International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 05 Issue: 04 | April – 2026 DOI:10.55041/ISJEM06882
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Climate-Induced Spread of Plant Pathogens and its Impact on Agriculture in the Kumaun Himalayas: A Threat to Food Security and Rural Livelihood

Zoya Shah[1]*, Dhani Arya[2]

[1,2] Department of Botany, Soban Singh Jeena University, Almora, Uttarakhand, India-263601

Abstract

Background:

Plant pathogens are expanding into new areas as a result of climate change and are consequently threatening crop production and the related rural living conditions. In the Indian Himalayas, the vertical migration of fungi has hardly been studied which is otherwise important for food security.

Methods:

We combine historical climate data (1985–2020), field sampling, lab-based pathogen isolation and farmer perception surveys to estimate the role of climate variability on pathogen dynamics in the Kumaun Himalayas. A total of 1,000 infected leaf samples and 30 fruit samples were collected from 11 economically important crop species. Pathogens were further identified through scotch tape imprinting, pure culture method, and morphological taxonomy. Climate trends were compared with disease incidence through statistical correlation analyses.

Results:

A total of 35 fungal species from 18 genera were identified, and *Alternaria alternata*, *Fusarium oxysporum*, and *Cercospora canescens* were three of the most obvious fungi that have migrated to the higher altitudes. Climatic assessment showed that both the minimum temperature rise (e.g., September, Z=0.553) and relative humidity increase (e.g., July, Z=0.676) were statistically significant, which facilitated pathogen propagation. These patterns were supported by the farmer surveys, reporting higher disease incidence and a change in disease zones.

Conclusion:

This investigation offers an empirical demonstration of climate-driven pathogen movement in a vulnerable montane ecosystem. The results illustrate the imperative for comprehensive climate-resilient agricultural interventions which include monitoring systems, disease resistant crops and farmer-led adaptation planning.

Keywords: Climate change, Fungal pathogens, Kumaun Himalaya, Altitudinal migration, Agricultural disease dynamics.

Introduction

The changes in plant disease patterns due to climate change are among the well-recognized negative aspects, more so in ecologically sensitive areas like Himalayas. Changes in temperature, humidity, and the pattern of precipitation have expedited the emergence and spread of plant pathogens through alteration of host pathogen relationship, extension of growing season, and spread of pathogens into previously uninhabitable ecosystems. [1, 2, 3]

Indian agriculture is especially vulnerable to such climate-induced perturbations. Estimates indicate significant decreases in staple cereal crops wheat, maize, and rice, in particular—as a result of increased temperatures and irregular precipitation patterns. [4, 5] These stresses, in the context of climate change, are exacerbated by the appearance of plant diseases, which are posing a challenge to the national food security and the livelihoods of millions of subsistence farmers.[6]

Mountain landscapes, both in the Western and the Eastern Himalayas, are experiencing disproportionately higher adversities of climate variability. Research in the Indian Himalaya has found changing minimum temperatures, changed snowfall patterns, and inconsistent monsoonal falls- all of which are likely to affect pathogen survival and dispersal.[7, 8] Presence of pests and fungal pathogens at higher elevations in the Central and Eastern Himalayas pose a threat of spread and emergence of common outbreaks in areas free from the diseases in the prior history.[9,10] In the face of an increasing alarm, empirical substantiation concerning the relationship between climate trends in the Western Himalaya, specifically the Kumaun region of Uttarakhand (India), and plant disease dynamics is lacking. Local Farming communities in this locality are experiencing high incidences of leaf spots, wilting, blights of some long-standing disease-resistant crops like potatoes, beans, and cabbage. But these observations are few and not well documented or scientifically proven.

This gap is unrealistic, and this study was conducted to synthesize historical climate, field pathogen sampling, and laboratory process to farmer perception. Precisely the aims will be: (i) to detect the pathogenic fungi related to economically important crops; (ii) to evaluate their, altitudinal, and temporal occurrence under increasing climatic variability; and (iii) to evaluate the climatic drivers and associations with the disease intensity. The findings are intended to support evidence-based disease management strategies and policy interventions aimed at improving agricultural resilience in mountain regions.

Materials and Methods

Study Area

The Mukteshwar subregion of Nainital district in the Kumaun Himalaya (29.47°N, 79.64°E; elevation 2170 m) was selected as the study area. It includes a wide range of agroecological zones from the subtropical foothills to the near subalpine belts. The local economy is predominantly based on agriculture which includes vegetable and cash-crop farming. This gradient enabled us to analyze climate–pathogen interactions.

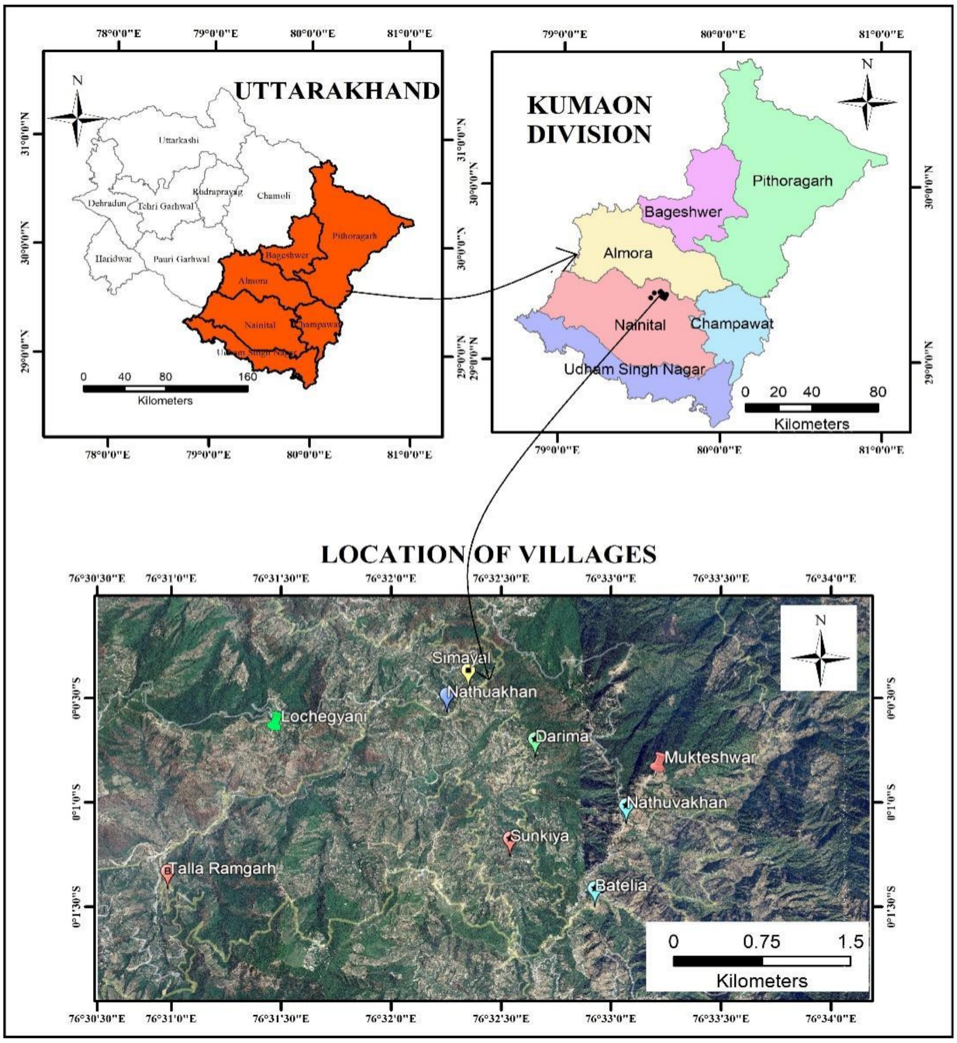


Fig 1: Intensive Study area

Farmer Survey

Around 100 farmers from nine purposefully sampled villages were surveyed using a structured questionnaire. Farmers aged over 20 with two decades of farming experience were aggregated through local leaders and agricultural extension officers. Surveys assessed perceptions of crop disease trends and climate variability over a long period of time. Instruments underwent pilot-testing for clarity before being translated into the local dialect. All participants gave verbal informed consent prior to enrolling in the study.

Sample Collection and Pathogen Isolation

During field surveys conducted from 2019 to 2022, more than 1,000 symptomatic leaves and 30 fruits from 11 cash-crop species were collected. Each sample was collected in sterile plastic bags, appropriately labeled, and was processed within a 48hr window. Fungal isolation techniques were carried out through two complementary means.

•Adhesive tape method: Clear tape was placed over the lesions, then the tape was put on slides and stained with lactophenol cotton blue for microscopic analysis.

•Tissue culturing: Tissue fragments were surface sterilized and then cultured in PDA which was enriched with 100 µg/mL streptomycin. Distinct colonies developed from the subcultured isolates.

Pathogen Identification

Fungi were identified based on their morphological characteristics and culture features under light microscopy (100–400× magnification). Identification was done using standard taxonomic references and general mycological keys.[11,12,13] Validation of species names was done on MycoBank and Index Fungorum.

Climatic Data and Statistical Analysis

Data regarding climate from 1985 to the year 2020 including temperature, precipitation, and relative humidity were obtained from the India Meteorological Department and the NASA POWER database. Trends were studied using the Mann–Kendall test and Theil–Sen slope estimator. To evaluate associations between climate variables and disease incidence, significance of the Pearson’s correlation coefficient (r) was calculated. All analyses were done in R version 4.2.1 and the level of significance utilized was $\alpha = 0.05$.

Results

Although there is increasing international concern regarding how climate change is affecting the distribution of plant pathogens, documented evidence in the context of high-altitude ecosystems is lacking. This research provides a detailed and field-oriented analysis of fungal pathogen spread along successional ranges in the Kumaun Himalayas. Our findings argue that climate change is impacting disease dynamics in this sensitive ecological zone and important agricultural interface region by integrating longitudinal climatic trend assessments, on-farm pathogen class identification, and farmer consultations.

Fungal Pathogen Distribution Changes with Altitude

Several upward movements were noted during the survey period relative to between 2019 and 2022. Some fungal pathogens that had previously been restricted to lower altitudes also showed upslope movements. The path of these increasing increments in pathogen reach ranges is listed below:

•*Alternaria alternata*: This pathogen was detected in Mukteshwar at approximately 2170m, indicating an elevation gain of nearly 670m. Formerly restricted to elevations below 1500m, this pathogen was found in 2170 Mukteshwar.

•*Fusarium oxysporum*: This species was found between 1800-2200m in current surveys. Previously dominant at lower altitudes, this species suggests an upward migration of 300-500m.

•*Cercospora canescens*: This pathogen was identified at elevations up to 2100m, a shift of about 500m, typically found below 1600m.

Such altiudinal migrations are in parallel with more broad patterns detected in the flora of the Himalayas, where ranging species expand upward by an average of 27.5 meters per decade, some species changing almost 1000 meters over a century. An increase in the upper elevation pathogen shifts is likely linked to greater temperatures and relative humidity, which is more favorable for the growth and reproduction of the pathogen.

Climate Change and Its Relation to Disease

Examination of meteorological records from 1985 to 2020 indicates that the Mukteshwar region has undergone several notable climatic changes. Minimum temperatures in September showed a statistically significant increase ($Z = 0.553$, $p < 0.0001$), alongside an increase in relative humidity for July ($Z = 0.676$, $p = 0.000$). Annual precipitation also changed positively, showing an increase ($Z = 0.250$, $p = 0.044$), signaling the onset of wetter climatic conditions. **(Table 1–3)**.

Strong correlations were found within the climatic parameters themselves and the incidence of disease in economically important cash crops, using the Pearson correlation method. Higher levels of humidity in monsoon months, with increased minimum temperatures in the post-monsoon season were strongly linked to higher disease levels in potato, cabbage, and kidney bean crops.

Interpretation

Shifts in climate may be exacerbating the distribution and intensity of fungal diseases in the high-altitude farming regions. Increased relative humidity promotes formation of spores and lengthens infection period which enhances *A. alternata* and *C. canescens* infection. In a like manner, warmer minimum temperatures may enable the pathogens to survive and remain active for longer periods. This evidence strengthens the argument that changes of climate trends are a primary focus when creating decision frameworks for Himalayan agriculture.

Statistical Correlation Between Climatic Variables and Disease Incidence

In order to better understand the interaction between climatic elements and prevalence of disease, seasons from climatic variables were correlated with the incidence rates of major fungal pathogens in potatoes and kidney beans using Pearson correlation analyses. Results are summarized in. **(Table 4)**

The hypotheses tested gave the following statistically significant correlations:

•There is a strong positive relationship between July potato *A. alternata* incidence and humidity ($r = 0.72$, $p = 0.003$).

•A moderate positive correlation exists between temperature in June and kidney bean *F. oxysporum* ($r = 0.58$, $p = 0.014$).

•There is a strong positive correlation between May rainfall and *C. canescens* incidence in potatoes ($r = 0.65$, $p = 0.007$).

Specific climatic variables have a strong influence on the key fungal pathogens seasonal dynamics and spread in the Kumaun Himalayas, as indicated by the findings. Those correlations are vital in foreseeing disease risk and in developing mitigative approaches in climate sensitive agroecosystems.

Discussion

This is the first time we observe in the Kumaun Himalayas the excessive modulation of fungal pathogens distribution towards higher altitude levels and this is most likely due to the overall temperature and humidity increases. This aligns with the global observation that climate change is increasingly being associated with the redistribution and increase in the severity of plant pathogens. As an example, Luck et al.[14] discusses how increased temperatures and CO_2 levels are likely to make necrotrophic pathogens more aggressive and worsen crop diseases. In the same vein Kumar and Mukhopadhyay[15] pointed out that in India climate change aggravates the relations between plants and pathogens by altering the life cycles of the pathogens and the vulnerability of the hosts. In the Indian situation, pathogens that have hitherto been considered as of secondary importance are now becoming a real challenge due to weather changes. For instance, there is a banded leaf and sheath blight in maize that has become very common in the Himalayan foothills driven by high temperatures and high humidity. [16]

Also, we found that farmers have their own views of a region's climate that do not necessarily align with observed meteorological figures. For instance, farmers reported declining rainfall and snowfall, but data indicates mixed values.

This demonstrates the gap that exists between integrating local perspective and scientific evidence which is essential in developing meaningful adaptation plans. Similar Chaudhary and Bawa[17] reported in the Central Himalayas where farmers had their set perception which does not correspond with what is recorded, nevertheless, their perception adaptive capacity was crucial for adaptation.

Similar patterns were also noted in the Kumaun Himalayas which resonates with other regions. Singh et al. [18] reported in the Eastern Himalayas that pests and diseases relocated to higher altitudes, and attributed this with shifts in climate parameter. In parallel, Sharma and Gupta[19] cited on an increase of fungal infection in apple orchards for Himachal Pradesh in association with rising temperature. Khan et al.[20] reported in the Western Ghats an increase in coffee plantation fungal diseases related to climate variability. *Aspergillus* species are also recognized as a growing concern worldwide due to their proliferation in certain new areas attributed to climatic warming. Romero-Olivares et al.[21] warned of a great increase of aspergillosis in Europe and Asia arguing has high prospects for climate-derived infection.

The increase in plant pathogens in Kumaun Himalayas creates big risks to food safety and hinder rural economies. Farmers are experiencing lower yields while increasing reliance on fungicides which is economically straining for them. This is not the case for just the particular region alone. In India, government schemes have concentrated on attempting to offset the impacts of climate change on agriculture through developing climate resilient seed varieties.[22] However, there remain issues concerning distribution and accessibility, education among farmers, and affordability. Apart from these changes, managing plant diseases with climate change impacts on plant immune systems further complicates the issue. Kim JH. et al[23] showed that higher temperatures pose a risk to defend the crop against pathogens and therefore weaken the immune system of the crops. This factor increases the importance of developing Integrated Pest Management (IPM) strategies alongside breeding programs aimed at developing more resilient plants.

Limitations

Although our research contributes to understanding important issues, there are set limitations. First, identifying plant pathogens were based mostly on visible morphology which cannot discriminate closely related species. With the introduction of molecular techniques like DNA barcoding, the identification of plant pathogens can be refined. Second, direct reliance on farmers' perception brings an undue burden of bias, as their perception is likely to be altered by the recency of certain events or social values. Such data need to be aligned with meteorological data and disease occurrence for extensive periods of time in order to validate the claims.

Conclusion

This study links climatic variability with the altitudinal dispersal of fungal pathogens on major crops in the Kumaun Himalayas. Intenser minimum temperature and relative humidity at higher altitudes have aided in the growth of pathogens like *Alternaria alternata*, *Fusarium oxysporum*, and *Cercospora canescens*. These changes in the evironmental conditions of the region will severely impact the food security of the agriculture and economy dependent minor farmers of the region. The integration of meteorological data, field sampling, lab identification, farmer surveys provide strong proof of the impact of climate change on crop disease dynamics in this fragile mountain ecosystem. Differences between local understanding and the scientific knowledge observation change highlights the need for new conduits of information and educational programmes. The mountain regions demand the immediate attention focused on building flexible agricultural policy frameworks for advanced climate responsive shifts responsive or sensitive high altitude farming systems policies.

Recommendations

1. Longitudinal Monitoring: Implement permanent monitoring stations within mountain agroecosystems to track long-term pathogen dynamics and their connection to climate variables.

2. Advanced Diagnostic Tools: Utilize molecular and genomic methods for precise identification and phylogenetic analysis of fungal pathogens to address the challenges of morphological classification.

3. **Climate-resilient crops:** Climate-resilient crops and crop varieties should be recommended as a way for farmers to cope with or adapt to climate change.

5. Integrated Disease Surveillance: Improve local disease surveillance systems by combining scientific research with farmer-reported data to enable early detection and swift action.

6. Farmer Education and Skill Development: Create and implement training programs for farmers on integrated disease management, climate-smart agricultural practices, and the analysis of climatic patterns.

7. Policy Support and Resource Distribution: Advocate for increased investment in agricultural research and rural infrastructure to enable adaptive measures. Collaborative efforts among research institutions, government bodies, and local communities are essential for building resilient agri-food systems.

References

1. Garrett KA, Dendy SP, Frank EE, Rouse MN, Travers SE. Climate change effects on plant disease: genomes to ecosystems. Annu Rev Phytopathol. 2006; 44:489–509.
2. Bebber DP, Ramotowski MAT, Gurr SJ. Crop pests and pathogens move polewards in a warming world. Nat Clim Chang. 2013;3(11):985–8.
3. Anderson PK, Cunningham AA, Patel NG, Morales FJ, Epstein PR, Daszak P. Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. Trends Ecol Evol. 2004;19(10):535–44.
4. Krishnan R, Sanjay J, Gnanaseelan C, Mujumdar M, Kulkarni A, Chakraborty S, et al. Assessment of climate change over the Indian region: A report of the Ministry of Earth Sciences (MoES), Government of India. New Delhi: Springer Nature; 2020.
5. Iqbal MA, Pingale SM. Impact of climate change on crop productivity in India: A review. J Earth Syst Sci. 2021;130(5):1–14.
6. Chaloner TM, Gurr SJ, Bebber DP. Plant pathogen infection risk tracks global crop yields under climate change. Nat Clim Chang. 2021;11(8):710–5.
7. Bhutiyani MR, Kale VS, Pawar NJ. Climate change and the precipitation variations in the northwestern Himalaya: 1866–2006. Int J Climatol. 2010;30(4):535–48.
8. Dimri AP, Thayyen RJ, Kumar P, Agnihotri G, Satyal G, Singh R. The western Himalayan climate system: Present and past. Earth Sci Rev. 2019;190:436–67.
9. Singh B, Singh A, Dhyani PP. Climate change and its impact on Himalayan agriculture. Indian J Agric Sci. 2018;88(5):731–40.
10. Sharma S, Gupta N. Climatic variability and its impact on apple production in Himachal Pradesh. Environ Dev Sustain. 2017;19(5):1989–2001.
11. Simmons EG. Alternaria: An Identification Manual. Utrecht: CBS Fungal Biodiversity Centre; 2007.
12. Leslie JF, Summerell BA. The Fusarium Laboratory Manual. Ames (IA): Blackwell Publishing; 2006.
13. Watanabe T. Pictorial Atlas of Soil and Seed Fungi. 3rd ed. Boca Raton (FL): CRC Press; 2010.
14. Luck J, Spackman M, Freeman A, et al. Climate change and diseases of food crops. *Plant Pathol*. 2011;60(1):113–121.
15. Kumar R, Mukhopadhyay S. Climate change and plant–pathogen interactions in India: a review. *Indian Phytopathol*. 2024;77(2):123–130.
16. Haque M, Singh R, Verma P. Emergence of banded leaf and sheath blight in maize under changing climate in the Himalayan foothills. *J Plant Dis Prot*. 2022;129(4):345–352.
17. Chaudhary P, Bawa KS. Local perceptions of climate change validated by scientific evidence in the Himalayas. *Biol Lett*. 2011;7(5):767–770.
18. Singh A, Das S, Roy M. Altitudinal migration of pests and diseases in Eastern Himalayas: a climate change perspective. *Environ Monit Assess*. 2018;190(3):1–10.
19. Sharma V, Gupta R. Rising temperatures and fungal infections in apple orchards of Himachal Pradesh. *Indian J Hortic*. 2017;74(1):56–60.
20. Khan M, Joseph B, Thomas G. Climatic variability and the surge of fungal diseases in coffee plantations of the Western Ghats. *Agrofor Syst*. 2019;93(2):567–576.

21.Romero-Olivares, A.L., Lopez, A., Catalan-Dibene, J., Ferrenberg, S., Jordan, S.E., & Osborne, B. (2024). *Effects of global change drivers on the expression of pathogenicity and stress genes in dryland soil fungi*. *mSphere*, 9(11), e00658-24
22.AP News. India develops climate-resilient seed varieties to combat agricultural challenges. *AP News*. 2024 May 10.
23.Kim JH, et al. "Increasing the resilience of plant immunity to a warming climate." *Nature*. 2022;607(7918):339–344.

Acknowledgements

The local farming communities in the Ramgarh provided invaluable insights and cooperation for the field surveys, for which the author is extremely grateful. For providing lab space and academic support during the study, I am deeply grateful to the Department of Botany at Kumaun University in Almora.

Declaration
Ethics Clearance and Participation Consent: There were no human or animal participants in this study. Consequently, ethical clearance was not necessary.
Permission to Publicize: Not relevant because neither patient data nor human subjects were used in the study.
Conflict of Interest: Regarding this work, the authors disclose no conflicts of interest.
Funding No particular grant from a public, private, or nonprofit organization was obtained for this study.

Table1. Trend analysis of monthly, annual and seasonally Rainfall

Period	MK Z-Value	*p*-Value	Sen's Slope	Trend
January	0.036	0.77	0.072	No significant trend
February	–0.032	0.795	–0.161	No significant trend
March	0.071	0.57	0.373	No significant trend
April	0.085	0.496	0.377	No significant trend
May	0.107	0.39	0.713	No significant trend
June	0.069	0.581	1.195	No significant trend
July	0.149	0.23	2.651	No significant trend
August	0.024	0.846	0.579	No significant trend
September	0.028	0.82	0.391	No significant trend
October	0.049	0.695	0.031	No significant trend
November	–0.057	0.658	0	No significant trend
December	0.043	0.732	0.029	No significant trend
Annual	**0.25**	**0.044***	**13.213**	**Significant increase**
Summer	0.169	0.173	4.309	No significant trend

Monsoon	0.177	0.154	5.847	No significant trend
Post-monsoon	0.032	0.795	0.114	No significant trend
Winter	–0.032	0.795	–0.333	No significant trend

Note: MK = Mann–Kendall trend test; Sen's slope = rate of change per year;
Significance: *p < 0.05

Table 2. Trend analysis of monthly, annual and seasonally maximum and minimum Temperature

Month	**Max Temp MK Z**	***p***	**Sen's Slope**	**Trend (Max Temp)**	**Min Temp MK Z**	***p***	**Sen's Slope**	**Trend (Min Temp)**
January	–0.022	0.858	–0.008	No significant trend	–0.061	0.626	–0.018	No significant trend
February	0.032	0.795	0.007	No significant trend	0.12	0.338	0.036	No significant trend
March	**0.257**	**0.039***	**0.105**	**Significant increase**	0.073	0.559	0.037	No significant trend
April	0.049	0.697	0.02	No significant trend	0.1	0.426	0.026	No significant trend
May	0.19	0.127	0.06	No significant trend	**0.468**	**<0.001***	**0.082**	**Significant increase**
June	0.043	0.733	0.011	No significant trend	**0.465**	**<0.001***	**0.097**	**Significant increase**
July	0.073	0.559	0.02	No significant trend	**0.435**	**0.001***	**0.082**	**Significant increase**
August	0.092	0.465	0.017	No significant trend	**0.482**	**<0.001***	**0.086**	**Significant increase**
September	0.154	0.217	0.032	No significant trend	**0.553**	**<0.0001***	**0.093**	**Significant increase**
October	0.087	0.485	0.019	No significant trend	0.128	0.306	0.023	No significant trend
November	0.198	0.115	0.058	No significant trend	0.16	0.2	0.043	No significant trend

December	0.154	0.218	0.05	No significant trend	0.067	0.592	0.024	No significant trend

*Significance: *$p < 0.05$, **$p < 0.01$, **$p < 0.001$

Table 3. Trend analysis of monthly, annual and seasonally maximum and minimum relative humidity

Month	**Max RH MK Z**	***p***	**Sen's Slope**	**Trend (Max RH)**	**Min RH MK Z**	***p***	**Sen's Slope**	**Trend (Min RH)**
January	0.352	0.167	0.211	No significant trend	0.089	0.476	0.107	No significant trend
February	0.39	0.142	0.193	No significant trend	–0.053	0.673	–0.084	No significant trend
March	0.096	0.62	0.038	No significant trend	–0.069	0.581	–0.122	No significant trend
April	0.162	0.4	0.056	No significant trend	0.139	0.263	0.221	No significant trend
May	0.276	0.151	0.097	No significant trend	0.085	0.496	0.183	No significant trend
June	0.383	0.247	0.2	No significant trend	0.17	0.173	0.34	No significant trend
July	**0.676**	**<0.001***	**0.262**	**Significant increase**	**0.366**	**0.003***	**0.245**	**Significant increase**
August	0.211	0.276	0.11	No significant trend	0.192	0.126	0.103	No significant trend
September	0.402	0.137	0.167	No significant trend	0.069	0.581	0.064	No significant trend
October	0.41	0.233	0.19	No significant trend	0.049	0.695	0.031	No significant trend
November	0.049	0.803	0.008	No significant trend	–0.133	0.284	–0.239	No significant trend
December	0.345	0.174	0.108	No significant trend	–0.121	0.33	–0.187	No significant trend

Significance: *$p < 0.01$

Table 4: Pearson Correlation Coefficients (r) and *p*-values Between Climatic Variables and Disease Incidence

Climatic Variable	**Crop**	**Pathogen (with Authority)**	**Pearson *r***	***p*-value**	**Significance**
July Humidity	*Solanum tuberosum* (Potato)	*Alternaria alternata* (Fr.) Keissl.	0.72	0.003	**
June Temperature	*Phaseolus vulgaris* (Kidney bean)	*Fusarium oxysporum* Schltdl.	0.58	0.014	*
May Rainfall	*Solanum tuberosum* (Potato)	*Cercospora canescens* Ellis & G. Martin	0.65	0.007	**

Note: r = Pearson correlation coefficient. Significance levels: $p < 0.05$ (), $p < 0.01$ (**) *

Figure 1. Representative symptoms and pathogen morphology in infected vegetable

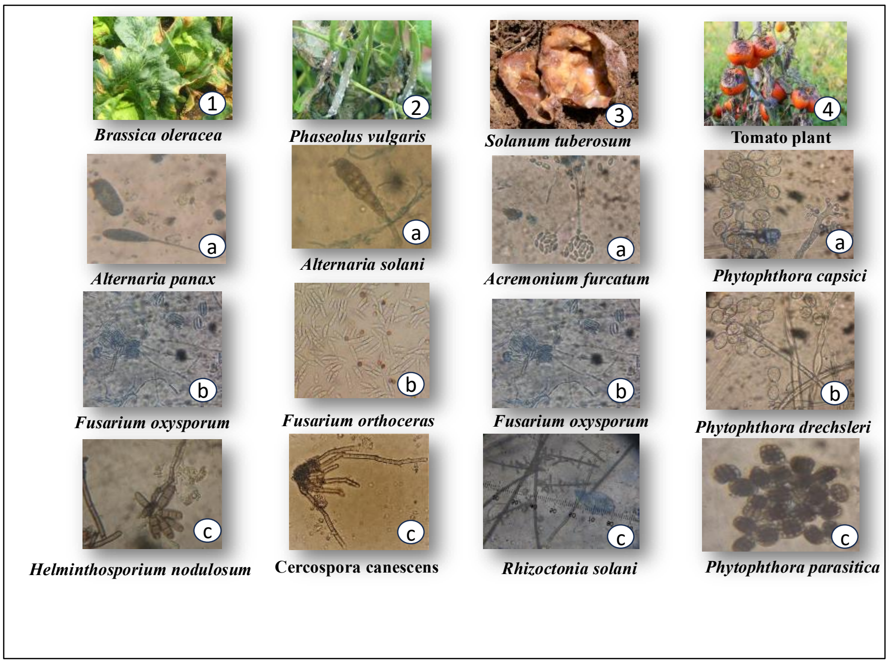


Photo plate (1)

1. Leaf blight due to (a) Alternaria panax Whetzel. (b) Fusarium oxysporum Schltdl. (c) Helminthosporium nodulosum on *Brassica oleracea* (cabbage)
2. Wilt symptoms caused by (a) Alternaria solani Sorauer. (b) Fusarium orthoceras Appel & Wollenw. (c) Cercospora canescens Ellis & G. Martin
on *Phaseolus vulgaris* (kidney bean).
3. Leaf spot caused by on (a) Acremonium furcatum W. Gams. (b) Fusarium oxysporum Schltdl. (c) Rhizoctonia solani J.G. Kuhn. on *Solanum tuberosum* (potato)
4. Early blight lesions caused by (a) Phytophthora capsici Leonian. (b) Phytophthora drechsleri Tucker. (c) Phytophthora parasitica Dastur.on *Solanum lycopersicum* (tomato).

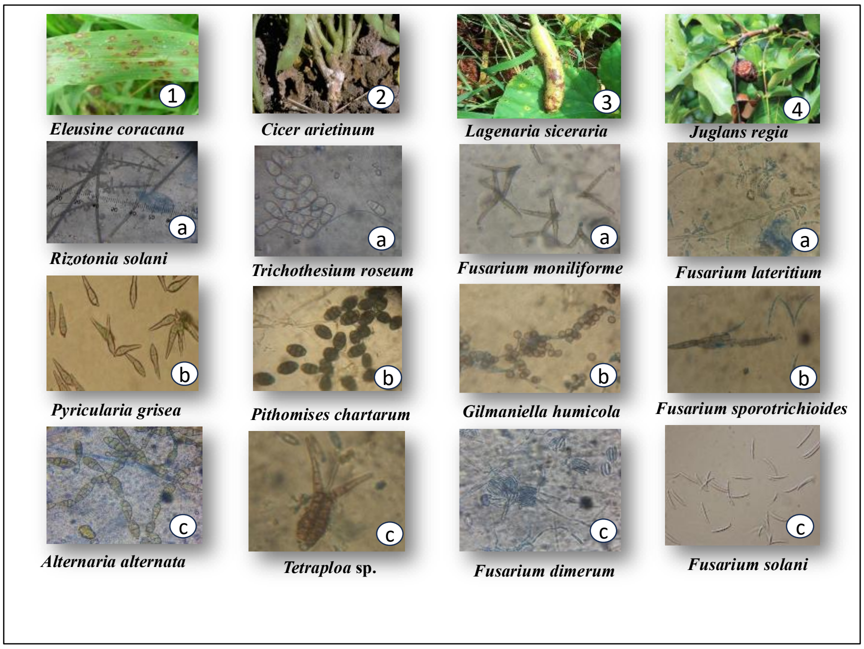
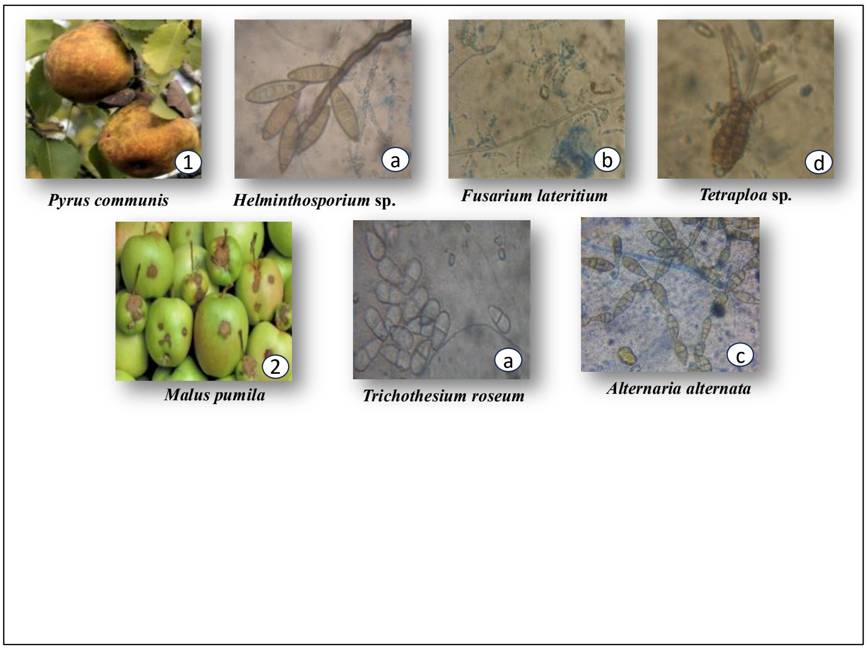


Photo plate (2)

1. Leaf spot caused by (a) Rhizoctonia solani J.G. Kuhn. (b) Pyricularia grisea Sacc. (c) Alternaria alternata (Fr.) Keissl. on *Eleusine coracana* (finger millet).
2. Blight symptoms on *Cicer arietinum* (chickpea) caused by (a) Trichothecium roseum (Pers.) Link (b) Pithomyces chartarum (Berk. & M.A. Curtis) M.B. Ellis. (c) *Tetraploa aristata* Berk. & Broome.
3. Fruit rot due to (a) Fusarium moniliforme J. Sheld. (b) Gilmaniella humicola (Oudem.) E. Mull. (c) Fusarium dimerum Penz.on *Lagenaria siceraria* (bottle gourd).
4. Anthracnose lesions caused by (a) Fusarium lateritium Nees. (b) Fusarium sporotrichioides Sherb. (c) Fusarium solani (Mart.) Sacc. on *Juglans regia* (walnut).

Figure 2. Representative symptoms and pathogen morphology in infected fruit



1. Black mold symptoms associated with (a) *Helminthosporium solani* Durieu & Mont. (b) Fusarium lateritium Nees. (c) *Tetraploa aristata* Berk. & Broome. on *Pyrus communis* Linnaeus (L.).

2. Fruit rot caused by (a) Trichothecium roseum (Pers.) Link. (b) Alternaria alternata (Fr.) Keissl. on *Malus pumilla* Borkh. (apple).

Above Photo plates are, representative images of infected crop species (top row) and their associated fungal pathogens (below). Microscopic observations were made under 40X or 100X magnification. Scale bars in each image represent 10 µm. This figure illustrates the diversity of fungal pathogens affecting economically important crops in the region and highlights the expanding host range and altitudinal spread of fungal pathogens in response to climate change and the importance of early identification for disease management and crop protection strategies.