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# UNVEILING THE PATHOGENIC AND BENEFICIAL FUNGI IN POTATO FARMING OF GILGIT BALTISTAN, PAKISTAN

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**ABSTRACT**

Plant pathogenic fungi pose a significant threat to potato crops worldwide, resulting in substantial yield losses. However, certain fungi, such as *Trichoderma* spp., have exhibited beneficial properties by protecting potato crops against these pathogenic counterparts. In Gilgit Baltistan (GB), Pakistan, potato cultivation serves as a vital cash crop and primary source of income. Despite the importance of the crop, systematic studies on pathogenic and beneficial fungi associated with potatoes in GB remain limited. Existing research mainly relies on symptom-based reports, lacking sufficient insights into disease severity and incidence. Furthermore, the recent impact of climatic factors, including heavy and unseasonal rainfall and warmer winter temperatures, has further exacerbated these diseases. Therefore, this study aims to investigate plant pathogenic fungi in three districts of GB: Gilgit, Hunza, and Nagar. Soil samples from the rhizosphere of potato plants were collected, and fungi were isolated using serial dilution, plating, and baiting techniques. Subsequently, fungal morphology was examined using microscopy, and identification was performed using standard keys and monographs. Additionally, the synonymy of the isolated pathogenic fungi was determined. The analysis revealed the presence of eight fungi across all three districts, including *Aspergillus flavus*, *A. nidulans*, *A. niger*, *A. terreus*, *Penicillium citrinum*, *Rhizopus stolonifer*, and *Trichoderma gamsii*. *P. chrysogenum* was detected in Gilgit and Nagar districts, while *T. aureoviride* was identified in Gilgit and Hunza. This comprehensive research sheds light on the incidence and coexistence of beneficial and harmful fungi in potato-growing areas, enhancing our understanding of the factors influencing potato cultivation in GB.

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## INTRODUCTION

The potato (*Solanum tuberosum* L.), a dicotyledonous tuber crop belonging to the Solanaceae family, is extensively cultivated and consumed on a global scale (Birch et al., 2012; Anwar et al., 2015; Abbas et al., 2022). It serves as a vital food source and source of income for millions worldwide. China is a leading producer of potatoes, contributing to over 20% of the global output, with an annual production of 71 million tonnes (Fiers et al., 2011). As a crop suited to moderate climates, potatoes possess significant nutritional value and find diverse applications in both raw and processed

forms, particularly for catering to low-income consumers. Comprising 79% water, 17% carbohydrates (including 88% starch), and 2% protein, potatoes offer substantial nutritional benefits (Mu et al., 2017).

Potato cultivation spans 187.2 thousand hectares in Pakistan, yielding 3853.9 thousand tons of potatoes. The country cultivates potatoes in three seasons: spring, summer, and autumn (Anonymous, 2019). The summer crop thrives in mountainous regions, while the spring and autumn crops dominate the plains. Gilgit-Baltistan (GB), a vast mountainous area in northern Pakistan, heavily relies on potato cultivation as a cash crop, serving as a primary income source (Kamal and Nasir, 1998; Rahman et al., 2013).

Recent years have witnessed an increased potato production in this region due to the introduction of high-yielding cultivars, resulting in approximately 1400-1600 kg per Kanal area production (Abbas, 2017). However, replacing traditional varieties with these high-yielding cultivars has heightened the incidence of potato diseases in GB (Agrios, 2005; Abbas, 2017; Hussain et al., 2017). Plant Pathogenic fungi significantly threaten potato crops, leading to substantial yield losses. Previous reports in GB have highlighted diseases such as black scurf, late blight, and early blight as economically important diseases causing significant damage to potato yields (Hussain et al., 2014; Hussain et al., 2017; Abbas et al., 2023).

*Aspergillus*, *Penicillium*, and *Rhizopus* are fungal genera that have been associated with potatoes. *Aspergillus* spp. are ubiquitous in the environment and can sporadically contaminate stored potatoes, resulting in post-harvest spoilage (Ahmad et al., 1995; Ahmad et al., 1997; Ahmad, 1998; Agrios, 2005; Agrawal and Kotasthane, 2012; Anwar et al., 2015; Abedi et al., 2023). *Penicillium* spp. are frequently encountered in potato storage facilities and can induce decay and deterioration, compromising potato quality and shelf life. However, it is important to note that not all *Penicillium* spp. are detrimental; select strains can contribute to the ripening and flavor enhancement of specific potato products. On the other hand, *Rhizopus* spp. is the causative agent of soft rot in potatoes. These fungi thrive under warm and humid conditions, emphasizing the criticality of proper storage and handling protocols to minimize their occurrence and avert spoilage.

Implementing appropriate storage practices and vigilant monitoring for fungal proliferation can effectively mitigate the risks of contamination by *Aspergillus*, *Penicillium*, and *Rhizopus* during potato storage and processing operations. Beneficial fungi, such as *Trichoderma* spp., play a crucial role in ensuring the health and productivity of potato crops. They are well-known for their antagonistic activity against various plant pathogens, making them valuable allies in integrated pest management strategies. When applied to potato plants or soil, they can colonize the rhizosphere and form a protective barrier, inhibiting the growth and development of pathogenic fungi. This natural antagonism can significantly reduce the incidence and severity of devastating plant pathogens that threaten potato production. Moreover, *Trichoderma* spp. exhibit additional beneficial effects by enhancing plant growth and nutrient uptake, improving soil structure, and promoting overall plant health. By harnessing the biocontrol potential of *Trichoderma* spp., farmers can reduce their reliance on chemical fungicides, leading to more sustainable and environmentally friendly potato cultivation practices while ensuring high crop yields and quality. However, no reports have documented the presence or association of *Trichoderma* spp. with potato crops in GB (Abbas et al., 2017).

This study aims to comprehensively investigate pathogenic and beneficial fungi associated with potato crops in GB. The study will shed light on the isolation and identification of these fungi through meticulous sampling and analysis. The findings will contribute to an improved understanding of the disease dynamics and facilitate the development of effective management strategies for sustaining potato cultivation in GB. Furthermore, none of the studies focus on the proper isolation and identification of these fungi associated with potato crops in GB.

Moreover, the severity of these fungi was predicted to increase due to climate change, primarily because of heavy and unseasonal rains, increased floods, and warmer winter temperatures. Additionally, the mean monthly maximum temperature steadily increases in GB. The knowledge of the diversity of these fungi associated with the potatoes of GB is therefore essential to adopt appropriate management measures to reduce the losses against these fungi. Therefore, the objectives of the present study are to isolate harmful and beneficial fungi from the rhizosphere soil of the potatoes using serial dilution, direct plating, and baiting methods; to identify beneficial and harmful fungi associated with potato

crops using keys and monographs; and to understand the diversity of beneficial and harmful fungi associated with potato crops in three districts of GB.

## MATERIALS AND METHODS

### Study Area

The study was carried out in the Gilgit, Nagar, and Hunza districts, situated between 36.2764°N to 35.8819°N latitude and 74.4643°E to 74.7200°E longitude in the Gilgit-Baltistan region of Pakistan. The elevations of these districts are 1500 m, 2500 m, and 2688 m, respectively. The climate in the study area is characterized as arid and semi-arid, exhibiting diverse average temperatures and levels of rainfall.

### Collection of soil samples

Soil samples were gathered from potato fields across the three districts: Gilgit, Hunza, and Nagar. In each district, five random potato fields were chosen, and soil samples were acquired from the rhizosphere of potato plants. These samples were collected from a depth of 0-6 cm, and several samples from diverse locations within each field were meticulously blended to form a comprehensive composite sample. Subsequently, these samples were carefully placed in appropriately labeled polythene bags, securely sealed, and then transported to the integrated plant diseases and pests management laboratories at the Department of Agriculture in Gilgit for the analysis and the isolation of harmful and beneficial fungi associated with potato crops.

### Preparation of culture media

Multiple growth media, including Potato Sucrose Agar (PSA), Water Agar (WA), Corn Meal Agar (CMA), Potato Carrot Agar (PCA), Malt Extract Agar (MEA), and Czapek-Dox Agar (CzA), were prepared to assess the growth of fungal pathogens affecting potatoes.

### Isolation beneficial and harmful fungi

Fungi were isolated using the given below methods. Antibiotic penicillin (100,000 U $L^{-1}$) and streptomycin (0.2 $gL^{-1}$) were added to suppress bacterial growth.

### Serial dilution method

The serial dilution method described by Waksman and Fred (1922) was employed. One gram of soil sample was mixed with 9 ml of sterilized water to achieve a 1/10 dilution. Subsequently, 1/100, 1/1000, and 1/10,000 dilutions were prepared by adding 1 ml of the dilution to 9 ml of autoclaved water using a sterile pipette. One milliliter of each dilution was spread onto the PSA medium in triplicate plates for each sample. The plates were incubated at room temperature (20-25℃) for 3-5 days, and growing colonies were transferred to Petri plates containing PSA for further purification.

### Direct plating technique

The direct plating technique was employed to extract fungi from soil and root samples. A small quantity of air-dried soil was carefully positioned on one side of Petri dishes containing agar medium. Subsequently, 1 ml of autoclaved water was added to the soil, and using a sterilized bent glass rod, the soil was evenly spread across the agar surface. The Petri dishes were then incubated at room temperature for 1-2 days. The resulting fungal growth on the agar surface was subsequently transferred to separate Petri dishes containing Potato Sucrose Agar (PSA) or Corn Meal Agar (CMA) for purification and further analysis.

### Baiting method

Following the procedure established by Harvey (1925), the baiting method was employed. The soil sample was placed in a polythene bag and moistened with autoclaved water. After thorough mixing, the sample was left undisturbed for 10-20 minutes to attain a paste-like consistency. Using a sterilized teaspoon, a portion of the soil sample was placed on one side of a Petri dish. Subsequently, 10-15 ml of autoclaved water was poured into the Petri dish. Three grass blades measuring 3 cm in length were positioned in each Petri dish, with one blade placed near the soil and the remaining two blades situated away from the soil. The Petri dishes were then incubated at room temperature (25-30℃) for duration of 6-8 days. The baits exhibiting mycelial growth were washed with sterilized autoclaved water and transferred to fresh sterilized Petri dishes that were half-filled with autoclaved water. Two additional baits were introduced, and the cultures were monitored daily. After 2-3 days, the baits were transferred to Petri dishes containing antibiotics-amended PSA and CMA for further purification.

### Baiting with potato slices

For this method, approximately 30-50 g of soil sample was placed in a plastic bag with sufficient moisture, ensuring it was not overly wet. Disinfected potato tuber slices measuring 3-4 mm in thickness were then placed on top of the soil in each plastic bag and left for 24 h at room temperature (25-30℃). The potato slices were subsequently rinsed with tap water to eliminate soil particles and transferred onto water agar plates. The plates were incubated for 24 h and examined under a

compound microscope to identify the presence of coenocytic hyphae. These hyphae were then repeatedly transferred to fresh agar plates for further purification.

**Morphological analysis of fungi**

In-depth investigations were conducted on the morphological characteristics of fungi using pure fungal cultures aged between 5 and 7 days. A small segment of fungal growth from a colony was carefully transferred onto a microscope slide and immersed in a drop of lactophenol to facilitate examination. A cover slip was then placed over the sample. In the case of hyaline fungi, lactophenol mixed with cotton blue was utilized. Various features of the fungi, including mycelial septation, branching patterns, colony shape, and colors, were meticulously observed and recorded. Accurate measurements of mycelial width and spore size were obtained by standardizing the compound microscope using an ocular and a stage micrometer. To determine the diameter of fungal mycelium in Petri plates cultivated on different solid media, two perpendicular lines were drawn through the center of the culture plates. The two resulting diameters of the fungal growth were measured, and their average value was noted as the diameter of the developing colony.

**Preservation of fungi**

To ensure the preservation of fungal cultures, stock cultures were maintained on PDA slants and stored in a refrigerated environment at temperatures ranging from 4 to 5°C. The fungi were regularly sub-cultured to maintain their freshness and viability.

**Identification of fungi**

In order to identify the fungi, various fungal structures such as branched, septate, and pseudo-hyphae, conidiophores, conidia, sporangia, and sporangiophores were meticulously examined using an Olympus BX51 compound microscope. Standard taxonomic keys specific to different taxa were followed during the identification process. To accurately determine the species, reliable references such as Raper and Fennell (1965), Ellis (1971, 1976), Barnett and Hunter (1972), Domsch et al. (1980), and Dick (1990) were consulted, utilizing their keys and monographs. To cross-reference and ensure synonymy, the website http://www.speciesfungorum.org was diligently utilized as a supplementary resource during the identification process.

## RESULTS

**Isolation of harmful and beneficial strains and genera**

A total of 83 harmful and beneficial fungal strains belonging to nine species and four genera were isolated from the five potato fields in three districts of GB (Figure 1). Among the dominant fungal genera, approximately 36% of the total isolated strains belong to the genera *Trichoderma* spp. These *Trichoderma* spp. were considered beneficial. At the same time, harmful fungi include *Aspergillus* (28%), *Penicillium* (24.21%), and *Rhizopus* (12.10%).

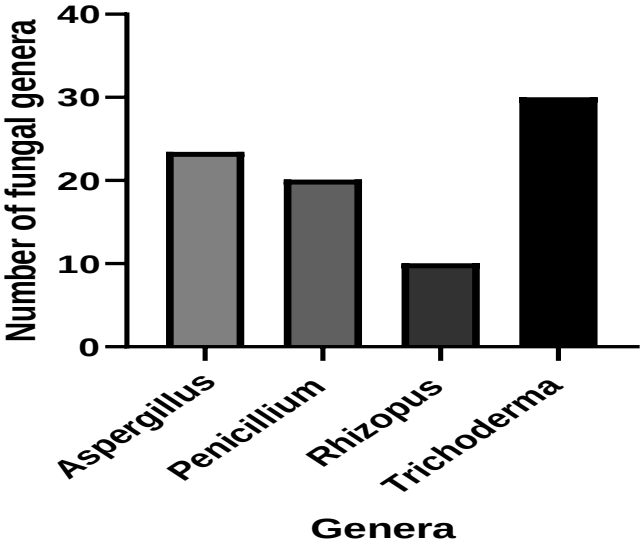


Figure 1: Dominant harmful and beneficial fungal genera associated with potato crop.

**Identification of harmful and beneficial fungal species**

Nine beneficial and harmful fungal species were *Aspergillus flavus*, *A. nidulans*, *A. niger*, *A. terreus, Penicillium chrysogenum*, *P. citrinum*, *Rhizopus stolonifer*, *Trichoderma aureoviridae*, and *T. gamsii* as shown in Table 1. Eight fungi, including *A. flavus*, *A. nidulans*, *A. niger*, *A. terreus*, *P. citrinum*, *R. stolonifer,* and *T. gamsii* were found across all three districts. *P. chrysogenum* was detected in Gilgit and Nagar districts, while *T. aureoviride* was identified in Gilgit and Hunza as shown in Table 1.

**Morphological study of identified fungi**

***Aspergillus flavus***

The colony grown on CZA agar reaches a diameter of 5 cm after 7 days. The colony color ranges from green to dark green, while the reverse side appears hyaline or light green. The conidiophores are hyaline, rough-walled, measuring 400-800 µm in length and 7-9 µm in width. The vesicles are globose, with a diameter of 15-23 µm, and they bear inflated metulae. The phialides are mostly uniseriate, occasionally biseriate. The conidia are globose and subglobose, with a diameter of 4-6 µm (Figure 2 A-D).

Table 1: Harmful and beneficial fungal species associated with the potato crop.

| S. No | Fungi Name | Gilgit | Hunza | Nagar | Beneficial/Harmful |
|---|---|---|---|---|---|
| 1 | *Aspergillus flavus* | + | + | + | Harmful |
| 2 | *Aspergillus nidulans* | + | + | + | Harmful |
| 3 | *Aspergillus niger* | + | + | + | Harmful |
| 4 | *Aspergillus terreus* | + | + | + | Harmful |
| 5 | *Penicillium chrysogenum* | + | - | + | Harmful |
| 6 | *Penicillium citrinum* | + | + | + | Harmful |
| 7 | *Rhizopus stolonifer* | + | + | + | Harmful |
| 8 | *Trichoderma aureoviride* | + | + | - | Beneficial |
| 9 | *Trichoderma gamsii* | + | + | + | Beneficial |

+ = detected, - = not detected

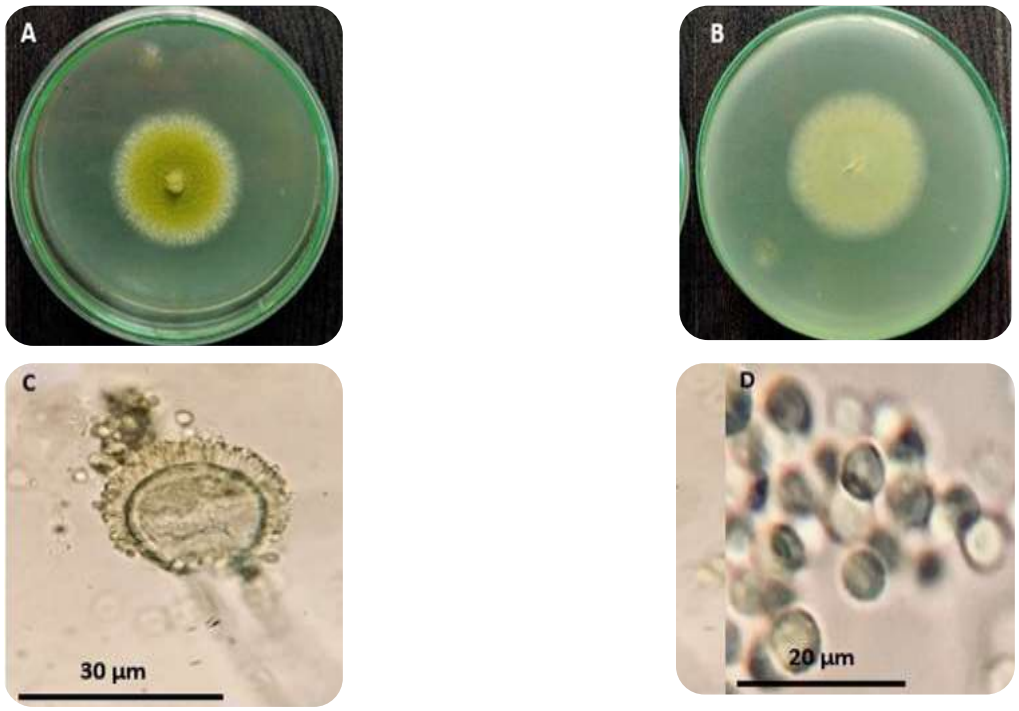


Figure 2: *Aspergillus flavus*: (A-B) Culture plate, front and reverse, (C) Conidiophore, vesicle, phialides, (D) Conidia.

***Aspergillus nidulans***

The colonies grown on CZA medium reach a diameter of 4.5 cm within 5-7 days. They exhibit a green color with reddish-brown cleistothecia, and the reverse side appears orange-red. The conidiophores are smooth and light brown, measuring up to 120 µm in length and 4 µm in diameter. The vesicles are oval to ovate, with a diameter of 8-12 µm. Sterigmata are arranged in two rows, and the metulae are 5-7 µm long and 3 µm wide. Phialides measure 4-6 µm in length and 2-3 µm in width. The conidia are globose and small, approximately 3 µm in diameter. The cleistothecia have a diameter of 190-300 µm. The ascospores are orange-red, with two thick equatorial crests and a smooth surface, measuring 4-5 µm in length and 2-3 µm in width. Hülle cells are globose and have a diameter of 16-20 µm (Figure 3 A-G).

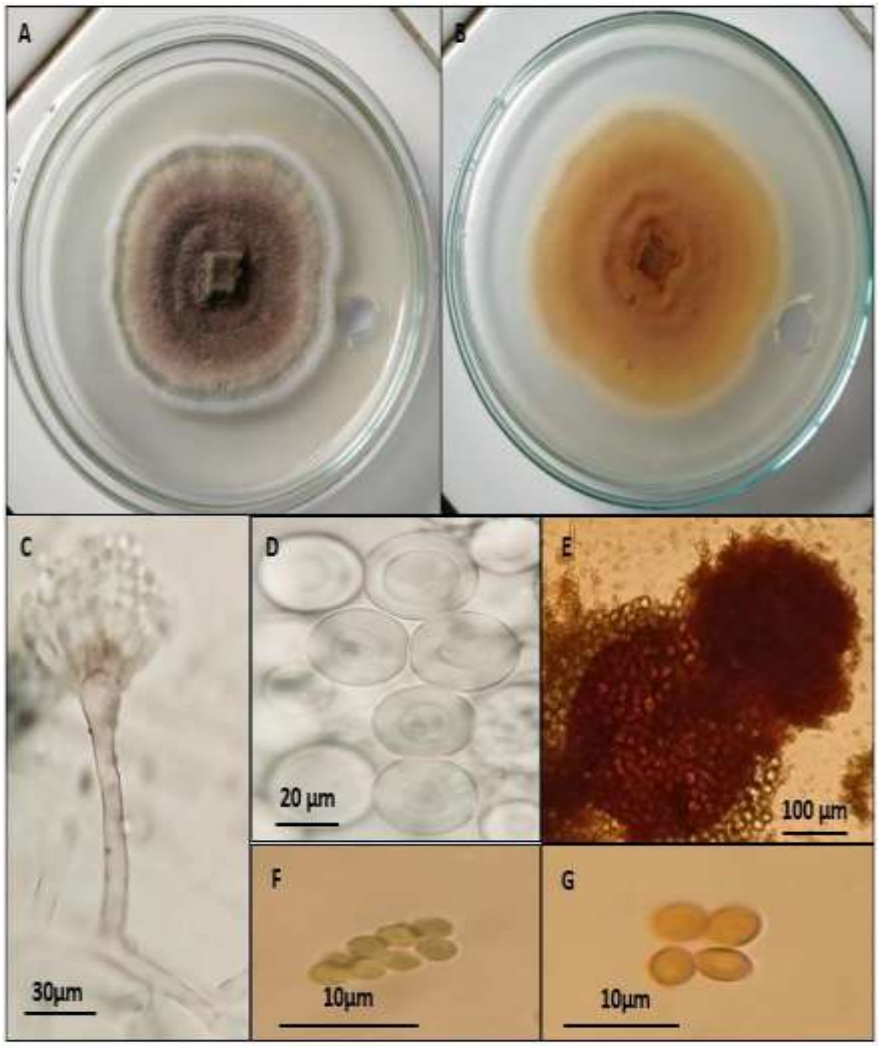


Figure 3: *Aspergillus nidulans*: (A-B) Culture plate, front and reverse, (C) Biseriate head with globose vesicle, metulae, phialides, (D) Hülle cells, (E) Cliestothecium, (F) Conidia, (G) Ascospores.

***Aspergillus niger***

The colony on CZA medium appears as a black powdery mass, with a hyaline-colored reverse side. It reaches a diameter of 4 cm within 6 days. The conidiophores are either hyaline or brown, simple in structure, and have a thick wall. They can reach lengths of up to 735 µm and widths of 9-13 µm. The vesicles are globose, measuring 50-73 µm in diameter. Phialides are arranged in two rows on the vesicle and are 5-11 µm long. The conidia are globose, brown to black in color, and have a diameter of 3-4 µm (Figure 4 A-D).

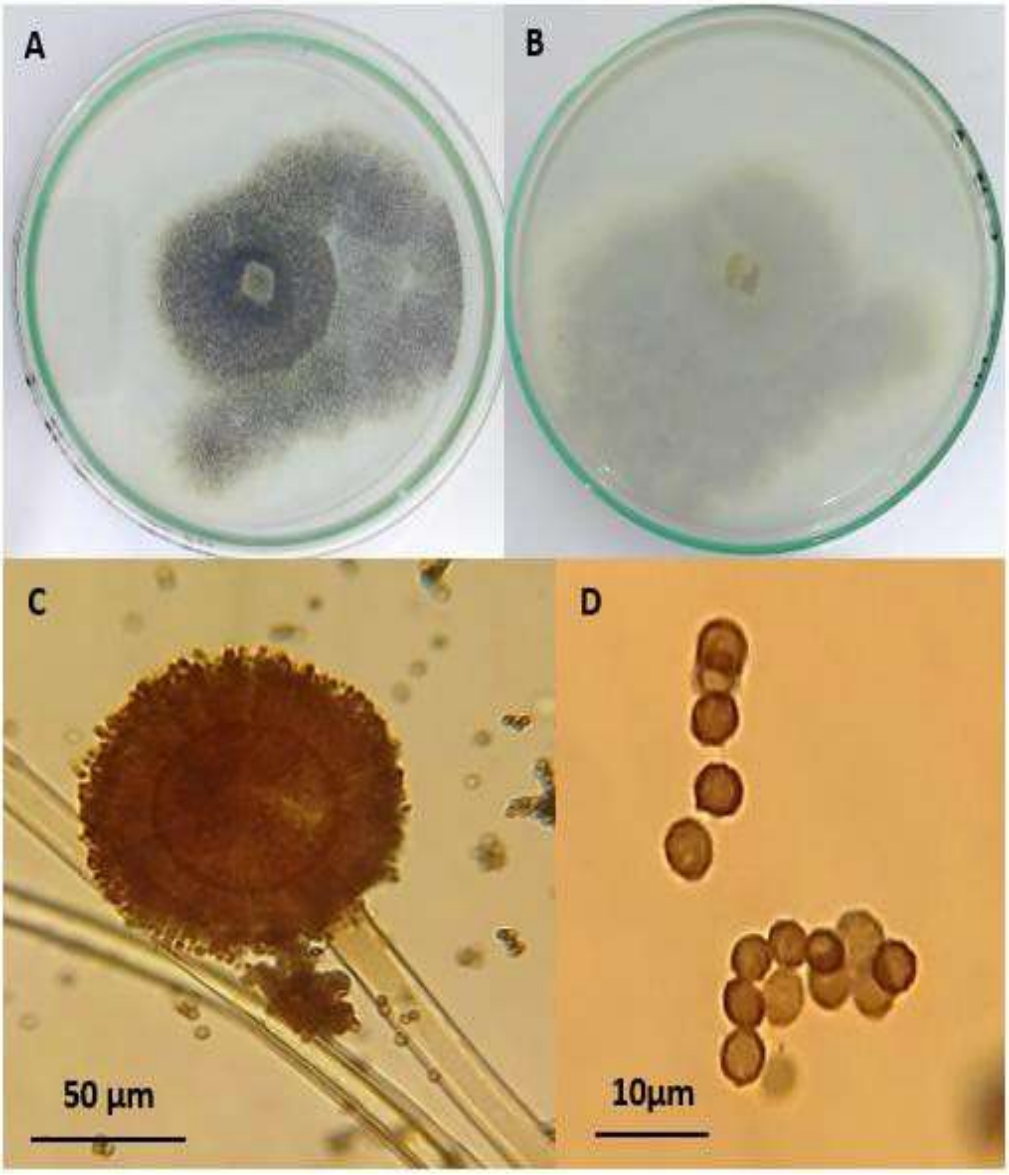


Figure 4: *Aspergillus niger*: (A-B) Culture plate, front and reverse, (C-D) Conidiophore, vesical, phialides and conidia.

***Aspergillus terreus***

On CZA medium, the colony exhibits a light brown or cinnamon color, with a light yellow reverse side. It reaches a diameter of 3.3 cm within 4 days. The conidiophores are hyaline, smooth, measuring 100-200 µm in length and 4-5 µm in width. The vesicles are globose to spherical, with a diameter of 10-19 µm. The sterigmata are arranged in two rows, and the metulae are ampuliform, measuring 5-8 µm in length and 1.5-2 µm in width. The phialides have dimensions of 5-7 µm in length and 1-2 µm in width. The conidia are globose, ranging from 1.5-2.5 µm in diameter. The conidial heads are compact and form short columnar structures, measuring 80-150 µm in length and 40-60 µm in diameter (Figure 5 A-D).

***Penicillium chrysogenus***

The colony displays a grass-green to bluish-green coloration, while the reverse side appears bright yellow. The conidiophores are mononematous, exhibiting branching or verticillate patterns with wide angles. They are hyaline and possess a smooth wall, measuring up to 3 µm in diameter. The metulae are divergent and have a smooth wall of 19-25 µm in length. The phialides are cylindrical and short, characterized by a distinct and conspicuous neck, measuring 13-19×3-3.5 µm. The conidia

have a smooth wall and are either globose or ellipsoidal in shape, with a diameter of 3-4 µm (Figure 6 A-D).

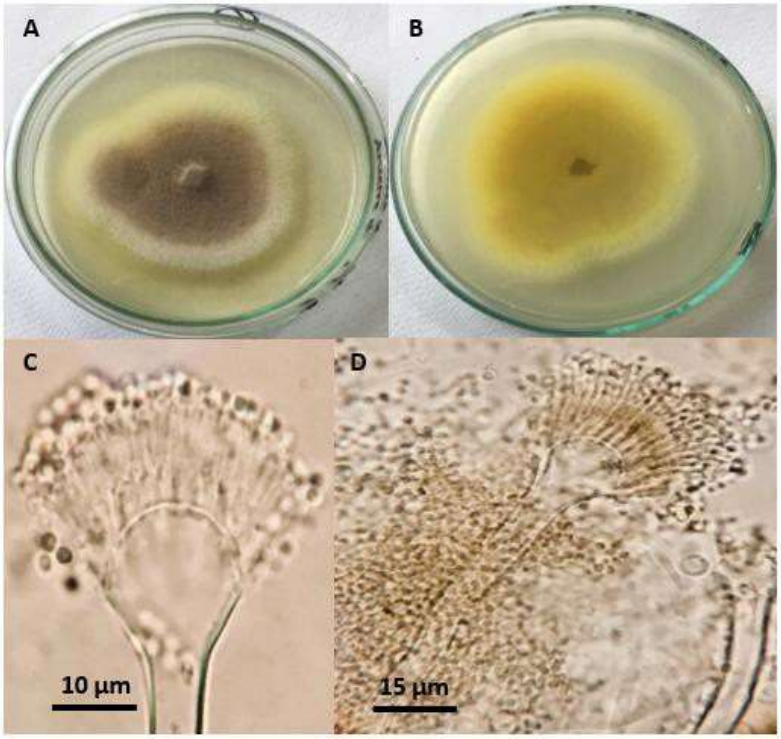


Figure 5: *Aspergillus terreus*: (A-B) Culture plate, front and reverse, (C-D) Conidiophore, vesical, Phialides and conidia.

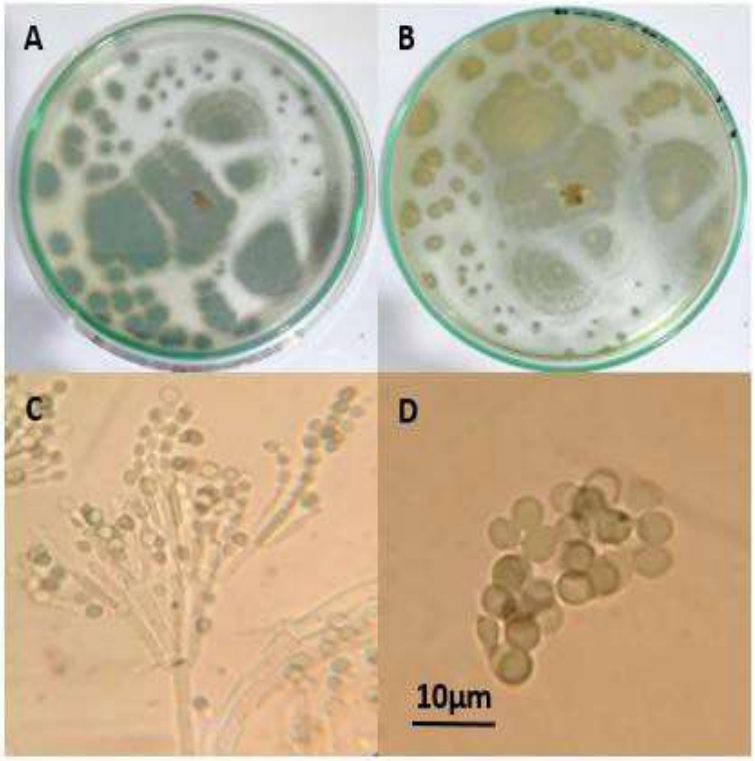


Figure 6: *Penicillium chrysogenum*: (A-B) Culture plate Front and reverse, (C) Conidiophore, metulae, Phialides, (C) Conidia.

***Penicillium citrinum***

The colony exhibits a creamy to dull yellow-green color, with an uncolored or dull yellow reverse side. It reaches a diameter of 5.1 cm within a span of 5 days. The conidiophores are smooth, erect, and branched at the apex, forming divergent metulae. The terminal phialides are flask-shaped, measure 12-14 µm in length. The conidia are smooth and have a globose or obvoid shape, with a diameter ranging from 2-3 µm (Figure 7 A-D).

***Rhizopus stolonifer***

The colony initially exhibits a white hue, gradually transitioning to shades of grey and eventually black. It displays a rapid growth pattern, covering a diameter of 5.7 cm within a span of 2 days. Well-developed rhizoids, characterized by their branching nature and dark brown coloration, measure between 4-15 µm in length. Sporangiophores emerge individually or in clusters from stolons positioned opposite to the rhizoids. The sporangia, possessing a spherical shape, appear black and exhibit an erect orientation. They are further characterized by apophyses, a well-developed columella, encrusted walls, and rapid deliquescence. Ranging from 40-210 µm in diameter, the columellae of the sporangia are globose or ovoid in shape. The sporangiospores, irregularly oval in morphology, showcase a light yellow coloration and distinct, prominent ridges. Additionally, there are observations of abnormal spores alongside these regular spores, measuring approximately 7-9 µm in size. chlamydospores, however, were not detected in the examined samples (Figure 8 A-D).

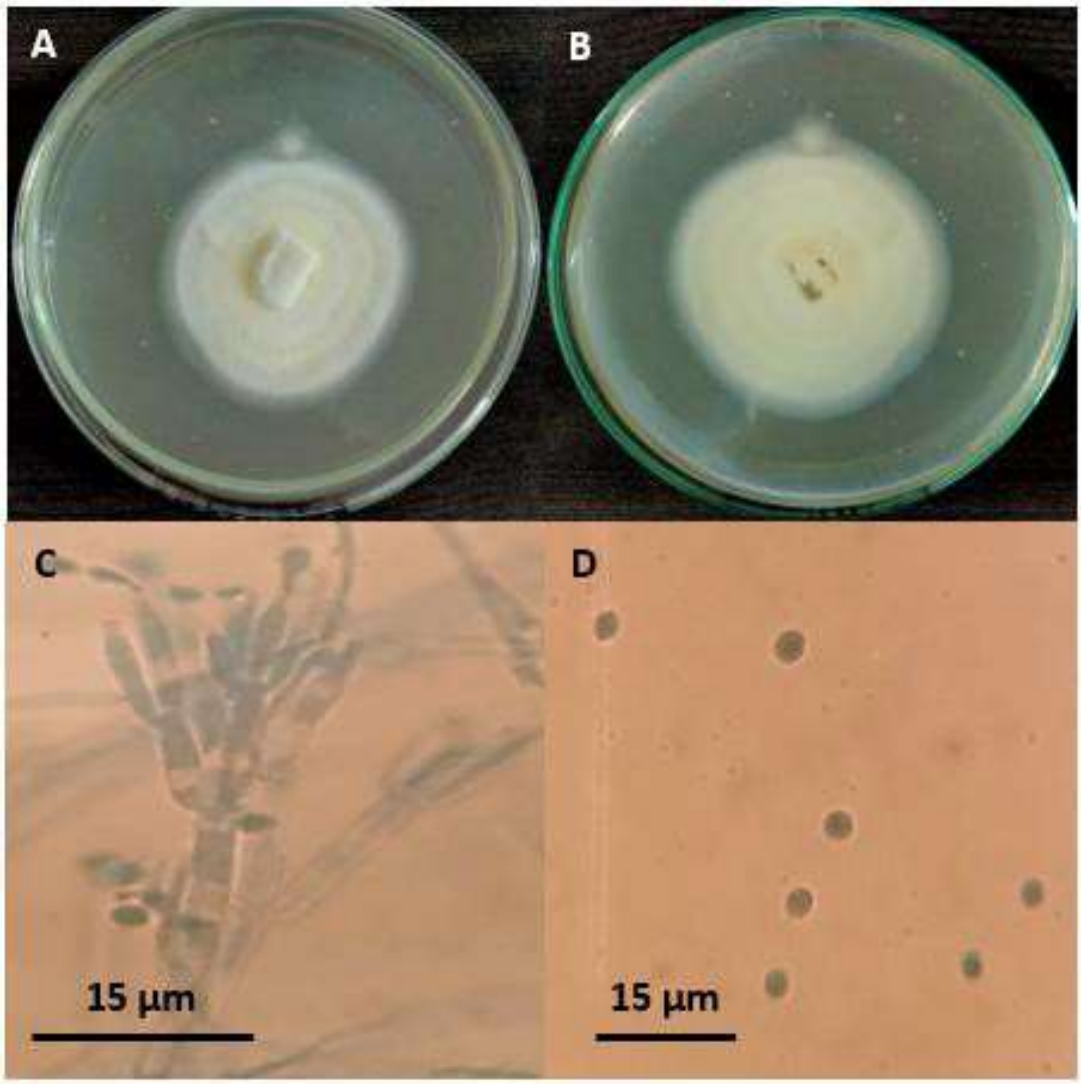


Figure 7: *Penicillium citrinum*: (A-B) Culture Plate, Front and reverse, (C) Conidiophore, phialide, (D) Conidia.

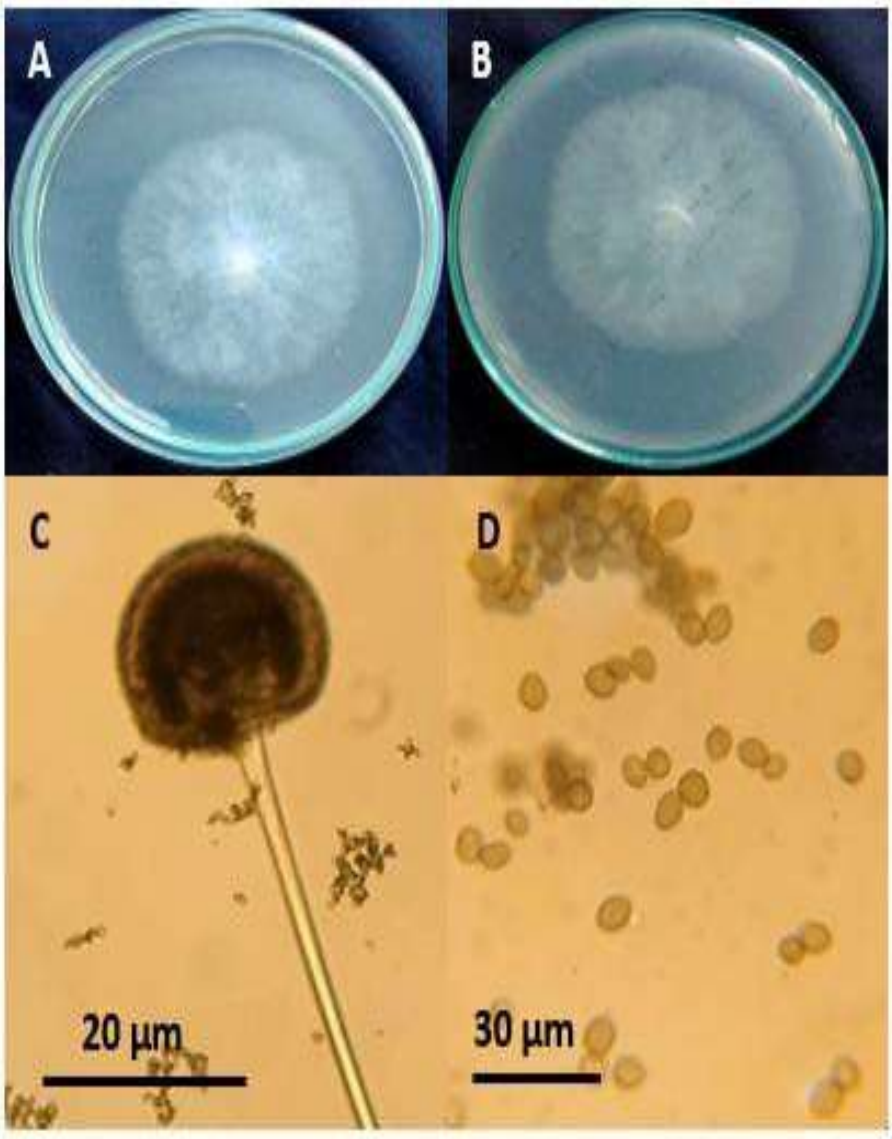


Figure 8: *Rhizopus stolonifer*: (A-B) Culture plate, front and reverse, (C) Sporangiophore with sporangium, (D) conidia.

***Trichoderma aureoviride***

The colony exhibits a green color and displays rapid growth on PDA, reaching a diameter of 7.1 cm in 6 days. It shows distinct zonation, while reverse side appears creamy to light green. The mycelium is hyaline and possesses a smooth wall. Abundant conidia and conidiophores are produced. The conidiophores are branched in structure. The phialides are bottle-shaped and cylindrical, measuring 7-10×2-3 µm. The conidia are olivaceous green with a truncated base, ellipsoidal in shape, and have a diameter of 4-5×2-3 µm (Figure 9A-D).

***Trichoderma gamsii***

The colony exhibits rapid growth on PDA, reaching a diameter of 8 cm within 3 days at a temperature of 30-35°C. Initially, the colony color is whitish green, which gradually transitions into a dark green hue. The reverse side of the colony appears whitish green. The mycelium is hyaline in color. The conidiophores are simply branched and measure approximately 3 µm in width.

The phialides are solitary and flask-shaped, with dimensions of 6-11 × 3 µm. Conidia, produced abundantly in a dense mass, are green in color. They are smooth, ovoid, and globose in shape, with a diameter of approximately 3 µm. Additionally, the presence of globose and intercalary chlamydospores is observed (Figure 10 A-D).

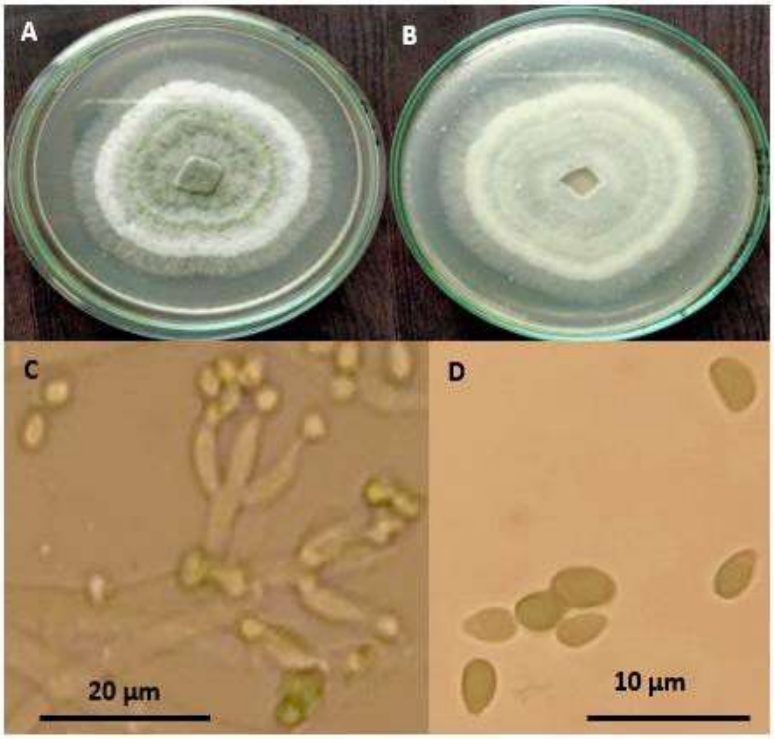


Figure 9: *Trichoderma aureoviride*: (A-B) Culture plate, front and reverse, Arrangement of conidiophore, phialides, phialospores Conidia.

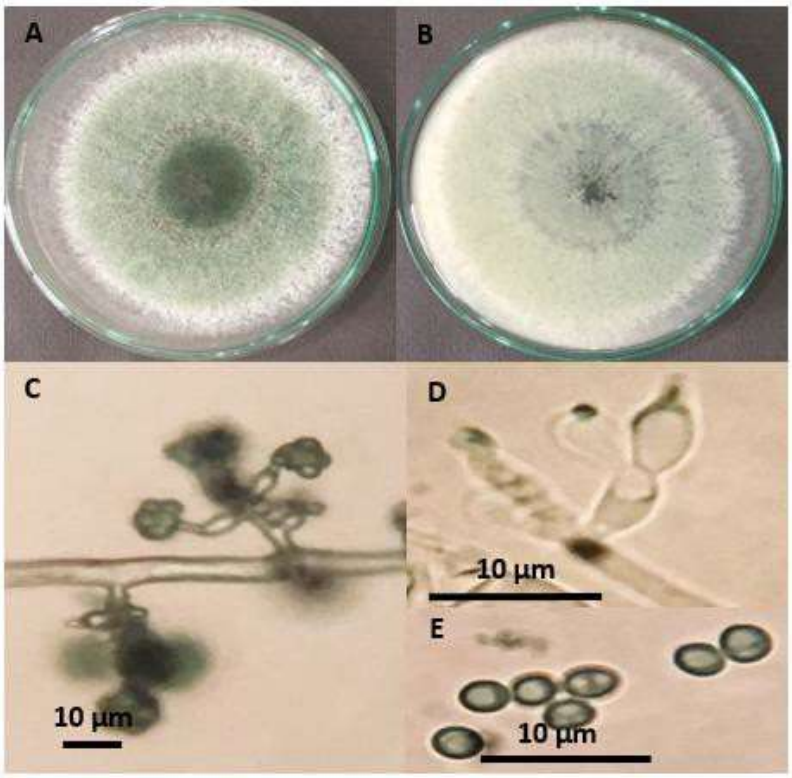


Figure 10: *Trichoderma gamsii*: (A-B) Culture Plate, front and reverse, (C-D) Arrangement of conidiophore, phialides, phialospores, Conidia.

**DISCUSSION**

Infectious plant diseases have been around since human agriculture began. It is impossible to overstate the importance of plant diseases to human progress and well-being. Millions of Irish people perished or were driven from their homes as a result of the famine brought on by the late blight of potatoes brought on by *Phytophthora infestans*. Climate change due to global warming has made plant diseases more severe and more widespread in recent years, making them serious concerns to food security. Therefore, it is crucial for the long-term viability of agriculture to identify and monitor plant diseases (Abbas et al., 2018). Several types of beneficial and harmful fungal species were identified in this investigation from three districts in GB, Pakistan. In terms of fungal genera, *Trichoderma* spp., *Aspergillus* spp., and *Penicillium* spp. were the most common. These genera are widespread across the potato farms of three districts.

The connection between potatoes and the *Trichoderma* spp. has been the subject of much research. Various *Trichoderma* spp. have been shown to have both helpful and harmful impacts on potato plants. Mycoparasitism and the generation of antifungal chemicals are two ways by which certain strains of *Trichoderma* have shown effective as a biocontrol agent against a wide range of potato diseases, including late blight and early blight. Root extension, nutrient absorption, and stress resistance are all areas where *Trichoderma* has been shown to benefit potato growth and development (Abbas et al., 2022).

*Aspergillus*, *Penicillium*, and *Rhizopus* are fungal genera that can be associated with potatoes. *Aspergillus* species are commonly found in the environment and can occasionally contaminate stored potatoes, leading to post-harvest spoilage. Certain *Aspergillus* spp. produce mycotoxins, such as aflatoxins, which pose a health risk if consumed. *Penicillium* spp. are also frequently encountered in potato storage facilities and can cause decay and rot, affecting the quality and shelf life of potatoes (Barnett and Hunter, 1972; Bhutta et al., 2004; Arora et al., 2012; Birch et al., 2012; Chakraborty, 2016; Chen et al., 2017). However, not all *Penicillium* species are detrimental; some can contribute to the ripening and flavor development of certain potato products. *Rhizopus*, another fungal genus, is known to cause soft rot in potatoes. These fungi thrive in warm and humid conditions, making proper storage and handling crucial to minimize their presence and prevent spoilage. Implementing appropriate storage practices and monitoring for fungal growth can help mitigate the risks associated with *Aspergillus*, *Penicillium*, and *Rhizopus* contamination in potato storage and processing (Dewan and Sivasithamparam, 1988; Daami-Remadi et al., 2012; Da Silva et al., 2016). In our study, we could not detect *Trichoderma aureoviride* in Nagar district while *Penicillium chrysogenum* in Hunza district. The cool and dry climate of Gilgit is generally favorable for the development and proliferation of these fungi. However, it is important to note that while some fungal pathogens may be less prevalent in the region, other fungi, including storage fungi, can still pose a risk to potatoes. Storage fungi, such as species of *Aspergillus* and *Penicillium*, can contaminate potatoes during storage, especially if there are moisture-related issues or inadequate storage conditions. These fungi can cause post-harvest rot and spoilage in stored potatoes (Ahmad et al., 1995; Ahmad et al., 1997; Ahmad, 1998; Agrios, 2005; Agrawal and Kotasthane, 2012; Anwar et al., 2015, 2019). To mitigate the risk of fungal contamination and spoilage, proper storage practices should be followed, including ensuring good ventilation, maintaining appropriate temperature and humidity levels, and regularly inspecting stored potatoes for any signs of fungal growth. Additionally, maintaining proper hygiene and handling practices throughout the potato production and storage chain can help minimize the impact of fungi on potato quality and storage longevity. For more specific information and data on the weather patterns and fungal associations with potatoes in Gilgit, we recommend consulting local agricultural research institutes, extension services, or scientific publications focusing on potato cultivation in the Gilgit region.

**CONCLUSION**

In conclusion, this study highlights the importance of investigating plant pathogenic and beneficial fungi associated with potato crops in Gilgit Baltistan, Pakistan. The presence of both harmful and beneficial fungi in potato-growing areas underscores the need for comprehensive research to understand their incidence, coexistence, and potential impact on potato cultivation. The identification of eight fungal species, including pathogenic fungi like *Aspergillus* spp. and *Rhizopus* spp., as well as the beneficial *Trichoderma* spp. provides valuable insights into the fungal dynamics in the region.

This research contributes to the knowledge base for effective disease management and emphasizes the significance of considering beneficial fungi like *Trichoderma* spp. in sustainable potato production practices.

## LIMITATIONS

However, it is important to acknowledge the limitations of this study. The scope of the study was limited to three districts in GB, and the findings may not be directly generalizable to other GB districts. Additionally, the investigation relied on morphological identification techniques, which may have limitations in accurately distinguishing between closely related fungal species. Further research incorporating molecular techniques and larger sampling sizes would provide more comprehensive insights into the diversity and dynamics of fungi associated with potatoes in Gilgit Baltistan.

## FUTURE PERSPECTIVES

Moving forward, future research should consider expanding the geographic scope to encompass a broader range of potato-growing areas in GB. Incorporating molecular techniques, such as DNA sequencing, would enable more precise identification of fungal species and provide a deeper understanding of their genetic diversity and population dynamics. Long-term monitoring of fungal populations in relation to changing climatic conditions, including temperature and rainfall patterns, is also crucial to assess the impact of climate change on fungal diseases affecting potato crops. Moreover, exploring the potential for harnessing beneficial fungi like *Trichoderma* for biocontrol purposes could contribute to sustainable disease management strategies. Overall, continued research efforts are necessary to improve disease management practices, enhance potato crop productivity, and ensure the long-term sustainability of potato cultivation in GB.

## AUTHORS' CONTRIBUTIONS

RA designed the study, identified the fungi, wrote the original draft, prepared figures of fungi collected the literature; AA co-supervised the research, assisted in preparation of figures, validated the data, critically revised and finalized the manuscript; SS supervised research and provided technical support; MH provided technical support; All the authors have read and agreed to the published version of the manuscript. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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