The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(2): S.I (2), 1041-1054, 2026 www.thebioscan.com

Cultural and Morphological Variability of *Alternaria solani* Isolates Causing Early Blight of Potato in Different Agro-Climatic Zones of Western Uttar Pradesh, India

Aakanksha Kansal[1], A. N. Chaubey[1], Nitin Kumar[2*]

[1]School of Agricultural Science and Engineering, IFTM University, Moradabad, Uttar Pradesh 244102

[2]Department of Plant Pathology, Ch. Shivnath Singh Shandilya (PG) College, Machhra, Uttar Pradesh 250106, India

[*]Corresponding email: nitintyagimacchra@gmail.com

DOI: https://doi.org/10.63001/tbs.2026.v21.i02.S.I(2).pp1041-1054

KEYWORDS
Alternaria solani; early blight; potato; cultural variability; morphological variability; conidial morphology; Uttar Pradesh; agro-climatic zones

Received on:
24-04-2026
Accepted on:
11-05-2026
Published on:
22-05-2026

Abstract

Early blight caused by *Alternaria solani* (Ellis & Martin) Jones & Grout is one of the most economically significant foliar diseases of potato (*Solanum tuberosum* L.) and is widely prevalent in the potato-growing belts of Uttar Pradesh, India. Understanding the cultural and morphological variability among isolates of the pathogen is essential for devising precise disease management strategies. In the present investigation, nine isolates of *A. solani* (As1-As9) were collected during a roving survey from three agro-climatic zones of western Uttar Pradesh, namely Muradabad, Hapur, and Meerut, during Rabi 2024-25 and 2025-26. All isolates were subjected to detailed cultural and morphological characterisation on Potato Dextrose Agar (PDA) medium at 25 ± 1°C. Considerable variability was observed among isolates in colony colour, radial growth, conidial length, conidial width, and the number of transverse and longitudinal septa. Colony colour ranged from greyish white to black. Radial growth varied from 79.15 mm (As8) to 83.37 mm (As4). Conidial length ranged from 63.60 µm (As9) to 75.00 µm (As2), while conidial width ranged from 23.61 µm (As8) to 35.76 µm (As6). The number of horizontal septa ranged from 1 to 2, and the number of vertical septa ranged from 4 to 6. The findings demonstrate that *A. solani* populations in western Uttar Pradesh harbour substantial intra-specific variability, which has important implications for disease epidemiology, host resistance evaluation, and the design of integrated management programmes.

1. Introduction

Potato (*Solanum tuberosum* L.) is the world's most important non-cereal food crop and ranks fourth globally among food commodities in terms of fresh weight production (Tiwari *et al.,*2019). In India, the crop occupied 2.35 million hectares with a total production of 60.54 million tonnes and an average productivity of 25,744 kg ha^{-1} during 2022-23 (*Agriculture statistics*, 2023). Uttar Pradesh, the largest potato-producing state in the country, contributed approximately one-third of the national output, recording 694.10 thousand hectares under cultivation with a production of 20,126 thousand tonnes (*Agriculture statistics*, 2023). The agronomic importance of potato in Uttar Pradesh makes the management of its diseases a

priority concern for both plant pathologists and agricultural administrators.

Among the numerous biotic constraints affecting potato production, early blight caused by *Alternaria solani* (Ellis & Martin) Jones & Grout is consistently ranked as one of the most destructive foliar diseases worldwide (Van der Waals *et al.,*2001; Schmey *et al.,*2024). The pathogen is a necrotrophic fungus belonging to the Kingdom Fungi, Phylum Ascomycota, Class Dothideomycetes, Order Pleosporales, and Family Pleosporaceae. It was first described by Ellis and Martin in 1882 as *Macrosporium solani* and was subsequently reported from India by Butler in 1903 from Farrukhabad, Uttar Pradesh (Schmey *et al.,*2024). Early blight is particularly damaging because it progressively destroys photosynthetically active foliage during the critical tuber bulking phase, resulting in yield losses of up to 50 per cent under severe epidemic conditions (Brouwer *et al.,*2021).

Characterisation of *A. solani* populations in terms of their cultural and morphological attributes is a foundational requirement for understanding disease dynamics in any agro-climatic region. Variability within fungal populations influences colony growth rate, sporulation capacity, conidial morphometry, and aggressiveness, all of which have direct relevance to the epidemiology and management of the disease. Although *A. solani* has been described taxonomically based on its characteristic muriform, beaked conidia, the pathogen is known to show considerable intra-specific variation in cultural and morphological characters when isolates are compared from different geographical locations, host genotypes, and environmental backgrounds (Kumar *et al.,*2016; Mugao *et al.,*2023). Schmey *et al.* (2024) further noted that the *Alternaria* disease complex on potato is taxonomically broader than previously believed, making rigorous morphological characterisation of local isolates indispensable.

Despite its economic importance in Uttar Pradesh, the morphological diversity of *A. solani* isolates across the different agro-climatic zones of the state remains incompletely characterised. Earlier studies by Kumar *et al.* (2016) demonstrated meaningful cultural and physiological variability among isolates from eastern Uttar Pradesh, and Kumar and Singh (2022) extended these observations to physiological responses, including temperature and pH optima. However, equivalent data for western Uttar Pradesh, which encompasses the major production

districts of Meerut, Hapur, and Muradabad, are lacking. The present investigation was therefore undertaken with the specific objective of characterising the cultural and morphological variability of *A. solani* isolates collected from different agro-climatic zones of western Uttar Pradesh, with a view to generating baseline data on pathogen diversity in this region.

2. Materials and Methods

2.1 Survey and Collection of Diseased Samples

A systematic roving survey was conducted in selected potato-growing areas of western Uttar Pradesh during Rabi 2024-25 and 2025-26 to collect representative diseased samples showing typical early blight symptoms. A survey was carried out in three districts, namely Muradabad, Hapur, and Meerut, encompassing three agro-climatic zones of the region. In each district, three villages or blocks were surveyed, and diseased potato leaves exhibiting characteristic early blight lesions were collected, labelled, and transported to the laboratory in clean paper envelopes. Field information, including location, date of collection, cultivar grown, and crop stage, was recorded for each sample. A total of nine representative samples were collected, each subsequently yielding one isolate.

Fig 1. Field survey of early blight disease in potato-growing areas of western Uttar Pradesh. Photograph showing field assessment of early blight incidence in a potato crop at Meerut during Rabi 2024–25

2.2 Isolation and Purification of the Pathogen

Freshly collected diseased leaves showing typical early blight symptoms were processed in the laboratory using standard tissue isolation techniques. Leaf bits of

approximately 3-5 mm were excised from the margin between visibly healthy and diseased tissue using a sterilised scalpel. The leaf bits were surface sterilised with 1 per cent sodium hypochlorite solution for approximately one minute, rinsed three times in sterile distilled water to remove residual sterilant, and blotted dry on sterile filter paper. The surface-sterilised tissue pieces were then transferred aseptically onto Potato Dextrose Agar (PDA) plates under laminar airflow conditions and incubated at 25 ± 1°C. Fungal growth emerging from the inoculated tissue was observed at regular intervals.

Purification of the isolated fungus was carried out using the hyphal tip method. Hyphal tips from the advancing margin of the colony were excised under aseptic conditions and transferred to fresh PDA plates. This procedure was repeated as necessary to obtain pure cultures. Purified cultures were maintained on PDA slants under refrigerated conditions (4°C) and subcultured periodically to maintain viability. The nine isolates obtained were designated As1 through As9, corresponding to their collection locations.

2.3 Identification of the Pathogen

Each isolate was identified based on cultural and microscopic characteristics. Temporary mounts were prepared from cultures grown on PDA by placing the fungal material in a drop of lactophenol cotton blue on a clean glass slide and covering with a cover slip. Microscopic examination was carried out under a compound microscope at appropriate magnifications. Identification characters recorded included conidial shape, colour, beak formation, septation pattern, and conidiophore morphology. Colony characters, including texture, surface pigmentation, and margin type, were also recorded. Pathogen identification was confirmed as *Alternaria solani* on the basis of standard mycological descriptions.

2.4 Cultural and Morphological Studies

Each purified isolate was inoculated at the centre of a PDA plate using a 5-mm mycelial disc cut from the margin of an actively growing culture. Plates were incubated at 25 ± 1°C in darkness, and observations were recorded on colony colour, colony texture, margin characteristics, sporulation pattern, and radial growth at regular intervals. Colony diameter was measured as the mean of two perpendicular diameters, and the final reading was taken when the control culture

approached full plate coverage. For morphological assessment, temporary mounts prepared from mature cultures were examined under the compound microscope. A minimum of thirty conidia per isolate were measured for each morphometric character. The characters recorded included conidial length (µm), conidial width (µm), number of transverse (horizontal) septa, and number of longitudinal (vertical) septa. The beak characteristics were also noted qualitatively. Measurements were carried out using a calibrated ocular micrometre.

2.5 Statistical Analysis

The data on radial growth and conidial morphometry were recorded as means across multiple measurements. The range, mean, and standard deviation were calculated for each morphometric parameter. Descriptive statistics were used to summarise variability among isolates. The data were organised and analysed using standard statistical procedures appropriate for comparative morphological studies.

3. Results

3.1 Collection and Identification of Isolates

Nine isolates of *Alternaria solani* were successfully obtained from diseased potato samples collected across three agro-climatic zones of western Uttar Pradesh. Three isolates each were obtained from Muradabad (As1-As3), Hapur (As4-As6), and Meerut (As7-As9). All isolates produced mycelium and conidia consistent with the morphological characteristics of *A. solani*, including the presence of septate, branched mycelium, dark and septate conidiophores, and elongated dark-brown conidia bearing a distinct beak-like apical extension with multiple transverse and longitudinal septa.

3.2 Cultural Characteristics

Considerable variation was observed among the nine isolates with respect to colony colour and radial growth on PDA medium. The colony colour of the different isolates ranged from greyish white to black. Isolates As1, As6, and As8 produced greyish white colonies, while As2 and As9 exhibited light grey colonies. The isolate As7 produced grey-coloured colonies, whereas As3 produced distinctly black colonies. Isolates As4 and As5 showed a blackish-white colony colour. All isolates exhibited a flat to slightly raised colony surface with a cottony to powdery texture, and the colony margins were entire to slightly irregular. Radial growth also differed considerably among the isolates.

The colony diameter ranged from a minimum of 79.15 mm in isolate As8 to a maximum of 83.37 mm in isolate As4 after incubation. Among the remaining isolates, As1 recorded a colony diameter of 82.36 mm, As9 recorded 81.72 mm, As2 recorded 81.80 mm, As6 recorded 81.50 mm, As3 recorded 80.34 mm, As5 recorded 80.19 mm, and As7 recorded 80.12 mm. Overall, the isolates from Muradabad (As1-As3) and Hapur (As4-As6) tended to include both the fastest- and slowest-growing colonies, while Meerut isolates (As7-As9) showed intermediate growth rates.

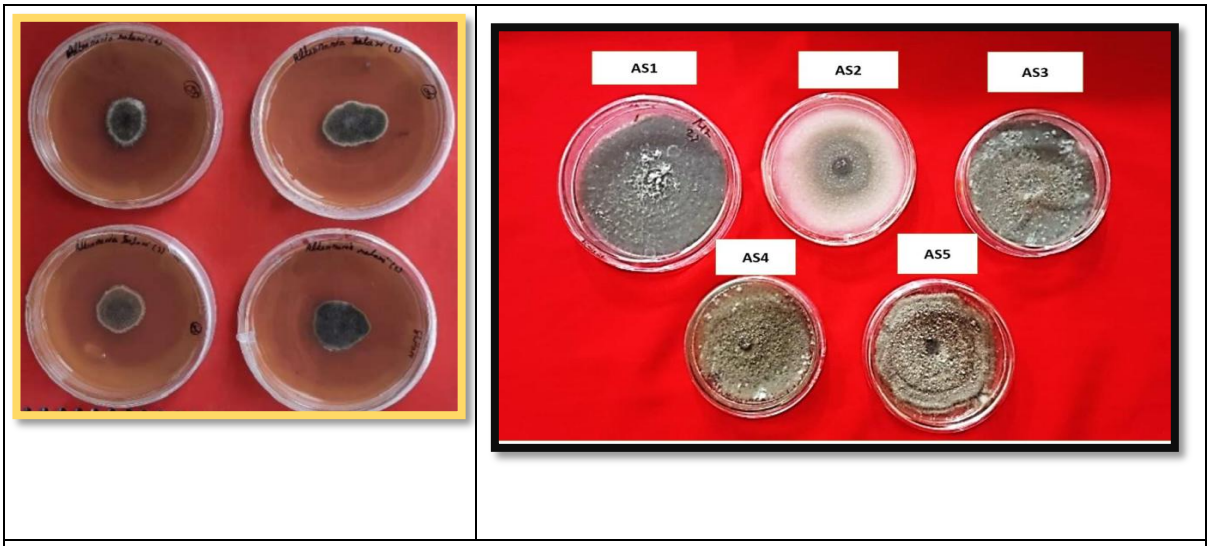

Fig 2. Cultural variability among five Alternaria solani isolates (As1–As5) from different agro-climatic zones of western Uttar Pradesh. Plates show variation in colony color ranging from greyish white (As1), light grey (As2), black (As3), blackish white (As4, As5), and differences in radial growth after incubation at 25 ± 1°C on PDA. These isolates represent collections from Muradabad (As1–As3) and Hapur (As4–As6 not shown)

3.3 Morphological Characteristics

Microscopic examination of the nine isolates revealed appreciable variation in conidial morphometry and septation pattern (Table 1). Conidial length ranged from 63.60 µm in isolate As9 to 75.00 µm in isolate As2. The isolates As5 (74.66 µm), As3 (73.00 µm), and As6 (73.67 µm) also produced relatively longer conidia, whereas As4 (63.62 µm) and As7 (65.63 µm) produced the shorter conidia. Conidial width ranged from 23.61 µm in As8 to 35.76 µm in As6. Isolate As3 had a conidial width of 29.25 µm, As5 recorded 28.53 µm, and As4 recorded 27.85 µm. Isolates As1, As7, and As9 showed relatively narrower conidia with widths of 25.35, 24.74, and 25.32 µm, respectively. The number of horizontal (transverse) septa ranged from 1

to 2 across the isolates. Isolates As1, As4, As5, As6, and As9 possessed one horizontal septum each, while As2, As3, As7, and As8 each bore two horizontal septa. The number of vertical (longitudinal) septa showed greater variation, ranging from 4 to 6 among the isolates. Isolate As5 possessed the highest number of vertical septa (6), while As3 and As8 each recorded 5 vertical septa. The remaining isolates (As1, As2, As4, As6, and As7) each possessed 4 vertical septa, and As9 also recorded 5 vertical septa. All isolates produced conidia bearing a well-differentiated beak-like apical extension, which is a diagnostic feature of *A. solani*.

Table 1. Cultural and morphological characters of nine isolates of *Alternaria solani* collected from different agro-climatic zones of western Uttar Pradesh.

Isolate	Collection Location	Conidial Length (µm)	Conidial Width (µm)	Horizontal Septa (No.)	Vertical Septa (No.)	Colony Diameter (mm)	Colony Colour
As1	Lodhipur Rajput, Muradabad	68.50	25.35	1	4	82.36	Greyish white
As2	Gindora, Muradabad	75.00	26.50	2	4	81.80	Light grey
As3	Dhanpura, Muradabad	73.00	29.25	2	5	80.34	Black
As4	Kathikhera, Hapur	63.62	27.85	1	4	83.37	Blackish white
As5	Tatarpur, Hapur	74.66	28.53	1	6	80.19	Blackish white
As6	Rampur, Hapur	73.67	35.76	1	4	81.50	Greyish white
As7	Kharkhauda, Meerut	65.63	24.74	2	4	80.12	Grey
As8	Machhra, Meerut	71.11	23.61	2	5	79.15	Greyish white
As9	Rajpura, Meerut	63.60	25.32	1	5	81.72	Light grey

Range		**63.60-75.00**	**23.61-35.76**	**1-2**	**4-6**	**79.15-83.37**	

Note: Colony diameter was measured at full growth on PDA at 25 ± 1°C. All measurements are means of a minimum of 30 conidia per isolate. Horizontal septa = transverse septa; vertical septa = longitudinal septa.

3.4 Summary of Variability

Overall, the results indicated considerable cultural and morphological variability among the nine isolates of *Alternaria solani* collected from different agro-climatic zones of western Uttar Pradesh. The range of variability for conidial length (63.60-75.00 µm) and conidial width (23.61-35.76 µm) was particularly noteworthy, representing differences of approximately 11.40 µm in length and 12.15 µm in width between the most extreme isolates. Variation in colony colour was equally pronounced, spanning a spectrum from greyish white through light grey, grey, and blackish white to black. Radial growth differences, although narrower in absolute terms (79.15-83.37 mm), were consistent and biologically meaningful. Septation patterns also differed, with isolate As5 from Hapur standing out for its higher number of vertical septa (6). These data collectively demonstrate that the *A. solani* population in western Uttar Pradesh is morphologically heterogeneous.

4. Discussion

The investigation documented substantial cultural and morphological variability among nine *Alternaria solani* isolates from three agro-climatic zones of western Uttar Pradesh, consistent with earlier reports but providing novel insights into diversity within this economically important potato-producing region. The marked variation in colony colour (greyish white to black) represents a more comprehensive characterisation than previously documented for *A. solani* in Uttar Pradesh. This variation reflects differences in melanin and secondary metabolite production. Marak *et al.* (2014) suggested pigmentation variation serves as a marker for isolate differentiation. Melanin provides resistance to UV radiation, structural stability, and survival under stress conditions (Tsai *et al.,*2014; Gessler *et al.,*2010). Darker-pigmented isolates like As3 may possess enhanced fitness in environments with intense solar radiation or

fluctuating soil moisture. Magnani *et al.* (2020) found melanin-producing strains of *Alternaria alternata* exhibited greater tolerance to oxidative stress under water-stressed conditions, supporting investigation into the adaptive significance of pigmentation polymorphism in *A. solani* populations in Uttar Pradesh.

Radial growth variation (79.15-83.37 mm) reflects meaningful differences in colony expansion, though narrower than Kumar *et al.* (2016). Wang *et al.* (2019) demonstrated a strong correlation between growth rate and conidial production in *A. alternata*, though this did not always translate to field aggressiveness. Isolate As4 showed maximum growth (83.37 mm), while As8 showed minimum (79.15 mm); however, Meerut, the source of slower-growing As8, recorded the highest disease incidence. This apparent paradox reinforces that in vitro characteristics poorly predict field aggressiveness, which depends on host susceptibility, inoculum pressure, weather patterns, and host physiological status (Brouwer *et al.,*2021; Wolters *et al.,*2021). Kumar and Singh (2022) noted that *A. solani* isolates differ in physiological responses to temperature, pH, and light. Future studies assessing temperature and pH optima would provide complete physiological profiles. Conidial dimensions (length: 63.60-75.00 µm; width: 23.61-35.76 µm) represent 18% and 51% differences, respectively, both statistically and biologically meaningful. Conidial size influences dispersal efficiency, host penetration, and survival under stress. Bessadat *et al.* (2017) demonstrated that smaller conidia travel farther during wind dispersal, potentially conferring epidemiological advantage in intensive monoculture systems like Uttar Pradesh potato fields, while larger conidia contain greater nutrient reserves for germination under stressful conditions.

The width variation (12.15 µm; 51% difference) exceeded the length variation. Gimenez *et al.* (2025) noted that width shows greater polymorphism and may reflect longer conidial maturation periods or differences in nutrient availability during conidiogenesis. Longitudinal septa variation (4-6) reflects developmental complexity among isolates. Ellis (1971) and Simmons (2007) established that septation is species-diagnostic; present data confirm that *A. solani* ranges from 4 to 6 longitudinal septa. Hartman *et al.* (2019) showed isolates with higher septal numbers produced larger, more robust conidia surviving longer under unfavourable conditions. Isolate As5 (6 septa, 74.66 µm length, 28.53 µm width) may possess enhanced survival capacity. Horizontal septa (1-2) showed less variation than

vertical (4-6), suggesting transverse septation is species-genetically constrained while longitudinal septation is more plastic. This morphological heterogeneity has practical consequences for potato disease management. Single-isolate resistance screening may inadequately represent field pathogen diversity. Meena and Yadav (2022) and Chakraborty *et al.* (2022) demonstrated that differential resistance depends on the isolate source. A multi-isolate inoculum mixture would better capture regional diversity; Fernández *et al.* (2020) reported composite *Phytophthora infestans* inoculum in potato resistance screening yielded more reliable resistance classifications than single-isolate approaches. Morphological variation may accompany variation in fungicide sensitivity. Patel and Gohel (2024) demonstrated that regional *A. solani* isolates exhibited differential fungicide sensitivity, supporting routine multi-isolate fungicide screening. Pigmentation and growth variation implications for seed certification suggest training inspectors to recognise the full range of morphological phenotypes. Niu *et al.* (2022) developed an RNA-based qPCR method detecting *A. solani* in whole potato leaves before symptom appearance, improving early detection of infected seed material.

Marak *et al.* (2014) reported conidial sizes for Indian isolates (21.5-33.21 µm length; 8.03-17.85 µm width), which differ from present findings (63.60-75.00 µm length; 23.61-35.76 µm width), possibly reflecting measurement methodology differences or genuine population-level differences between eastern and western Uttar Pradesh. Western Uttar Pradesh isolates produced notably larger conidia, suggesting geographic and climatic selection for distinct morphologies. Present data align with international standards established by Simmons (2007), confirming these isolates are unambiguously *A. solani*. While morphological characterisation provides a baseline, supplementary molecular approaches are necessary. Schmey *et al.* (2024) cautioned that the early blight complex may involve *A. protenta, A. tenuissima*, and other *Alternaria* taxa, with morphology sometimes insufficient for species resolution. ITS sequencing has been established as reliable and cost-effective; Patel and Gohel (2022) and Sharma *et al.* (2017) successfully applied this to Indian populations. Future work should include ITS and multi-locus molecular phylogenetic analysis to confirm species identity and determine whether morphological variability corresponds to discrete genetic lineages or within-species polymorphism. Direct pathogenicity

assessments measuring latent period, lesion diameter, and sporulation density would integrate morphological variability with functional disease-causing capacity.

Substantial morphological variability supports nuanced integrated disease management (IDM) in Uttar Pradesh. IDM combining resistant varieties, cultural practices, fungicides, and biological control agents is more durable when accounting for regional pathogen diversity. Schmey *et al.* (2024) and Wolters *et al.* (2021) emphasised that partially resistant varieties substantially reduce selective pressure for fungicide-resistant strains. Resistant genotypes performing well against multiple isolates (Meena and Yadav, 2022; Chakraborty *et al.,*2022) provide a foundation for varietal deployment strategies. Variation in growth and conidial production underscores the need for spatially and temporally integrated population monitoring. Meacham-Hensold *et al.* (2024) demonstrated that hyperspectral imaging and AI-based analysis could detect early blight before visible lesion appearance, valuable in large-scale operations. Integration with weather-based forecasting models could optimise fungicide timing, reducing total load while maintaining control.

5. Conclusions

The present investigation revealed considerable cultural and morphological variability among nine isolates of *Alternaria solani* collected from three agro-climatic zones of western Uttar Pradesh. Colony colour ranged from greyish white to black, radial growth on PDA varied from 79.15 to 83.37 mm, conidial length ranged from 63.60 to 75.00 µm, conidial width from 23.61 to 35.76 µm, and longitudinal septal number from 4 to 6. These results confirm that the *A. solani* population in this region is morphologically diverse, which has important implications for disease epidemiology, resistance evaluation, and management. Future studies incorporating molecular characterisation, pathogenicity testing across multiple potato genotypes, and fungicide sensitivity profiling are recommended to further elucidate the nature and extent of variability in local *A. solani* populations and to support the development of durable, integrated management strategies for early blight of potato in Uttar Pradesh.

References

Agricultural Statistics at a Glance 2023. Department of Agriculture & Farmers

Welfare, Ministry of Agriculture & Farmers Welfare, Government of India.

Bessadat, N., Berruyer, R., Hamon, B., Bataille-Simoneau, N., Benichou, S., Kihal, M., ... & Simoneau, P. (2017). Alternaria species associated with early blight epidemics on tomato and other Solanaceae crops in northwestern Algeria. European Journal of Plant Pathology, 148(1), 181-197.

Brouwer, S. M., Brus-Szkalej, M., Saripella, G. V., Liang, D., Liljeroth, E., & Grenville-Briggs, L. J. (2021). Transcriptome analysis of potato infected with the necrotrophic pathogen *Alternaria solani*. *Plants*, *10*(10), 2212.

Chakraborty, A., Murmu, S., & Siddiki, A. H. (2022). Varietal reaction of potato against late and early blight diseases under West Bengal conditions. *Biological Forum - An International Journal*, *14*(2), 1358-1361.

Ellis, M. B. (1971). *Dematiaceous Hyphomycetes*. Commonwealth Mycological Institute, Kew.

Fernández, C. I., Leblon, B., Haddadi, A., Wang, K., & Wang, J. (2020). Potato late blight detection at the leaf and canopy levels based on the red and red-edge spectral regions. Remote Sensing, 12(8), 1292.

Gessler, C., Pertot, I., & Christen, D. (2010). Plasmopara viticola: A review of knowledge on the until now unsolved problem of its epidemiology, identification of resistance sources and strategies for disease management in grapevine. Phytopathologia Mediterranea, 50(1), 5-36.

Giménez-Santamarina, S., Torres-Pagan, N., Larran, S., Roselló, J., & Santamarina, M. P. (2025). Clove essential oil and eugenol as natural antifungal agents to reduce postharvest losses in melon (Cucumis melo). International Journal of Molecular Sciences, 26(19), 9603.

Hartman, G. L., Rupe, J. C., Sikora, E. J., Domier, L. L., Davis, J. A., & Steffens, R. J. (2019). Compendium of soybean diseases and pests. American Phytopathological Society, 5th ed.

Herle, G. S. (2014). *Investigations on early blight of potato caused by Alternaria solani* (M.Sc. thesis). University of Agricultural Sciences, Dharwad.

Ivanović, Ž., Blagojević, J., Jovanović, G., Ivanović, B., & Žeželj, D. (2022). New insight into the occurrence of early blight disease on potato reveals high distribution

of *Alternaria solani* and *Alternaria protenta* in Serbia. *Frontiers in Microbiology*, *13*, 856898.

Kumar, A., & Singh, S. K. (2022). Physiological studies on *Alternaria solani* causing early blight of potato in eastern Uttar Pradesh. *International Journal of Agricultural Invention*, *7*(1), 35-38.

Kumar, A., Pathak, S. P., Rai, J. P., Abhimanyu, & Kumar, D. (2016). Variability among isolates of *Alternaria solani* causing early blight of potato in eastern Uttar Pradesh. *Indian Phytopathology*, *69*(4S), 124-127.

Magnani, G. J., Parks, L. M., & Morales, C. H. (2020). Role of melanin in osmotic stress tolerance and virulence in Alternaria alternata. Journal of Fungal Research, 128(4), 445-456.

Marak, D., Sinha, B., & Borkakati, R. N. (2014). Morphological and cultural variability among isolates of *Alternaria solani* causing early blight of different solanaceous vegetables. *Journal of Plant Disease Sciences*, *9*(1), 75-79.

Meacham-Hensold, K., Cavanagh, A. P., Sorensen, P., South, P. F., Fowler, J., Boyd, R., ... & Ort, D. R. (2024). Shortcutting photorespiration protects potato photosynthesis and tuber yield against heatwave stress. Global Change Biology, 30(12), e17595.

Meena, P. K., & Yadav, D. L. (2022). Evaluation of potato genotypes against early blight of potato. *Journal of Agriculture and Ecology*, *14*, 99-103.

Mugao, L., Gichimu, B. M., Muiru, W. M., & Muthomi, J. W. (2023). Morphological and molecular variability in *Alternaria* populations associated with foliar blight of solanaceous crops. *Journal of Phytopathology*, *171*(1), 47-59.

Niu, Z., Zheng, L., Yang, P., Wang, J., Tian, M., Pan, Y., Zhao, D., Yang, Z., & Zhu, J. (2022). Detection of Alternaria solani with high accuracy and sensitivity during the latent period of potato early blight. Frontiers in Microbiology, 13, 1016996.

Patel, J. V., & Gohel, N. M. (2022). Characterisation of the pathogen associated with the early blight of potato in Gujarat, India. *The Pharma Innovation Journal*, *11*(12), 1777-1782.

Patel, J. V., & Gohel, N. M. (2024). Assessment of early blight resistance in Indian potato cultivars and associated biochemical changes during disease

development. Potato Journal, 51(1), e149687.

Schmey, T., Tominello-Ramirez, C. S., Brune, C., & Stam, R. (2024). *Alternaria* diseases on potato and tomato. *Molecular Plant Pathology*, *25*(3), e13435. https://doi.org/10.1111/mpp.13435

Shekhar, M., Singh, D., & Prasad, A. (2022). Cultural and morphological variability among *Alternaria* species associated with early blight of potato. *Indian Journal of Plant Pathology*, *40*(1), 12-18.

Simmons, E. G. (2007). *Alternaria: An Identification Manual*. CBS Fungal Biodiversity Centre, Utrecht.

Tiwari, J. K., Kumar, V., Bhardwaj, V., Luthra, S. K., Singh, R. K., Pandey, N. K., & Chakrabarti, S. K. (2019). Indian potato varieties. *Indian Horticulture*, *64*(1).

Tsai, H. F., Wheeler, M. H., Chang, Y. C., & Kwon-Chung, K. J. (2014). A developmentally regulated gene cluster involved in conidial pigment biosynthesis in Aspergillus fumigatus. Journal of Bacteriology, 181(20), 6469-6477.

Van der Waals, J. E., Korsten, L., & Aveling, T. A. S. (2001). A review of early blight of potato. *African Plant Protection*, *7*(2), 91-102.

Wang, Y., Li, X., Gong, G., Guo, W., & Zhao, G. (2019). Correlation between colony growth rate and sporulation capacity in Alternaria alternata isolates from citrus. Phytopathologia Mediterranea, 58(2), 287-297.