J. Phytol. Res. **37**(2): 53-64, 2024 **ISSN 0970-576**

ROLE OF MEDICINAL PLANTS OF RAJASTHAN WITH ANTIFUNGAL PROPERTIES: A REVIEW

SHRUTI OJHA*, SURBHI AGARWAL, and RENU JANGID
Department of Botany, Maharshi Dayanand Saraswati University, Ajmer, Rajasthan, India
Corresponding Author's Email: ojhashruti@gmail.com

Medicinal flora from the Rajasthan state of India is a rich source of herbal species. The arid and semi-arid ecosystems provide great diversity and abundance of traditional yet valuable medicinal plants. Commercial antifungal chemicals are not only harmful to plant life but are known to affect the genetic system, resistance, growth, development, and productivity of plants. This review paper aims to assemble the vast research on the antimicrobial bioassay of medicinal plants in Rajasthan, India. A systematic categorization of infected plants, plants with antimicrobial properties, isolated fungal pathogens, and applications has been conducted.

Keywords: Antifungal, Fungal Pathogens, Herbal, Medicinal, Plants.

Introduction

Rajasthan, India's northwestern state, is known to occupy 10.4% of the total geographical area[1]. Biogeographically, the state can be broadly divided into four major regions: western deserts with sandy plains and barren lands, Aravalli hills, eastern plains with rich soil lands, and southeastern regions[2]. Additionally, geographical land with rich soil and diverse climatic conditions reflects a rich biodiversity of both flora and fauna. The majority area of Rajasthan is reported as an arid to semi-arid ecosystem including desert, and sandy plains. Moreover, extreme climatic conditions of humid and rainfall conditions make it more stressful for the plants to survive and flourish[3]. However, despite the unfavorable climatic and habitat conditions, the state is rich in diverse floral species specifically medicinal plants. Since ancient times in the rural areas of India, medicinal plants have been used for traditional medicines and curing diseases[3, 4]. About 18,000 angiosperm plant species including 2,500 medicinal have been reported from India[5]. These medicinal plants hold significant importance in curing severe hazardous diseases of both humans and plants. A global issue is the destruction of economically important crops and plants due to microbial communities. Farmers use harmful chemicals to maintain the productivity and growth of the plants. However, this compromises the quality of crops on various parameters including genetically, morphologically, and structurally. Therefore, a biological, harmless, and economically useful approach has been initiated using plant extracts as antifungal agents[6]. This review study aims to assemble the vast data knowledge of medicinal plants of Rajasthan related to antifungal activity. Additionally, the data has also been studied for the fungal pathogens isolated and identified from the flora of the state.

- *Fungal Pathogens*

Fungal pathogens significantly affect the plants and decrease crop yield and quality. In prevention, farmers use chemical pesticides against crop diseases, which leads to ecological and environmental disturbances including soil compaction, water pollution, and an increase in resistant weed populations. These possess a negative impact on the long-term viability of the agricultural industry[7]. Consequently, plant diseases have become a major barrier to the advancement of sustainable agriculture. In recent years, plant fungal diseases have severely affected crop yield with common diseases including rust, mildew, and botrytis blight. These pathogens thrive in moist environments and can spread through spores carried by wind, water, or insects. Fungal infections have become a major barrier to the advancement of sustainable agriculture [8,9].

Figure 1 shows plant-fungal interactions through various symbiotic and phytopathogenic mechanisms.

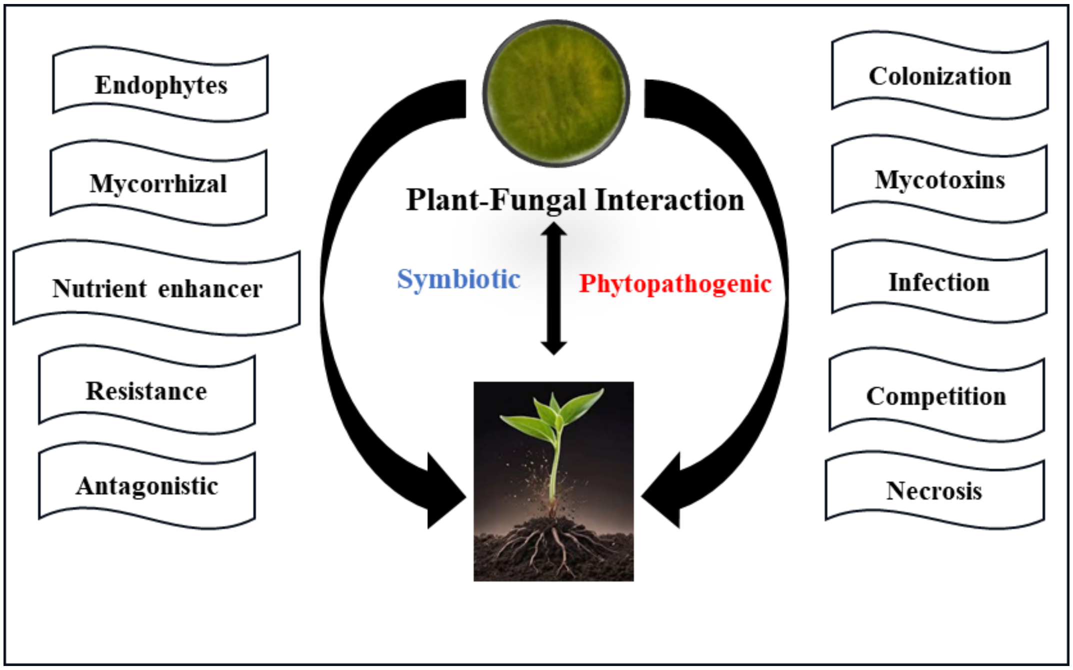

Figure 1. Plant-Fungal Interaction: Mechanism showing positive and negative effects of the association.

More than 10,000 fungal species are known to be pathogens to plants. *Pythium* and *Phytophthora* have been reported to cause more severe plant damage than others. The majority of the fungal pathogens belong to the phylum Ascomycota and Basidiomycota[10]. The disease symptoms can be categorized into three sections depending upon the morphology of symptoms on the host: 1. Necrotic Symptoms: involve the death and destruction of plant tissues resulting in brittle appearance of the tissue. 2. Abnormal growth and development of plant tissues: hypertrophy and hyperplasia due to the interaction of toxins produced by the pathogen and the host tissue. 3. Other Symptoms: rusts, smuts, wilt, and ergot[11]. The data on plant diseases caused by fungal pathogens and their symptoms has been summarized in Table 1.

- *Botanicals with medicinal properties as antifungal agents:*

Biological products including plant extracts, microbial community compounds, and other extracted substances have emerged as alternatives for future agriculture development. The phytopathogens and related plant diseases have caused severe devastation in the last few decades and hence need prime attention to secure resources for future generations. Botanicals as antimicrobial agents have proved to be meaningful replacements against harmful chemicals in the floral community. Significant research has been conducted in the past few years in Rajasthan state related to antifungal bioassays. This review, therefore, highlights the importance of medicinal plants from Rajasthan. Moreover, fungal pathogens isolated from different locations and substrates have also been assembled. Angiosperm plants belonging to diverse families contributed to various scientific investigations related to antifungals, which have been studied and reviewed. The families described below have been considered based on the maximum usage by researchers in the past few years from Rajasthan. Moreover, two families have been grouped based on their common morphological and anatomical characteristics.

i. *Apocynaceae and Asclepiadaceae*

The two diverse families of the order Gentianales with around 5000 species have been reported around the globe so far[12]. Herbs, shrubs, and trees of the two families have been observed with secondary metabolites including indole alkaloids and cardenolides[12-16]**.**Additionally, Patil et al. (2023) reported alkaloids, flavonoids, phenols, terpenoids, and other compounds in several Apocynaceae members[17]. Ojha and Goyal (2019)have studied the ethanol extracts of *Calotropis procera* and *Catharanthus roesus* belonging to the Asclepiadaceae and Apocynaceae families respectively. The fungal pathogen *Curvularia* from the medicinal tree *Aegle marmelos* (Rutaceae) was isolated and treated with the plant extracts[18]. In a similar study, Ojha and Goyal (2024) studied the medicinal and antifungal effects of *Nerium indicum* against *Alternaria* and *Fusarium*[19]. Arora and Jain (2018) used *C. procera* for an antimicrobial assay[20]. Bharti et al. (2012) studied the synergistic impact of medicinal plants including *N. indicum* (Apocynaceae) with transitional metal Ferrocyanides against isolated fungal pathogen *Rhizoctonia solani* [21]. The results indicated a positive impact of *N. indicum* against the growth retardation of the tested fungal pathogen. Similarly, the methanolic extracts of *C. roseus* were tested against fungal pathogens including *Aspergillus* sp., *Curvularia* sp., and *Microsporium* species. The well diffusion assay from Jaipur, Rajasthan, India, was determined to have antifungal activity. The medicinal plant extract tested against the selected fungal pathogens showed positive growth retardation[22]. A similar study on the leaf extracts of *C. roseus* and *N. indicum* showed a positive impact against *Mucor circinelloides* (Zygomycota), *Aspergillus* species (Ascomycota), and dermatophytes from Ajmer, Rajasthan, India[23-25]. The former study was based on the disease control of mucormycosis, specifically during covid-19 epidemic. Sharma et al. (2012) conducted research using stem, leaf, and root extracts of *Durenta erecta* (Verbenaceae) against *A. niger, A. flavus, A. fumigatus,*and *Penicillium* sp. The study was conducted in Jaipur, Rajasthan, India which showed positive to negative effects among all the extracts tested[26]. Jadon and Shah (2012) studied the antifungal activity of fifty-eight plants from Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India. *Drechslera bicolor* isolated from a diseased bell pepper plant (*Capsicum annuum* var. grossum (L.) Sendt.) from Udaipur was tested by the aqueous leaf extracts of selected fifty-eight plants. The plants mainly included *Vinca roseus* (*C. roseus*), *N. indicum*, *C. procera*, *Argemone maxicana*, *Chrysanthemum* spp., *Allium sativum*, and many more[27]. Ojha and Goyal (2017) studied the aqueous and ethanol extracts of *N. indicum*, and *C. procera* against *Curvularia* species from Ajmer, Rajasthan[28].

Table 1.: Plant Disease by Fungal Pathogen

Plant	Causal agent	Disease	Symptoms	Year	Ref.
1. Necrotic Symptoms					
Bottle guard	*Alternaria*	Leaf blight and leaf spot	The blighted tissue appearance burnt with fire.	2013	[49]
Bottle guard, Mustard	*Cercospora* *Alternaria brassicae*	Leaf Spot	The localized lesions on the host plant leaves.	2013	[49, 50]
Pearl Millet	*Pyricularia pennisetigenna*	Blast disease	Necrotic lesions visible on the leaves, nodes, and at the base of heads.	2020	[51]
Citrus	*Phytophthora*	Cankers	The localized necrotic lesions sunken, surrounded by successive layers of cork cells.	2018	[52]
Apple	*Venturia inaequalis*	Scab	The localized lesions slightly raised and cracked.	2011	[53, 54]
Opium Poppy	*Pythium*	Damping off	The young or seedlings collapse at the base.	1999	[55]
Citrus, Mustard	*Phomopsis citri*, *Sclerotinia sclerotiorum*	Rot Disease	Rottening and destruction of infected tissue.	2013, 2014	[56, 57]
Groundnut	*Aspergillus niger*	Collar Rot	Drying plant tissue, foliage turns slightly yellow before death.	2017	[58]
Maize, Pearl Millet	*Perenosclerospora sorghi*, *Perenosclerospora heteropogoni*, *Sclerospora graminicola*	Downy mildew	Pale yellow to whitish discolorations on the leaf blade. Tasselsdeformed,ears aborted.	2004, 2005	[59, 60]
2. Abnormal growth and development of tissues					
Coriandrum, Medicinal plants	*Protomyces macrospores*	Galls	Abnormal growths on the leaves, stems, roots, or flowers.	2016, 2017	[61-63]
		Warts	Hard, benign protuberances called warty produced on the stems or tubers	2004	[64]
Potato	*Spongosporasub terranea*	Powdery scab	Infected tissue has brown spongy spots, which are dry and in severe conditions give appearance of warts.	2019	[65]
3. Other symptoms					
Wheat, Barley	*Puccinia striiformis*	Rusts	Rusty appearance on the leaves and stems of the host plant	2020, 2024	[66, 67]
Mustard	*Albuga candida*	White rust	small white pustules on the undersides of affected leaves.	2020, 2023	[68, 69]
Wheat, Barley	*Urocystis agropyri*	Smuts	masses of dark, powdery appearance on the host tissue.	2010, 2017	[70, 71]
Muskmelon, Cumin	*Fusarium*	Wilts	the loss in turgidity and drooping of the leaves and shoots of the plant	2013, 2022	[47, 72]
Peral Millet, Sorghum	*Claviceps purpurea*	Ergots	The grains of the cereals are replaced by black or purple-coloured sclerotia	2020	[73, 74]

many more[27]. Ojha and Goyal (2017) studied the aqueous and ethanol extracts of *N. indicum*, and *C. procera* against *Curvularia* species from Ajmer, Rajasthan[28].

ii. *Fabaceae and Moringaceae*

Moringa oleifera belonging to Moringaceae family was studied for antimicrobial activity by Arora and Jain (2018) from south-east Rajasthan and Jadon and Shah (2012) from Udaipur, Rajasthan, India. *Acacia arabica*, *Acacia senegal*, and *Acacia nilotica*are important tree species, responsible for antifungal properties. *Acacia nilotica* (Fabaceae) was studied for its antifungal activity against *R. solani* from Banasthali University, Rajasthan, India. The synergistic effect of the medicinal plant was observed with transitional metal Ferrocyanides which however showed minimum but positive results compared to the other medicinal plants tested[20,27]. *A. nilotica* was also studied by Jadon and Shah (2012) against *D. bicolor* isolated from a bell pepper plant from Udaipur, Rajasthan, India[27]. Menghani et al. (2011) studied antifungal activity against bacterial and fungal isolates including *Pseudomonas aeruginosa*, *Escherichia coli*, *Candida albicans*, and many others. *Neltuma juliflora* (*Prospois juliflora*) and *Cassia fistula* belonging to the family Fabaceae were also examined against *D. bicolor*[29].

iii. *Solanaceae and Apiaceae*

Withania somnifera (Solanaceae) was investigated for antifungal potential by Bharti et al. (2012) from Banasthali University, Rajasthan, India[21]. Arora and Jain (2018) from south-east Rajasthan, and Jadon and Shah (2012) from Udaipur, Rajasthan[20,27]. Chittoriya et al. (2020) investigated the phytochemical properties of central Rajasthan medicinal weed plants. Four medicinal plants including *Datura stramonium* (Solanaceae), *Oxalis corniculate* (Oxalidaceae), *Tridax procumbens* (Asteraceae), and *Phyllanthus niruri* (Phyllanthaceae) were analyzed. Results revealed the presence of important secondary metabolites including alkaloids, phenols, and flavonoids[30]. Similarly, Ojha and Goyal (2019) studied the phytochemical analysis of *C. roseus*, *C.procera*, *Ocimum sanctum*, and *N. indicum* from Ajmer, Rajasthan, India. Leaf extracts of *T. procumbens* were studied by Chittoriya et al. (2020) from Ajmer, Rajasthan against *Helminthosporium sativum*[30]. The fungal pathogen was isolated from *Luffa acutangula* from Ajmer district, India. However, Menghani et al. (2011), studied the plant extracts of *Luffa acutangula* (Fabaceae) as an antimicrobial agent as well[29]. Aqueous leaf extracts of *Coriandrum sativum* (Apiaceae) were studied by Jadon and Shah (2012) against the fungal pathogen *D. bicolour* causing leaf blight of bell pepper from Udaipur, Rajasthan[27].

iv. *Other families*

Arora and Jain (2018) studied 47 plants from 29 families for therapeutic and herbal treatments from Southeast Rajasthan. Out of all, 18 plants were investigated for antimicrobial potential. Plants included *Anthocephalus cadamba* (Rubiaceae), *Ficus glomerata* (Moraceae), *Diospyrous melanoxylon* (Ebenaceae), *Salvadora persica* (Salvadoraceae), *Terminalia alata* (Combretaceae), *Terminalia arjuna* (Combretaceae), and *Vitex negundo* (Verbenaceae)[20]. *Emblica officinalis* (Rutaceae) was studied for antimicrobial assay by Bharti et al. (2012) from Jaipur, Rajasthan, India. Gupta et al. (2014), examined several plants belonging to the families Euphorbiaceae (*Ricinus communis*, *Jatropha curcas*), Menispermaceae (*Tinospora cordifolia*), Zingiberaceae (*Curcumalonga*), Cupressaceae (*Thuja occidentalis*), Cannabaceae (*Cannabis sativa*), Rutaceae (*Murraya koenigii*), Meliaceae (*Azadirachta *indica*), Alliaceae (*Allium cepa*) for antimicrobial activity against three selected pathogens including *Aspergillus* sp., *Curvularia* sp., and *Microsporium* species[22]. Lamiaceae (*Ocimum sanctum*) was reported to have antimicrobial and antifungal activity by Jadon and Shah (2012) and Arora and Jain (2018)[20, 27]. Arid ecosystem plants of Rajasthan play an important role as antibacterial and antifungal agents which was reported by Jain et al. (2010)[31]. The plants mainly included *Lepidagathis trinervis* Nees. (Acanthaceae), *Polycarpaea corymbose* Lam. (Caryophyllaceae), and *Sericostoma pauciflorum* Stocks. ex-Wight (Boraginaceae). The research was conducted at the University of Rajasthan, Jaipur, India. The agar well diffusion method was used which demonstrated maximum inhibition of *Bacillus subtilis, Enterobacter aerogenes, Pseudomonas aeruginosa, Aspergillus flavus,* and *Trichophyton rubrum* by extract of *L. trinervis.*

- *Plant-fungal interaction*

German botanist Heinrich Anton de Bary has been reported to haveisolated the first fungal pathogen (rust and smut) from plants.[32] Plants interact with fungi in different ways including symbiotic and phytopathogenic associations. Symbiotic relationships include fungi interacting positively with plants as endophytes, mycorrhizal association, nutrient enhancers, and resistance providers for about 90% of plant species. Research shows that mycorrhizal associations can significantly influence plant biodiversity within ecosystems and affect overall ecosystem health[33]. However, negative effects of plant-fungal associations have also been reported which can affect overall plant parts including leaves, stems, roots, flowers, fruits, and seeds. Additionally, it can disturb the morphology and physiology leading to plant death[34]. Pathogenic fungi utilize various mechanisms to colonize and infect plants. Fungal spores adhere to the surface of the host plant and develop structures such as appressorium, infection cushion, and haustorium. Penetration can lead to host cell invasion and consequently colonization through intercellular and intracellular spaces. Fungi are known to secrete effector proteins, cell-wall degrading enzymes, and mycotoxins that suppress plant immune responses[35, 36]. Effector proteins interact with host plant cells, manipulate plant defenses, and thus promotes mooth fungal survival[7]. Enzymes such as cellulase, hemicellulases, and proteases break down plant cell walls, facilitating fungal penetration, infection, and thus colonization. Fungi can synthesize a broad range of secondary metabolites known as mycotoxins. Moreover, they can disrupt the physiology of plants, leading to symptoms like chlorosis, necrosis, and wilting [37].

- *Plant defense mechanism against Pathogens*

Plants have evolved special defense mechanisms to protect themselves from fungal pathogens such as physical, chemical, and systemic responses. Physical barriers such as thorns, spines, prickles, trichomes, cuticles, and cell walls provide primary defense against pathogens. Additionally, they serve as a barrier against pathogen invasion[38, 39].

Plants primarily detect the presence of fungal pathogens and produce a variety of secondary metabolites in their defense. Phytoalexins are antimicrobial substances that accumulate at infection sites to inhibit fungal growth, Glucosinolates and Isothiocyanates can deter fungal attacks as reported from the Brassicaceae or Cruciferae family[40]. Plants generate reactive oxygen species (ROS) which can damage the pathogen's cellular components and signal further defensive actions [38].

In systemic response, plants trigger microbe-associated molecular pattern (MAMP)-triggered immunity, pattern-triggered immunity, and effector-triggered immunity[41]. The Plants can activate two types of systemic plant immunity mainly systemic acquired resistance (SAR) and induced systemic resistance (ISR). SAR involves the synthesis and accumulation of salicylic acid which lead to increased resistance throughout the plant. ISR is often triggered by beneficial fungi and involves the synthesis of jasmonate and ethylene signalling pathways, increasing the plant's overall resilience against fungal pathogens[42, 43]. Recent research highlights the role of epigenetic modifications in plant defense mechanisms. The expression of defense-related genes is regulated through changes in DNA methylation and histone modifications. These regulations allow plants to modify their responses based on past encounters with fungal pathogens[39].

Plant-fungal infections across various biogeographical regions of Rajasthan vary significantly due to the diverse climatic and environmental conditions. The north-western region of Rajasthan state experiences low rainfall (100-450 mm annually) and high temperatures, which can increase fungal infections especially downy mildew and leaf rust caused by *Perenosclerospora sorghi* on maize and *Puccinia triticina* on wheat respectively[9, 44]. However, compared to north-western Rajasthan, eastern Rajasthan has more rainfall, which raises humidity levels that favor the growth of fungi. Black leaf spot and *Alternaria* leaf spot are common fungal infections in eastern Rajasthan[45, 46]. Northern Rajasthan has a mixture of arid and semi-arid climates, with varying rainfall patterns that favor wilt disease caused by *Fusarium oxysporum* (Chickpeas and eggplants) and powdery mildew caused by *Erysiphe polygoni* (Cumin)[47]. The Desert region has very low rainfall and high temperatures which can exacerbate leaf spot disease (particularly on medicinal plants). Fungal endophytes may lead to various diseases due to stress conditions[48].

Conclusions

Medicinal plant extracts are known to have potential phytochemicals. These chemicals contain valuable compounds and secondary metabolites useful in treating several plant diseases and pathogen control. The natural source of antifungal compounds has reported negative side effects on plants, environment, and productivity. Additionally, the review focused on the collective data of fungal pathogens involved in plant diseases of Rajasthan state. The mechanisms involved in the plant-fungal interaction have also been evaluated and explained. Focus has been emphasized on the communication and defense mechanisms, resistance, and susceptibility of the plants as well as fungal pathogens.

Future perspectives

The broader unexplored bioactive compounds of plants need to be investigated. Discovery of novel-resistant plant varieties especially those with medicinal properties could be a great natural resource in future studies. This may additionally include hybrid disease-free varieties as well. The bioactive compounds and the secondary metabolites with improved structures and molecular modifications would increase the plant mechanisms. Furthermore, symbiotic and synergistic interactions of plant-plant, plant-fungal, or fungal-fungal will enhance the research in multiple improved pathways. This will be a pure natural resource procedure that will discover new mechanisms for future research. Such interactions can be both harmful and beneficial. The prospects also revolve around in-vivo applications of these natural antifungal extracts on more commercial and broader platforms by agriculturists and industries.

Acknowledgments
The authors thank the Department of Botany, Maharshi Dayanand Saraswati University, Ajmer, Rajasthan, India for guidance and support.

References

1. Kumar S, Vyas S, Tirole R, Vyas M, Sharma SS and Rao SS 2021, Strategies to Enhance Solar Energy Utility in Agricultural Area of Rajasthan State, India. *Journal of Physics: Conference Series*; IOP Publishing. DOI 10.1088/1742-6596/1854/1/012013.
2. Hussain M 2015, Agro-climatic zones and economic development of Rajasthan. *International Journal of Humanities and Social Science Invention*, **4**(2) 50-7.
3. Tripathi Y, Prabhu V, Pal R, Mishra R 1996, Medicinal plants of Rajasthan in Indian system of medicine. *Ancient Science of life* **15**(3) 190-212.
4. Sandhu DS and Heinrich M 2005, The use of health foods, spices and other botanicals in the Sikh community in London. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives* **19**(7) 633-42.
5. Babel S, Guptha R and Sachihar L 2018, Phytochemical Analysis of Plant Resources having Antimicrobial Properties Obtained from Aravali Hills of Rajasthan, India. *Int J Curr Microbiol App Sci*. **7**(3) 1121-5.
6. Ojha S, Goyal M and Chittoriya D 2021, Efficacy of Ocimum Sanctum against Alternaria Causing Diseases on Medicinal Plants. *Int J Sci Res in Biological Sciences* **8**(1).
7. Peng Y, Li SJ, Yan J, Tang Y, Cheng JP and Gao AJ 2021, Research progress on phytopathogenic fungi and their role as biocontrol agents. *Frontiers in Microbiology* **12** 670135.
8. Marín-Menguiano M, Moreno-Sánchez I, Barrales RR, Fernández-Álvarez A and Ibeas JI 2019, N-glycosylation of the protein disulfide isomerase Pdi1 ensures full Ustilago maydis virulence. *PLoS pathogens.* **15**(11).
9. Jain A, Sarsaiya S, Wu Q, Lu Y and Shi J 2019, A review of plant leaf fungal diseases and its environment speciation. *Bioengineered* **10**(1) 409-24.
10. Doehlemann G, Ökmen B, Zhu W and Sharon A 2017, Plant Pathogenic Fungi. *Microbiol Spectr* **5** (1). doi: 10.1128/microbiolspec. FUNK-0023-2016.
11. Williams SD, Boehm MJ and Mitchell TK 2008, Fungal and fungal-like diseases of plants. In: *OSU Fact Sheet (PP401.07), Agriculture and Natural Resources,* The Ohio State University, Ohio, USA. Accessed from: https://plantpath.osu.edu/http%3Aplantpath.osu.edu/mitchelllab/mitchell-publicaions
12. Sennblad B and Bremer B 1996, The familial and subfamilial relationships of Apocynaceae and Asclepiadaceae evaluated with rbc L data. *Plant Systematics and Evolution* **202** 153-75.
13. Dahlgren R1983, General aspects of angiosperm evolution and macrosystematics. *Nordic journal of botany*, **3**(1)119-49.
14. Cronquist A 1981, *An integrated system of classification of flowering plants.* Columbia University Press, New York, pp. 1262
15. Takhtajan A 1987, *Systema magnoliophytorum: Nauka,* **2** XLV *Springer Dordrecht*, p. 871 doi: https//doi.org/10.1007/978-1-4020-9609-9
16. Thorne RF 1992, An updated phylogenetic classification of the

flowering plants. *Aliso: A Journal of Systematic and Floristic Botany* **13**(2) 365-89.

17. Patil RH, Patil MP and Maheshwari VL 2023, Morphology, ecology, taxonomy, diversity, habitat and geographical distribution of the Apocynaceae family. In: *Apocynaceae Plants: Ethnobotany, Phytochemistry, Bioactivity and Biotechnological Advances.* (Eds.) Patil RH, Patil MP and Maheshwari VL Springer Singapore, pp. 1-11.
18. Ojha S and Goyal M 2019, Preliminary phytochemical screening of plant extracts prepared from traditional medicinal plants of Rajasthan. *Asian Journal of Research in Chemistry and Pharmaceutical Sciences* **7**(3) 819-23.
19. Ojha S and Goyal M 2024, Efficacy of organic and inorganic extracts of Nerium indicum against pathogenic fungi of Aegle marmelos. *Journal of Innovative Research in Technology* **10**(11) 1736 – 1743.
20. Arora A and Jain S 2018, Ethnomedicinal documentation of antimicrobial plants from south east Rajasthan, India. *The Journal of Phytopharmacology* **7**(2) 203-6.
21. Bharti D, Arora C and Gupta S 2012, Synergistic effect of antifungal activity of medicinal plants with transition metal ferrocyanides against Rhizoctonia solani. *Asian Journal of Chemistry* **24**(10) 4650.
22. Gupta S, Agrawal P, Rajawat R and Gupta S 2014, Antifungal and phytochemical screening of wild medicinal plant against fungal clinical isolates from dermatitis. *Am J Pharm Tech Res.* **4**(3) 754-66.
23. Jangid R 2020, Antimycotic Activity of Leaf Extracts of Medicinal Plants Against Dermatophytes. *Journal of Fungal Diversity* **1**(1) 33-40.
24. Jangid R and Begum T 2022, Antimycotic activity of some medicinal plants against *Mucor circinelloides*. *BioMed Research International* **2022**(1), 3523920. https://doi.org/10.1155/2022/3523920
25. Jangid R 2019, Antifungal Activity of leaf extracts of *Nerium indicum* against Pathogenic Fungi *Aspergillus* spp. *International Journal Science Research in Biological Sciences* **6**(3) 137-40.
26. Sharma P, Khandelwal S, Singh T and Vijayvergia R 2012, Phytochemical analysis and antifungal potential of *Duranta erecta* against some phytopatogenic fungi. *International Journal of Pharmaceutical Sciences and Research* **3**(8) 2686.
27. Jadon KS and Shah R 2012, Antifungal activity of different plant extracts against *Drechslera bicolor* causing leaf blight of bell pepper. *Archives of Phytopathology and Plant Protection* **45**(12) 1417-28.
28. Ojha S and Gouyal M 2017, First report of biocontrol of phytopathogen *Culvularia* in Emblica officinalis by plant extracts in Rajasthan. *Indo-American Journal of Pharmaceutical Research* **7**(8) 580-3.
29. Menghani E, Ojha C, Negi R, Agarwal Y and Pareek A 2011, Screening of Indian medicinal plants and their potentials as antimicrobial agents. *Global Journal of Science Frontier Research* **11**(2) 1-7.
30. Chittoriya D, Goyal M and Ojha S 2020, Analysis of phytochemical constituents of selected medicinal weed plants occurring in central region of Rajasthan. *Asian Journal of Research in Chemistry and Pharmaceutical Sciences* **8**(1) 72-77.
31. Jain S, Pancholi B, Singh R and Jain R 2010, Antibacterial and antifungal

potential of some arid zone plants. *Indian journal of pharmaceutical sciences* **72**(4) 510.

32. Balfour B 1889, Professor Heinrich Anton De Bary. *Transactions of the Botanical Society of Edinburgh*. **17** 350-354.
33. Bonfante P and Genre A 2010, Mechanisms underlying beneficial plant–fungus interactions in mycorrhizal symbiosis. *Nature communications* **1**(48) 1-11.
34. Priyashantha AH, Dai DQ, Bhat DJ, Stephenson SL, Promputtha I and Kaushik P 2023, Plant–fungi interactions: where it goes? *Biology* **12**(6) 809.
35. Li L, Zhu XM, Zhang YR, Cai YY, Wang JY and Liu MY 2022, Research on the molecular interaction mechanism between plants and pathogenic fungi. *International Journal of Molecular Sciences* **23**(9) 4658.
36. Rajendhran J, Yun Y, Tang W and Li Y 2023, Molecular mechanism in the development and pathogenesis of fungi. *Frontiers Media SA* **13**(4) 1231925.
37. Salvatore MM and Andolfi A 2021, Phytopathogenic fungi and toxicity. *Toxins* **13**(10) 689.
38. Freeman B and Beattie G 2008, An overview of plant defenses against pathogens and herbivores. *The Plant Health Instructor*. https://doi.org/10.1094/PHI-I-2008-0226-01
39. Mierziak J and Wojtasik W 2024, Epigenetic weapons of plants against fungal pathogens. *BMC Plant Biology* **24**(1) 175.
40. Saur IM and Hückelhoven R 2021, Recognition and defence of plant-infecting fungal pathogens. *Journal of Plant Physiology* **256** 153324.
41. Wilson SK, Pretorius T and Naidoo S 2023, Mechanisms of systemic resistance to pathogen infection in plants and their potential application in forestry. *BMC Plant Biology* **23**(1) 404.
42. Conrath U 2006, Systemic acquired resistance. *Plant signaling and behavior* **1**(4) 179-84.
43. Heil M and Bostock RM 2002, Induced systemic resistance (ISR) against pathogens in the context of induced plant defences. *Annals of botany* **89**(5) 503-12.
44. Nair SK, Prasanna BM, Garg A, Rathore R, Setty T and Singh N 2005, Identification and validation of QTLs conferring resistance to sorghum downy mildew (*Peronosclerospora sorghi*) and Rajasthan downy mildew (*P. heteropogoni*) in maize. *Theoretical and applied genetics* **110**(8) 1384-92.
45. Deep S and Sharma P 2012, Host age as predisposing factor for incidence of black leaf spot of cauliflower caused by *Alternaria brassicae* and *Alternaria brassicicola*. *Indian Phytopathology* **65**(1) 71-5.
46. Fagodiya R, Trivedi A, Fagodia B and Ratnoo R 2021, Prevalence and distribution of Alternaria leaf spot in soybean growing areas of Rajasthan. *Indian Journal of Agricultural Sciences* **91**(5) 699-702.
47. Sharma Y, Kant K, Solanki R and Saxena R 2013, Prevalence of cumin diseases on farmer's field: A survey of Rajasthan and Gujarat states. *Int. Journal of Seed Spices* **3**(2) 46-9.
48. Yadav G and Meena M 2021, Bioprospecting of endophytes in medicinal plants of Thar Desert: An attractive resource for biopharmaceuticals. *Biotech. Reports*, **30** e00629. https://doi.org/10.1016/j.btre.2021.e00629.
49. Maheshwari S, Choudhary B and Singh D 2013, Occurrence of fungal diseases

of bottle gourd in Rajasthan. *Progressive horticulture*, **45**(1) 206-8.
50. Khan I, Masood A and Ahmad A 2013, Mustard Leaf Spot Disease Caused by *Alternaria brassicae* and their Biocontrol. *Agrica* **2**(1-2) 27-51.
51. Singh S, Solanki R and Kakani R 2020, Pearl millet blast disease caused by *Pyricularia pennisetigena* in western arid Rajasthan, India. *Current Science* **119**(10) 1690-4.
52. Gade R and Lad R 2018, Biological management of major citrus diseases in Central India-a review. *Int J Curr Microbiol App Sci.* **2018(**6) 296-308.
53. Puttoo BL 2010, Seventeen Decades of Mycology and Plant Pathology in Jammu and Kashmir. *Indian Phytopathology*, **63**(2)117-121.
54. Bhargava K, Kashyap A, Gonsalves TA 2014, Wireless sensor network based advisory system for Apple Scab prevention. In: (2014) *Twentieth national conference on communications (NCC)*, Inst. Elect. Electr. Eng., Kanpur, India. pp. 1-6 https://doi.org/10.1109/NCC.2014.6811263
55. Bajpai S, Gupta M and Kumar S 1999, Identification of Indian landraces of opium poppy *Papaver somniferum* resistant to damping-off and downy mildew fungal diseases. *Journal of Phytopathology* **147**(9) 535-8.
56. Yadav M, Singh N, Singh S, Ahmad N and Godika S 2013, Assessment of prevalence and severity of Sclerotinia rot of Indian mustard in Rajasthan and Haryana. *Indian Journal of Plant Protection* **41**(3) 249-52.
57. Meena NL and Shah R 2014, Pathological and nutritional studies of *Phomopsis citri* causing fruit rot of Mandarin in Rajasthan. *Journal of Plant Disease Sciences* **9**(1) 1-7.
58. Kumari M, Sharma O and Singh M 2017, Collar rot (*Aspergillus niger*) a serious disease of groundnut, its present status and future prospects. *International Journal of Chemical Studies* **5**(4) 914-919.
59. Nair SK, Prasanna B, Rathore R, Setty T, Kumar R and Singh N 2004, Genetic analysis of resistance to sorghum downy mildew and Rajasthan downy mildew in maize (*Zea mays* L.). *Field crops research* **89**(2-3) 379-87.
60. Rao V, Thakur R, Rai K and Sharma Y 2005, Downy mildew incidence on pearl millet cultivars and pathogenic variability among isolates of *Sclerospora graminicola* in Rajasthan. *SAT eJournal* **46** 107-10.
61. Malhotra S, Kakani R, Sharma Y and Singh D 2016, Ajmer coriander-1 (NRCSS, Acr-1), resistant to stem gall disease-an innovative farming technology. *Indian Journal of Arecanut, Spices and Aromatic Crops* **18**(3) 3-7.
62. Gupta J 2011, Enzymes involved in phenol metabolism of gall and normal tissues of insect induced leaf galls on some economically important plants in Rajasthan India. *Bioscience Discovery* **2**(3) 345-7.
63. Mishra R and Pandey V 2017, Evaluation of coriander (*Coriandrum sativum* L.) genotypes for resistance to stem gall disease and seed yield. *Journal of Spices and Aromatic Crops* **26**(1) 224-229.
64. Khurana SP 2004, Potato diseases & crop protection scenario. *Journal Of The Indian Potato Association* **25**(1,2) 1-90.
65. Tsror L, Erlich O, Hazanovsky M and Lebiush S 2019, Control of potato powdery scab (*Spongospora subterranea*) in Israel with chloropicrin, metam sodium or fluazinam. *Crop Protection* **124** 104836.

66. Devendra KG 2024, Management of Yellow Rust of Wheat Caused by *Puccinia striiformis* f. sp. tritici Through New Generation Fungicides: MPUAT, Udaipur.
67. Singh DP, Kumar S and Kashyap PL 2020, Disease spectrum in wheat and Barley under different agro-ecological conditions in India and management strategies. In: *Diseases of field crops diagnosis and management* (Eds.) Shrivastava JN and Singh AK, Apple Academic Press, New York, pp. 57-79.
68. Dev D, Tewari A, Upadhyay P and Daniel G 2020, Identification and nomenclature of *Albugo candida* pathotypes of Indian origin causing white rust disease of rapeseed-mustard. *European Journal of Plant Pathology* **158**(4) 987-1004.
69. Gupta G, Gauttam S, Meena SK, Nagar R and Dogra P 2023, Productivity, White Rust and Alternaria Blight of Indian Mustard Influenced by Chemical Fungicide Seed Treatment under Humid Southeastern Agro-climatic Zone of Rajasthan, India. *Current Journal of Applied Science and Technology* **42**(5) 29-39.
70. Shekhawat PS and Majumdar V 2010, Effect of flag smut caused by *Urocystis agropyri* on yield components of popular wheat cultivars in Rajasthan. *Plant Disease Research* **25**(2) 139-43.
71. Shekhawat PS, Bishnoi SP and Ghasolia RP 2017, Disease spectrum on barley in Rajasthan and integrated management strategies. In: *Management of wheat and barley diseases*. (Es.) Singh DP. Apple Academic Press, New York, pp. 467-503
72. Maheshwari S, Choudhary B, Haldhar S and Berwal M 2022, Effectiveness of botanicals, inorganic salts and fungicide against Fusarium wilt of muskmelon under hot arid region of Rajasthan. *J. of Agri. and Eco.* **14** 21-5.
73. Kumari P, Godika S, Geat N and Pandia S 2020, Ergot of bajra and its management. *Journal of Pharmacognosy and Phytochemistry* **9**(2) 274-7.
74. Tooley PW, Carras MM, Sechler A and Rajasab AH 2010, Real-time PCR detection of sorghum ergot pathogens *Claviceps africana*, *Claviceps sorghi* and *Claviceps sorghicola*. *Journal of phytopathology* **158**(10) 698-704.