic capacity, extending crop duration while reducing overall productivity.

Black scurf disease is widely distributed in potato farming and current control methods are not fully effective. There is an urgent need for thorough research for better understanding and management of the disease. The current practices of using agrochemicals against these stress factors can often result in severe environmental pollution problems [Shi *et al.,*(2011)]. The use of alternative and environmentally friendly solutions is crucial in replacing synthetic inputs with organic materials while improving the chemical, physical and biological characteristics of soils [Kotroczó & Fekete (2020)].

Farah (2006) conducted a study that evaluated *Trichoderma harzianum* and boric acid for managing black scurf of potato. Trichoderma application significantly prevented soil-borne inoculum, while boric acid treatment provided substantial protection to eyes and sprouts, enhancing crop stand and reducing yield loss.

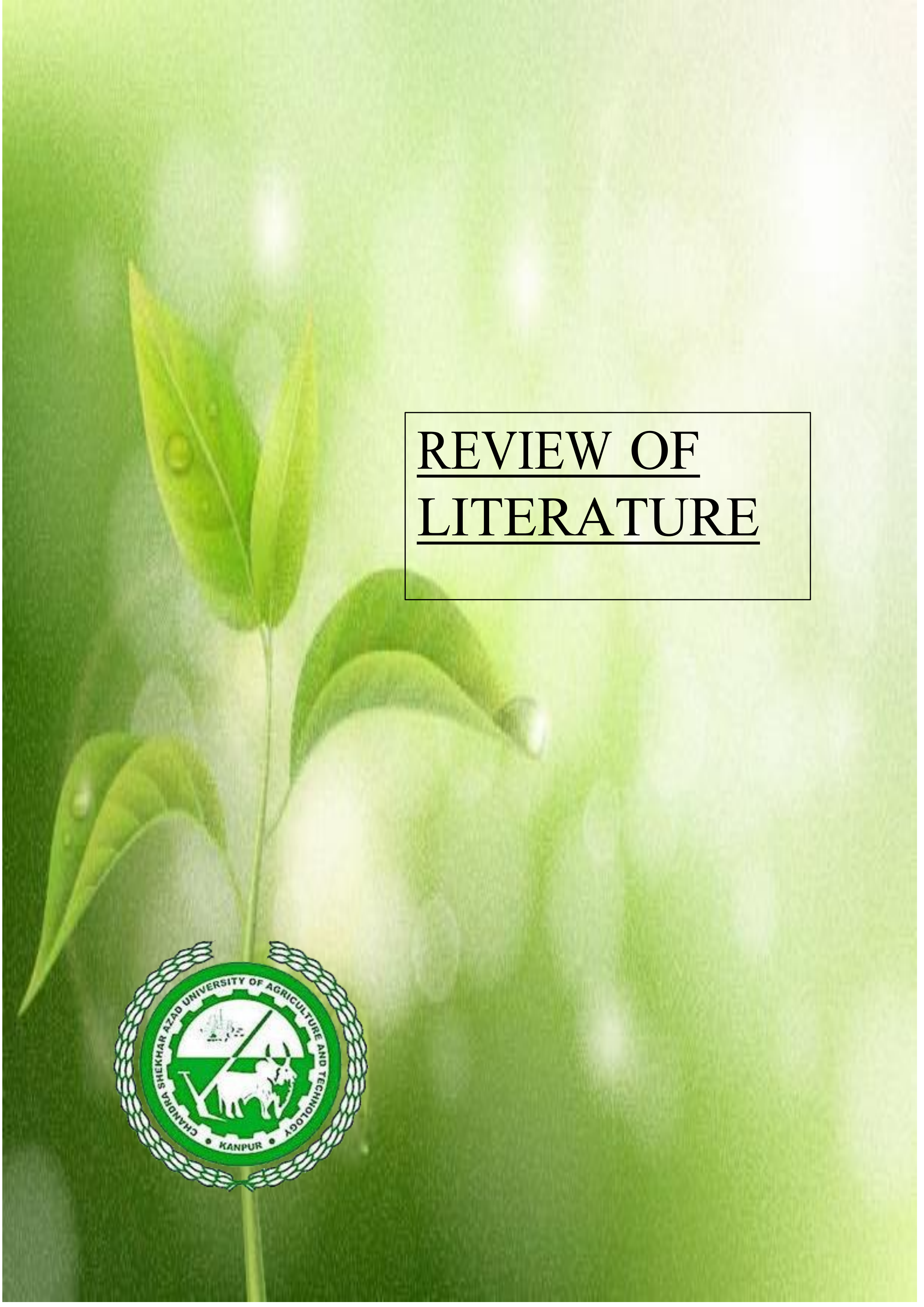
Wilson *et al*., 2008 conducted a study that evaluated *Trichoderma harzianum* and the chemical flutolanil. The results suggest that combining the application of the antagonist *Trichoderma harzianum* with seed dressing with flutolanil may provide the best protection of the potato crop against damage caused by *Rhizoctonia solani* throughout the growing season. While considerable progress has been made in understanding certain aspects of the pathogen’s biology and epidemiology, substantial knowledge gaps remain, particularly regarding regional pathogen diversity, host-pathogen interaction mechanisms and integrated management strategies suitable for diverse production contexts.

Thus the following work entitled **"Efficacy of eco-compatible inputs for managing Black Scurf Disease of Potato (*Solanum tuberosum L.*) incited by *Rhizoctonia solani kuhn*"** is undertaken to address these knowledge gaps with the following objectives :

Objectives :

1. Isolation , purification and pathogenecity of pathogen associated with Black scurf of potato .
2. To evaluate the *In vitro* antagonistic potential of *Trichoderma harzianum* and efficacy of fungicides at different concentrations against the pathogen.
3. To evaluate the impact of various treatments on the growth and yield attributes of potato under field conditions.
4. To find out the suitable eco-compatible strategy for management of Black Scurf of potato.

REVIEW OF LITERATURE



Black scurf of potato, incited by the soil borne pathogen *Rhizoctonia solani*, is a major constraint in potato production globally. The disease appears as stem cankers and the development of sclerotia on tubers, the disease inflicts considerable losses in yield and market quality. This review consolidates research findings, while acknowledging key pioneering studies, to comprehensively discuss the disease's nature, economic impact, global distribution, pathogen biology, symptom expression and management strategies.

1. The Disease

The Black scurf disease of potato, caused by *Rhizoctonia solani*,is first documented by Julius Kühn in the 19th centuary.The disease encompasses two prominent phases: stem canker during early crop growth and the formation of black sclerotia on mature tubers. While the sclerotia blemish tubers superficially without penetrating the inner flesh, they substantially downgrade the marketability of potatoes.

The pathogen's infection of underground stems and stolons during early growth disrupts nutrient translocation, leading to weakened plants or complete seedling mortality. First documented by Julius Kühn in the 19th century. The disease persists as a critical issue in potato cultivation due to the robust survival structures (*sclerotia*) produced by the fungus, allowing it to withstand adverse environmental conditions and persist across seasons.

2. Economic Importance

The infection process results in delayed sprout emergence and the development of characteristic brown to black sunken lesions on young, tender plant tissues (Tsror *et al.,* 2001).

Erampalli and Johnston (2001) highlighted that *Rhizoctonia solani* not only reduces the quantity of progeny tubers but also impairs their quality. The disease inflicts both quantitative losses - through infections of stems, stolonsand roots leading to reductions in tuber size and number and qualitative losses, notably through the generation of deformed tubers and the development of black scurf on the tuber surface.

According to Brewer & Larkin, 2005 Roland, the proportion of marketable tubers is notably diminished. Furthermore, lesions that develop on the stem interfere with nutrient transport within the plant, ultimately leading to reductions in total tuber yield.

According to El Bakali & Martín, 2006, the disease affects potato plants from the point of emergence through to harvest. Typical symptoms include the death of pre-emerging sprouts, cankers on underground stems and stolons, a compromised root systemand the appearance of sclerotia on daughter tubers.

Keiser (2008) reported yield reductions exceeding 50% as a result of black scurf, severely impairing overall potato productivity.

According to Keiser *et al.,* (2012), the principal financial burden stems from the degradation of tuber quality, particularly in potatoes destined for the fresh market.

According to Naher *et al*., 2014, black scurf disease, caused by *Rhizoctonia solani*, is economically important as it affects potato yield and quality, leading to reduced germination, plant height, and tuber yield, significantly impacting potato production in Bangladesh and globally.

Bagri *et al*., 2017 reported that Black scurf disease, caused by *Rhizoctonia solani*, leads to significant economic losses in potato production, particularly in Rajasthan, due to reduced tuber yield and increased management costs. Effective management strategies are essential to mitigate these economic impacts.

Larkin & Brewer, 2020 reported that the economic repercussions of black scurf are multifaceted, affecting both quantitative and qualitative aspects of potato production. Yield losses associated with *Rhizoctonia solani* infection range from 7% to 36%, with some severely affected regions reporting up to 50% loss during favourable seasons .

Tjimune *et al*., 2022 reported that black scurf disease, caused by *Rhizoctonia solani* AG 3-PT, significantly reduces both the qualitative and quantitative yield of potato tubers, impacting food and nutritional security in Namibia, where potatoes are a vital vegetable crop contributing approximately 10,000 tonnes annually.

3. Occurrence and Distribution

Dillard *et al.,* (1993) conducted a survey involving 251 potato growers across South Australia. They identified that the most frequently encountered diseases were target spot, caused by *Alternaria solani* and stem canker, attributed to *Rhizoctonia solani*.

Similarly, Khan *et al.,* (1995) surveyed potato-growing areas within the Swat Valley during August 1994. Their observations, based on visits to thirty-two potato fields, revealed that black scurf, common scab and powdery scab were among the most widespread diseases in the region. Black scurf, in particular, was reported in nearly all surveyed locations except for two sites. Additionally, the emergence of powdery scab and common scab was noted as a growing problem in the last three to six years within these fields.

Ahmed *et al.,* (1995) further emphasized that low soil temperatures, elevated moisture levels and zinc deficiency were the primary factors contributing to the development and proliferation of black scurf in the surveyed areas.

Jager & Velvis, 1985 reorted the occurrence of *Rhizoctonia solani* causing black scurf was initially dense and homogeneous in both fields. Over successive years, distribution became heterogeneous and patchy, with AG 3 declining and AG 5 increasing, indicating complex dynamics in pathogen populations.

Rhizoctonia solani exhibits a cosmopolitan distribution, thriving in diverse potato-growing regions ranging from temperate zones of North America and Europe to the subtropical and tropical belts of Asia, Africa and Latin America. Disease incidence is particularly aggravated under cool, moist soil conditions during planting, which favor slow sprout emergence and enhance fungal infection opportunities (Banville *et al.,* 1996).

Truter & Wehner, 2004 reported that *Rhizoctonia solani* causing black scurf was isolated from 28 plant and 56 soil samples across seven potato-production regions in South Africa. AG-3 was predominant, with additional AGs identified, indicating a widespread occurrence and distribution of the pathogen.

Lehtonen *et al*., 2008 reported that *Rhizoctonia solani*, predominantly AG-3, is the main causal agent of black scurf disease in potatoes in Finland. It was found in various lesions on potato plants, indicating its widespread occurrence in the northern potato-cultivation environment.

Ferrucho, 2011 reported that *Rhizoctonia solani* AG-3 is the most common anastomosis group associated with black scurf disease in Colombian potato fields. Isolates show high genetic variability, with no geographical structure, indicating significant gene flow among populations across main potato-producing areas.

Malik *et al.,* (2014) conducted a survey across several locations,including Narangaabad, Band Bosan, Kaian Pur, Kotla Abdul-Fateh and Dhillun, to assess the prevalence of black scurf disease in the Multan region. Among the surveyed areas, the highest incidence and severity were observed at Kotla Abdul-Fateh, with disease incidence reaching 95.00% and a severity rating of 3.1.

Esfahani, 2020 reported that *Rhizoctonia solani* causing black scurf disease of potato was isolated from six regions in Iran: Isfahan, Ardebil, Fars, Hamedan, Kurdestan and Kerman, with

120 isolates retrieved from infected stems, indicating widespread occurrence in these potato-growing areas.

Hussain & Khan, 2020 reported that black scurf disease of potato can cause yield losses up to 25% in hilly areas and about 10% in plains, significantly impacting potato production and quality, which is crucial for food security in both developed and developing countries.

Betancourth-García *et al*., 2021 reported that *Rhizoctonia solani* causing black scurf disease was isolated from potato tubers in Nariño, Colombia, specifically in Pasto, Ipiales, Tuquerres, and Ospina, with 494 strains collected, showing significant morphological variability and pathogenicity across different potato varieties.

Mothibeli *et al*., 2023 reported that *Rhizoctonia solani* was prevalent in potato producing areas of Lesotho, isolated from four districts: Maseru, Thaba-tseka, Quthing, and Berea, across three agro-ecological zones. This study marks the first report of R. solani causing black scurf in Lesotho.

Singh *et al*., 2024 reported the incidence and severity of black scurf of potato in different districts of Madhya Pradesh is high, with maximum disease incidence and severity recorded at Sheopur district and minimum disease incidence at Bhind district.

Naqvi *et al*., 2024 reported that AG-3 of *Rhizoctonia solani*, causing black scurf disease in potatoes, is widely distributed, particularly in Sweden, China, and the USA. The study highlights AG-3 as the most prevalent group, with varying genetic diversity across different geographic regions.

4. The Pathogen

Ogoshi, 1987 reported that *Rhizoctonia solani*, synonymized with *Hypochnus sasakii* and its sexual teleomorphic stage *Thanatephorus cucumeris* (Frank) Donk, is recognized as one of the most widespread, destructive and adaptable plant pathogens, affecting a broad range of host species worldwide, including potatoes where it causes black scurf and stem canker.

Carling *et al.,* 2002,inorder to address its high variability, the classification of *Rhizoctonia solani* isolates into anastomosis groups (AGs) has become a widely accepted method for subdividing this heterogeneous species into more genetically and pathogenicity-homogeneous groups. This system primarily relies on the pairing of unknown isolates with known reference strains and assessing hyphal anastomosis reactions

According to Kirk *et al.,*2008, the fungus exhibits two distinct stages: the imperfect (asexual) stage known as *Rhizoctonia solani* and the perfect (basidial) stage identified as *Thanatephorus cucumeris*. Taxonomically, it is classified under Kingdom Fungi, Phylum Basidiomycota, Subphylum Agaricomycotina, Class Agaricomycetes, Order Cantharellalesand Family Cantharellaceae .

According to Khan *et al.,* 2016, *Rhizoctonia solani* is associated with a wide spectrum of economically significant plant diseases. In addition to black scurf in potatoes, it is implicated in damping-off of seedlings, bare patch disease in cereals, root rot in sugar beet, belly rot in cucumber and sheath blight in rice, among others.

According to Jaradat *et al.,*2023, *Rhizoctonia solani* AG-3PT is the major pathogen associated with black scurf in potatoes. This study confirms its identity and pathogenicity, highlighting its significant impact on potato crops in Jordan, marking the first report of this pathogen's isolation in the region.

Accroding to Mothibeli *et al.,* 2023, the pathogen that causes black scurf of potato is *Rhizoctonia solani*, a destructive soil-borne fungus. This study reports its presence in Lesotho, highlighting its morphological variability and pathogenicity across different potato cultivars in the region.

5. Symptomatology

Truter & Wehner, 2004 reported that *Rhizoctonia solani* causes black scurf disease characterized by sclerotia on tubers, leading to lesions, girdling, and death of potato sprouts. Symptoms manifest on tubers and stems, with AG-3 being the most virulent, causing significant damage.

According to Lehtonen *et al*., 2008 *Rhizoctonia solani* causes black scurf disease on potato by forming dark sclerotia on tuber surfaces. It also induces stem canker symptoms, including brown, sunken lesions on sprouts and underground parts of the stem, affecting overall plant health and yield.

According to Ferrucho *et al*., 2012 *Rhizoctonia solani* AG-3PT causes black scurf disease in potatoes, characterized by dark, irregular lesions on tubers. It primarily affects the stems of solanaceous plants, leading to stem canker, while root damage is severe in other plant species.

According to Woodhall *et al*., 2013 Black scurf, caused by *Rhizoctonia solani*, manifests as dark, rough lesions on potato tubers. This symptom results in qualitative losses, affecting the tubers' marketability and quality, and is indicative of the presence of the pathogen in infected crops.

According to Malik *et al*., 2014 symptoms of black scurf disease caused by *Rhizoctonia solani* include black sclerotial masses on tuber surfaces and aerial tubers on foliar parts, leading to significant disease incidence and severity in potato crops, particularly in the Multan region.

According to Yang *et al*., 2015 *Rhizoctonia solani* causes black scurf disease on potatoes, characterized by the presence of sclerotia on tubers, brown canker lesions on subterranean stems, delayed emergence and the development of cracked or malformed tubers, leading to both quantitative and qualitative yield losses.

Abdlla *et al*., 2017 reported symptoms of *Rhizoctonia solani* causing black scurf disease in potatoes include visible lesions on vegetative and tuber plants. The disease severity varied across Egyptian governorates, with the highest severity observed in Ismailia and Behera, and the lowest in Menofyia.

Gush *et al.,* 2019 reported that *Rhizoctonia solani* causes symptoms such as dark brown scab lesions (elephant hide), deformation, cracking and pitting on potato tubers. It also produces brown sunken lesions (cankers) on stolons, stems and roots, affecting yield and quality.

Muzhinji *et al*.,2022 reported that *Rhizoctonia solani* causes black scurf on potato tubers, characterized by sclerotia formation, brown sunken lesions (cankers) on stolons, stems, and roots, as well as tuber deformation, cracking, “elephant hide,” and pitting, significantly affecting yield and quality.

Yang *et al*., 2022 reported the symptoms of *Rhizoctonia solani* causing black scurf disease in potatoes include black scurf on tubers and stem cankers. Infected plants exhibit typical cankers, while healthy control plants remain disease-free, confirming the pathogenicity of the isolate.

Yang *et al*.,2023, reported the first report of AG 2-2IV causing disease on potatoes in Heilongjiang Province, China, where potatoes are grown for propagation in the breeding nursery.

López-Corrales *et al*., 2023 reported the first confirmed report of R. solani AG-7 causing potato stem canker in Mexico, using the Maximum Likelihood method with ITS sequences for anastomosis groups (AG) of *Rhizoctonia solani*.

6. Disease Management

6.1 *In vitro* efficacy of Biocontrol Agents

Sivakumar *et al.,* (2000) isolated *Trichoderma* species from soil samples collected from rambutan fields using serial dilution techniques and incubated on PDA at 28°C for five days.

Adesina *et al.,* (2009) evaluated the rhizosphere competence of fifteen *in vitro* antagonists against *Rhizoctonia solani* four weeks after sowing lettuce seeds in non-sterile soil. Eight strains were selected for growth chamber experiments and among them, four significantly reduced disease severity, although all were able to colonize the rhizosphere.

Todorova and Kozhuharova (2010) reported antagonistic *Bacillus* strains from soil and evaluated their activity against five phytopathogenic fungi, including *Alternaria solani*, *Botrytis*, *Monilia linhartiana*, *Phytophthora* and *Rhizoctonia* species. Two strains i.e., TS 01 and ZR 02 exhibited broad-spectrum antibiotic activity against both Gram-positive and Gram-negative bacteria, with the largest inhibition zones observed against *Pseudomonas syringae* pv. *tomato* Ro and *Xanthomonas campestris*. *Bacillus subtilis* strains were identified as promising candidates for biological disease control.

Sreedevi *et al.,* (2011) isolated five *Trichoderma* spp. from the rhizosphere of healthy groundnut plants and evaluated their antagonistic potential through dual culture assays. *Trichoderma viride* and *Trichoderma harzianum* reduced mycelial growth of *Rhizoctonia solani* by 61.1% and 64.4%, respectively.

Rahman *et al.,* (2011) collected and identified several *Trichoderma* strains from various habitats, including *Trichoderma harzianum*, *Trichoderma pseudokoningii* and *Trichoderma virens*. Among these, *Trichoderma harzianum* was the most prevalent across different ecological niches, with colony-forming units (CFUs) varying significantly with the habitat's physicochemical properties.

Seema and Devaki (2012) reported that dual culture assays showed percentage growth inhibition of *Rhizoctonia solani* by *Trichoderma viride* (70%), *Trichoderma harzianum* (67%), *Aspergillus niger* (57%), *Bacillus subtilis* (50%)and *Penicillium* spp. (44%).

Srivastava *et al.,* (2012) reported that *Trichoderma harzianum* and *Trichoderma viride* exhibited rapid growth on potato dextrose agar and demonstrated antagonistic activity against *Fusarium oxysporum* f. sp. *udum* and *Pythium aphanidermatum*, with a maximum mycelial inhibition of 65%.

Lal *et al.,* (2013) investigated the antagonistic properties of seven biocontrol agents against three major potato pathogens i.e., *Rhizoctonia solani*, *Fusarium* spp.and *Phytophthora infestans* under *in vitro* conditions. Both volatile and non-volatile metabolites produced by the bioagents significantly inhibited pathogen growth. Optimal growth conditions for *Trichoderma* species were identified as 25–30°C and pH 6.0–8.0, while bacterial agents showed optimal growth at 30°C and pH 7.0.

Asad *et al.,* (2014) tested three isolates of *Trichoderma* spp. against *Rhizoctonia solani*, reporting 67.8% to 74.4% inhibition of pathogen growth through water-soluble metabolites and 10.6% to 15.3% inhibition through volatile metabolites under *in vitro* conditions. *Trichoderma asperellum* was particularly effective, reducing disease incidence by up to 19.3% in laboratory tests and 30.5% under greenhouse conditions.

Herath *et al.,* (2015) confirmed the biocontrol potential of *Trichoderma erinaceum* against seven plant pathogens and also reported significant production of chitinase and glucanase enzymes.

Kumari *et al.,* (2016) isolated multiple *Trichoderma* spp. and assessed their antagonistic activity against *Rhizoctonia solani* using dual culture techniques. Seven isolates, including RCT1, RCT22 and RCT3, showed strong inhibition (>50%) of *Rhizoctonia solani* mycelial growth. Seventeen additional isolates demonstrated moderate inhibition, while two isolates inhibited less than 40% of pathogen growth.

Iqbal *et al.,* (2017) evaluated methods for the isolation, purification and preservation of *Trichoderma viride* through serial dilution techniques. Their findings suggested that prolonged monitoring and storage could help maintain isolate viability.

Prasad *et al.,* (2017) screened twenty-four fungal and twelve bacterial biocontrol agents against *Rhizoctonia solani* using dual culture assays. Among them, *Trichoderma harzianum-1* and *Pseudomonas fluorescens-2* achieved the highest inhibition of *Rhizoctonia solani* mycelial growth at 62.53% and 62.20%, respectively, under *in vitro* conditions.

Recent findings of Zill-e-Huma, 2022 demonstrated that isolates of *Trichoderma harzianum*, *Trichoderma viride* and *T. asperellum* inhibited *Rhizoctonia solani* growth by over 70% in dual-culture assays. Furthermore, *Trichoderma* colonization stimulates induced systemic resistance (ISR) in potato plants,fortifying host defenses prior to pathogen attack. The promising *in vitro* performance of *Trichoderma* spp. underpins their candidacy as integral components of black scurf management frameworks.

6.2 *In vitro* efficacy of Fungicides

Chemical fungicides remain crucial for managing *Rhizoctonia solani*, particularly at the seed tuber stage. Boric acid, applied as a 3% dip treatment to seed tubers, has demonstrated consistent efficacy in inhibiting pathogen viability without phytotoxic effects on potato sprouts (Arora & Khurana, 2004).Laboratory assays confirm that boric acid disrupts fungal metabolism and impairs sclerotial development.

Owais *et al.,* (2014) chemical fungicides i.e., Monceren, Topsin-Mand Triton, using the poisoned food technique and assessed their biochemical efficacy against *Rhizoctonia solani* under *in vitro* conditions

Similarly, Malik *et al.,* (2014) evaluated three chemical fungicides i.e., Monceren, Topsin-M and Triton—using the poisoned food technique and assessed the antagonistic effects of two *Trichoderma* species, *Trichoderma harzianum* and *Trichoderma viride*, against *Rhizoctonia solani*. Under *in vitro* conditions, *Trichoderma harzianum* and *Trichoderma viride* exhibited substantial inhibition rates of 70% and 66%, respectively.

Muhammad *et al.,* (2015) tested the efficacy of three fungicides i.e., Moncerene (pencycuron), Curon (pencycuron) and Topsin-M (thiophanate-methyl) against *Rhizoctonia solani* under laboratory conditions. Moncerene and Curon, both tested at 700 ppm, achieved mycelial growth inhibition rates of 96% and 87%, respectively. In contrast, Topsin-M displayed 74% inhibition but required a higher concentration of 2500 ppm to achieve this result.

Further, Ullah *et al.,* (2018) assessed the effectiveness of five fungicidesi.e., Helonil (chlorothalonil), Clipper (copper oxychloride), Antracol (propineb), Ridomil Gold (metalaxyl-M + mancozeb)and Desomile Platinum (cymoxanil + mancozeb) at various concentrations (100, 200, 300, 400, 500 and 1000 ppm) against *Rhizoctonia solani* under *in vitro* conditions. Their findings revealed that Helonil was the most effective fungicide, followed by Clipper. Both Helonil and Clipper completely inhibited the mycelial growth of *Rhizoctonia solani*. In contrast, Antracol, Ridomiland Desomile Platinum were found to be comparatively less effective in suppressing pathogen growth.

7. Disease Management Under Field Conditions

Effective management of black scurf demands an integrated approach, combining cultural, chemical and biological methods. Field management strategies for black scurf necessitate an integrated framework encompassing seed sanitation, soil management and pathogen suppression through biocontrol and chemical agents.

7.1 Disease Management with Fungicides

Field application of fungicides, particularly through seed tuber treatments, remains a cornerstone for managing black scurf. Numerous fungicides have been reported effective against *Rhizoctonia solani*, the causal agent of black scurf in potato.

Kataria *et al.,* (1991) reported cyproconazole and tolclofos methyl as inhibitors of *Rhizoctonia solani*. Thakur *et al.,* (1991) found that carbendazim, bitertanol, benalaxyl + copper oxychlorideand thiabendazole inhibited pathogen growth under greenhouse conditions. De and Sengupta (1992) confirmed the efficacy of Agallol, Emisan and Bavistin as effective tuber treatments.

Krick *et al.,* (1993) identified fenpiclonil as highly effective against *Rhizoctonia solani* causing black scurf and stem canker. Jalali *et al.,* (1994) suggested that dipping tubers in a 3% boric acid suspension for 30 minutes, or spraying 4% boric acid before planting, significantly reduced disease incidence and increased yield. Wicks *et al.,* (1995) observed that a 2% formaldehyde suspension for tuber treatment did not affect germination rates.

Khanna *et al.,* (1996) demonstrated that 3% boric acid treatment reduced *Rhizoctonia solani* seed and soil inoculum and increased populations of beneficial actinomycetes and bacteria.Welsh and Callaghan (1996) endorsed the use of fenpiclonil (50 g/tonne) as an effective seed dressing. Pepelnjak (1999) found that treating tubers with fludioxonil, pencycuron, or tolclofos methyl prior to planting reduced both the incidence and the number of sclerotia on tubers. Rathaiah (2000) reported the use of carbendazim (1g/L) tuber dip treatments to manage black scurf effectively.

Arora (2013) confirmed that seed tuber treatment with Pencycuron (0.057% a.i.) or spraying with 3% boric acid effectively controlled black scurf without adversely impacting emergence. Lal *et al.,* (2014) tested penflufen at different concentrations and found that penflufen 240 FS at 0.083% was highly effective, reducing disease incidence by nearly 90% over two years, with no adverse effects on germination or plant growth.

Bagri *et al.,* (2017) found that tuber dip treatments with penflufen (0.083%) and boric acid (3%) significantly reduced disease incidence and severity while increasing tuber yields. Bagri *et al.,* (2018) further confirmed that tuber dip treatment with penflufen (0.083%) before planting resulted in the maximum yield and the least disease severity.

Goswami *et al.,* (2014) tested Monceren 250 SC and Amistar 25 SC fungicides, both effectively controlling black scurf. Other treatments like Luster 37.5% SE, UPF-106 and Quental 50 WP also significantly reduced disease severity compared to untreated controls, while treatments with boric acid, Indofil M-45, Emisan-6, Tilt 25 EC, Score 25 EC and Hexadhan 5 EC showed low disease severity levels.

Boric acid treatments at 3% concentrations effectively disinfect seed tubers, minimizing primary inoculum and ensuring healthy crop establishment (Rahman *et al.,* 2020). Fungicides tested for managing black scurf included Boric acid (3%), Carbendazim (50% WP at 1%), Mancozeb (0.2%) and Pencycuron (0.2%). Mancozeb showed the lowest disease incidence (12.00%), while boric acid resulted in the highest yield (Singh *et al.,* 2023).

7.2 Integrated disease management including organic amendments

Jagar *et al.,* (1991) reported that applying tolclofos-methyl, pencycuronand mepronil alongside *Verticillium biguttatum* significantly reduced disease incidence and improved yields.

Sangeetha *et al.,* (1993) found FYM to be the best substrate for *Trichoderma* spp. formulations, followed by wheat and rice bran. Peat soil and rice straw were less effective. Hausvater and Trnkova (1993) found that using a reduced dose of pencycuron along with *Trichoderma harzianum* effectively controlled black scurf in both greenhouse and field conditions.

Chet and Inbar (1994) highlighted that *Trichoderma harzianum* was a potent biocontrol agent of soilborne fungal pathogens, with lectins and chitinase enzymes playing roles in fungal recognition and degradation. Mukherjee *et al.,* (1995) observed that *Trichoderma harzianum* effectively suppressed *Sclerotium rolfsii* and *Rhizoctonia solani*, destroying their sclerotia.

Cultural practices involve using certified, disease-free seed tubers, crop rotation with non-host species, optimizing planting time to promote rapid sprout emergence and improving soil drainage to minimize conducive conditions for infection (Banville *et al.,* 1996).

Drepper *et al.,* (1996) confirmed the biological control potential of *Verticillium biguttatum* against black scurf. Additionally, various strains of *Bacillus subtilis* were effective against both stem canker and black scurf under greenhouse and field trials.

Singh *et al.,* (1997) demonstrated that *Trichoderma viride* and *Trichoderma harzianum* reduced disease incidence in infested soils, leading to significant yield increases. Dasgupta (1997) emphasized the importance of integrating organic amendments, biocontrol agents and cultural practices for economically viable management of soilborne diseases.

Singh *et al.,* (1998) reported that frequent irrigation combined with applications of *Trichoderma viride* and *Trichoderma harzianum* led to 62.5% and 61.5% control of black scurf, respectively, under field conditions.

Shamarao *et al.,* (1998) explored the mass multiplication and sporulation of *Trichoderma viride* using substrates like oil cake, FYM, wheat bran, poultry manure and neem cake, with wheat bran identified as the most favorable medium.

Zafari (1999) reported that field applications of *Trichoderma* spp. significantly reduced black scurf incidence and boosted tuber yields by over 10 tonnes per hectare.

Rettinassababady and Ramadoss (2000) found that *Trichoderma* spp. mass multiplied best in substrates like FYM and coir waste, achieving high spore counts within three weeks.

Tsror *et al.,* (2001) documented that furrow application of *Trichoderma harzianum*, non-pathogenic *Rhizoctonia* and cattle manure compost under field conditions reduced black scurf incidence. Sultana *et al.,* (2001) found that *Trichoderma* treatment improved seed germination in eggplant by up to 48.62% compared to controls.

Shamsuzzaman *et al.,* (2003) showed that rice straw, chickpea bran and wheat bran mixtures supported the highest conidia production for mass multiplication of *Trichoderma harzianum*. Pandey (2005) reported that tomato seeds treated with *Trichoderma viride* demonstrated increased germination rates against *Fusarium solani* and *Sclerotium rolfsii*, while *Trichoderma virens* was most effective against *Rhizoctonia solani* and *Macrophomina phaseolina*.

Integrated disease management of black scurf involves combining seed treatment with boric acid, biofumigation using canolaand soil application of *Trichoderma harzianum*, resulting in significant protection against *Rhizoctonia solani* and reduced yield loss compared to individual treatments (Farah, 2006).

Arora, 2008 observed that the integrated disease management of black scurf of potato involves treating seed tubers with 1.5% boric acid before cold storage and applying *Trichoderma viride* at planting, effectively reducing disease levels while being more environmental friendly than conventional methods .

Ramanujam *et al.,* (2010) highlighted that *Trichoderma* formulations applied as seed treatments or soil amendments provided effective control of several soilborne diseases across various crops.

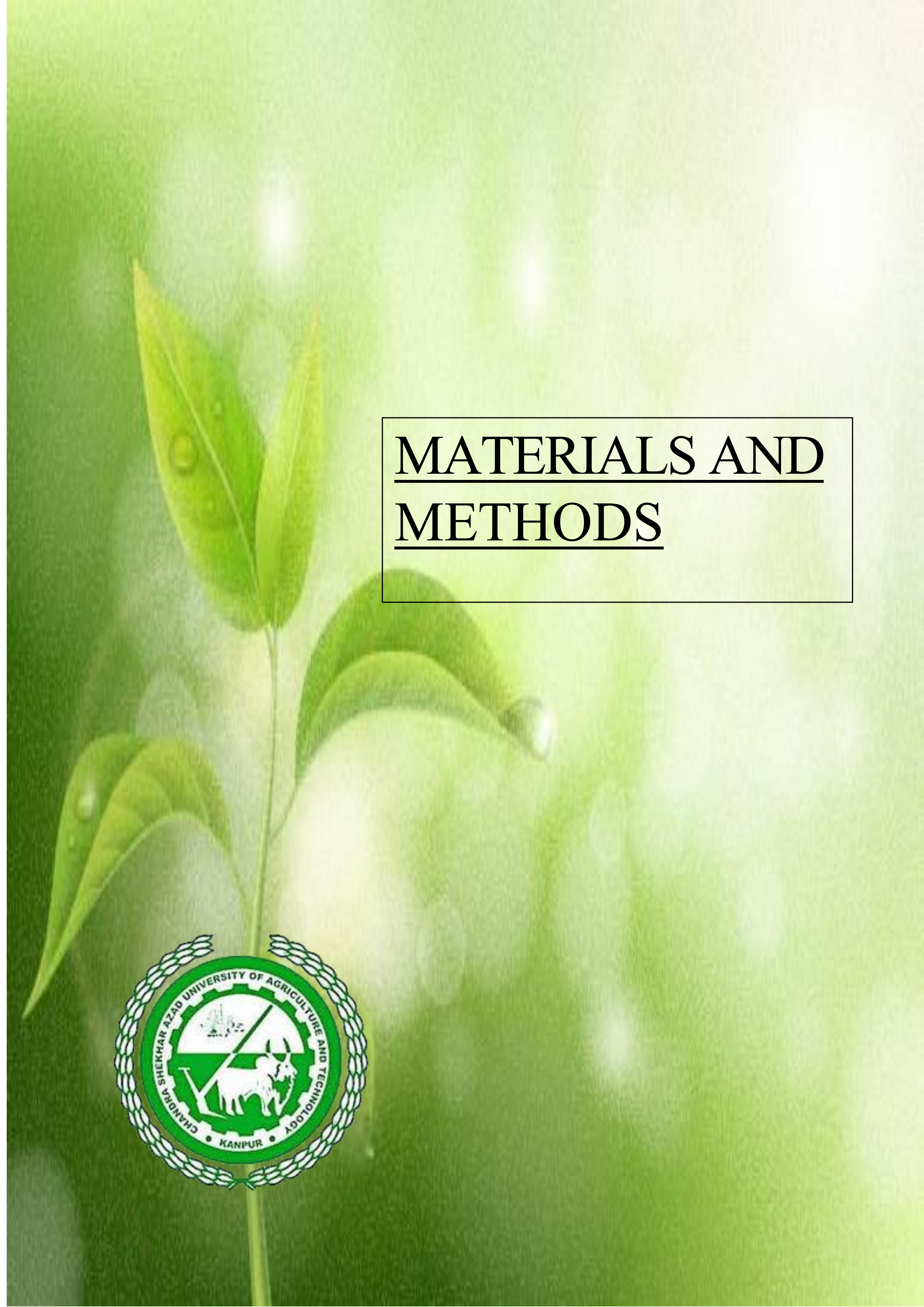
Pandya *et al.,* (2011) observed that shifts toward intensive farming and monoculture practices had led to increased prevalence of soilborne pathogens such as *Pythium*, *Phytophthora*, *Botrytis*, *Rhizoctonia* and *Fusarium*. *Trichoderma* was recognized as an efficient biocontrol agent due to its high reproductive capacity, competitiveness and ability to stimulate plant defenses.

Subash *et al.,* (2014) demonstrated that *Trichoderma harzianum* exhibited optimal growth and sporulation on sugarcane bagasse, followed by vermicompost, talcum powder and paddy straw. Agricultural substrate-grown *Trichoderma harzianum* applied to soil significantly enhanced plant growth parameters. Singh *et al.,* (2014) evaluated two *Trichoderma* isolates against *Sclerotium rolfsii* under field conditions, concluding that the use of compatible *Trichoderma* mixtures was a promising strategy for controlling sclerotial plant pathogens.

Rauf *et al.,* (2015) demonstrated that soil application of *Trichoderma harzianum* at sowing, followed by two or three applications at 20-day intervals, provided significant disease control, leading to better crop stand and yield compared to untreated controls.

Abbas *et al.,* (2017) reported the first comprehensive study on the biological control activity of *Trichoderma* spp. against various *Rhizoctonia solani*-induced diseases. Manandhar *et al.,* (2019) reported that six isolates of *Trichoderma* spp., particularly T363, achieved more than 80% inhibition of *Rhizoctonia solani* mycelial growth, demonstrating strong antagonistic potential.

Singh *et al.,* 2023 reported that field-based studies affirm the efficacy of combining organic amendments with biocontrol agents in mitigating black scurf incidence.Organic matter decomposition releases bioactive compounds that suppress pathogen proliferation and bolster soil suppressiveness (Larkin & Brewer, 2020).



MATERIALS AND METHODS

CHANDRA SHEKHAR AZAD UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
KANPUR

The present investigation entitled **"Efficacy of eco-compatible inputs for managing Black Scurf Disease of Potato (*Solanum tuberosum L.*) incited by *Rhizoctonia solani kuhn*"** was conducted in the Department of Plant Pathology, College of Agriculture, Chandra Shekar Azad University of Agriculture and Technolgy, Kanpur, Uttar Pradesh during the year 2024-2025. The details of materials used and experimental method adopted during course of investigations are described in the following under different sub-headings.

3.1 Experimental site and location

In the present studies, the entire field experiments were conducted at the Department of Plant Pathology during *Rabi* season 2024-2025 and the laboratory work was conducted in the Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (Uttar Pradesh). It is located at 26.45^0 North latitude and 80.31^0 East longitude having an altitude of 152.40 meters above mean sea level (MSL) in the Central Indo-Gangetic Plains. The mean annual rainfall of Kanpur is 872 mm and more than 80% generally occurs during the monsoon season (June- September).

3.2 Collection of diseased samples

The infected potato tuber and stem were collected from the potato field at Vegetable Research Farm, Chandra Shekar Azad University of Agriculture and Technology, Kanpur. The collected infected potato tuber and stem were kept in rough dry envelopes for isolation and purification of the pathogen. Each envelops marked clearly to show details of the location, date of collection etc.

3.3 Materials used

3.3.1 Glassware

All glassware used in the study—including beakers, conical flasks, culture tubes, measuring cylinders, funnels, glass rods, Petri dishesand pipettes—was first treated with a cleaning solution comprising 60 grams of potassium dichromate ($K_2Cr_2O_7$) and 60 milliliters of sulfuric acid (H_2SO_4). The items were then thoroughly washed with tap water, rinsed using sterilized distilled water and dried in a hot air oven before being utilized.

3.3.2 Equipment

The present investigation was conducted using a variety of instruments and apparatus, including an autoclave, BOD incubator, compound and stereo microscopes, cork borer, filter papers, glass slides, hot air oven, hot plate, inoculation needle, laminar airflow chamber, LPG gas burner, mortar and pestle, microwave oven, muslin cloth, parafilm, plastic trays, razor blades, refrigerator, spatula, scalpel, shaker, syringes water bath, weighing scale and vortex mixer.

3.3.3 Cleaning and sterilization of metal and glasswares

For Cleaning , the required glassware were kept in the solution containing 60 g potassium dichromate ($K_2Cr_2O_7$) and 60ml of concentrated sulphuric acid (H_2SO_4) in one litre of water for a day. Then, they were cleaned by washing with tap water several times. All glassware's, solid and liquid media were subjected to sterilization by autoclaving at 15psi. (121.6°c) for 15 minutes or hot oven. The tips of inoculation needle, forceps and corkborers were sterilized under flame.

3.3.4 Preparation of Culture Media

Potato Dextrose Agar (PDA) was the primary medium used for isolation and purification of the pathogen, as well as for conducting various other studies. The composition of PDA included:

- Peeled potatoes – 200 g
- Dextrose – 20.0 g
- Agar – 20.0 g
- Distilled water – 1000 ml

3.3.5 Preparation of Potato Dextrose Agar (PDA)

To prepare the PDA medium, 200 grams of peeled potato extract, 20 grams of dextroseand 20 grams of agar were combined and dissolved in one liter of distilled water. The standard protocol for media preparation was followed. The medium was dispensed into 250 ml Erlenmeyer flasks and culture tubes, filling the tubes up to one-third of their volume. These containers were sealed with non-absorbent cotton plugs. The prepared media was sterilized by autoclaving at 121.6°C (15 psi pressure) for 15 minutes.

3.3.6 Preparation of Slants

After sterilization, the culture tubes containing the molten medium were removed from the autoclave and placed in a slanted position to form solid agar slants. Similarly, the flasks containing the sterilized medium were taken outand their outer surfaces were cleaned with sterile filter paper. The medium was then poured into pre-sterilized Petri plates inside a laminar air flow chamber and allowed to solidify.

3.4 Method of Isolation

Potato tubers and stems showing clear disease symptoms were collected from Vegetable Research Farm, Chandra Shekar Azad University of Agriculture and Technology, Kanpur. These samples were brought to the laboratory for isolatiom and identification the responsible fungus. After rinsing the samples under running water, small bits were cut from the infected stems and tuber sclerotia. These parts were then surface-sterilized using a 1% sodium hypochlorite solution for one minute, followed by thorough washing three times in clean water to eliminate any remaining chemical.

Under sterile conditions in a laminar airflow chamber, these pieces were placed on Petri dishes containing sterile Potato Dextrose Agar (PDA) medium. Each Petri plate was prepared by pouring 20 ml of the PDA medium and allowing it to solidify before use. The infected bits were then planted carefully on the medium and incubated at a temperature of 27 ± 1°C for three days.

By the fourth day, fungal growth from the infected tissues appeared and was carefully transferred to PDA slants using an inoculation needle. A pure culture of the fungus was obtained by following the hyphal tip method under sterile conditions. To prevent contamination, regular sub-culturing was done every 15 days. The PDA slants containing *Rhizoctonia solani* were stored in a refrigerator at 6 to 8°C for future research.

3.4.1 Identification of the Fungus

The pathogen was recognized based on its cultural traits and microscopic structure, described as follows :

3.4.2 Colony and Growth Characteristics

After incubating the fungus on Potato Dextrose Agar (PDA) for 5–6 days, its colony color and the type of mycelium were examined. These characteristics were observed under a microscope.

3.4.3 Mycelial Characters

The color, the presence of septa (cross-walls) and the branching pattern of the fungal hyphae were noted through microscopic observation.

3.4.4 Sclerotial Characteristics

The sclerotia, which are hard, resting structures of the fungus, were observed after 20 days of incubation. Their color, shapeand size were carefully documented.

3.5 Preparation of Inoculum

To prepare a large quantity of fungal inoculum, potato-dextrose broth was used. First, 200 grams of peeled potatoes were cut into small cubes of about 12 mm in size. These potato pieces were rinsed in water and then boiled in 500 ml of water for 20 minutes. The resulting potato broth was filtered through a clean cloth (cheesecloth) and the extract was poured into a measuring cylinder. To this, 20 grams of dextrose were added and the volume was made up to 1000 ml using distilled water. The pH was adjusted to 7.0.

The broth was then poured into sterilized conical flasks and autoclaved at 15 psi pressure for 20 minutes. After cooling, three discs (each 5 mm in diameter) taken from a pure culture of *Rhizoctonia solani* growing on Petri dishes were placed into each flask. These flasks were then incubated at 26 ± 1°C for three daysand shaken by hand daily to promote better fungal growth.

After five days of incubation, the contents of each flask were crushed using a pestle and mortar, then filtered through cheesecloth to obtain a suspension. The prepared mycelial suspension, containing about 15–20 fungal fragments per field under 100x magnification, was used for artificial inoculation of plants.

3.5.1 Pathogenicity Test

To confirm the pathogenic nature of the isolate of fungus, a pathogenicity test was conducted following Koch's Postulates (1876). The inoculum was introduced using two different methods: first, by mixing it into sterilized soil in pots before planting the tubers and second, by placing the inoculum near the plants after the tubers had been sown in the pots.

Earthen pots, each with a diameter of 30 cm, were filled with sterilized soil. A fungal culture, 15 days old and grown on PDA, was added to the top layer of soil at a rate of 1% by weight. In each pot, 2–3 healthy and surface-washed potato tubers were planted. Another set of pots, also filled with sterilized soil and planted with the same number of healthy tubers but without any fungal inoculum, was maintained as a control .

Soil moisture was kept at 25% of its water-holding capacity by regularly adding sterilized water, measured by weight, throughout the experiment. After 45 days of growth, plants displaying typical symptoms of stem canker as dark brown to black lesions were uprooted. These plants were carefully washed with distilled water and the fungus was re-isolated from the infected tissues. The new culture obtained from these infected plants was then compared with the original fungal culture to confirm that the same pathogen was responsible for the symptoms.

3.5.2 Mass Multiplication of Fungal Inoculum (*Rhizoctonia solani)*

To produce a large quantity of fungal inoculum, *Rhizoctonia solani* was cultured using on Sorghum grains as a growth medium. The grains were first washed thoroughly with water to remove dust and impurities. After cleaning, the grain was soaked in a 2% sucrose solution for eight hours to enhance fungal colonization. Once soaked, the excess water was drained off and the grains were dried in the shade until their moisture content dropped to approximately 60–70%.

Each 500 ml bag was filled with 250 grams of the pre-treated sorghum grains (as described by Paulitz and Schroeder, (2005). These bags were then inoculated with a one-week-old culture of *Rhizoctonia solani* that had been grown on PDA medium. The inoculated bags were kept at room temperature (around 26 ± 2°C) for 15 days. To encourage even fungal growth, the contents were gently stirred every three days.

After full colonization, the infected sorghum grains served as the fungal inoculum. This inoculum was applied at a rate of 75 grams (wet weight) per square meter of field soil, three days before planting, in all experimental treatments. The purpose was to infect the potato tubers or seedlings with black scurf disease.

3.6.1 *In vitro* efficacy of fungicides against *Rhizoctonia solani* using the Poisoned Food Technique

The effectiveness of fungicides like Boric acid, Mancozeb and Monceren at various concentrations against *Rhizoctonia solani* was tested using the Poisoned food technique. For this, Potato Dextrose Agar (PDA) medium was prepared and dispensed in equal amounts of 100 ml into 250 ml conical flasks, followed by sterilization in an autoclave. Once cooled to about 45°C, the required quantity of each fungicide was mixed separately into the sterilized PDA to achieve the desired concentrations. The flasks were then shaken thoroughly to ensure uniform mixing of the fungicide throughout the medium.

Next, 20 ml of the fungicide-amended (poisoned) PDA was poured into sterilized Petri dishes and left to solidify. Each plate was then inoculated with the test fungus. A 5 mm disc was taken from a one-week-old fungal culture using a sterile cork borer and placed at the center of each Petri plate containing the poisoned medium. For comparison, control plates were prepared using plain PDA without any fungicide, under the same conditions.

All plates were incubated at room temperature (28 ± 2°C) for seven days. After the incubation period, the diameter of the fungal colonies was measured in millimeters. The percentage of mycelial growth inhibition was calculated using Vincent's formula (1927), which is as follows:

$$PI = \frac{C-T}{C} X\ 100$$

Where,

PI=Percentage of inhibition ;

C =Average colony diameter in the control plates (mm)

T =Average colony diameter in the treated plates (mm)

The collected data were analyzed statistically wherever required.

3.6.2 *In vitro* efficacy of *Trichoderma harzianum* against *Rhizoctonia solani*

To evaluate the antagonistic effect of *Trichoderma harzianum* against *Rhizoctonia solani*, a dual culture assay was carried out under invitro conditions on Potato Dextrose Agar (PDA) medium (Morton and Strouvle, 1935). Seven treatments were tested using different inoculation strategies, as described below. The Treatments for conducting the dual culture technique are taken as, T_1– Simultaneous Inoculation (Pathogen+Antagonist), T_2– 24-Hour Head start to Pathogen, T_3– 24-Hour HeadStart to Antagonist, T_4– Simultaneous Inoculation on Modified Medium, T_5– Multiple Inoculation Points, T_6– Variation in Antagonist Culture Age, T_7– Control.

Potato dextrose agar (PDA) was prepared and 100 ml of the media was taken in each 250 ml flasks and sterilized. Then 20 ml molten PDA was poured in each petri plate and kept until solidify. Effect on the growth *of Rhizoctonia solani* was studied by inoculating the pathogen at one side of the petri plates and antagonist at exactly opposite side of the same plate by leaving about 4 cm gap. In a petri dish 5 mm circular bits from freshly growing pathogen and antagonist culture taken and were placed at both the peripheral ends. For this, actively growing cultures were used and three replications were maintained for each treatment. After 48, 96 and 144 hours of incubation the radial growth of the pathogen was measured. The per cent inhibition of the growth over control was calculated by following the equation given by (Vincent, 1927).

$$I = = \frac{C-T}{C} \text{ X } 100$$

Where, I = Per cent inhibition

C = Growth in control

T = Growth in treatment

3.7 Integrated effect of fungicides, bio-agents and organic amendments against the black scurf of potato under field conditions

The field experiments were conducted during *Rabi* season 2024-2025 at the Department of Plant Pathology, Chandra Shekar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh. The field experiment was conducted in randomized block design (RBD) with three replications and Plot size 1.75 × 1.5 m^2. A combination of management practices such as addition of organic amendments (e.g. FYM,Neem Cake, Mushroom spent), biological control agents (e.g., *Trichoderma harzianum*), mixing in soil and seed treatments at the sowing time and seed treatment of fungicides with Boric acid and foliar spray of Boric acid were applied.

3.7.1 Field preparation

The experimental field was prepared by giving two cross harrowing followed by planking for making a good soil texture, fine tilt and smooth soil surface. Recommended doses of nitrogen (170 kg/ha), phosphorus (250 kg/ha) and potash(250 kg/ha) were drilled and mixed thoroughly in soil by light harrowing before sowing. Band preparation and earthing of potato at 30 days after planting and 45 days after planting respectively.

3.7.2 Layout and sowing

Sowing of Potato Tubers was done on 1 December,2024. Each treatment was sown in 1.75 meter length and 1.5 meter width and 3 replications with inter and intra row spacing of 60cm and 45cm, respectively.The required amount of seed material was obtained from Department of Vegetable Science, Chandra Shekar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh (Fig-3.72).

3.7.3 Experimental details :

Season	Rabi (2024-2025)
Crop	Potato *(Solanum tuberosum L.)*
Experimental design	Randomised Block Design
No. of treatments	7
No. of replications	3
Variety	Kufri Sindhuri
Plot size	a) Length : 1.75 m
	b) Width : 1.5 m
	c) Plot Area : 2.62 m^2
Spacing	60cm X 20cm
No. of rows per plot	03
No. of tubers planted per row	06

3.7.4 Treatment details

Treatment	**Treatment Details**
T_1	Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2 % Boric Acid
T_2	Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2 % Boric Acid
T_3	Soil Application of Neem Cake+Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2 % Boric Acid
T_4	Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2 % Boric Acid
T_5	Soil Application of Spent Mushroom Substrate+ Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2 % Boric Acid
T_6	Soil Application of Spent Mushroom Substrate+ Seed treatment of 2 % Boric Acid + Foliar treatment with 2 % Boric Acid
T_7	Control

3.7.5 Planting of treated seed tuber

Potato seed tubers weighing 20-30g of variety ‘Kufri Sindhuri’ were taken by discarding tubers with visible signs of disease or damage. Potato seed tubers were given treatment for 20 minutes by dipping them in bucket containing well dissolved solution of fungicides and biocontrol agents. After 20 minutes potato seed tuber were taken out from bucket containing solution of inorganic chemical fungicide and then tubers were dried for overnight by placing them on concrete floor before sowing in well prepared ploughed field. The treated tubers seeds of about 20-30g weight each were planted in the furrows at a spacing of 60 cm row to row and 20 cm plant to plant. Thereafter, the lines planted with tubers were covered with soil to make ridges of about 15 cm high.

3.7.6 Fertilizer application and irrigation

Fertilizer was applied uniformly to different plots at recommended dosage. First irrigation was given 20 DAS i.e approximately after germinating of the tuber and subsequently, 3 irrigations were given at 10-15 days interval during whole crop season. Irrigation was applied in such a way that water would not touch top 1/3rd of the ridge.

3.7.7 Intercultural operations and weed management

Intercultural operations like hoeing, weeding, topdressing of nitrogen and earthing up operations were carried out at 25 days after planting. Another light earthing up was done at 40 days after planting.

3.8 Observations pertaining to the effect of different treatments

1. Germination percentage (upto15 days after sowing)
2. Plant height (cm)
3. Number of tubers per plant
4. Tuber Weight per Plant (g)
5. Tuber Size and Grade Distribution
6. Disease Incidence (%)
7. Disease severity
8. Yield(kg/plot)

3.8.1 Germination percentage (%)

Seed tuber treated with different bio formulations was responsible for early breaking of seed tuber. Germination percentage was calculated by use of following formula (Abdul Baki and Anderson, 1971)

$$\text{Germination } \% = \frac{\text{Number of germinated seed tubers}}{\text{Number of total seeds}} \times 100$$

3.8.2 Plant height (cm)

For this purpose, three plants were selected randomly from tagged plots. The shoot height was measured (in cm) from the soil surface with the help of meter scale and height of the plants was recorded at 30, 45 and 60 days after planting. The average ofthree plants height was divided by 3 for obtaining their mean to consider plantheight.

3.8.3 Tuber yield

To explore the possible effect of the disease management approaches on tuber yield was observed . A random number of 3 plants from each treatment were taken and the observations were made regarding number of tubers per plant, weight of tuber per plant and size of tubers to distribute them into small, medium and large grades.

3.8.4 Tuber Size and Grade Distribution

The grading of potatoes were done at two stages of crop period i.e, at tuber formation stage (52 DAS) and after harvesting (100 DAS). The potato tubers from each plot were collected, cleaned and weighed to determine the total yield per treatment. Grading was carried out based on individual tuber weight inorder to distribute them into different sizes. Tubers were categorized into three standard commercial grades. Each category was weighed separately using a digital balance and the number of tubers in each grade was estimated based on average weight per grade as in 35-50 g for small, 50-80 g for medium and >80 g for large tubers.

3.8.5 Disease incidence

After harvest number of tubers having scurf was recorded and per cent of infected tuber was calculated for each plot. The per cent disease incidence was calculatedas described by Mathur *et al.* (1972) by using the formula :

$$\text{Disease Incidence} = \frac{\text{No. of infected tubers}}{\text{Total tubers observed}} \times 100$$

3.8.6 Disease severity

Disease severity was assessed on a visual disease rating scale 0-5 based on per cent tuber surface showing disease showing disease symptom as described by Ahmad *et al.,*(1995),

Where:

0= no symptoms on tuber present

1= less than 1% tuber area affected

2= 1-10% tuber area affected

3=11-20% tuber area affected

4=21-50% tuber area affected

5=51% or more tuber area affected

3.8.7 Black Scurf Disease Index

Five plants were selected randomly in each plot before cutting of stem of plant in field. The tubers were collected in polyethylene bags. Then the visual observation was taken to observe the black scurf incidence and severity. Black scurf disease severity and incidence was expressed as Black Scurf Disease Index (BSDI) and was calculated with following formula as described by Farah Naz *et al*. (2008) :

$$\text{BSDI} = \frac{0(n1)+1(n2)+2(n3)+3(n4)+4(n5)+5(n6)}{\text{N (Total number of tubers)}} \times \frac{100}{5}$$

Where:

n1=Number of tubers in 0 rating

n2=Number of tubers in 1 rating

n3=Number of tubers in 2 rating

n4=Number of tubers in 3 rating

n5=Number of tubers in 4 rating

n6=Number of tubers in 5 rating

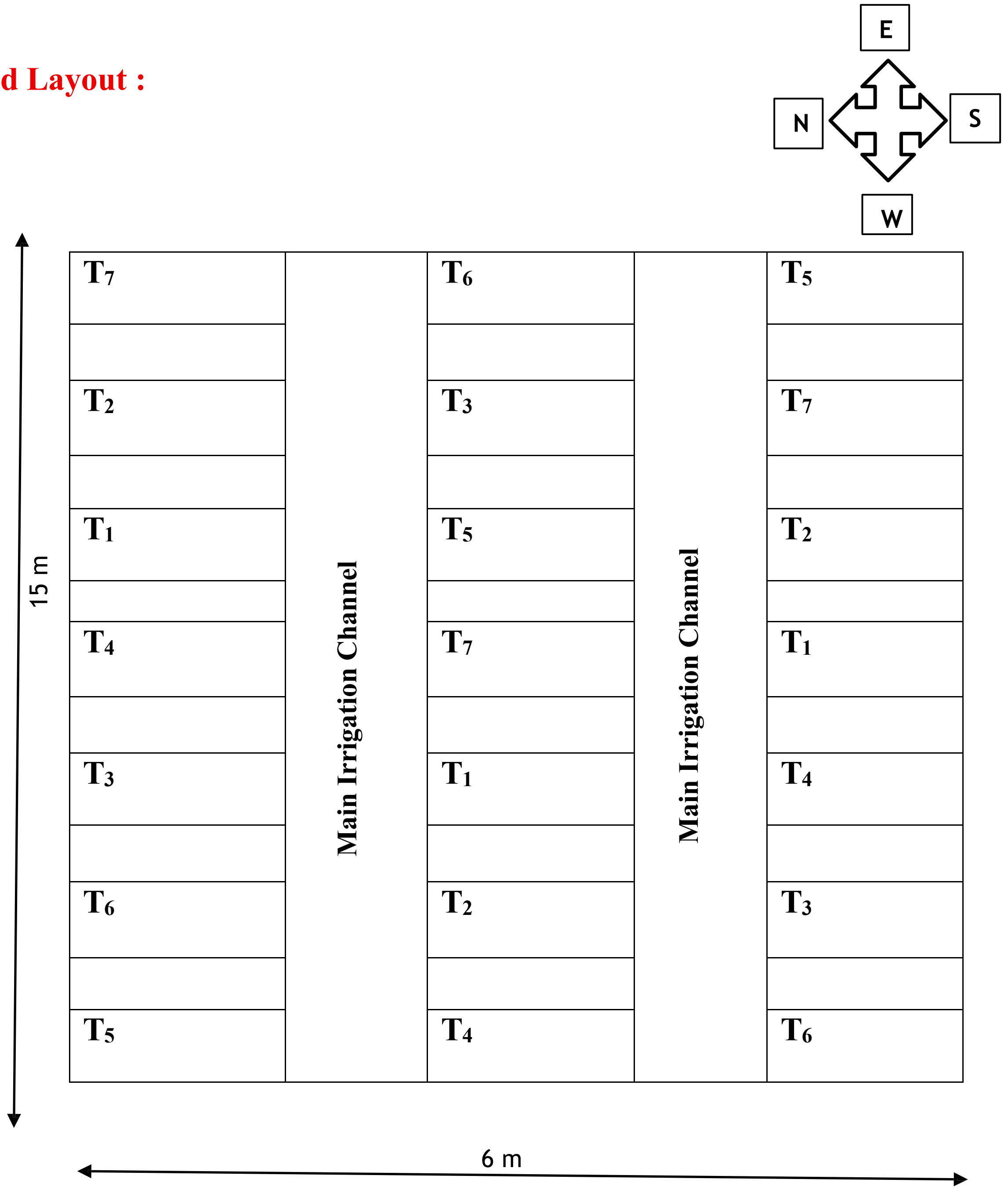
3.8.8 Yield (kg/plot)

The yield from all the replications of each treatment is collected, weighed and analyzed separately and the observations are recorded accordingly.

3.9 Statistical analysis

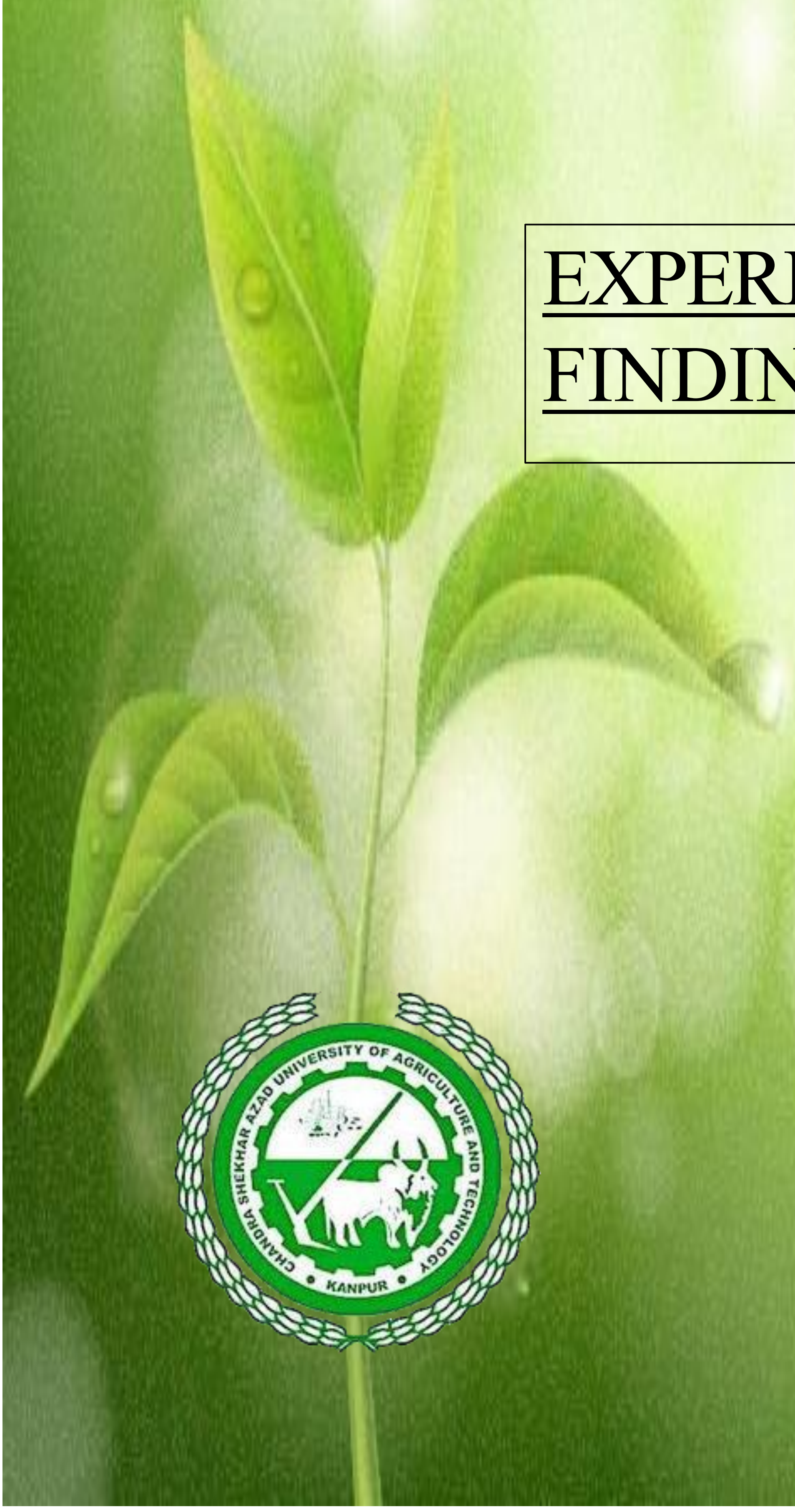
The data of experiments conducted at laboratory and in the field were subjected to the statistical analysis. The critical difference was worked out at 5 percent probability level to find out the difference between treatments.

Field Layout :



Where, T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

EXPERIMENTAL FINDINGS



CHANDRA SHEKHAR AZAD UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
KANPUR

Black scurf disease which is caused by *Rhizoctonia solani Kühn*, is an important soil and tuber borne disease of potato that leads to significant yield losses and quality reduction. The pathogen not only affects tuber appearance, reducing market value but also impacts plant growth by damaging sprouts and roots. Traditional chemical control methods, though effective, pose environmental and health risks. Therefore, exploring eco-compatible inputs for sustainable management of this disease has become increasingly important. The current study was undertaken with the main aim of assesing the efficacy of eco-compatible inputs for managing Black Scurf Disease of Potato. The research was conducted during the *Rabi* season of 2024–2025 at the Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh. In the light of above objectives, the following results were obtained from the experiments conducted :-

4.1 Collection, Isolation and Purification of *Rhizoctonia solani*

Infected potato tubers showing symptoms of black scurf were collected from the Vegetable Research Farm, Chandra Shekar Azad University of Agriculture and Technology, Kanpur. These samples were brought to the laboratory for isolation and further examination. Using aseptic techniques, the pathogen was isolated from the diseased tubers on Potato Dextrose Agar (PDA) medium. Upon incubation, the fungal growth emerging from the tuber sections exhibited dense aerial mycelium which gradually turned greyish-brown to black. Pure cultures were obtained through the hyphal tip method for further study (Plate-1).

4.2 Identification of the Pathogen

The identification of the fungus was carried out based on its cultural and morphological features, both visually and under a microscope. Observations included (Plate-2) :

(a) Growth Characteristics: Colonies on PDA ranged in color from light to dark greyish-white with dense, fluffy mycelial growth. The fungus produced extensive surface mycelium along with sclerotia. These sclerotia were seen forming on both the host tissues and the culture surface, with larger structures observed on host material (Plate-2A).

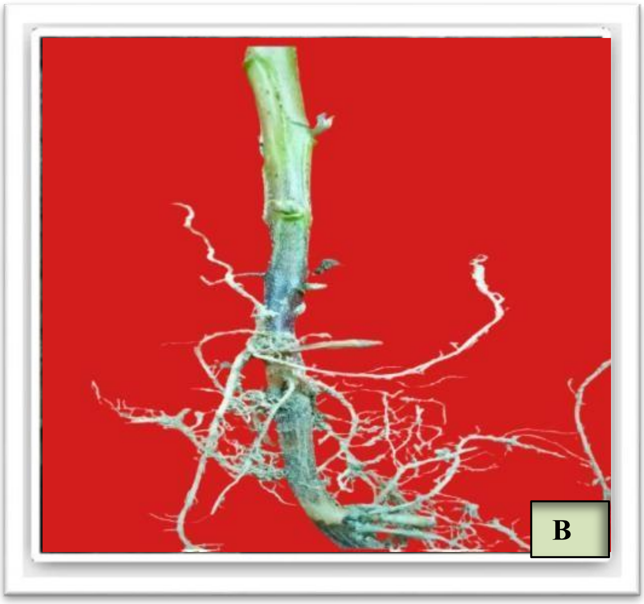
(b) Mycelial Features: Initially, the mycelium appeared greyish-white and became dark brown with age. It was septate and highly branched, measuring approximately 4.5–7.3 µm in width on PDA. Septa were more prominent in older hyphae. Lateral branches typically formed at right angles with visible constrictions and a septum located near the origin point (Plate-2B).

(c) Colony Characteristics: Colonies were fast-growing, fluffy and dark brown, covering the petri dish within 3 to 4 days. They had smooth margins and displayed a black coloration on the reverse side of the plate. Sclerotia were abundant throughout the colony surface (Plate-2A).

Plate-1 : Collection of diseased sample from Vegetable Research Farm, CSAUA&T,Kanpur

A. Infected potato tuber with sclerotia

B. Stem canker on potato stem



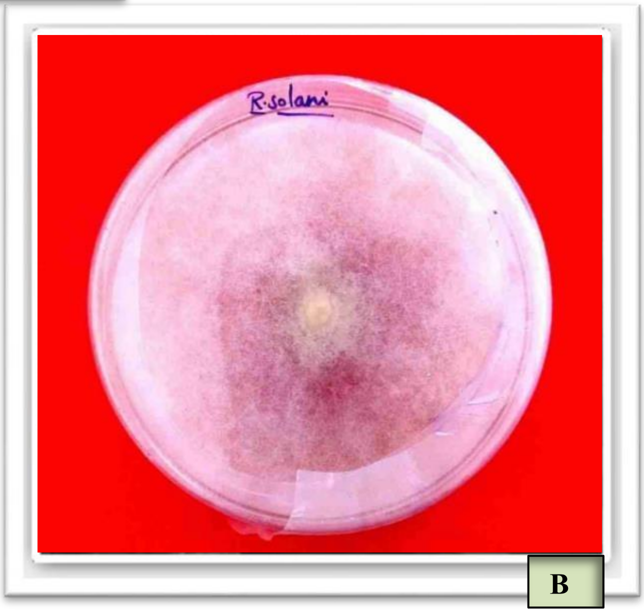
C. Sunken lesions on potato tubers

Plate-2 :Isolation, purification and identification of *Rhizoctonia solani*

A

A. Colony growth characters of *R.solani*

B. Pure culture of *R.solani*



B

C

C. Microscopic view of mycelium of *R.solani*

D. 15 days culture with developed sclerotia

E. Maintenance of *R.solani* by slants

(d) Sclerotial Features: Sclerotia developed both on the infected tubers and PDA medium. They were generally globose, oval or irregular in shape and dark brown in color. Microsclerotia began forming within two days and were covered with dark hyphae, giving a hairy appearance. On tubers, their diameter ranged from 81.50 to 90.50 µm and was consistently smaller than those produced on culture medium (Plate-2D) .

(e) Microscopic observation: It is observed that the branches of mycelium frequently emerged at right angles with a characteristic constriction and a nearby septum at their origin. The abundance and morphological traits of sclerotia supported the identification of the pathogen as *Rhizoctonia solani* (Plate-2C) .

4.3 Pathogenecity test

The isolate of *Rhizoctonia solani* Kühn obtained from infected potato tubers was confirmed to be pathogenic by artificial inoculation of both tuber and soil through Koch postulates. Under controlled conditions, typical symptoms of stem canker began to appear approximately 30 days after inoculation. The most prominent sign was the sudden wilting and death of young potato plants. Initially, the stem exhibited dark brown to black discoloration, followed by progressive drying. This was accompanied by root rot, eventually leading to the collapse of the entire plant. Affected stems displayed dark lesions ranging from brown to black in color. Re-isolation from these artificially infected plants consistently yielded *Rhizoctonia solani*, confirming its role as the causal organism (Plate-5).

4.4 Efficacy of fungicides against *Rhizoctonia solani* using the Poisoned Food Technique

The efficacy of different chemical treatments in suppressing the growth of *Rhizoctonia solani* was assessed under *in vitro* conditions using the Poisoned food technique in the laboratory of Department of Plant Pathology, Chandra shekar azad university of Agriculture and Technology, Kanpur. Radial mycelial growth was recorded at 1, 3, 5 and 7 days after inoculation (DAI) and the percentage inhibition over control was calculated accordingly. The results of the poisoned food technique were recorded on different intervals after inoculation(Table-1). Among all the treatments, Boric Acid @ 3% concentration (T_3) showed the highest efficacy in reducing fungal growth, with minimal mycelial spread observed across all intervals as 1.5 mm at 1 DAI and only 8.9 mm at 7 DAI, resulting in 89.87% inhibition over control (Table-1). The treatment T_6 (Mancozeb @ 0.2%) and T_9 (Monceren @ 0.2%), whose also significantly suppressed mycelial growth with inhibition percentages of 87.59% and 86.89%, respectively indicating seecond and third highest among all the treaments. Lower concentrations of Boric Acid (T_1 and T_2) also performed well, demonstrating a dose-dependent reduction in mycelial growth, achieving 81.11% and 85.83% inhibition at 1% and 2% concentrations, respectively. Mancozeb and Monceren at lower concentrations (0.05% and 0.1%) were comparatively less effective, indicating 70.75% to 77.24% for Mancozeb (T_4 and T_5) and 69.73% to 73.48% for Monceren (T_7 and T_8). The control treatment (T_{10}), which did not receive any fungicide, recorded the highest mycelial growth at all

Plate- 4- Mass multuplication of *Rhizoctonia solani*

Mass multiplication of *R.solani*

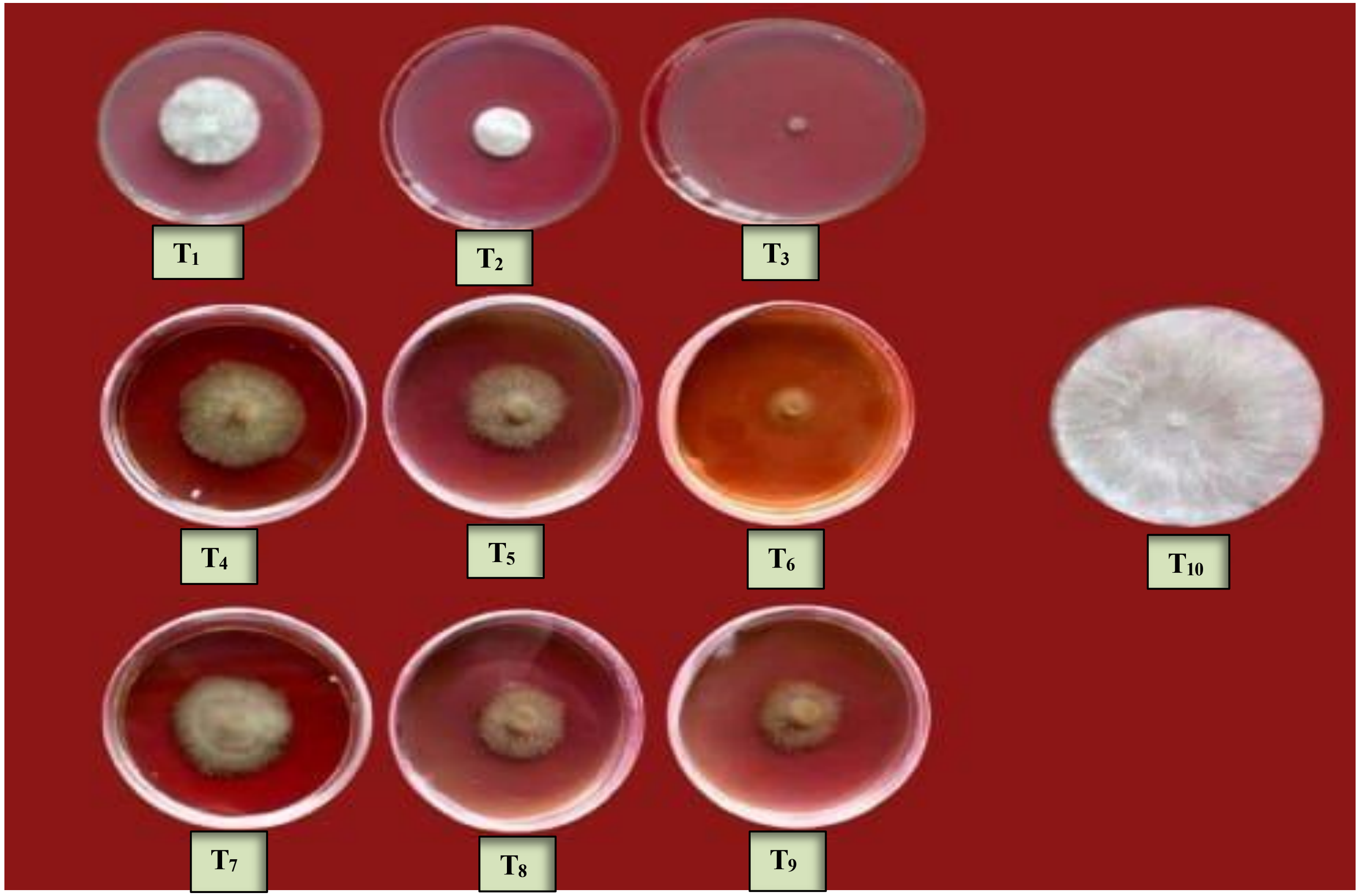
Plate-5– Pathogenecity test

A – Healthy Plant ; B – Infected Plant

Table-1 : Efficacy of fungicides against *Rhizoctonia solani* using Poisoned Food Technique

S.No.	**Chemical**	**Concentration (%)**	**Radial mycelial growth at different intervals (mm)**				**Per cent inhibition over control**
			1 DAI	**3 DAI**	**5 DAI**	**7 DAI**	
T_1	Boric Acid	1	3.2	7.2	14.5	16.6	81.11
T_2	Boric Acid	2	2.6	5.6	11.1	13.2	85.83
T_3	Boric Acid	3	1.5	3.9	7.8	8.9	**89.87**
T_4	Mancozeb	0.05	5.0	9.8	19.6	25.7	70.75
T_5	Mancozeb	0.1	4.0	8.3	17.2	20.0	77.24
T_6	Mancozeb	0.2	2.2	5.0	9.6	10.9	87.59
T_7	Monceren	0.05	5.2	9.9	20.1	26.6	69.73
T_8	Monceren	0.1	4.5	8.8	18.7	23.3	73.48
T_9	Monceren	0.2	2.4	5.5	10.3	11.5	86.89
T_{10}	Control	—	9.0	24.8	61.8	87.88	00.00
C.V.			8.047	8.636	9.355	8.821	-
SE(m)			0.184	0.443	1.034	1.434	-
C.D.			3.125	1.326	3.084	4.293	-

Plate-6- Efficacy of fungicides on radial mycelial growth of *Rhizoctonia solani* using the Poisoned Food Technique



T_1-Boric Acid @ 1% ; T_2- Boric Acid @2% ; T_3- Boric Acid @3% ; T_4-Mancozeb @0.05% ; T_5- Mancozeb @0.1% ; T_6- Mancozeb @0.2% ; T_7- Monceren @0.05% ; T_8- Monceren @0.1% ; T_9- Monceren @0.2% ; T_{10}- Control time points, reaching 87.88 mm at 7 DAI, confirming the aggressiveness of the pathogen in the absence of chemical intervention (Plate-6).

4.5 Evaluation of the efficacy of *Trichoderma harzianum* on radial mycelial growth of *Rhizoctonia solani*

To evaluate how effectively *Trichoderma harzianum* can suppress the growth of *Rhizoctonia solani* causing black scurf disease in potatoes, several treatment approaches are used. These treatments mimic real-world conditions where timing, method and nutrient availability might affect disease control. The treatments included ,T_1– Simultaneous Inoculation (Pathogen+Antagonist), T_2– 24-Hour Headstart to Pathogen, T_3–24-Hour Headstart to Antagonist, T_4–Simultaneous Inoculation on Modified Medium, T_5– Multiple Inoculation Points, T_6– Variation in Antagonist Culture Age and T_7 – Control. Each of these setups is designed to reflect a different field scenario, whether the biocontrol agent is applied as a prophylactic measure or curative measure, whether it's competing for space and nutrients and how its age affects its efficacy.

By observing how *Trichoderma harzianum* performs in each of these conditions, it is better understood when and how to apply it for maximum impact. The goal is to find the most practical and effective method to reduce black scurf in potato crops under real field conditions. The results of the dual culture process were recorded on different intervals after inoculation(Table-2). Among all treatments, T_5 (Multiple inoculation points of *Trichoderma harzianum*) demonstrated the highest suppression of *Rhizoctonia solani* growth, with a radial mycelial growth of only 16.67 mm at 7 days after inoculation (DAI) and a remarkable 85.24% inhibition over control (Plate-7). T_3 (24-hour head start to *Trichoderma harzianum*) also showed significant inhibition (69.77%), with radial mycelial growth restricted to 26.86 mm at 7 days after inoculation (DAI). T_4 (Simultaneous inoculation on modified medium) and T_1 (Simultaneous inoculation on regular medium) followed with inhibition rates of 65.77% and 62.57%, respectively. In T_6 (Variation in culture age of *Trichoderma harzianum*), inhibition was moderate (60.01%). On the other hand, T_2 (24-hour head start to *Rhizoctonia solani*) recorded a lower inhibition percentage (49.54%) with a radial myceial growth of 44.84 mm after 7 DAI. The control treatment (T_7), where *Rhizoctonia solani* was grown alone, showed the maximum radial mycelial growth of 88.88 mm at 7 DAI, serving as the baseline for comparison.

4.6 Integrated effect of fungicides, bio-agents and organic amendments on germination percentage and plant height of potato at different days after sowing

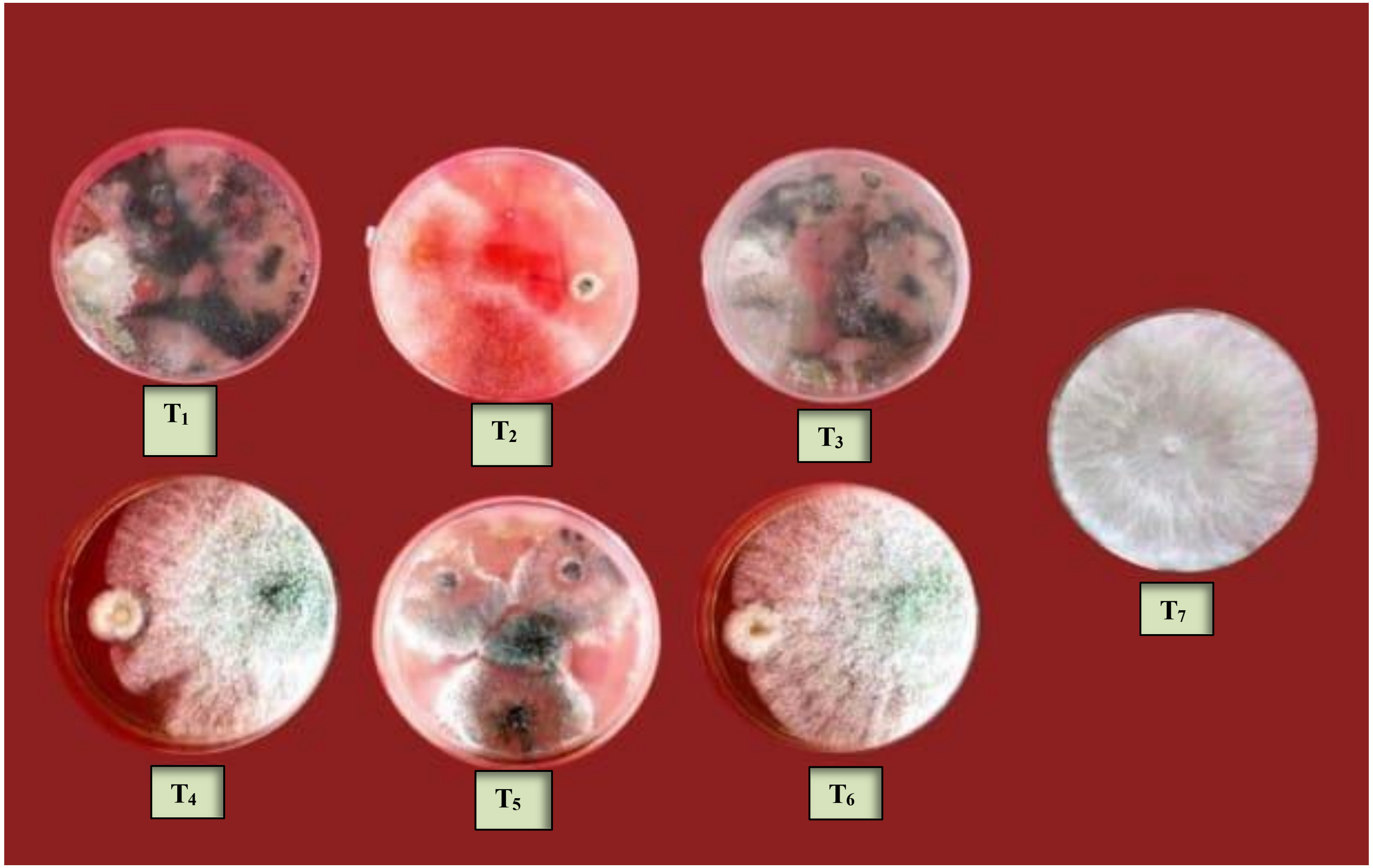
Germination percentage :

A comparative evaluation was conducted to assess the effectiveness of various treatments including fungicides, bio-agents and organic amendments on the germination percentage and plant height of potato over time in the field available at Department of Plant Pathology, Chandra shekar azad university of Agriculture and Technology, Kanpur.The germination persent is recorded and calculated at the emergence stage of the potatoes i.e after 30 DAS and a random number of 5 plants were selected, tagged and observed regularly inorder to

Table -2 : Efficacy of *Trichoderma harzianum* against *Rhizoctonia solani* using dual culture technique

S.No.	Treatment details	Radial mycelial growth (mm)				Per cent Inhibition over control
		1 DAI	3 DAI	5 DAI	7 DAI	
T_1	Simultaneous inoculation (Pathogen + Antagonist)	6.6	15.5	26.7	33.33	62.57
T_2	24-hour head start to *Rhizoctonia solani*	9.0	21.0	35.5	44.84	49.54
T_3	24-hour head start to *Trichoderma harzianum*	5.3	12.8	21.9	26.86	69.77
T_4	Simultaneous inoculation on modified medium	6.1	13.7	23.8	30.48	65.77
T_5	Multiple inoculation points of *Trichoderma harzianum*	3.3	7.8	13.5	16.67	**85.24**
T_6	Variation in culture age of *Trichoderma harzianum*	7.1	16.4	28.4	35.54	60.01
T_7	Control	17.7	40.0	70.5	88.88	0.00
C.V.		6.233	6.146	6.077	6.186	-
SE(m)		0.283	0.645	1.104	1.411	-
C.D.		1.882	2.009	3.440	4.396	-

Plate-7- Evaluation of the efficacy of *Trichoderma harzianum* on radial mycelial growth of *Rhizoctonia solani*



T_1= Simultaneous inoculation (Pathogen + Antagonist) ; T_2=24-hour head start to *Rhizoctonia solani* ; T_3= 24-hour head start to *Trichoderma harzianum* ; T_4= Simultaneous inoculation on modified medium ; T_5 = Multiple inoculation points of *Trichoderma harzianum* ; T_6 = Variation in culture age of *Trichoderma harzianum* ; T_7 = Control record plant height at variuos growth stages of the cropping period. Observations were recorded at a regular 7-day intervals from 7 to 63 days after sowing (DAS) (Table-3). Among all treatments, T_5 (Soil Application of Spent Mushroom Substrate+ tuber treatment of *Trichoderma harzianum* + Foliar treatment with 2 % Boric Acid) demonstrated the most superior performance throughout the growth period. The germination percentage recorded under T_5 was 89.70%, which was the highest among all treatments, indicating that this combination of spent mushroom substrate, seed treatment with *Trichoderma harzianum*, and foliar application of 2% boric acid created optimal conditions for early sprouting and establishment. This was followed closely by T_6 at 87.82%, which also incorporated spent mushroom substrate but used boric acid as both seed and foliar treatment. The lowest germination was observed in the untreated control (T_7), which recorded only 75.33%, affirming the detrimental impact of black scurf disease when no protective or supportive treatments are applied.

Plant height :

In terms of plant height, T_5 consistently led at all observed intervals, beginning with a height of 1.5 cm at 7 DAS and reaching 61.3 cm by 63 DAS. This steady and substantial increase across each observation point indicates that T5 not only aided in early germination but also significantly enhanced vegetative growth throughout the crop's early lifecycle. T_3 also performed notably well, starting at 1.4 cm and reaching 60.1 cm at 63 DAS, showing that the treatment involving neem cake as a soil amendment along with *Trichoderma harzianum* and boric acid foliar spray was also highly effective in promoting sustained plant development. T_1 followed closely, ending with a plant height of 59.0 cm, further confirming that the combination of FYM and *Trichoderma harzianum* works synergistically to improve plant health under disease pressure. Moderate growth trends were observed in T_2 (Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2 % Boric Acid) and T_6 (Soil Application of Spent Mushroom Substrate+ Seed treatment of 2 % Boric Acid + Foliar treatment with 2 % Boric Acid) which reached final heights of 55.3 cm and 57.0 cm, respectively. T_4(Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2 % Boric Acid) displayed a relatively slower growth trajectory, culminating in 52.2 cm at 63 DAS, suggesting that the treatment combination applied there was less supportive of long-term plant growth despite achieving a fairly high germination percentage. The control treatment (T_7), with no chemical, biological, or organic intervention, consistently recorded the lowest values throughout the study, with plant height reaching only 47.1 cm by 63 DAS. When analyzed in terms of percent increase over control, T_5 showed the most pronounced advantage, with a 30.13% increase in plant height at 63 DAS, followed by T_3 and T_1 with 27.61% and 25.27%, respectively. This further substantiates the beneficial impact of treatments combining organic amendments with biocontrol agents. T_2 and T_6 also recorded notable increases over control at 17.39% and 21.02%, respectively, while T_4 showed a more modest increase of 10.83%. These figures underline the fact that not all treatments are equally effective and their success largely depends on the combination among the soil amendment, seed treatment method and the nature of the foliar application used.

Table-3 : Integrated effect of fungicides, bio-agents and organic amendments on germination and plant height of potato at different days after sowing

Treatment	Germination (%)	Plant height (cm)									Per cent increase over control
		7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	
T_1	84.67	1.3	6.4	12.6	20.3	29.6	38.7	46.8	53.2	59.0	25.27
T_2	83.33	1.2	5.9	11.5	18.9	27.1	36.0	43.5	49.6	55.3	17.39
T_3	80.67	1.4	6.7	13.1	21.1	30.4	39.5	47.5	54.1	60.1	27.61
T_4	85.67	1.1	5.5	10.8	17.5	25.3	33.8	40.9	47.0	52.2	10.83
T_5	**89.70**	1.5	7.0	13.5	21.7	31.2	40.7	48.6	55.4	61.3	**30.13**
T_6	87.82	1.3	6.1	12.0	19.7	28.5	37.0	44.8	51.3	57.0	21.02
T_7	75.33	1.0	5.0	9.7	15.9	23.0	30.5	36.7	42.4	47.1	-
C.V.		6.585	5.137	5.645	5.596	5.465	5.503	5.522	5.569	5.552	-
SE(m)		0.048	0.181	0.387	0.624	0.880	1.163	1.407	1.622	1.795	-
C.D.		0.149	0.563	1.207	1.943	2.740	3.622	4.438	5.052	5.121	-

T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

4.7 Integrated effect of fungicides, bio-agents and organic amendments on size and number of potatoes at Tuber Formatation Stage (52 DAS)

The present study aimed to evaluate the effectiveness of different treatments in reducing the effects of black scurf disease caused by *Rhizoctonia solani* on potato yield characteristics at the tuber formation stage(52 DAS). A random number of 3 plants per plot were selected, removed carefully from the soil, cleaned and observed for different growth parameters at the field in Department of Plant Pathology, Chandra shekar azad university of Agriculture and Technology, Kanpur. Parameters observed include the number and weight of tubers in three distinct size categoriesi.e, small (<25g), medium (25–50g) and large (>50g) as well as the total yield per plot and the percentage increase over the untreated control was calculated. The data revealed distinct differences in yield parameters across treatments, strongly influenced by the composition and mode of action of the applied inputs (Table-4).

Among all the treatments, T_5 emerged as the most effective in enhancing both tuber yield and quality. The total yield recorded in T_5 was 1105 grams per plot, which represents the highest among all treatments and translates to a 72.66% increase over the untreated control (T_7). Although it had a modest number of small tubers (5 tubers weighing 195 g), it produced the highest medium tuber yield (5 tubers weighing 550 g) and the greatest contribution from large tubers (3 tubers weighing 360 g). This treatment included the use of spent mushroom substrate, seed treatment with *Trichoderma harzianum*, and foliar application of 2% boric acid, indicating that the synergistic effect of organic amendment, bio-agent and micronutrient played a critical role in maximizing productivity (Plate-8). T_6 also performed significantly well, with a total yield of 935 grams per plot, showing a 46.09% increase over control. This treatment yielded 6 small tubers (220 g), 5 medium tubers (510 g) and 2 large tubers (205 g). The notable presence of large and medium tubers again highlights that the treatment spent mushroom + boric acid contributed positively to disease control and plant vigor. However, compared to T_5, the slightly lower yield may be due to the absence of *Trichoderma harzianum* in the seed treatment, indicating the importance of including biocontrol agents in disease-prone environments. T_4 recorded a total yield of 900 grams per plot, translating to a 40.63% increase over control. While it had the highest number of large tubers (2) among treatments after T_5, contributing 235 g, it also performed well in the medium tuber category (4 tubers, 435 g) and had 6 small tubers (230 g). T_1, which used FYM as the base amendment along with *Trichoderma harzianum* and foliar boric acid, yielded 862 grams, showing a 34.69% increase over control. Though it had the good medium tuber count (4 tubers weighing 415 g) and a good contribution from small tubers (7 tubers, 290 g), the large tuber yield was relatively modest (1 tuber, 157 g). T_2 and T_3 recorded lower but still had meaningful gains over control. T_2 yielded 760 grams per plot (18.75% increase) with the good number of small tubers (8, 305 g), fewer medium (3, 370 g), and only 1 large tuber (85 g). T_3 yielded 720 grams per plot (12.50% increase) and had the highest total number of tubers (13), though a majority were smaller in size. The large tuber contribution (75 g) again reflects limited ability to promote tuber bulking, likely due to insufficient suppression of disease or lower nutrient availability. In sharp contrast, the control treatment (T_7), which received no fungicide, bio-

Table-4 : Integrated effect of fungicides, bio-agents and organic amendments on size and number of potatoes at Tuber Formatation Stage (52 DAS)

S.No.	Small (<25 g)		Medium (25-50 g)		Large (>50 g)		Total Yield (g/plot)	Per cent increase Over Control
	Number of tubers	Weight of tubers (g)	Number of tubers	Weight of tubers (g)	Number of tubers	Weight of tubers (g)		
T_1	7	290	4	415	1	157	862	34.69
T_2	8	305	3	370	1	85	760	18.75
T_3	9	325	3	320	1	75	720	12.50
T_4	6	230	4	435	2	235	900	40.63
T_5	5	195	5	550	3	360	**1105**	**72.66**
T_6	6	220	5	510	2	205	935	46.09
T_7	7	340	3	250	1	80	670	-
C.V.	5.618	8.332	5.418	9.729	7.128	6.058	10.457	-
SE(m)	0.223	0.013	0.121	0.023	0.065	1.054	0.014	-
C.D.	0.694	0.039	0.377	0.072	0.203	0.865	4.625	-

T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

Plate-08 – Integrated effect of fungicides, bio-agents and organic amendments on size and number of potatoes at Tuber Formatation Stage (52 DAS)

T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

agent, or amendment, recorded the lowest yield at 670 grams per plot. This treatment had a disproportionately high number of small tubers (7, 340 g) and the lowest contribution from medium and large categories, with only 3 medium tubers (250 g) and a single large tuber (80 g). The percent increase in yield over control clearly establishes the order of treatment effectiveness, with T5 standing out prominently, followed by T_6, T_4 and T_1.

4.8 Integrated effect of fungicides, bio-agents and organic amendments on size and number of tubers after harvesting (110 DAS)

The present study aimed to evaluate the effectiveness of different treatments in reducing the effects of black scurf disease caused by *Rhizoctonia solani* on potato yield characteristics after harvesting stage (100 DAS). The analysis conducted in the field at Department of Plant Pathology, Chandra shekar azad university of Agriculture and Technology, Kanpur , focuses on total yield per plot (kg), as well as the number and weight of tubers in three commercial size categories i.e., small (<25 g), medium (25–50 g) and large (>50 g). The performance of each treatment was compared to the untreated control (T_7) and the percent increase in yield over control was used as a measure of treatment efficacy. At 100 days after sowing, the data recorded for tuber yield and size distribution across the different treatments showed notable variation in both the number and weight of small, medium and large tubers as shown (Table 5). The total yield per plot ranged from 5.7 kg in the control (T_7) to 10.9 kg in T5. In T_5, the highest total yield of 10.9 kg was supported by 54 small tubers weighing 1096.44 grams, 145 medium tubers with a cumulative weight of 5454.88 grams and 58 large tubers that together weighed 4348.68 grams. The medium sized tubers contributed the highest weight among all categories within this treatment. T_6 produced a total yield of 8.71 kg per plot. It included 65 small tubers weighing 1317.87 grams, 128 medium tubers with a total weight of 4799.96 grams and 35 large tubers amounting to 2592.17 grams. The distribution showed a substantial number of medium-sized tubers, followed by a significant contribution from large tubers in terms of weight. T_4 recorded a total yield of 7.88 kg per plot. It comprised 59 small tubers totaling 1189.72 grams, 116 medium tubers weighing 4337.37 grams and 32 large tubers that weighed 2352.91 grams. The highest number of tubers in this treatment belonged to the medium size category and the large-sized tubers made a notable contribution to the overall yield. In T_1, the total yield was 7.5 kg per plot. This yield consisted of 75 small tubers with a total weight of 1530.08 grams, 100 medium tubers contributing 3756.65 grams and 30 large tubers weighing 2213.27 grams. The medium-sized tubers formed the largest group by number and weight. T_2 had a total plot yield of 6.55 kg. It produced 82 small tubers amounting to 1648.25 grams, 87 medium-sized tubers that weighed 3276.57 grams and 22 large tubers with a combined weight of 1655.18 grams. The medium tubers again constituted the highest contributing group to the overall yield.

T_3 showed a total yield of 6.15 kg per plot. It included 92 small tubers with a weight of 1846.79 grams, 82 medium tubers weighing 3080.89 grams and 16 large tubers totaling 1222.32 grams. The small tuber category had the highest count among all treatments, while the medium tubers contributed the most by weight. The control treatment, T_7, yielded 5.7 kg per plot. Within this, 86 small tubers weighed 1719.43 grams, 76 medium tubers weighed 2855.84 grams and

Table -5 : Integrated effect of fungicides, bio-agents and organic amendments on size and number of tubers after harvesting (110 DAS)

S.No.	Total Yield (kg/plot)	Small (<25 g)		Medium (25-50 g)		Large (>50 g)		Per cent increase over control
		Number of tubers	Weight of tubers (g)	Number of tubers	Weight of tubers (g)	Number of tubers	Weight of tubers (g)	
T_1	7.5	75	1530.08	100	3756.65	30	2213.27	31.57
T_2	6.55	82	1648.25	87	3276.57	22	1655.18	14.91
T_3	6.15	92	1846.79	82	3080.89	16	1222.32	7.89
T_4	7.88	59	1189.72	116	4337.37	32	2352.91	38.24
T_5	10.9	54	1096.44	145	5454.88	58	4348.68	91.22
T_6	8.71	65	1317.87	128	4799.96	35	2592.17	52.80
T_7	5.7	86	1719.43	76	2855.84	15	1124.73	-
C.V.	5.524	5.700	5.711	5.593	5.583	5.521	5.462	-
SE(m)	0.243	1.412	0.146	2.182	3.245	0.947	2.943	-
C.D.	0.758	1.193	4.324	3.534	4.258	2.951	4.153	-

T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

15 large tubers had a total weight of 1124.73 grams. Although small tubers were numerically dominant, medium tubers had the highest contribution to total weight. Each treatment showed distinct trends in the number and weight distribution among tuber size classes. The data reflects variation in productivity patterns under different treatment conditions, with considerable shifts in tuber size profiles across treatments.

4.9 Integrated effect of fungicides, bio-agents and organic amendments in managing the black scurf disease of potato under field conditions

Black scurf disease which is caused by *Rhizoctonia solani*, is a common and harmful problem in potato crops, especially under field conditions. The present study was carried out to observe how integration of different treatments such as fungicides, bio-agents and organic amendments affect the level of disease in the field.The study was carried out in the field at Department of Plant Pathology, Chandra shekar azad university of Agriculture and Technology, Kanpur. To understand this better, disease incidence and severity were recorded at four different stages of crop growth i.e, at 45, 60, 75 and 90 days after sowing (DAS). In addition to these, the percentage reduction in disease compared to untreated control plots was calculated, along with the Black Scurf Disease Index (BSDI), which combines both severity and incidence to show the overall disease pressure. The data below provides a detailed look at how the disease developed in each treatment throughout the crop's growth (Table-6).

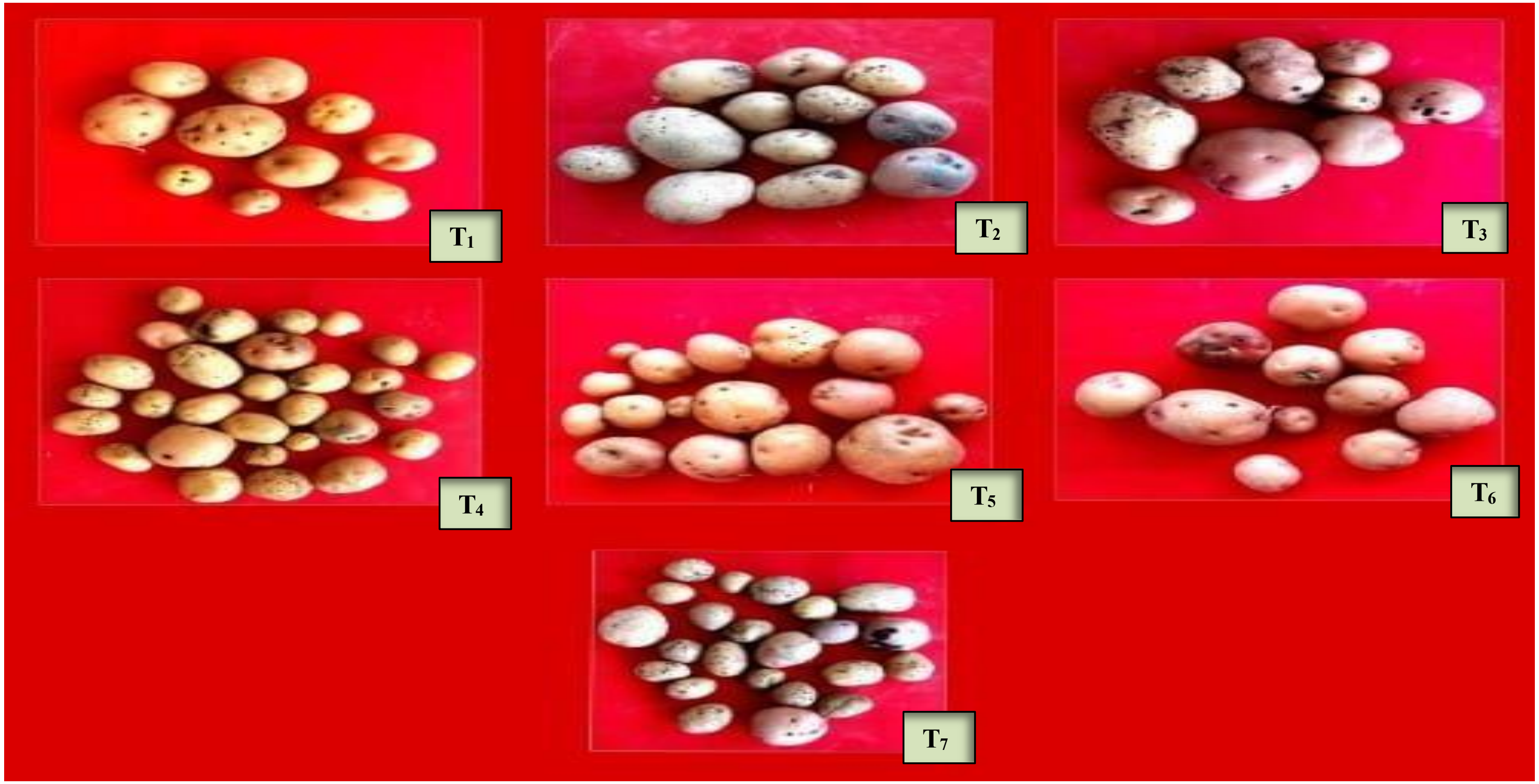
Among all the treatments studied for their effectiveness against Black Scurf Disease caused by *Rhizoctonia solani*, Treatment T_5 emerged as the most efficient in suppressing the disease under field conditions (Plate-9). It exhibited the lowest disease incidence of 15%, indicating that very few plants in this treatment group were infected. The progression of disease severity was also notably slow and minimal, with values starting at 3.6% at 45 days after planting (DAP) and rising only slightly to 6.6% at 60 DAP, 9.6% at 75 DAP, and finally 12% at 90 DAP. This gradual and controlled development of symptoms reflected a strong and consistent suppression of the pathogen throughout the crop cycle. The percentage reduction in disease severity over untreated control was remarkably high at 81.54%, and the Black Scurf Disease Index (BSDI) was the lowest recorded at 3.53. Following T_5, Treatment T6 also showed considerable effectiveness in managing the disease. The treatment recorded a moderate disease incidence of 28%, significantly lower than the untreated control. The severity of disease symptoms progressed steadily, starting from 6.6% at 45 DAP to 12.1% at 60 DAP, 17.6% at 75 DAP, and 22% at 90 DAP. Despite a visible increase with crop age, the overall severity remained well below the highly affected treatments. The percent reduction over control was 66.15% and the final BSDI value stood at 7.44, indicating a successful level of disease suppression. Treatment T_4 presented another promising result, with a relatively low disease incidence of 32% and steady suppression of severity over the cropping period. The severity values were 9% at 45 DAP, 16.5% at 60 DAP, 24% at 75 DAP, and 30% at 90 DAP, showing a uniform and manageable increase in symptoms. Compared to the untreated control, disease severity was reduced by 53.85% and the BSDI value was 10.2, which is still within a moderate range. This suggests that the treatment helped delay the onset and limited the progression

Table-6 : Integrated effect of fungicides, bio-agents and organic amendments in managing the black scurf disease of potato under field conditions

S.No.	**Disease Incidence (%)**	**Disease Severity at different days (%)**				**Per cent decrease over Control**	**Black Scurf Disease Index (BSDI)**
		45 DAP	**60 DAP**	**75 DAP**	**90 DAP**		
T_1	38	10.5	19.3	28	35	46.15	11.68
T_2	45	13.5	24.8	36	45	30.77	14.85
T_3	48	15	27.5	40	50	23.08	16.63
T_4	32	9	16.5	24	30	53.85	10.2
T_5	15	3.6	6.6	9.6	12	**81.54**	**3.53**
T_6	28	6.6	12.1	17.6	22	66.15	7.44
T_7	76	19.5	35.8	52	65	0	21.49
C.V.	6.228	6.259	6.316	6.263	6.296	-	6.286
SE(m)	1.449	0.401	0.743	1.070	1.345	-	1.258
C.D.	4.514	1.250	2.314	3.334	4.191	-	4.348

T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

Plate-09 - Integrated effect of fungicides, bio-agents and organic amendments in managing the black scurf disease of potato under field conditions



T_1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T_6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T_7: Control

of black scurf symptoms, offering a balanced level of disease management. Moving toward moderately effective treatments, Treatment T_1 recorded a disease incidence of 38%, with severity starting at 10.5% at 45 DAP and rising gradually to 19.3% at 60 DAP, 28% at 75 DAP and 35% at 90 DAP. Though the increase in severity was more pronounced than in T_4–T_6, it still represented a 46.15% reduction in disease over the untreated control, with a BSDI of 11.68. Treatment T_2 showed a comparatively higher disease incidence of 45% and its severity readings were 13.5% at 45 DAP, 24.8% at 60 DAP, 36% at 75 DAP and 45% at 90 DAP. The reduction in disease severity compared to the control was 30.77% and the BSDI stood at 14.85. In contrast, Treatment T_3 was among the least effective treatments after the control. It recorded the highest disease incidence among the treated plots at 48%, indicating a substantial spread of infection. The severity values also increased sharply, from 15% at 45 DAP to 27.5% at 60 DAP, 40% at 75 DAP and reaching 50% at 90 DAP. The reduction in disease severity compared to the control was only 23.08% and the BSDI was relatively high at 16.63, showing poor suppression. As expected, Treatment T_7, which served as the untreated control, recorded the highest levels of disease throughout the experiment. The disease incidence was 76%, and severity readings were the highest at each observation point 19.5% at 45 DAP, 35.8% at 60 DAP, 52% at 75 DAP and 65% at 90 DAP. The final BSDI value was 21.49, the highest of all treatments. These values confirmed the aggressive nature of *Rhizoctonia solani* infection in the absence of any treatment and served as the baseline reference for evaluating the effectiveness of all other treatments.

Plate-10 – Different stages of field experiment at Department of Plant Pathology

Tuber treatment with boric acid

Tagging of plots

Earthing up of potato plants

Application of fertilizer

Harvesting of potatoes

DISCUSSION

CHANDRA SHEKHAR AZAD UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

KANPUR

Potato (*Solanum tuberosum* L.) is a globally important staple and commercial crop, cultivated across over 125 countries and ranking third in consumption after rice and wheat. Its adaptability to diverse agro-climatic zones makes it vital for food security and rural livelihoods, especially in developing nations like India. As per FAOSTAT (2023), global potato production reached 383 million tonnes, with India contributing 57.05 million tonnes in 2023–24. Major potato-growing states include Uttar Pradesh, West Bengal and Bihar due to favorable climatic conditions and long-standing cultivation practices (Horticulture Statistics Division, 2023–24). Despite its value, potato cultivation is threatened by multiple biotic and abiotic stresses, with diseases caused by soil and tuber borne pathogens being particularly harmful. Fungal, bacterial, viral and nematode diseases affect different growth stages and impact both yield and tuber quality. Common diseases include common scab (*Streptomyces scabies*), powdery scab (*Spongospora subterranea*), brown rot (*Ralstonia solanacearum*), black leg (*Erwinia carotovora*), Verticillium wilt, early and late blight and viral infections like Potato Virus Y and Potato Leaf Roll Virus. These diseases result in reduced productivity, poor storage and lowered market value. Among them, Black Scurf disease, caused by *Rhizoctonia solani* Kuhn, is particularly damaging. It causes black sclerotia on tubers and stem cankers that hinder plant growth, leading to yield losses of 16–28% under moderate conditions and up to 50% in severe infestations (Singh *et al.*, 2014). While chemical fungicides like pencycuron, mancozeb, and carbendazim have been used for management, they raise concerns over environmental safety, cost, residue buildup and resistance development.

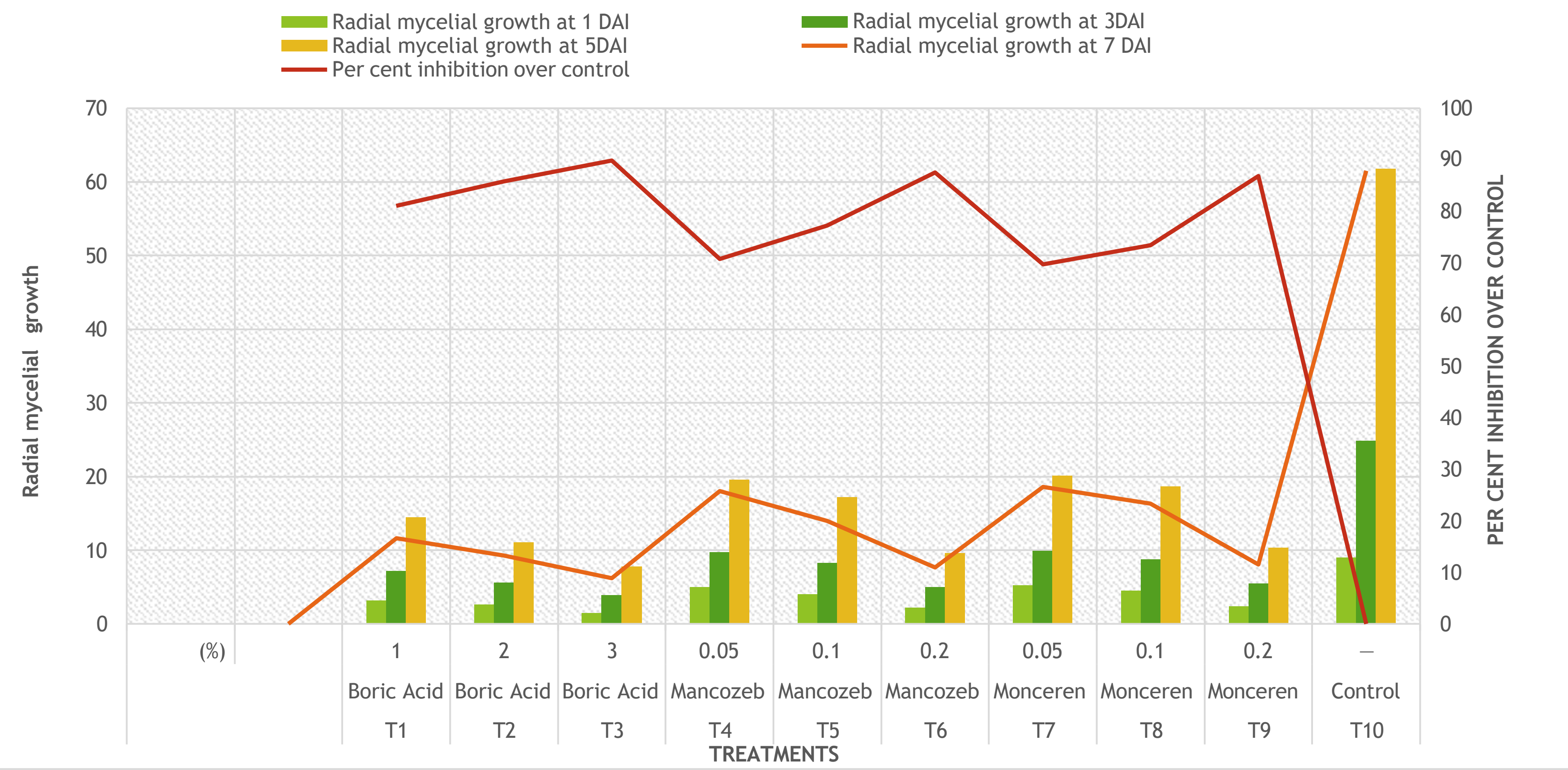
In light of the need for sustainable alternatives, the present study entitled **"Efficacy of Eco-Compatible Inputs for Managing Black Scurf Disease of Potato (*Solanum tuberosum* L.) incited by *Rhizoctonia solani* Kuhn"** was undertaken during Rabi 2024–25 at the Department of Plant Pathology, CSAUA&T, Kanpur. The objective was to assess the efficacy of biocontrol agents, organic amendments, and safe chemical alternatives under laboratory and field conditions for effective and eco-friendly management of the disease.

Initially the pathogen was isolated, purified and identified as *Rhizoctonia* by visual observation of hyphal characteristics on potato dextrose agar (PDA) medium as mentioned by Ogoshi (1987). It was found that hyphae of *Rhizoctonia* have right-angled branches at the distal 'septae of cells and dolipore septae. Their identity was confirmed by hyphal staining with 0.05 per cent trypan blue in lactophenol as mentioned by Meyer *et al.*,(1998), followed by light microscopy under a compound microscope to determine their hyphal morphology. The similar morpho-cultural keys were also reported by Pandit (2017) who found that hyphal staining of the isolates had characteristic of *Rhizoctonia solani* with typical right angle branches at the distal septae of cells and dolipore septae. After seven days of incubation on PDA, *Rhizoctonia solani* produced dark brown to black coloured sclerotia.

In vitro efficacy of selected fungicides i.e, Boric Acid, Mancozeb and Monceren at various concentrations using the poisoned food technique. Radial mycelial growth inhibition was measured at different intervals (1, 3, 5 and 7 days after inoculation) and percentage inhibition over the untreated control was calculated to assess fungicidal potential. Among the treatments evaluated, Boric Acid at 3% concentration (T_3) demonstrated the highest antifungal efficacy, significantly reducing radial mycelial growth across all observation intervals (Fig-1,Table-1). The growth was restricted to 1.5 mm at 1 DAI and only 8.9 mm at 7 DAI, culminating in a remarkable inhibition of 89.87% over control. This indicates that Boric Acid, particularly at elevated concentrations, effectively disrupts fungal growth, possibly by interfering with enzymatic activities or cellular structures critical for *Rhizoctonia solani* proliferation (Erper *et al.*, 2019). Arora & Khurana (2004) also found the gradual reduction in growth with increasing Boric Acid concentrations (from 1% to 3%) supporting a dose dependent antifungal action. Following Boric Acid, Mancozeb at 0.2% (T_6) also exhibited notable inhibitory effects, recording a mycelial growth of 2.2 mm at 1 DAI and 10.9 mm at 7 DAI, corresponding to 87.59% inhibition. Mancozeb is a dithiocarbamate fungicide, is known for its multi-site mode of action, which might have contributed to the suppression of mycelial expansion during early colony development (Debbarma *et al.*, 2021). A similar trend was observed with Monceren at 0.2% (T_9), which showed growth inhibition of 86.89%, reinforcing its effectiveness against *Rhizoctonia solani*. Comparatively, lower concentrations of Mancozeb (T_4 and T_5) and Monceren (T_7 and T_8) exhibited moderate suppression, with inhibition ranging between 69.73% and 77.24%. The observed radial growth at 7 DAI in these treatments remained significantly below the control (87.88 mm), indicating partial efficacy and the possibility of optimizing dosages for field-level recommendations. The untreated control (T_{10}) showed radial mycelial growth progression from 9.0 mm at 1 DAI to 61.8 mm at 5 DAI and 87.88 mm at 7 DAI, establishing a strong baseline for comparison and highlighting the virulence of the pathogen under *in vitro* conditions.

Kumar *et al.*, 2018 have also reported a dose dependent inhibition of *Rhizoctonia solani* by commercial fungicides like monceren, boric acid, chlorothional and mancozeb. Rajendraprasad *et al.* (2017) observed complete inhibition of *Rhizoctonia solani* by fungicides such as Tebuconazole + Trifloxystrobin and Carbendazim. These results align with the current study where boric acid, mancozeb and pencycuron were highly effective. Elshahawy *et al.* (2024) reported that boric acid at 1000–2000 mg/L significantly suppressed *Rhizoctonia solani* growth in vitro, confirming the antifungal potential of boron compounds and supporting its observed efficacy in the present study. Kumar *et al.* (2023) also reported the antifungal fungal activity of boric acid at higher concentrations against *Rhizoctonia solani* in comparision to other fungicides like mancozeb and monceren.

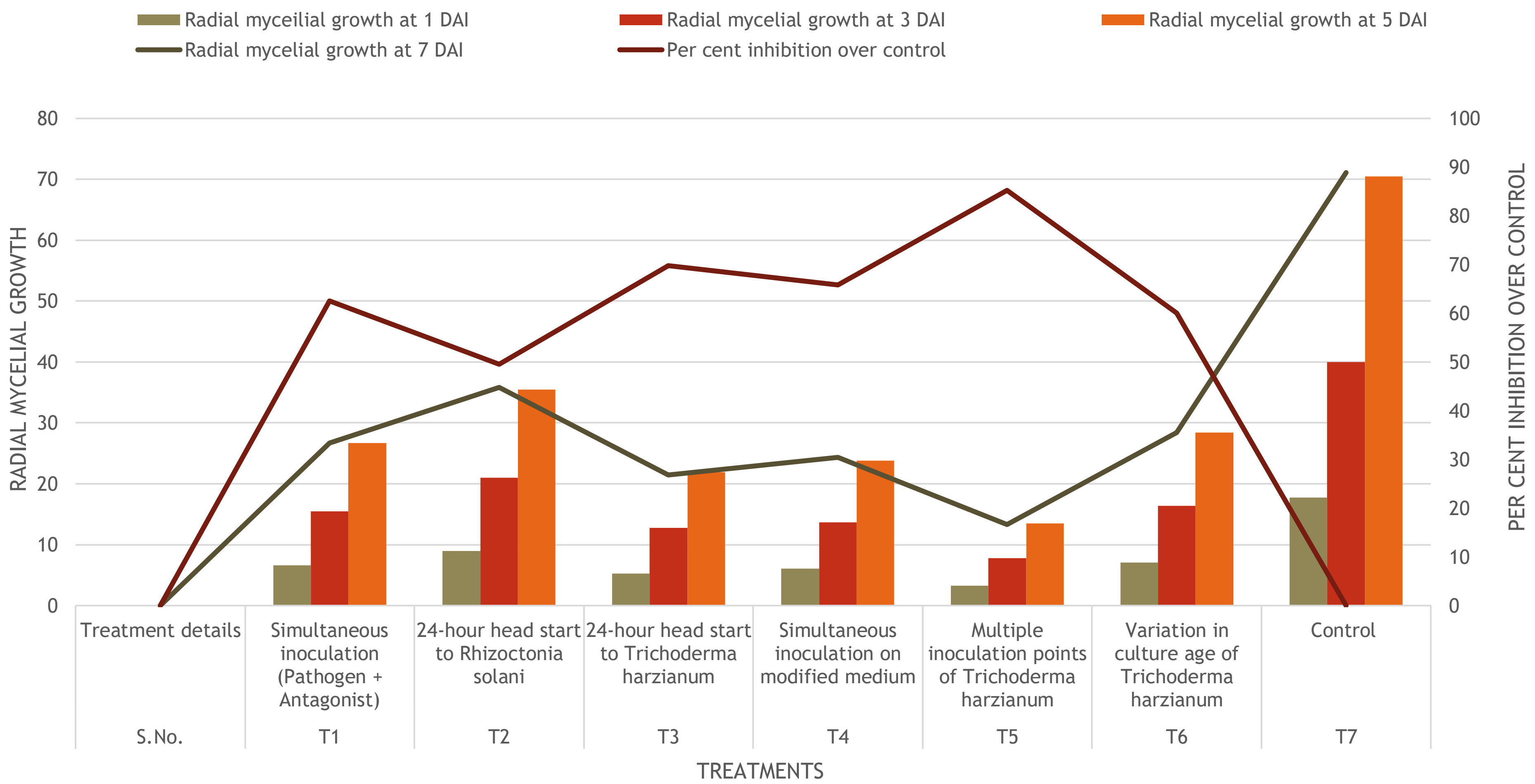
Fig-1: Efficacy of fungicides against *Rhizoctonia solani* using Poisoned Food Technique



Following this, *in vitro* screening was undertaken to evaluate the antagonistic behavior of *Trichoderma harzianum* against *Rhizoctonia solani* using dual culture assay. Different treatments were laid out including simultaneous inoculation, inoculation with a 24-hour lead for either the pathogen or the antagonist and tests using cultures of varying ages. Among all the treatments, multiple inoculation points of *Trichoderma harzianum* (T_5) emerged as the most effective, significantly suppressing the growth of *Rhizoctonia solani*. This treatment showed the least radial mycelial growth of 16.67 mm at 7 DAI and the highest inhibition rate (85.24%). These observations highlight that introducing the biocontrol agent at multiple sites creates robust antagonism by effectively limiting the pathogen's spread through competition and direct interaction (Fig-2,Table-2). The second most effective treatment was the 24-hour head start given to *Trichoderma harzianum* (T_3). Providing this slight advantage allowed the biocontrol agent to establish dominance before the pathogen's introduction, resulting in notable growth inhibition (69.77%) and limited radial growth of 26.86 mm at 7 DAI. This clearly demonstrates the advantage of early colonization of the medium by *Trichoderma harzianum*, showing the importance of timing in biological control strategies. Simultaneous inoculation on a modified medium (T_4) also yielded encouraging results, exhibiting considerable suppression of 65.77% inhibition, with a pathogen radial growth of 30.48 mm at 7 DAI. This treatment suggests that modifying the growth medium could potentially enhance antagonistic properties, possibly by optimizing nutrients that favor *Trichoderma harzianum* over the pathogen. Another treatment was simultaneous inoculation on the standard medium (T1), which provided moderate inhibition (62.57%), with pathogen growth reaching 33.33 mm at 7 DAI gave considerable results. Although slightly less effective than treatments T_5, T_3 and T_4, simultaneous inoculation remains practically relevant as it reflects the real world scenario of applying the biocontrol agent at the time of pathogen exposure. The least effective inoculation method among tested biological treatments was allowing a 24-hour head start to *Rhizoctonia solani* (T_2). This treatment showed the lowest inhibition rate of 49.54%, allowing substantial radial growth (44.84 mm at 7 DAI). Such results emphasize the importance of applying the antagonist promptly, as delayed introduction reduces the efficiency of biocontrol agents. Additionally, varying the culture age of *Trichoderma harzianum* (T_6) resulted in moderate pathogen suppression, achieving around 60.01% inhibition with radial growth of 35.54 mm at 7 DAI. This indicates that while the antagonist's culture age does influence its effectiveness, factors like timing and inoculation points seem to be of greater practical importance. The control treatment (T_7) without any biocontrol agent displayed unrestricted pathogen growth, recording the highest radial growth of 88.88 mm at 7 DAI, clearly demonstrating the aggressive growth potential of *Rhizoctonoia solani* underscoring the necessity of effective disease management measures.

These findings align with earlier reports by Kumar *et al*. (2023), which showed that strategic inoculation and timing are critical to maximizing the antagonistic potential of biocontrol agents. Chao *et al*., (2017) reported that when *Trichoderma* and *Rhizoctonia solani* were placed 5 cm apart on PDA, with varied timings showed significant inhibition due to early antagonist application. Andrés *et al*. (2022) compared multiple *Trichoderma* species and strains under varied pH and temperature regimes and documented consistent *in vitro* inhibition of

Fig-2: Efficacy of *Trichoderma harzianum* against *Rhizoctonia solani* using dual culture technique

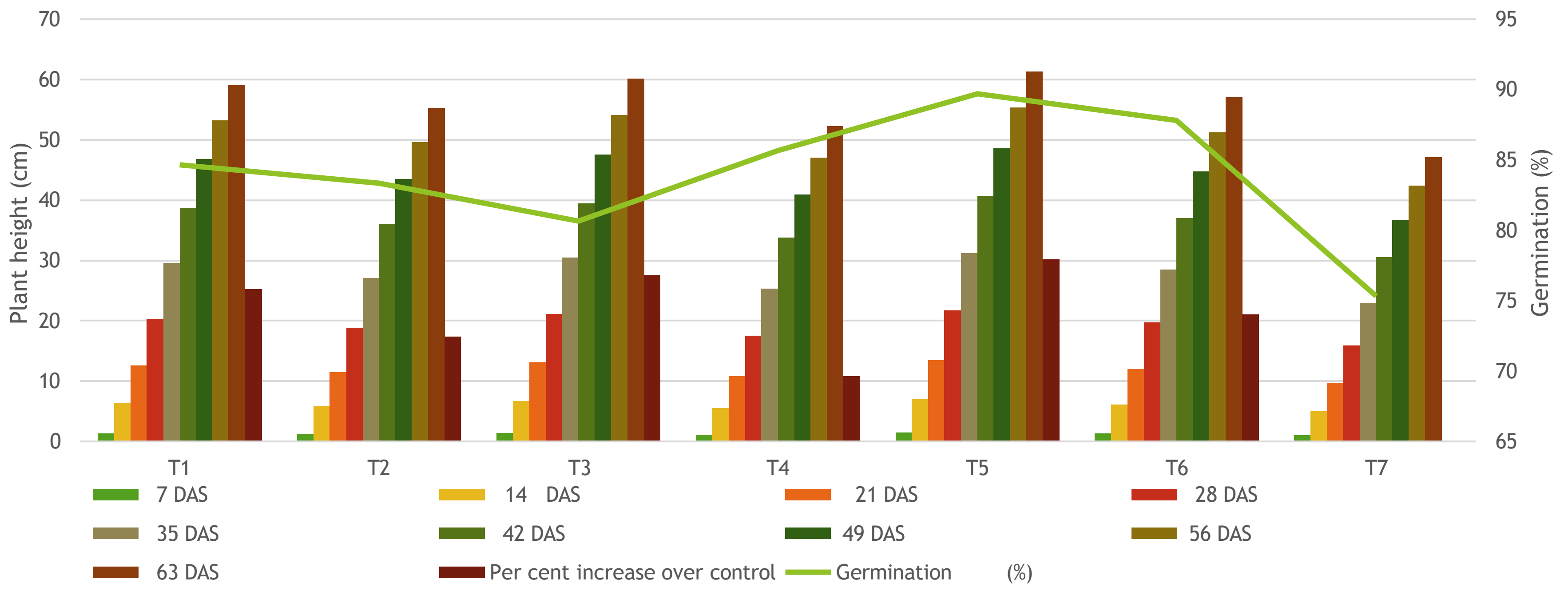


Rhizoctonia solani by *Trichoderma harzianum*, highlighting its robust antagonistic potential. Almaghasla *et al*. (2023) reported the influence of culture age and medium composition on *Trichoderma and Rhizoctonia solani* interactions. They found that younger cultures and specific growth media significantly improved antagonistic performance.

The subsequent field evaluation was designed using a Randomized Block Design (RBD) comprising seven treatments with three replications. The experimental plots received combinations of soil amendments (Farm Yard Manure, Neem Cake or Spent Mushroom Substrate), seed treatments (with either *Trichoderma harzianum* or boric acid) and a standardized foliar spray of 2% boric acid applied during the vegetative stage. The potato cultivar selected for the experiment was 'Kufri Sindhuri', which is regionally adapted and widely cultivated in North India. Uniformly healthy and disease-free tubers were used for planting across all plots, and agronomic practices were kept consistent. Field observations included germination percentage, plant height at multiple intervals (7, 14, 21, 28, 35, 42, 49, 56, and 63 DAS), disease incidence and severity at 45, 60, 75, and 90 DAS and yield measurements at 52 DAS (tuber formation stage) and at 100 DAS (final harvest). Among the seven treatments evaluated, T_5 (Spent Mushroom Substrate + *Trichoderma harzianum* + foliar Boric Acid spray) emerged as the most effective. It recorded the highest germination percentage of 89.70%, surpassing all other treatments, including the control (T_7), which showed the lowest germination of 75.33% (Fig-3,Table-3). This suggests that the combined application of spent mushroom substrate and *Trichoderma harzianum* not only improved soil health and microbial activity but also significantly contributed to better seed germination. The foliar spray of boric acid possibly enhanced metabolic activity and membrane integrity during early seedling emergence.

Plant height observations taken at successive intervals (7 to 63 DAS) further reinforced the superiority of T_5. It maintained a consistent edge in promoting plant growth, reaching 61.3 cm at 63 DAS, the tallest among all treatments. A notable 30.13% increase in height over control was also recorded, confirming its sustained efficacy in supporting vegetative growth under pathogen stress. The inclusion of organic amendments like spent mushroom substrate is believed to have improved soil structure, aeration, and nutrient availability, creating a conducive rhizosphere for the activity of *Trichoderma harzianum*, a proven biocontrol agent against *Rhizoctonia solani*. Treatment T_3, which included neem cake as a soil amendment along with *Trichoderma harzianum* and foliar boric acid, also performed remarkably well. It recorded a germination of 80.67% and a plant height of 60.1 cm at 63 DAS, showing a 27.61% increase over the control (Fig-3,Table-3). Mathew *et al*., 2023, also reported that the antifungal and soil-conditioning properties of neem cake, coupled with the antagonistic potential of *Trichoderma harzianum*, likely contributed to the increased outcome. Other treatments such as T_1 (FYM + *Trichoderma harzianum*) and T_6 (Spent Mushroom Substrate + Boric Acid without bio-agent) also recorded notable improvements over control. T_1 yielded 84.67% germination with a final plant height of 59.0 cm, while T6 showed 87.82% germination and 57.0 cm plant height. However, the

Fig-3: Integrated effect of fungicides, bio-agents and organic amendments on germination and plant height of potato at different days after sowing

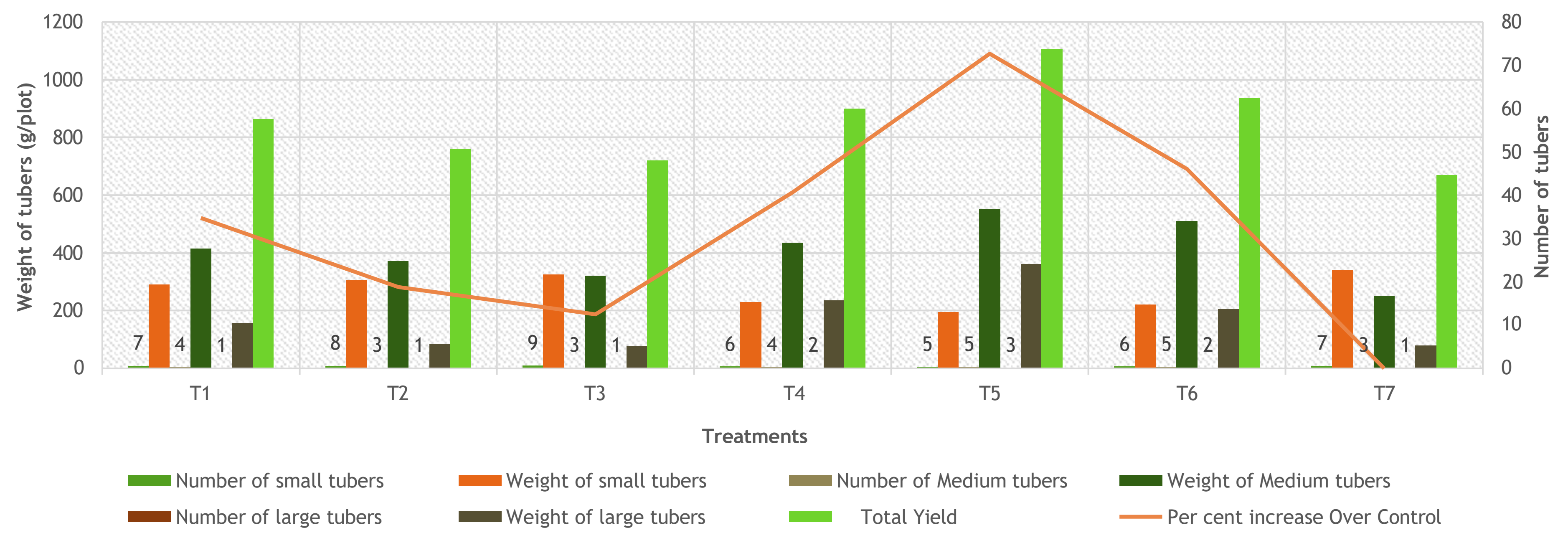


T1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T7: Control

absence of *Trichoderma harzianum* in T_6 resulted in comparatively reduced efficacy, showing the importance of the bio-agent in suppressing the pathogen and stimulating growth. Treatments that lacked *Trichoderma harzianum*, namely T_2, T_4, and T_6, while still effective compared to control, generally recorded lower plant height increments and germination percentages. For instance, T_4 showed a germination rate of 85.67% but exhibited only a 10.83% increase in plant height over control, the least among all treated plots. This implies that although neem cake and boric acid had some beneficial effects, their combined action was not as effective in promoting growth or managing the pathogen as treatments incorporating the biocontrol agent. The control plot (T_7) consistently exhibited the lowest values across all parameters. The final plant height of 47.1 cm and the germination rate of 75.33% were significantly lower than all treated plots, reaffirming the suppressive effect of *Rhizoctonia solani* in the absence of any management input. This also highlights the importance of integrating organic and biological approaches for effective disease mitigation and growth promotion. The progressive increase in plant height across time intervals reflects the positive physiological response of the crop to disease management treatments. The enhanced growth observed particularly in treatments involving *Trichoderma harzianum* can be attributed not only to its antagonistic action against *Rhizoctonia solani* but also to its growth-promoting effects such as production of plant hormones and improved nutrient uptake. Similar results were also obtained by Brewer, M. T., & Larkin, R. P. (2005) where they reported that use of organic amendments like compost and green manures reduced disease incidence and increased potato plant vigor. Singh *et al.*, 2023 also tested various bio-agents and fungicides under field conditions, revealing that Boric acid @ 3% treatment resulted in maximum yield of 275.00 q/ha, enhancing plant growth.

Yield performance at 52 DAS also provided further evidence to these trends. Among all treatments, T_5 (Soil application of spent mushroom substrate, seed treatment with *Trichoderma harzianum* and foliar application of 2% boric acid) resulted in the highest yield, recording a total of 1105 g/plot, with a significantly greater contribution from medium (550 g) and large-sized tubers (360 g). This translated into a 72.66% increase in yield over the untreated control (Fig-4,Table-4). The enhanced yield under T_5 can be attributed to synergistic effects of organic amendment and bio-agents which likely improved soil health, facilitated better nutrient uptake, and suppressed soil borne pathogens such as *Rhizoctonia solani*. Previous findings by Gupta and Sharma (2019) support this, reporting that spent mushroom substrate (SMS) significantly enhanced soil microbial activity and tuber yield in potato under disease stress conditions. The role of *Trichoderma harzianum* as a biocontrol agent has been well documented for its ability to colonize the rhizosphere, produce antifungal metabolites and induce systemic resistance in plants (Harman *et al.*, 2004). The notable yield improvement in T_5 and T_6 treatments also confirms the effectiveness of integrating *Trichoderma harzianum* with either organic manure or boric acid applications. Treatment T_4, which involved soil application of neem Cake, seed treatment of 2% Boric Acid and foliar treatment with 2% boric acid produced a yield of 900 g/plot with two large-sized tubers weighing 235 g and medium tubers contributing 435 g, resulting in a 40.63% increase over control. T_6 followed closely with a yield of 935 g/plot and a 46.09% increase, demonstrating

Fig-4: Integrated effect of fungicides, bio-agents and organic amendments on size and number of potatoes at Tuber Formatation Stage (52 DAS)



T1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T7: Control.

that even combinations with boric acid and SMS, when paired with bio-agents, offer consistent results in promoting tuber development. Boric acid is known to play a critical role in cell wall integrity and carbohydrate translocation, which are vital during tuber bulking stages (Dell & Huang, 1997). Treatments T_1, T_2 and T_3 showed moderate efficacy, with yields ranging from 720 to 862 g/plot. While these treatments led to an increase in small and medium tuber numbers, the contribution from large tubers remained relatively low, particularly in T_2 and T_3. This could be a result of insufficient pathogen suppression or lower physiological efficiency of the applied treatment combinations. Notably, T_1 exhibited a 34.69% yield increase, highlighting that even early-stage interventions, though less effective than integrated ones, still contribute positively to tuber development. The control treatment (T_7) recorded the lowest total yield (670 g/plot), reaffirming the impact of disease pressure on tuber growth and size. The minimal weight of large-sized tubers (80 g) and the lowest number of medium-sized tubers indicated that unprotected crops are more vulnerable to infection, particularly during the critical tuber initiation phase.

The influence of treatments became even more pronounced at the time of harvest (100 DAS), where notable differences were observed in the final tuber yield and its distribution across size categories. The integrated application of fungicides, bio-agents and organic amendments resulted in improved productivity and a shift toward larger marketable tubers, confirming the sustained effectiveness of disease management strategies throughout the cropping period. T_5 once again outperformed all other treatments, achieving a total yield of 10.9 kg/plot, which marked a 91.22% increase over the untreated control (T_7). Not only did this treatment yield the highest number of medium-sized tubers (145 tubers weighing 5454.88 g) and large tubers (58 tubers weighing 4348.68 g), but it also recorded the lowest number and weight of small-sized tubers, reflecting an effective translocation of assimilates into economically valuable tubers (Fig-5,Table-5). The results clearly indicate the enhanced physiological efficiency and disease suppression capacity offered by the synergistic interaction between spent mushroom substrate (SMS), *Trichoderma harzianum* and foliar boric acid spray. These inputs likely improved soil structure, rhizosphere colonization and nutrient cycling, contributing to improved tuber bulking and uniformity. Supporting literature affirms that SMS not only suppresses soil borne pathogens but also increases tuber size and marketable yield by improving nutrient availability and microbial biomass (Pathma & Sakthivel, 2012; Gupta & Sharma, 2019). Moreover, *Trichoderma harzianum* is known for its persistent rhizosphere activity and ability to release growth-promoting substances such as auxins and siderophores, which could further explain the marked improvement in tuber weight across size grades (Yedidia *et al.*, 2001). T_6, the treatment that substituted SMS with neem cake while retaining the same biocontrol and micronutrient strategy, recorded the second-highest yield (8.71 kg/plot, a 52.80% increase over control). It resulted in 128 medium-sized and 35 large-sized tubers, suggesting that neem cake too offers considerable benefits in enhancing soil suppression of *Rhizoctonia solani*. This aligns with findings by Sarma *et al.* (2010), who observed that neem-based organic amendments improved root health and tuber productivity in disease affected potato crops. The T_4 treatment, comprising soil application of neem cake, Seed treatment of 2% Boric Acid and foliar treatment with 2% boric acid application, also delivered promising

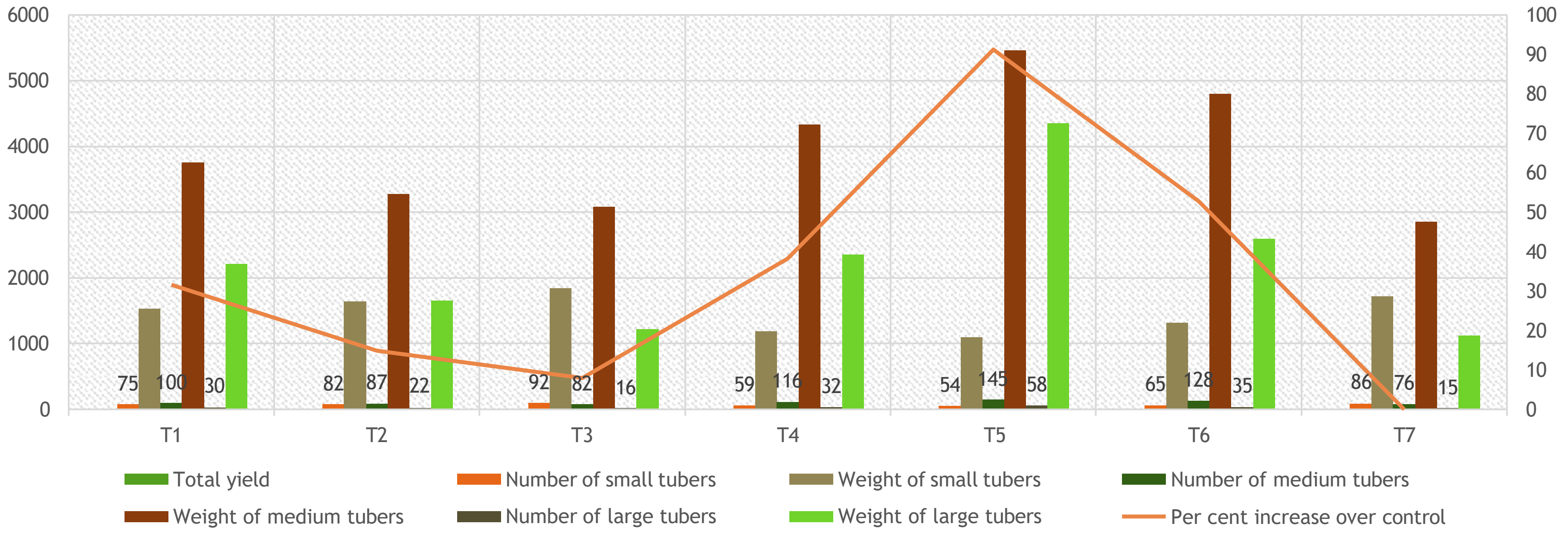


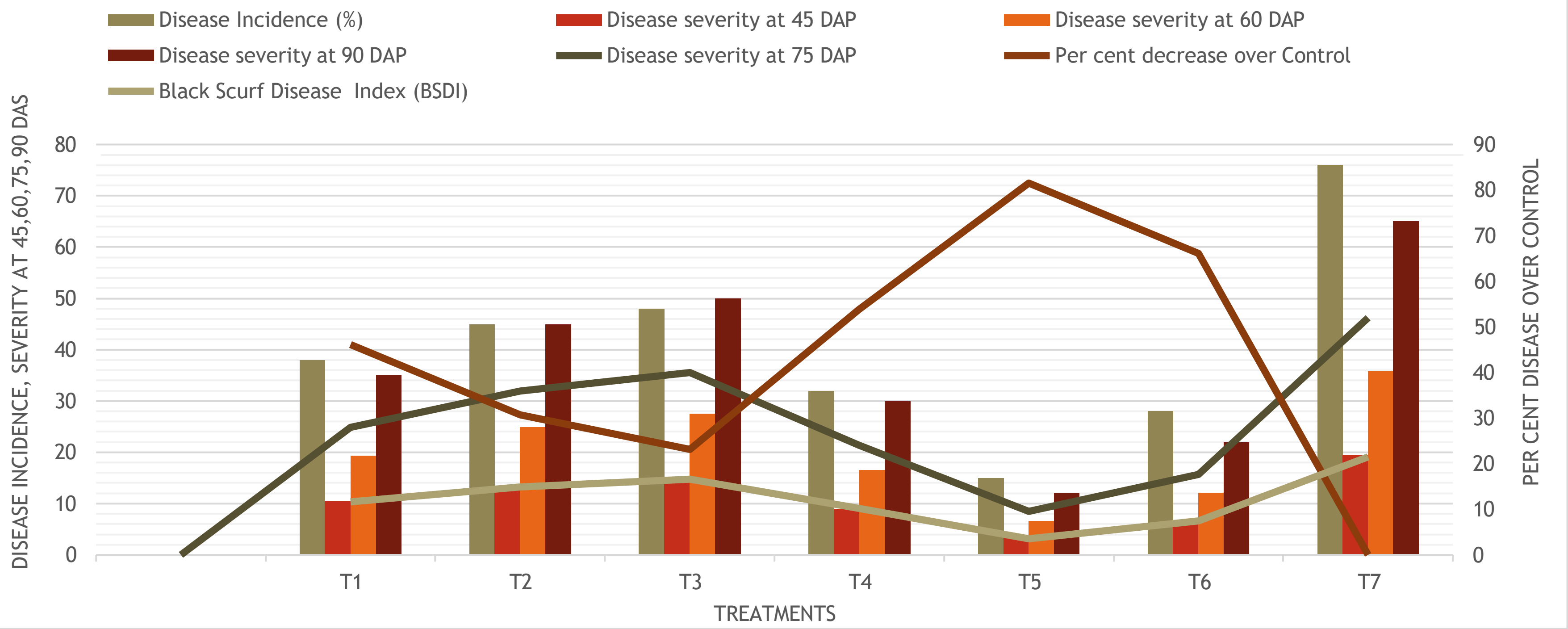
Fig-5: Integrated effect of fungicides, bio-agents and organic amendments on size and number of tubers after harvesting (110 DAS)

T1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T7: Control

results, with a yield of 7.88 kg/plot and a 38.24% yield increase, marked by a higher number of large-sized tubers (32 tubers weighing 2352.91 g) and the highest count of medium-sized tubers (116). Conversely, T_1, T_2 and T_3 exhibited relatively moderate effects, with total yields ranging from 6.15 to 7.5 kg/plot, corresponding to 7.89% to 31.57% yield improvement. These treatments had higher proportions of small tubers, suggesting that the combination of inputs was not as effective in sustaining late-stage disease suppression or resource allocation during tuber bulking. For instance, T_3 had the highest count of small tubers (92) and the lowest count of large ones (16), which reflects either continued pathogen interference or suboptimal nutrient assimilation during the latter half of crop development. The control (T_7), which received no protective input, consistently recorded the lowest total yield (5.7 kg/plot), with the smallest number and weight of large tubers (15 tubers, 1124.73 g) and a higher accumulation of small-sized ones. This confirms the natural severity of *Rhizoctonia solani* in untreated conditions, leading to compromised tuber size and overall productivity. The coefficient of variation (C.V.) values across tuber counts and weights remained below 6%, indicating that the data were robust and repeatable. The critical difference (C.D.) values further supported statistically significant separation among treatments, especially for medium and large tuber categories, reinforcing the credibility of the observed outcomes.

In addition to yield and tuber size, the efficacy of the applied treatments was clearly reflected in the suppression of black scurf disease, in terms of disease incidence, progressive disease severity and the calculated Black Scurf Disease Index (BSDI). The integrated management practices significantly reduced disease pressure compared to the untreated control, indicating their long term effectiveness in field conditions. Among the treatments, T_5 emerged as the most effective, achieving a drastic reduction in disease incidence (15%) and maintaining consistently low severity across all growth stages, with final severity at 90 DAP limited to just 12%. The BSDI for T_5 was the lowest (3.53), representing a remarkable 81.54% decrease in disease pressure over the control. These results highlight the cumulative disease-suppressive effect of combining spent mushroom substrate, *Trichoderma harzianum* seed treatment and 2% boric acid foliar spray (Fig-6,Table-6). The efficacy of *Trichoderma harzianum* in parasitizing *Rhizoctonia solani* and activating plant defense mechanisms is well documented by Harman *et al*., 2004, while boric acid, as a micronutrient with antifungal properties, may contribute to cell wall stability and reduced pathogen penetration (Shorrocks, 1997). Additionally, the application of SMS improves soil microbial diversity and introduces competitive microflora that suppress pathogen activity (Pathma & Sakthivel, 2012). Treatment T_6, which replaced SMS with neem cake, also performed well, reducing disease incidence to 28% and final severity to 22%, resulting in a BSDI of 7.44 and a 66.15% decrease over control. These results confirm the role of neem cake in modifying soil pathogen populations and releasing azadirachtin compounds that inhibit fungal activity (Isman, 2006). On the other hand, treatments T_1, T_2 and T_3 demonstrated only moderate suppression of disease. T_1 recorded a BSDI of 11.68, while T_2 and T_3 followed closely with 14.85 and 16.63,

Fig-6: Integrated effect of fungicides, bio-agents and organic amendments in managing the black scurf disease of potato under field conditions

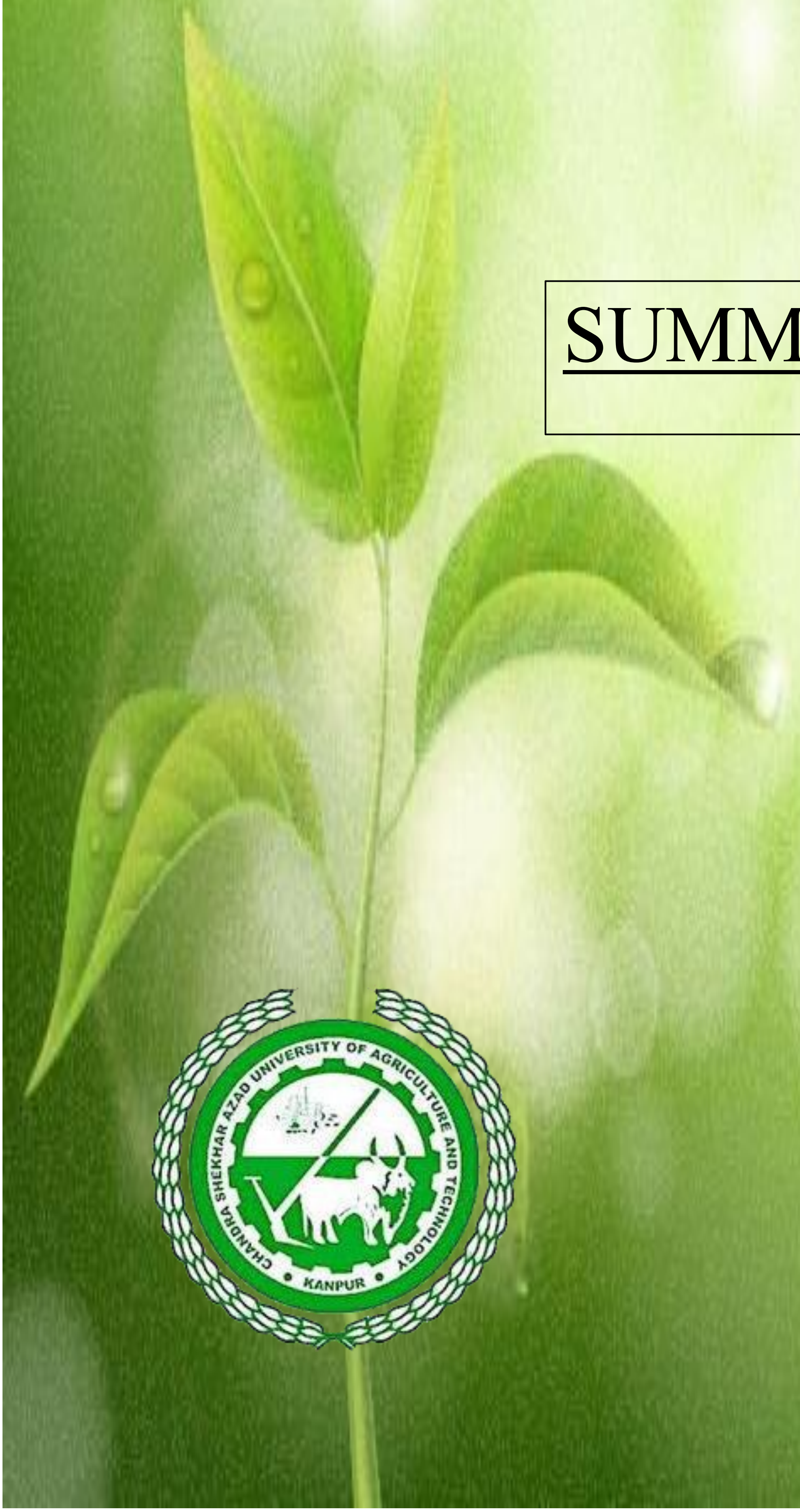


T1: Soil Application of FYM + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T2: Soil Application of FYM + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T3: Soil Application of Neem Cake + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T4: Soil Application of Neem Cake + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T5: Soil Application of Spent Mushroom Substrate + Seed treatment of *Trichoderma harzianum* + Foliar treatment with 2% Boric Acid ; T6: Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid ; T7: Control

respectively. Although these treatments lowered disease severity compared to the control, their limited performance, particularly at later growth stages (75–90 DAP), indicates a lack of sustained protection or reduced antagonistic activity in the soil environment. These observations suggest that isolated or partial treatment strategies may not suffice under high disease pressure and integrated interventions are crucial for consistent disease suppression throughout the crop duration. The untreated control (T_7) recorded the highest disease incidence (76%) and maximum severity at each recorded interval, increasing progressively from 19.5% at 45 DAP to 65% by 90 DAP, leading to a BSDI of 21.49. These figures underscore the aggressive nature of *Rhizoctonia solani* under unprotected conditions and highlight the urgency of adopting integrated disease management strategies. Such high disease intensity without intervention has been reported previously, with similar trends observed by Banville *et al.* (1996) in untreated potato fields. The coefficient of variation (C.V.) across all disease parameters remained under 7%, reflecting minimal experimental variation. The critical difference (C.D.) values for severity and BSDI confirm statistically significant differences between treatments, reinforcing the validity of the observed trends.

Similar observations were also made by Tsror *et al.*, (2001) who reported that *Trichoderma harzianum*, organic cattle manure composts reduced disease incidence and severity of the pathogen *Rhizoctonia solani*. The present findings are also in conformity with the reports of Singh and Chaudhari, (2012) as the black scurf disease of potato was managed effectively by treatment of tubers with *Trichoderma harzianum* @ 8 g/kg and neem ban @ 5ml/lt, which showed the disease incidence (20.96 and 25.41 per cent) and disease control (63.21 and 47.00 per cent) over control, as well as it reduced the disease index (0.62 and 0.76%), respectively. The similar finding of efficacy of above treatments against *Rhizoctonia solani* has also been reported by Kumar *et al.*,(2011) under pot conditions. They showed that *Trichoderma harzianum* was found most effective followed by Topsin-M, *Pseudomonas fluorescens*, *Trichoderma virens*, neem seed powder and FYM. Similarly, Larkin and Brewer (2020) emphasized that the use of mushroom substrate as a soil amendment improved microbial diversity, which in turn reduced the pathogen population density in soil. The cumulative outcome of the present study strongly supports the shift towards sustainable disease management practices. These findings were supported with the earlier studies by Singh *et al.* (2023), who reported enhanced disease suppression and tuber yield with the integration of *Trichoderma* species and organic matter. Mwangi *et al.*, 2024 also reported that Spent mushroom compost (SMC) can be used as a soil amendment and organic fertilizer, improving soil properties and controlling crop diseases in vegetables like tomato, potato, pepper, lettuce, cucumber and eggplant by enhancing plant resistance.

SUMMARY


CHANDRA SHEKHAR AZAD UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
KANPUR

Potato (*Solanum tuberosum* L.) plays an essential role in global food security and livelihoods. It is the third most consumed food crop worldwide after rice and wheat, due to its adaptability, short growth cycle and high yield potential. Potatoes are cultivated in diverse agroclimatic zones and are a valuable source of nutrition, especially in regions where dietary diversity and caloric intake are still major concerns. Production of potato supports millions of small and marginal farmers, making the crop economically important as well. India, as the second largest potato producer in the world, contributes significantly to both domestic consumption and global supply chains. The state of Uttar Pradesh remains a key region for potato cultivation due to its suitable climatic and soil conditions. However, the sustainability of potato production continues to face challenges due to several pests and diseases. Among these, *Black Scurf* disease, caused by the soil borne fungus *Rhizoctonia solani*, has emerged as a significant and often underestimated constraint. The pathogen affects multiple stages of crop development, from pre-emergence to tuber formation and causes both quantitative and qualitative losses. The disease is characterized by black, crust-like sclerotia on the tuber surface and stem cankers below the soil line. While the external appearance may be the most visible sign, the real damage often lies underground, where infected stems and roots lead to poor stand establishment, weak plant growth and ultimately, lower yields and compromised tuber quality. Conventional methods to manage this disease have primarily relied on synthetic fungicides. While effective to some extent, these chemical approaches raise environmental and health concerns. Over use of such inputs can lead to chemical residues in food, contamination of soil and water resources and a gradual decline in beneficial soil microflora. In light of increasing demand for sustainable farming, there is a need for alternative strategies that not only manage the disease effectively but also support soil health and reduce ecological harm. This includes the use of biological control agents, organic soil amendments and natural compounds that enhance disease suppression while promoting crop growth. With this background, the present investigation was undertaken to explore eco-compatible methods for managing Black Scurf disease in potato. The research focused on identifying treatment combinations that would provide effective disease control without relying heavily on synthetic chemicals. The results of the research findings are summarized as following:

1. The pathogen isolated from infected potato tubers showing black scurf symptoms was initially identified as *Rhizoctonia solani* based on typical hyphal characteristics under compound microscopy. The fungal hyphae exhibited right-angled branching and dolipore septa.
2. Under *in vitro* conditions, Boric Acid at 3% concentration (T_3) exhibited the highest antifungal efficacy against *Rhizoctonia solani*, achieving 89.87% mycelial growth inhibition over the untreated control and recording minimal radial growth (8.9 mm at 7 DAI).

3. Among all treatments, T_5 (Multiple inoculation points of *Trichoderma harzianum*) proved to be the most effective, achieving 85.24% inhibition of *Rhizoctonia solani* over the untreated control, with significantly restricted radial mycelial growth (16.67 mm at 7 DAI).
4. The highest germination percentage was observed in T_5 (Soil application of Spent Mushroom Substrate + Seed treatment with *T. harzianum* + Foliar spray with 2% Boric Acid), which showed uniform sprouting and early seedling establishment compared to other treatments and control.
5. Maximum plant height was recorded in T_5 (Soil application of Spent Mushroom Substrate + Seed treatment with *T. harzianum* + Foliar spray with 2% Boric Acid), followed by T_1 and T_3, at all observational intervals. In T_5, plant height was recorded as 6.15 cm, 14.32 cm, 21.44 cm and 32.68 cm at 30, 45, 60 and 75 DAS respectively.
6. At the tuber formation stage (52 DAS), the treatment involving Spent Mushroom Substrate + Seed Treatment with *Trichoderma harzianum* + Foliar Application of 2% Boric Acid (T_5) was found to be the most effective, resulting in the highest total yield of 1105 g per plot, which marked a 72.66% increase over the untreated control (T_7).
7. At the harvesting stage (110 DAS), the treatment involving Spent Mushroom Substrate + Seed Treatment with *Trichoderma harzianum* + Foliar Application of 2% Boric Acid (T5) was the most effective, producing the highest total yield of 10.9 kg per plot, which is a 91.22% increase over the untreated control (5.7 kg).
8. Disease incidence was minimum(15%) in T_5 (Soil application of Spent Mushroom Substrate + Seed treatment with *T. harzianum* + Foliar spray with 2% Boric Acid), followed by T_6 (28%), whereas control (T_7) showed the highest incidence at 76%.
9. The disease severity progression was slowest in T_5(Soil application of Spent Mushroom Substrate + Seed treatment with *T. harzianum* + Foliar spray with 2% Boric Acid), where values increased modestly from 3.6% at 45 DAP to 12% at 90 DAP. In contrast, the control (T_7) showed severity rising sharply from 19.5% to 65% over the same interval.
10. T_5(Soil application of Spent Mushroom Substrate + Seed treatment with *T. harzianum* + Foliar spray with 2% Boric Acid) recorded the highest percent reduction in disease severity over control (81.54%), followed by T_6(Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid) with 66.15%.
11. The Black Scurf Disease Index (BSDI) was found to be lowest(3.53) in T_5(Soil application of Spent Mushroom Substrate + Seed treatment with *T. harzianum* + Foliar spray with 2% Boric Acid), followed by T_6 (Soil Application of Spent Mushroom Substrate + Seed treatment of 2% Boric Acid + Foliar treatment with 2% Boric Acid) with 7.44.

The results of this research strongly support the use of integrated, eco-compatible management strategies for the control of black scurf disease in potato. Chemical control alone, though effective, poses environmental risks and cannot be relied upon sustainably. In contrast, biological control using *Trichoderma harzianum* and organic amendments like FYM and spent mushroom substrate, when combined with boric acid foliar applications, provided a better solution that is both efficient and sustainable. Adoption of integrated approaches not only minimizes the disease burden but also enhances plant vigor, tuber quality and overall farm profitability.

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Department of Plant Pathology

Chandra Shekhar Azad University of Agriculture and Technology,

Kanpur-208002

Name	: D.Devi Indrani	Id. No.	: CA-12980/2023
Major advisor	: Prof. S. K. Biswas	Degree	: M.Sc. Plant Pathology

Thesis Title : Efficacy of eco-compatible inputs for managing Black Scurf Disease of Potato (*Solanum tuberosum L.*) incited by *Rhizoctonia solani kühn*

Abstract

Black scurf of potato, caused by *Rhizoctonia solani* Kühn, poses a serious threat to tuber quality and yield, particularly under the cool, moist soil conditions prevalent during the *Rabi* season in northern India. The present study was undertaken with the aim of identifying effective and environmentally sound strategies for managing this disease. A comprehensive set of treatments combining fungicides, bio-control agents and organic amendments were evaluated under field conditions using a randomized block design with three replications. The interventions targeted different crop stages, incorporating soil amendments (FYM, neem cake and spent mushroom substrate), seed treatments (with *Trichoderma harzianum* or boric acid) and foliar sprays of 2% boric acid. Laboratory investigations laid the groundwork for treatment selection. Among chemical fungicides tested *in vitro*, 3% boric acid showed the highest inhibition (89.87%) of *Rhizoctonia solani*, followed by Mancozeb at 0.2% (87.59%) and Monceren at 0.2% (86.89%). These results demonstrated the potential of boric acid not only as a micronutrient but also as a potent suppressor of pathogen growth. In dual culture assays, *Trichoderma harzianum* displayed strong antagonistic activity, particularly when applied at multiple inoculation points, achieving 85.24% inhibition of *Rhizoctonia solani* and significantly restricting mycelial development. These findings validated the inclusion of both boric acid and *Trichoderma harzianum* in the field based integrated treatments. Field observations revealed considerable differences in crop performance depending on the treatment combinations. Among all tested strategies, the integration of spent mushroom substrate (SMS) as soil amendment, *Trichoderma harzianum* as seed treatment and 2% boric acid foliar application emerged as the most effective approach. This treatment not only enhanced vegetative growth, with a germination rate of 89.7% and plant height reaching 61.3 cm at 63 DAS, but also led to a significant increase in tuber yield. At harvest, this combination recorded a total yield of 10.9 kg/plot which is a 91.22% increase over the

untreated control with a remarkable distribution of 145 medium-sized tubers (5454.88 g) and 58 large-sized tubers (4348.68 g). This suggests enhanced nutrient uptake and better physiological development throughout the crop duration. The trend observed in yield was closely mirrored in disease suppression. The combination of SMS + *Trichoderma harzianum* seed treatment + foliar boric acid spray resulted in the lowest disease incidence (15%) and severity (12% at 90 DAP), with a Black Scurf Disease Index (BSDI) of just 3.53 representing an 81.54% reduction over the untreated control. Overall, the data from this study strongly support the integrated use of spent mushroom substrate, *Trichoderma harzianum* and foliar boric acid as the most effective and eco-compatible approach for managing black scurf disease and enhancing productivity in potato. The outcomes hold considerable promise for replacing or minimizing chemical fungicide use while ensuring high-quality, disease-free potato production under field conditions.