Environment and Ecology 42 (3B) : 1342—1348, July—September 2024
Article DOI: https://doi.org/10.60151/envec/YWFG7533
ISSN 0970-0420

Epidemiological Studies on Aonla Rust: A Novel Weather-Based Model for Predicting *Ravenelia emblicae* Styd. Infection in Aonla Fruits

Jitendra Kumar, H. K. Singh, Abhishek Singh, Shubham Patel, Vishwa Vijay Raghuvanshi

Received 21 December 2023, Accepted 6 July 2024, Published on 4 September 2024

ABSTRACT

The present investigation on cultivar NA-7 proposed under natural conditions during first appearance of the disease at 35th standard meteorological week (date of 2nd September), the minimum per cent disease intensity was observed (0.33%) and maximum 43.33% during 52 standard meteorological weeks when the corresponding to weather parameters viz., temperature maximum 19.2 ^{0}C, minimum 7.1 ^{0}C, relative humidity morning 90.2% and evening 58.5%, rainfall 0.0 mm, evaporation 3.4 mm, and sunshine 3.8 hrs/day were convenient for the growth, initiation and escalation of Pathogen. Further investigations on the correlation of each individual parameter with the development and progress of the disease. Revealed that minimum temperature was recorded negatively correlated highly significant (-0.96) with per cent disease intensity, followed by maximum temperature (-0.94), evening relative humidity (-0.78) and evaporation (-0.82), whereas morning relative humidity (-0.50) and rainfall (-0.48) were found significant negative correlation with PDI. Sunshine (0.14) was observed positive correlation non-significant with PDI. The highest infection rate in 36th standard meteorological week which is amount of 0.206 and lowest infection rate was found 41th standard meteorological week which was 0.006. The AUDPC values ranged from 1.16 to 295.96, indicating a rapid progression of the disease.

Keywords Epidemiology, AUDPC, Infection rate, Prediction model, Correlation.

INTRODUCTION

Aonla, also known as Indian gooseberry (*Emblica officinalis* Gaertn.), holds significant importance as a traditional and underutilized fruit of Indian origin. It belongs to the family Euphorbiaceae and includes about 350 to 500 species and sub-family Phyllanthaceae. The fruit is highly nutritious and it is the next richest source of vitamin C among fruits after Barbados cherry. It has edible fruit tissues that contain approximately three times more protein and 160 times more vitamin C compared to apples. Aonla trees produce two types of shoots: Long or indeterminate, and short or determinate. The dried fruit of aonla is used to treat various health conditions, including haemorrhage, diarrhea, chronic dysentery, diabetes, jaundice, dyspepsia, and cough. It is a key ingredient

Jitendra Kumar[1], H. K. Singh[2]*, Abhishek Singh[3], Shubham Patel[4], Vishwa Vijay Raghuvanshi[5]

[2]Professor
[1,2,4,5] Department of Plant Pathology, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya 224229, (UP), India

[3]Assistant Professor
School of Agricultural Sciences, Career Point University Kota 325003, Rajasthan, India

Email: hksndu@gmail.com
*Corresponding author

in popular Ayurvedic medicines like chavanprash and triphla. Aonla holds promising potential as a future fruit due to its high medicinal and nutritional value, productivity per unit area, and adaptability to grow in wastelands and salt-affected soils. India is the leading country in both the area under aonla cultivation and its production. However, aonla trees can also be found growing naturally in other regions such as Sri Lanka, Cuba, Puerto Rico, USA (Hawaii and Florida), Iran, Iraq, Pakistan, China, Malaysia, Bhutan, Thailand, Vietnam, Philippines, Trinidad, Panama, and Japan. The fruit has vast possibilities for processing and value addition since it is not usually consumed fresh or in its raw state due to its high acidity and astringent taste. The information on different aonla species and their status of prevalence in different parts of the world, particularly in South and Southeast Asia. In India, the major states where aonla is grown include Uttar Pradesh (UP), Maharashtra, Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, Karnataka, Haryana, Punjab, and Himachal Pradesh. Among these, Uttar Pradesh has one of the oldest commercial plantations, dating back to 1936, located in Pratapgarh. Remarkably, this plantation is still in production, showcasing the longevity and success of aonla cultivation in the region. Several investigators have determined the efficacy of aonla as an anti-atherosclerotic, antidiabetic, antimutagenic and anticancer agent. Various parts of the aonla plant, including the root bark, stem bark, leaves, fruits, and seeds, possess medicinal properties. The extract from the Emblica fruit has demonstrated antioxidant properties, particularly its aqueous extract, which is effective in inhibiting lipoid peroxidation and scavenging hydroxyl and superoxide radicals *in vitro.* Rust is a significant and economically important disease affecting aonla plants. A maximum disease incidence of 21% was noted in the last week of December and the development was higher when relative humidity increased and temperature decreased. The fruits exhibit the development of black pustules, which gradually form a ring pattern. As the disease progresses, numerous pustules merge, covering a substantial portion of the fruit surface. Initially, these pustules are covered by a papery layer, but as they mature, the covering ruptures, revealing black spores. Aonla rust is caused by an obligate parasite (*Ravenelia emblica* Syd.), which requires the live host for infection and establishment under favorable conditions. For effective control of aonla rust, integrated approaches that combine multiple methods should be adopted. These approaches encompass cultural methods, chemical control, and the use of resistant cultivars. Clean cultivation practices are crucial, and infected fruits and leaves should be collected and properly disposed of Additionally, appropriate pruning techniques to maintain optimal canopy density and prevent humidity buildup can significantly reduce the incidence and intensity of the pathogen's infection. By integrating these strategies, a comprehensive and sustainable approach can be achieved for managing aonla rust.

MATERIALS AND METHODS

The experiment was conducted to know the impact of weather parameters on aonla rust epidemic. Simultaneously, Meteorological data on temperature °C (minimum and maximum), relative humidity % (morning and evening). Rainfall (mm), sunshine (hrs) wind velocity and evaporation were also recorded for the intervening period between two consecutive disease intensity data recorded and bivariate correlation analysis was conducted to determine the effect of individual as well as combine weather factor on disease development. Meteorological parameters were recorded from Department of Agriculture Meteorological Observatory located at ANDUA and T., Kumarganj, Ayodhya, (UP), India. Three plants unit of cultivar NA-7 with three replications, each were tagged randomly before initiation of the disease and the data on per cent disease intensity (PDI) was recorded at weekly intervals for starting with appearance of disease form 1^{st} week of September to 4^{th} week of December 2022. Correlation and regression coefficient between per cent disease intensity and weather parameter were calculated by followings formula as described by Gomez and Gomez (1984). The correlation coefficient ranges from -1 to +1, indicating the strength and direction of the relationship between variables. Regression lines have been created based on the data. Weekly disease severity was assessed using a scale of 0 to 5 points after the appearance of aonla rust. The disease-infected fruits were classified into six different categories based on their incidence levels.

Plate 1. Infected aonla leaves.

Plate 2. Infected aonla fruits.

The first appearance of the disease was recorded. The initial symptoms were observed (Plates1–2) and recorded for further investigation. The per cent intensity of the disease was calculated by observing the symptoms on the leaves of the infected plant. The disease rating was done on the basis of 0-5 standard evaluation scale (SES) given by McKinney (1923) (Table 1). The per cent disease intensity was calculated by using the following formula given by McKinney (1923).

$$\text{Per cent disease intensity} = \frac{\text{Sum of all numerical ratings}}{\text{Total no. of leaves examined} \times \text{Highest rating}} \times 100$$

Disease prediction model

The regression values were also recorded to find out the effect of single as well as combination of different meteorological factors on disease development. Disease prediction equation for aonla rust:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots\ldots + b_n X_n$$

Apparent infection rate of aonla rust

The rate of infection was calculated by using the following formula given by van der Plank (1963).

$$r = 2.3 / (t_2 - t_1) \log10 X_2/X_1$$

Where,

r = Rate of infection
$t_2 - t_1$ = Time interval
X_2 = Disease at time t_2
X_1 = Disease at time t_1

Table 1. Aonla rust disease rating scale McKinney (1923).

Sl. No.	Grade	Infection/ leaves area covered (%)
1	0	No infection (Healthy fruits)
2	1	1-10% fruit/leaves area covered
3	2	10.1-25% fruit/leaves area covered
4	3	25.1-50% fruit/leaves area covered
5	4	50.1-75% fruit/leaves area covered
6	5	75.1-100% fruit/leaves area covered

Area under disease progress curve (A-value)

The disease progression was recorded on weekly basis.The effect of disease on cultivar NA-7 was recorded in the form of Area Under Disease Progress Curve (AUDPC) is a useful quantitative summary of disease intensity over time.

The trapezoidal method is the most employed technique for estimating the Area Under the Disease Progress Curve (AUDPC). It involves examining the time variable (hours, days, weeks, months, or years) and computing the average disease intensity between each pair of consecutive time points. It is given by following formulas suggested by Madden *et al.* (2007).

$$AUDPC=\sum_{i=1}^{n-1}\frac{y_i+y_{i+1}}{2}X\,(t_{i+1}-t_i)$$

Where,

y_i =An assessment of a disease at the i^{th} observation
t_i = Time (in days, hours) at the i^{th} observation
n = The total number of observations

RESULTS AND DISCUSSION

The present study was conducted to investigate or examine the weather parameters that influence the development of the aonla rust in its natural conditions.

Disease development of aonla rust in relation to weather parameters

An observation of the data presented in Table 2 and

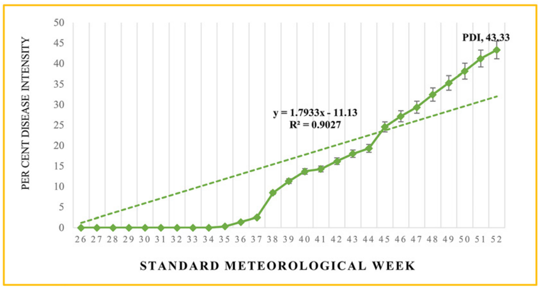

Fig. 1. Meteorological weeks and per cent disease intensity on aonla rust cultivar NA-7.

embellished in Fig. 1. exposed that the susceptible cultivar NA-7 proposed under natural conditions during first appearance of the disease at 35^{th} standard meteorological week (date of 2^{nd} September), the minimum per cent disease intensity was observed (0.33%) when the corresponding to temperature maximum 33.7 ^{0}C and minimum 25.5 ^{0}C, relative humidity morning 86.4% and evening 70.5%, and rainfall (mm), evaporation (mm), sun shine (hrs/day) were 18.8 mm, 4.8 mm, and 4.0 hrs/day, respectively. The maximum per cent disease intensity 43.33 % was recorded during 52 standard meteorological weeks when the corresponding to weather parameters viz. temperature maximum 19.2 ^{0}C, minimum 7.1 ^{0}C, relative humidity morning 90.2% and evening 58.5 %, rainfall 0.0 mm, evaporation 3.4 mm, and sunshine 3.8 hrs/day were convenient for the growth, initiation and escalation of pathogen.

Similarly, result was found by Anonymous (2003), the symptoms of rust disease on aonla fruits first appeared in the second week of August in the year 2000. The disease reached its peak severity in

Table 2. Correlation matrix on weather parameters with per cent disease intensity of aonla rust.

	PDI	Max temp (^{0}C)	Min temp (^{0}C)	Morning RH (%)	Evening RH (%)	Rainfall (mm)	Evaporation (mm)	Sun shine (hrs.)
PDI	1							
Max temp. (^{0}C)	**-0.94289**	1						
Min temp. (^{0}C)	**-0.96398**	**0.895904**	1					
Morning RH (%)	-0.50289	0.317018	0.662203	1				
Evening RH (%)	**-0.78469**	0.663279	**0.858089**	**0.800339**	1			
Rainfall (mm)	-0.48059	0.372937	0.590361	0.66719	0.644993	1		
Evaporation (mm)	**-0.81821**	**0.778396**	**0.839084**	0.529439	0.531373	0.511797	1	
Sun shine (hrs)	0.139434	0.041575	-0.32937	-0.67705	-0.50591	-0.51825	-0.15356	1

Values in bold are different from 0 with a significance level alpha=0.05.

Table 3. Correlation, regression coefficient and regression equation in between per cent disease intensity of rust of aonla and meteorological factors during the year 2022.

Environmental factor	Correlation coefficient (r) value	Regression coefficient (R^2) value	Regression equation
Max temp (^{0}C)	-0.94289**	0.8763**	Y= -0.6863x + 35.597
Min temp (^{0}C)	-0.96398**	0.9553**	Y= -1.283x + 28.544
Morning RH (%)	-0.50289*	0.2921^{NS}	Y= -0.467x + 90.175
Evening RH (%)	-0.78469**	0.6252*	Y= -1.3185x + 77.414
Rainfall (mm)	-0.48059*	0.2569^{NS}	Y= -4.2601x + 64.515
Evaporation (mm)	-0.81821**	0.6919*	Y= -0.0934x + 4.8934
Sun shine (hrs)	0.139434^{NS}	0.0522^{NS}	Y= -0.0806x + 5.29

December, with a per cent disease intensity (PDI) of 34.25. During this period, the disease incidence increased slightly from August and spread rapidly between August to December. The study also analyzed weather parameters and their correlation with the disease development. In the month of August, the average maximum temperature ranged from 33.49°C to 24.73°C, and the average relative humidity ranged from 81% to 60%. These conditions were found to favor the development of the rust disease. Further observations showed that maximum temperatures between 26.00°C to 33.49°C and minimum temperatures ranging from 26.29°C to 24.73°C, along with morning relative humidity between 70% to 81% and evening relative humidity ranging from 27% to 60%, were also favorable for the disease's development and spread of the disease during the season. These weather parameters played a crucial role in the incidence and severity of aonla rust disease in the mentioned regions, indicating the importance of monitoring and managing environmental conditions to control the spread of the disease in aonla orchards. Similarly, the rust disease symptoms appeared at September first fortnight on fruits was observed. The maximum and minimum temperature 31.7 and 25 ^{0}C, relative humidity morning and evening 92.40 and 67.90%, rainfall 24 mm, sunshine hrs/day 1.4 and evaporation was 4.1 (Prajapati *et al.* 2021). These results were also found in support with reported of Pandey *et al.* (2007) and Singh *et al.* (2015).

Correlation of disease intensity with weather parameters

It is evident from data Table 2 that the rust disease of aonla symptoms were appeared at 35th week of September and continue to till maturity during, 2022. The per cent disease intensity data was recorded from 35th week of September to last 52 weeks of December. The relationship of the disease intensity (dependent variable) with weather parameters was considered by employing simple correlation. The study proposed a correlation coefficient matrix to examine the relationships between the dependent variable (PDI) and several independent variables, including maximum and minimum temperature, morning and evening relative humidity, rainfall, evaporation, and sunshine. After conducting further investigations on the correlation of each individual parameter with the development and progress of the disease. Revealed that in Tables 2 –3 minimum temperature was recorded negatively correlated highly significant (-0.96) with per cent disease intensity, followed by maximum temperature (-0.94), evening relative humidity (-0.78) and evaporation (-0.82), whereas morning relative humidity (-0.50) and rainfall (-0.48) were found significant negative correlation with PDI. Sunshine (0.14) was observed positive correlation non-significant with PDI. According to Maheshwari and Haldhar (2018) were found that temperature showed highly significant negative correlation whereas relative humidity and sunshine hrs/day showed significant positive correlation with per cent disease intensity. Similarly, Singh *et al.* (2015) studies were found on correlation matrix resulted that, temperature (max and min) and evaporation were found highly significant but negative correlated while evening relative humidity and rainfall had also shared significant but negative correlation with PDI. Anonymous (2003) the correlation matrix showed that temperature, relative humidity and rainfall indicated negative correlation whereas, sunshine hours had positive correlation.

Table 4. Weather based prediction model for aonla rust.

Year	Coefficient of determination (R^2)	Regression equation
2022	0.961	$Y = 41.47 + 0.303 X_1 - 1.811 X_2 + 0.478 X_3 - 0.355 X_4 - 0.004 X_5 - 1.551 X_6 - 1.809 X_7$

Where.

X_1 = Maximum temperature (^{0}C),
X_2 = Minimum temperature (^{0}C),
X_3 = Morning relative humidity (%),
X_4 = Evening relative humidity (%),
X_5 = Rainfall (mm),
X_6 = Evaporation (mm),
X_7 = Sunshine (hrs/day),
Y= PDI

Multiple correlation coefficient

The multiple correlation coefficient presented in Table 4. demonstrated a significant relationship between aonla rust and the weather variables examined in the study. Specifically, temperature (maximum and minimum), relative humidity (morning and evening), rainfall, evaporation and sunshine during the disease development phase contributed to more than 96.1% of the variations observed in the development of aonla rust.

The analysis revealed that weather factors played a significant role in the development of aonla rust. A regression model was constructed to predict the disease severity, indicating that different weather variables could influence the severity to some extent, particularly when favorable weather conditions persisted over a specific period. The disease prediction model, $Y = 41.47 + 0.303 X_1 - 1.811 X_2 + 0.478 X_3 - 0.355 X_4 - 0.004 X_5 - 1.551 X_6 - 1.809 X_7$, with a coefficient of multiple regression (R^2 value) of 0.96, indicated that approximately 96.1% of the variation in aonla rust severity could be attributed to the weather parameters under consideration. These findings are similar with the results of Singh *et al.* (2015) and Maheshwari and Haldhar (2018), Devi *et al.* (2022) was conducted based on weather conditions to predict the disease severity model for aonla rust in year, 2021 coefficient of determination 0.78 and regression equation was $Y = 159.422 - 0.317 X_1 - 1.296 X_2 - 0.740 X_3 - 0.729 X_4 + 0.026 X_5$. 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.

Apparent infection rate of disease development (r/unit/day)

The apparent infection rate of disease development (r/unit/day). The data presented on the Table 5 and Fig. 2, initially increased at the beginning of the disease outbreak and continued to rise gradually until the first five weeks of September. To favorable conditions of aonla rust disease, including the susceptible age of the plant and temperatures, relative humidity, evaporation and rainfall were decrease. The disease spread rapidly between 35th SMW to 39th SMW when there was heavy rainfall but, after these weeks no rainfall till end, relative humidity average ranging from 72.6% to 90.1%, and average temperature range between 24.7°C and 33.1°C. The apparent infection rate was observed at weekly intervals. The results in Table 4 were found highest infection rate in 36th SMW which is amount of 0.206 and after slightly low infection was recorded in 38th SMW which is amount of 0.175, the lowest infection rate was found 41th SMW and 52th SMW which was 0.006 and 0.007, respectively. Similar results were found in Devi *et al.* 2022. At Jammu and Kashmir, observed the highest infection rate of 0.12 on Standard Meteorological Week 37th during the year 2021.

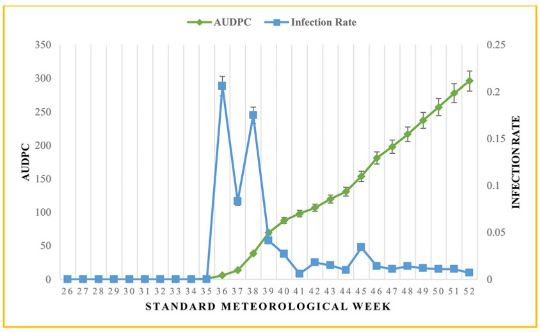

Fig. 2. Rate of infection and area under disease progress curve of aonla rust disease at weekly intervals.

Table 5. AUDPC and rate of infection (r) of rust on aonla in different standard meteorological week during the year 2022.

Standard meteoro-logical week	Dates	Per cent disease intensity	AUDPC	Infection rate
26	25 Jun- 01 Jun	0	0	0
27	02 Jun- 08 Jun	0	0	0
28	09 Jun- 15 Jun	0	0	0
29	16 Jun- 22 Jun	0	0	0
30	23 Jun- 29 Jun	0	0	0
31	30 Jun- 05 Aug	0	0	0
32	06 Aug- 12 Aug	0	0	0
33	13 Aug- 19 Aug	0	0	0
34	20 Aug- 26 Aug	0	0	0
35	27 Aug- 02 Sep	0.33	1.16	0
36	03 Sep- 09 Sep	1.40	6.05	0.206
37	10 Sep - 16 Sep	2.50	13.65	0.083
38	17 Sep - 23 Sep	8.50	38.50	0.175
39	24 Sep- 30 Sep	11.33	69.40	0.041
40	01 Oct - 07 Oct	13.70	87.60	0.027
41	08 Oct - 14 Oct	14.30	98.00	0.006
42	15 Oct - 21 Oct	16.20	106.75	0.018
43	22 Oct - 28 Oct	18.03	119.80	0.015
44	29 Oct - 04 Nov	19.33	130.76	0.010
45	05 Nov- 11 Nov	24.58	153.68	0.034
46	12 Nov- 18 Nov	27.18	181.16	0.014
47	19 Nov- 25 Nov	29.40	198.03	0.011
48	26 Nov- 02 Dec	32.50	216.65	0.014
49	03 Dec- 09 Dec	35.33	237.40	0.012
50	10 Dec- 16 Dec	38.18	257.28	0.011
51	17 Dec- 23 Dec	41.23	277.93	0.011
52	24 Dec- 31 Dec	43.33	295.96	0.007
	Total AUDPC value		**2489.80**	

Area under disease progress curve (A-value)

The data provided in Table 5 and Fig. 2. demonstrates the AUDPC (Area Under Disease Progress Curve) calculated for cultivar NA-7 based on the intensity of plant disease recorded on a weekly basis throughout the year 2022. The AUDPC values ranged from 1.16 to 295.96, indicating a rapid progression of the disease.

CONCLUSION

This study provides valuable insights into the relationship between weather parameters at Ayodhya center disease appeared in September month on NA-7 and the disease intensity peak on December, highest infection rate 0.206 and maximum progression of aonla rust 295.96. Disease prediction model though predict the disease 96.1% approx. Which could contribute to the development of effective strategies for disease management in aonla cultivation.

ACKNOWLEDGMENT

This study was supported by All India Coordinated Research Project on Arid Fruits. Authors are thankful to Director, ICAR- Central Institute for Arid Horticulture, Bikaner, Rajasthan, India.

REFERENCES

Anonymous (2003) Epidemiological Studies on aonla rust. Biennial report of All India Coordinated Research Project on Arid Zone Fruits, ICAR-Central Institute for Arid Horticulture, Bikaner, Rajasthan, India, pp 138-139.

Devi L, Singh VB, Singh SK, Sharma R, Gupta S (2022) Management of aonla rust through host resistance and fungicides. *Plant Disease Research* 37(2): 227-227.

Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research (2nd) John wiley and sons. New York, pp 680.

Madden LV, Hughes GF. van den Bosch (2007) The Study of Plant Disease Epidemics. APS Press, St. Paul, MN.

Maheshwari SK, Haldhar SM (2018) Disease management in arid horticultural crops. CIAH/Tech/Pub-No.68, ICAR-Central Institute for Arid Horticulture, Bikaner, Rajasthan, India, pp 42.

Mckinney HK (1923) Influence of soil temperature and moisture on infection of wheat seedlings by *Helminthosporium sativum. Journal of Agricultural Research* 26: 195-218.

Pandey S, Singh AK, Singh AK (2007) Effect of weather parameters on aonla rust (*Ravenalia emblicae* Syd.). *Indian Phytopathol* 61: 412.

Prajapati RK, Pandey CS, Gupta PK, Singh VK, Singh SR (2021) Recent advances in diseases management of aonla (*Emblica officinalis*). *Innovative Approaches in Diagnosis and Management of Crop Diseases,* pp 365-407.

Singh DA, Kumar S, Singh S, Vishwakarma G (2015) Epidemiology and management of rust disease (*Ravenalia emblicae* Styd.) of aonla.

Singh HK, Pratap B, Maheshwari SK, Gupta A, Chug A, Singh AP., Singh D (2023) Spray prediction model for aonla rust disease using machine learning techniques. *Journal of Agricultural Science and Technology* 13: 1-12.

Van der Plank JE (1963) Plant Diseases - Epidemics and Control. New York: Academic, pp 349.