Review Article

ISAH Indian Journal of Arid Horticulture
Year 2024, Volume-6, Issue-1 (January - June)

Aonla rust, its causes, epidemiology and management- A review

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ARTICLE INFO

Received: 09 November 2024
Accepted: 30 December 2024

Keywords: Aonla, Rust, Epidemiology, Fungal Disease, Crop Management

doi:10.48165/ijah.2024.6.1.1

ABSTRACT

Aonla or Indian Gooseberry is an important fruit crop grown in the Indian sub-continent, celebrated for its exceptional nutritional and rejuvenating properties and highly valued in Unani and traditional Indian medicine for its medicinal benefits. However, Aonla rust caused by the fungus *Ravenelia (Phakopsora) emblicae*, poses significant threat to productivity of this fruit crop as it can severely impact crop yield and quality, leading to economic losses for farmers. This fungal disease thrives in warm, humid conditions and is exacerbated by factors such as improper planting density and poor water management. The effects of Aonla rust include reduced fruit production, lower fruit quality, and overall tree health decline, ultimately affecting the economic viability of Aonla farming. Effective management of Aonla rust involves a combination of cultural practices, chemical treatments, use of bioagents and the use of resistant varieties. The common chemical treatment interventions involve foliar application of wettable sulphur / Mancozeb 75 WP/ Chlorothalinil @ 0.2% and Copper oxychloride 50 WP @ 0.3% at 10-12 days' intervals starting in August. Bio-agents such as *Trichoderma harzianum* and *Pseudomonas fluorescens* and organic pesticides like neem oil, NSKE, and neem leaf extract have also been proven effective in disease control. Strategies such as proper spacing, pruning, and the application of fungicides are essential in disease management. Additionally, the development and use of rust-resistant Aonla varieties is crucial for sustainable production. Ongoing research and integrated disease management approaches will be key to mitigating the impact of Aonla rust and ensuring the continued success of Aonla cultivation.

Introduction

Emblica officinalis Gaertn. or *Phyllanthus emblica* L. is commonly known as Indian Gooseberry or Aonla which thrives in the tropical and subtropical regions of India, China, Indonesia, Myanmar, Sri Lanka, and the Malay Peninsula (Benthal, 1946; Liu *et al.,* 2008; Macmillan, 1943; Perianayagam *et al.,* 2005; Thakur *et al.,* 1988). Additionally, it has been reported to grow naturally in other parts of the world, including Cuba, Puerto Rico, Iran, Iraq (Hooper and Field, 1937), Hawaii, Florida (Barrett, 1956; Sturrock, 1959), Java, the West Indies, and Trinidad (Webster, 1956). India

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holds the top position globally in terms of both the area dedicated to Aonla cultivation and its production. It is grown at an estimated area of 100,000 ha with an annual production of 12.06 lakh tonnes (National Horticulture Board, 2022). In India, the plant is found abundantly in northeastern states such as Mizoram, Tripura, and Assam, particularly in the Khasi and Garo hills of Meghalaya (Pandey *et al.,* 1993). Intensive cultivation, however, is primarily concentrated in Uttar Pradesh, especially in the districts of Pratapgarh, Azamgarh, Varanasi, and Jaunpur (Bajpai and Shukla, 2002). Other states, including Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Jharkhand, Chhattisgarh, Bihar, West Bengal, Orissa, Andhra Pradesh, Karnataka, Haryana, and Himachal Pradesh, also cultivate Indian gooseberry (Chandra and Singh, 2015; Rawat and Uniyal, 2003).

Aonla is a significant minor crop in India and belongs to the family Euphorbiaceae (Kumar and Sagar, 2009). Although, it is classified as an underutilized crop (Scartezzini *et al.,* 2006), such crops have the potential to enhance national food security (Mayes *et al*., 2012). This plant is adaptable to various soil types, ranging from sandy loam to clay, and thrives in arid and semi-arid regions. Its cultivation is beneficial for farmers, as it grows well even on marginal lands. It is known for its numerous health benefits and is frequently used in Ayurveda and Unani medicine (Pathak, 2003). It is particularly noted for its high vitamin C content, which is about 20 times greater than that of orange (Tarwadi and Agte, 2007). Aonla juice, being highly acidic, helps protect the vitamin C from degradation during heating or drying (Hassan *et al.,* 2014). Ascorbic acid in Indian gooseberry acts as an antioxidant due to its ability to scavenge free radicals (Cort, 1982). However, besides ascorbic acid, Indian gooseberry is rich in polyphenols such as ellagic acid, gallic acid, and hydrolysable tannins (including Emblicanin A, Emblicanin B, punigluconin, and pedunculagin), which also contribute significantly to its antioxidant properties (Bhattacharya *et al.,* 1999; Ghosal *et al.,* 1996). Research by Ihantola-Vormisto *et al.* (1997) has shown that Indian gooseberry possesses anti-inflammatory and antipyretic properties. Tasduq *et al.* (2005) and Reddy *et al.* (2010) have demonstrated hepatoprotective activity of Aonla fruit by using its 50% hydroalcoholic extract and 5% aqueous extracts respectively. The fruit's anti-tumor properties are largely attributed to its polyphenolic compounds, particularly tannins and flavonoids. For instance, pyrogallol extracted from Indian gooseberry has been shown to have an anti-proliferative effect on human lung cancer cell lines (Yang *et al.,* 2009), while gallic acid from its leaves induces apoptosis in human hepatocellular carcinoma cells (Huang and Zhong, 2011). Additionally, extracts from *E. officinalis* fruits inhibit the transcription factor AP1 and disrupt the expression of viral oncogenes, which may prevent the development and progression of cervical cancer, making the fruit a potential source for drug development against Human Papilloma Virus (HPV)-induced cervical cancer (Mahata *et al.,* 2013). Beyond these properties, Indian gooseberry also exhibits hypolipidemic (Thakur and Mandal, 1984; Yokozawa *et al.,* 2007), hypoglycemic (Jamwal *et al.,* 1959; Liu *et al.,* 2012), and analgesic effects (Perinayagam *et al.,* 2004). In India, popular commercial cultivars include 'Banarasi,' 'Francis,' 'Chakaiya,' 'Kanchan (NA-4),' 'NA-6,' and 'NA-7' (Pathak, 2003; Scartezzini *et al.,* 2006). The cultivated area in India under Aonla variety "NA-7" spans about 85% of total cultivated area. Pakistan cultivates the 'Desi,' 'Shisha,' and 'Banarasi' varieties, while in China, cultivars such as 'Langen,' 'Fen'gan,' 'Liuyuebai,' 'Bian'gan,' 'Quibai,' and 'Shan'gan' are prevalent. Indian gooseberry is commonly processed into products like pickles, candy, Murabba (whole fruit preserve), juices, mouth fresheners, and fruit leathers, which have substantial economic value (Bhattacherjee *et al.,* 2011; Daniel and Dudhade, 2010; Nath and Sharma, 1998). It serves as the main ingredient in Chyavanprash, a popular Ayurvedic preparation, with the Chyavanprash industry in India valued at Rs 200 crore, involving both large companies and small-scale producers. Due to the fruit's sour and astringent taste, it is typically consumed in processed forms rather than raw. However, the cultivation of Indian gooseberry faces challenges, notably from Aonla rust, a significant disease caused by the fungus *Ravenelia emblicae*, which affects the leaves, stems, and fruits of the plant. This disease can lead to severe yield losses, with reports indicating up to a 50% reduction in fruit yield under severe infection. It also impacts fruit quality, reducing its market value and overall profitability for farmers.

Aonla can be grown in light as well as heavy soils except purely sandy soil. Calcareous soil with rocky substratum also promotes Aonla growth. The Aonla plant thrives in well-drained, fertile loamy soil, which is ideal for achieving higher yields. It is adaptable to dry regions and can also grow in moderately alkaline soils. It can be grown in acidic to saline/ sodic (pH up to 9.5, ESP-35 and ECe-6-9 ds/m) soils (Pathak and Pathak, 2001). Although, it is considered a subtropical fruit, it can be cultivated successfully in tropical climates as well. Annual rainfall of 630-800 mm has given good yields. In India, Aonla is cultivated in a wide range of altitudes, including areas near the sea coast up to an altitude of 1800 meters (Pathak, 2003). Mature Aonla tree can tolerate freezing as well as high temperature of 48° C, but the plants are susceptible to frost in winter and sometimes heavy damage occurs owing to frost in hot arid ecosystem of western part of Rajasthan (Pathak *et al.,* 2006). After fruit set in spring, the fruits remain dormant throughout summer without any growth. This quality makes it highly suitable fruit crop for dry arid region.

This review synthesizes the current knowledge on Aonla rust and highlights the importance of continued research and extension efforts to support Aonla growers in managing this devastating disease.

Major diseases of Aonla

Aonla is considered a hardy crop but there are few important diseases, which create quantitative as well as qualitative losses in fruit yield of Aonla. Among them, rust (*Ravenalia emblica*e Styd.), anthracnose (*Colletotrichum* state of *Glomerella cingulata*) (Mishra and Shivpuri, 1983), dieback (*Botrydiplodia theobromae* Pat.) (Arya *et al.*, 1987), blue mould (*Penicillium citrinum*). Losses of Aonla during storage are considerable mainly due to sprouting and contamination by microorganisms. Rajam (1992) reported that among the post-harvest disease of Aonla in India, sooty mould (*Capnodium sp*.), fruit rot (*Penicillium indicum, P. oxalicum, Aspergillus niger*), soft rot (*Phomopsis phyllanthi* Punith), black soft rot (*Syncephalastrum racemosum*) are important diseases which cause heavy loss to the growers (Singh *et al.*, 2010). Rust disease, anthracnose and post-harvest diseases are major constraints in its crop production in some parts of Uttar Pradesh and Rajasthan states. In other countries like China, the brown spot, false anthracnose and powdery mildew have been reported widely.

Etiology, occurrence and distribution of Aonla rust

Aonla rust is a significant and economically detrimental disease affecting Indian gooseberry (*Phyllanthus emblica*). The primary pathogen responsible for this disease is *Ravenelia emblicae*, a biotrophic, obligately parasitic, fungus that depends on living host tissue for its growth and reproduction. This pathogen poses a serious threat to Aonla cultivation not only in Uttar Pradesh but also in other major Aonla-producing states such as Rajasthan, Andhra Pradesh, Tamil Nadu, and Haryana. The disease was first identified and reported in Rajasthan, India in 1967 (Tyagi, 1967) and has since been observed in various regions across India, causing substantial losses to growers (Tyagi, 1967; Rawal, 1993). Aonla rust requires living host for causing infection and establishment under favourable conditions. It causes fruit and leaf infection leading to significant fruit losses.

Disease symptoms and development

The initial symptoms of Aonla rust include the appearance of small, circular, orange-brown pustules on the upper surface of the leaves. As the disease progresses, these pustules enlarge, reaching sizes of 3-4mm, and may turn the leaves yellow or red. In some cases, the pustules also develop on green leaves. On fruits, the disease manifests as brown to black pustules that often arrange themselves in a ring. Over time, these pustules coalesce, covering larger areas of the fruit surface, which can significantly reduce the marketability of the produce (Tyagi and Pathak, 1988; Jat and Goyal, 2004; Jarial *et al.,* 2011; Prakash and Misra, 1993).
Interestingly, it has been noted that severe infections on fruits do not always coincide with symptoms on leaves, and vice versa, indicating a complex disease dynamic (Tyagi, 1967). This variability in symptom expression can complicate early detection and management efforts.

Pathogen biology and disease cycle

The genus *Ravenelia* is one of the largest (third) genera of the order Pucciniales. The genus is global in distribution and species are reported to infect different plants. With the discovery of type species, more than 250 described species are widely distributed in subtropical and tropical regions (Cummins 2003; Ebinghaus, 2020). It parasitizes the trees and bushes of families Fabaceae and Euphorbiaceae with high host specificity towards Mimosoideae, Faboideae and Caesalpinioideae (Fabaceae). The genus was introduced in the year 1853 by Berkeley; over time, the genus has undergone several taxonomic and systematic transformations. However, all species of *Ravenelia* shared the most prominent morphological features including the production of multicellular teliospores on compound pedicels composed of two to several hyphae with autoecious and macro- and demi- to hemi-, and, more rarely, to microcyclic modes of their life cycle. With the addition of many species in recent years, this genus has become one of the largest genera of rust fungi (Avasthi *et al.* 2024).
Ravenelia emblicae primarily infects the leaves of the Aonla plant, where it forms characteristic rust pustules. These pustules contain uredospores, which are dispersed by wind, facilitating the spread of the disease (Fig. 1). The infection process begins when the uredospores land on the leaf surface and germinate, leading to the formation of specialized structures called appressoria. These appressoria penetrate the epidermal cells of the leaf, establishing the infection and leading to the development of new rust pustules (Fig. 1). As the cycle continues, new uredospores are released from the pustules, causing secondary infections throughout the growing season. The disease thrives in warm and humid conditions, particularly during the onset of the rainy season. Such environmental conditions are ideal for the pathogen's sporulation and dissemination, leading to widespread outbreaks (Raj and Arya, 2005).
Two distinct types of rust have been identified on Aonla plants (Jansen and Cardon, 2005). The first type is leaf rust, caused by *Phakopsora phyllanthi*, and the second is ring rust, caused by *Ravenelia emblicae*. The rust caused by *Ravenelia emblicae* was first documented on Aonla in Saharanpur, Uttar Pradesh, by Nirwan *et al*., 1969-1971. This disease has since been recognized as a significant issue in traditional Aonla varieties in Rajasthan, particularly in the Udaipur district, and has also been reported in other regions,

including Lucknow and Pratapgarh in Uttar Pradesh (Pathak *et al.*, 2003; Singh and Mishra, 2007). *Ravenelia emblicae* has been associated with substantial losses in key Aonla-growing areas of Uttar Pradesh (Rawal, 1993). While both *Phakopsora phyllanthi* and *Ravenelia emblicae* have been reported in various major Aonla cultivation regions across India (Pathak *et al.*, 2003; Singh and Mishra, 2007; Rawal, 1993), there has yet to be a report of *Phakopsora phyllanthi* affecting Aonla in Himachal Pradesh.

Ravenelia emblicae is a biotrophic fungus, meaning it depends on living host tissue for its growth and reproduction (Smith *et al.*, 2019). The fungus primarily targets the leaves of its host, where it forms characteristic rust pustules (Jones and Brown, 2021). These pustules house uredospores, which are dispersed by wind, thereby spreading the disease (Doe and Lee, 2020). The disease cycle begins when uredospores germinate on the leaf surface, leading to the formation of appressoria, which penetrate the leaf's epidermal cells (Miller *et al.*, 2018). This process establishes the infection, resulting in the development of rust pustules (Taylor and Green, 2022). The cycle continues as new uredospores are produced and released, leading to secondary infections throughout the growing season (Nguyen and Patel, 2023).

Epidemiology and environmental factors

Aonla rust, caused by *Ravenaliia emblicae*, is significantly influenced by various environmental factors, which play a critical role in the disease's development and spread. Understanding these factors is crucial for effective disease management. The onset of the rainy season typically marks the beginning of Aonla rust outbreaks. This period is characterized by warm and humid conditions, which are ideal for the pathogen's development. Specifically, high humidity levels combined with moderate temperatures ranging between 20-25°C provide an optimal environment for the pathogen to thrive (Raj and Arya, 2005; Saharan and Meena, 2001). During this period, the fungus sporulates,

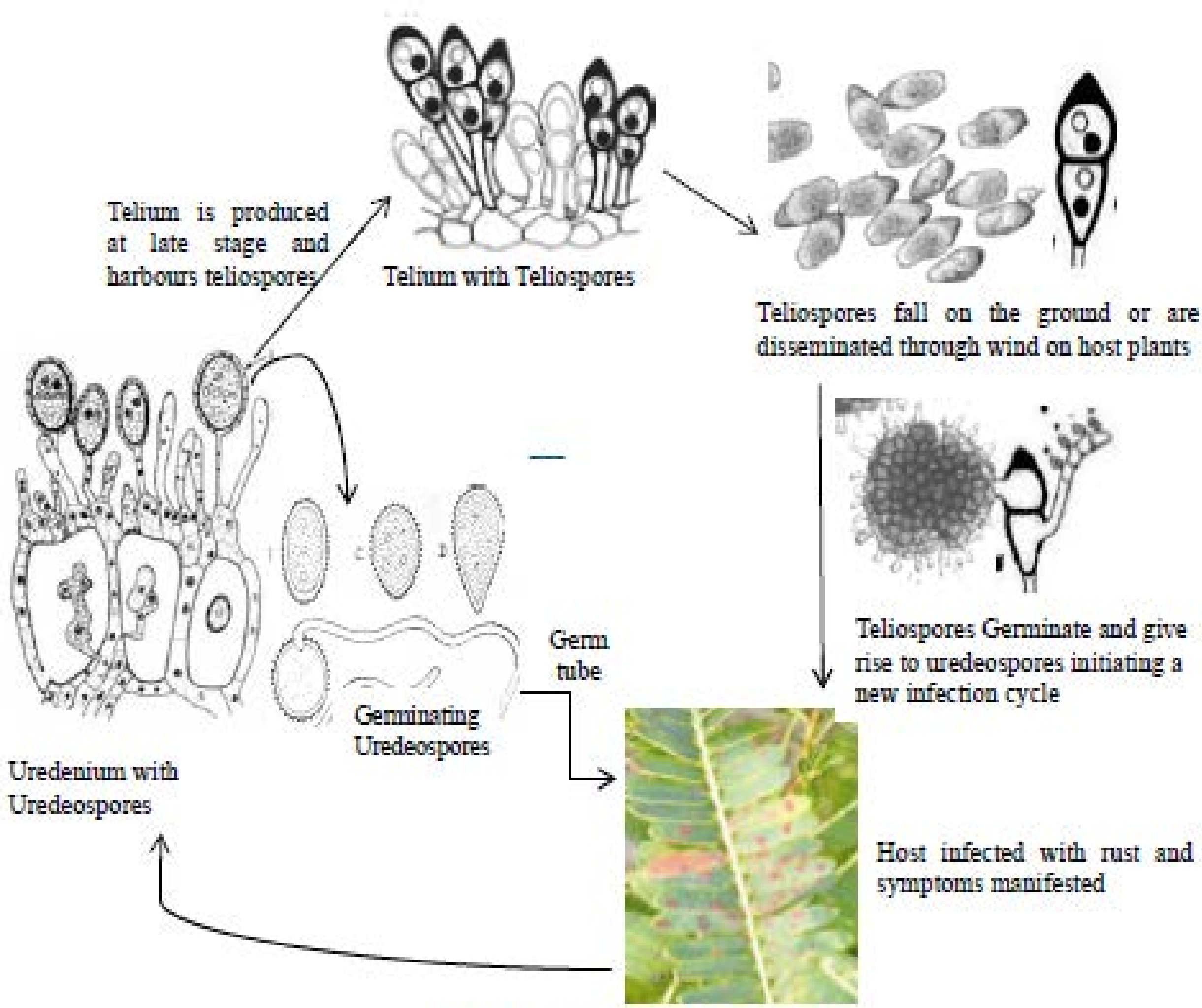

Fig. 1. Disease cycle of Aonla Rust

producing uredospores that are capable of infecting the host plant. The high humidity helps maintain the moisture on leaf surfaces, which is necessary for the germination of these spores and subsequent infection.

Rainfall is another critical factor in the epidemiology of Aonla rust. It aids in the dispersal of uredospores, which are carried by raindrops and wind to new infection sites. Additionally, rainfall creates a favorable microclimate by increasing humidity and reducing evaporation, which are essential conditions for the pathogen's life cycle. However, while rainfall promotes the spread of the disease, it also presents a challenge for disease management, as it can wash away protective fungicide sprays applied to the crop, necessitating more frequent applications.

Correlation studies have provided further insights into how different environmental factors correlate with the severity of Aonla rust. For instance, temperature (both maximum and minimum) and evaporation have been found to have a highly significant negative correlation with the percent disease index (PDI) (Pandey *et al.,* 2007; Anonymous, 2002-03). This means that higher temperatures and greater evaporation rates are associated with lower disease severity. This could be due to the fact that higher temperatures and increased evaporation lead to drier conditions, which are less favorable for the pathogen's survival and infection processes. On the other hand, relative humidity, particularly in the evening, and rainfall have shown a significant positive correlation with PDI. High relative humidity in the evening can prolong the leaf wetness period, providing the necessary conditions for spore germination and infection. Similarly, increased rainfall not only aids in spore dispersal but also sustains the high humidity levels needed for the disease to proliferate. These findings highlight the importance of monitoring environmental conditions to predict disease outbreaks and implement timely control measures.

The significance of these correlations is underscored by studies conducted by Kumar *et al.,* 2023; Kumar *et al.,* 2024; Devi *et al.,* 2022; Sharma, 2020; Singh *et al,.* 2015; Mitra *et al.,* 2011. Singh *et al.* (2023) spray prediction model for Aonla rust disease using machine learning techniques can be used to predict weather the weather conditions of a particular day- minimum temperature, maximum temperature, morning relative humidity, evening relative humidity, rainfall and sunshine hours, are conductive or non-conductive for growth of rust disease in Aonla plants which further confirm the strong relationship between environmental factors and Aonla rust incidence. These studies emphasize the need for an integrated disease management approach that takes into account the prevailing weather conditions. For instance, in regions where high humidity and moderate temperatures are expected during the rainy season, preventive measures such as timely fungicide applications and the use of resistant cultivars should be prioritized.

Management strategies

Aonla rust, caused by *Ravenalia emblicae*, is a significant disease that can result in substantial yield losses for growers (Singh *et al.,* 2010). Several management practices have been studied and found effective in controlling this disease.

Chemical control

The application of fungicides is a common approach to managing Aonla rust. Sprays of wettable sulphur (0.2%) or Mancozeb 75 WP (0.2%) have been shown to effectively manage rust disease when applied at intervals of 10-12 days, starting in early August (Singh *et al.,* 2009; Singh *et al.,* 2014). Additionally, Copper oxychloride 50 WP at a 0.3% concentration, combined with deep ploughing and healthy cultivation practices, has been found beneficial in controlling the disease (Singh *et al.,* 2009, Singh *et al.,* 2014). Chlorothalonil, applied at 0.2% concentration, resulted in the minimum disease severity (5.80%) and the maximum percentage of disease control (71.80%). A combination of 1% *Trichoderma viride* and 0.1% chlorothalonil also showed significant effectiveness, with a disease severity of 8.82% and disease control of 57.12%, along with a significant increase in fruit yield compared to other treatments (Jat *et al.,* 2013; Kumar *et al.,* 2017; Maheshwari and Haldhar 2018).

Integrated management approaches

Singh *et al.* (2023) explored the efficacy of different fungicides, bioagents, and organic pesticides in managing Aonla rust. The study evaluated mancozeb (0.2%), copper oxychloride (0.3%), wettable sulphur (0.2%), *Trichoderma harzianum* (1%), *Trichoderma viride* (1%), *Pseudomonas fluorescens* (1%), neem oil (0.5%), neem seed kernel extract (NSKE) (5%), and neem leaf extract (5%) on Aonla cultivars NA-7 and Chakaiya. Amongthem, mancozeb (0.2%) was the most effective, showing the highest reduction in disease intensity over control, followed by copper oxychloride (0.3%) and wettable sulphur (0.2%).

Bio-agents and organic pesticides

Bio-agents such as *Trichoderma harzianum* and *Pseudomonas fluorescens* also showed promising results in reducing disease intensity, although they were slightly less effective than chemical fungicides. Organic pesticides like neem oil, NSKE, and neem leaf extract had a moderate impact on disease control, with neem oil being the most effective among them. However, water treatment was found to be the least effective Singh *et al.,* 2009; Singh *et al.,* 2010; Singh *et al.,* 2014; Jat *et* *al.*, 2013; Singh *et al.*, 2023; Kumar and Singh, 2000; Devi *et al.*, 2022; Singh *et al.*, 2015).

Future aspects of Aonla rust management

Development of disease-resistant varieties

- **Ongoing research:** Significant research efforts are focused on breeding Aonla varieties with genetic resistance to Aonla rust. Advances in molecular biology and genetic engineering offer the potential to develop varieties that are inherently resistant to rust, thereby reducing the need for chemical treatments and increasing sustainability in Aonla cultivation (Mawalagedera *et al*., 2016; Gantait *et al*., 2021).
- **Biotechnological approaches:** Techniques such as marker-assisted selection (MAS) and CRISPR/Cas9 gene editing are being explored to identify and manipulate genes responsible for disease resistance. These tools can accelerate the development of resistant varieties and ensure long-term protection against Aonla rust (Thilaga *et al*., 2017).

Climate change and disease dynamics

- **Impact of climate change:** Climate change is expected to alter the epidemiology of Aonla rust by affecting the environmental conditions that favor its spread. Warmer temperatures and changes in precipitation patterns could lead to more frequent and severe outbreaks. Understanding these dynamics will be crucial for developing adaptive management strategies (Prajapati *et al*., 2020; Kumar *et al*., 2024)
- **Predictive modeling:** Future research may focus on predictive modeling to anticipate Aonla rust outbreaks based on climatic data. Such models could help farmers take preemptive actions, such as adjusting planting schedules or applying preventive treatments at optimal times (Singh *et al*., 2023; Kumar *et al*., 2024; Agarwal *et al*., 2023; Prema *et al*., 2023.)

Extension and farmer education

- **Capacity building:** The future of Aonla rust management also depends on effective extension services that educate farmers on the latest research and best practices. Building capacity among farmers through training programs and access to timely information will be essential for the widespread adoption of new technologies and approaches.
- **Digital tools:** The use of digital tools, such as mobile apps and online platforms, to disseminate information about disease identification, management practices, and weather forecasts could become more prevalent. These tools can empower farmers to make informed decisions and respond quickly to disease threats (Bhattacharyya *et al*., 2021).

Conclusion

Aonla rust is significantly influenced by various environmental factors including high humidity levels combined with moderate temperatures ranging between 20-25°C and reduction in evaporation at the onset of rainy season. Fungal uredospores are carried by raindrops and wind to new infection sites. Different environmental factors correlate with the severity of Aonla rust. Temperature and evaporation have been found to have a highly significant negative correlation with the percent disease index. Higher temperatures and greater evaporation rates are associated with lower disease severity. Aonla rust remains a significant challenge to its cultivation, but advancements in research and management practices offer hope for better control. Integrated approaches that combine cultural, chemical, and biological methods, along with the development of resistant cultivars, are key to sustainably managing this disease. The common disease control treatment interventions involve foliar application of Chemicals such as wettable sulphur, Mancozeb, Chlorothalinil and Copper oxychloride; Bio-agents such as *Trichoderma harzianum* and *Pseudomonas fluorescens* and organic pesticides like neem oil, NSKE, and neem leaf extract. Strategies such as proper spacing, pruning, and the application of fungicides have been proven beneficial in disease management. Additionally, the development and use of rust-resistant Aonla varieties is crucial for sustainable production.

Acknowledgements

The authors sincerely express their heartfelt gratitude to the authorities of Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.), for their invaluable support and encouragement in compiling this information.

Conflict of Interest

The authors have no conflict of interest.

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