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Chilli Leaf Curl Disease: An Emerging Threat to Chilli Cultivation in Maharashtra, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Chilli leaf curl disease (ChiLCD) locally known as 'Churda Murda' is a most destructive disease of chilli (*Capsicum annuum*) in India. The ChiLCD is caused by whitefly (*Bemisia tabaci*)-transmitted *Begomovirus*, belonging to the family *Geminiviridae*. A study was conducted to investigate the current status of ChiLCD in Maharashtra. Survey was carried out in chilli growing districts of Maharashtra to study the disease incidence (DI) and percent diseases index (PDI) of ChiLCD. Artificial Intelligence (AI)-based application (App) 'Plantix–your crop doctor' was used to assess the diagnosis of ChiLCD. During the survey different symptoms of ChiLCD, leaf curling, leaf yellowing,

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crinkling, puckering, vein banding and stunting were observed in diseased chilli plants. In this study, 'Plantix–your crop doctor' App accurately diagnosed the ChiLCD and its pathogen *Chilli leaf curl virus* (ChiLCV). High ChiLCD incidence of 85-100% with PDI of 53.8-62.7% was observed at Kemwadi village in Osmanabad district and 80-90% with PDI of 42.3-45.7% at Ranmasle village in Solapur district of Maharashtra. The high incidence of ChiLCD in Maharashtra has been taken into consideration and this can be correlated with various factors such as weather conditions, insecticide resistance in whitefly populations, and the appearance of virulent strains of ChiLCV. Early detection of ChiLCV using the AI-based 'Plantix–your crop doctor' App and effective management of insect vector whitefly could prevent ChiLCV spread and minimize the crop yield losses.

Keywords: Chilli leaf curl disease; begomovirus; artificial intelligence; diagnosis; disease incidence; percent disease index.

1. INTRODUCTION

The *Geminiviridae* family is one of the largest families of plant viruses, causing severe crop losses in both monocotyledonous and dicotyledonous plants [1]. It is classified into fourteen genera and the *Begomovirus* is the largest genus in the family *Geminiviridae* which consists of more than 445 species [2,3]. Begomovirus is a major constraint to vegetable production throughout tropical and subtropical regions of the world [4]. India is the world's largest producer of dry red chilli (*Capsicum annuum*) and contributes 43% of world chilli production. Leaf curl diseases of chilli caused by begomoviruses has emerged as a serious threat to chilli cultivation in India. Yield losses of 20–50% of marketable fruit have been recorded in Chilli leaf curl disease (ChiLCD) [5]. In many cases begomovirus epidemics lead to complete loss of the crop particularly in seasons favouring whitefly population buildup [6]. Climatic conditions such as sudden increase in temperature, rainfall and relative humidity, intensification of cropping systems, and the presence of alternate hosts have promoted whitefly population buildup which leads to the rapid spread of begomoviruses [4]. ChiLCD is caused by monopartite begomoviruses in Indian subcontinent [7]. The genome of monopartite begomoviruses has a single-stranded (ss) circular DNA of ~2.7 kb designated as DNA-A, which is encapsidated in a quasi-isometric geminate particles of 20–30 nm [8]. The DNA-A component of monopartite begomovirus is often found to be associated with ss DNA satellite molecules of ~1.3 kb designated as alphasatellite and betasatellite [2,9,10]. The betasatellite depends on helper begomovirus for its replication and movement; whereas the self-replicating alphasatellite depends on begomovirus only for their movement [11,12]. The betasatellite and alphasatellite is involved in overcoming host defense by suppressing the host antiviral innate immunity [12,13]. The betasatellite also functions as a pathogenicity determinant and plays multifaceted roles in the disease development [14]. The *Chilli leaf curl virus* (ChiLCV) is identified as one of the major begomoviruses causing ChiLCD in India [5,15]. The ChiLCD affected chilli plants exhibit symptoms such as leaf crinkling, leaf curling, leaf rolling, vein clearing, vein thickening, vein banding, chlorosis, bushy appearance of plants and stunting [15]. The initial diagnosis of ChiLCD is depends on the visual inspection of disease symptomatology. Sometimes plant virus diseases are difficult to diagnose and are often confused with nutrient deficiencies. A subject matter expert can accurately identify the viral diseases of plant. However, diagnosis of begomovirus disease is difficult for farmers due to lack of necessary knowledge about disease symptomatology [16]. Artificial Intelligence (AI) has emerged as a transformative force in various industries, and agriculture is no exception. One notable application of AI in agriculture is its ability to assist farmers in identifying and managing plant diseases. AI technologies, including machine learning and computer vision, have proven to be invaluable tools in enhancing the precision and efficiency of plant disease identification for farmers [17]. Now-a-days farmers are rapidly adopting AI technology in smart farming practices. Therefore, assessment of AI technology by subject matter experts is deemed necessary to make this technology sustainable in modern agriculture. In the present study, AI-based application (App) 'Plantix–your crop doctor' was used to assess the diagnosis of ChiLCD. A survey was carried out in Osmanabad and Solapur districts of Maharashtra to investigate the leaf curl disease of chilli crop.

2. MATERIALS AND METHODS

2.1 Field Survey

Survey was carried out at Kemwadi and Ranmasle village in Osmanabad and Solapur districts of Maharashtra respectively. My GPS Coordinates android application was used for geotagging of farmer's field location. Satellite map was obtained using the gps-coordinates webserver (https://www.gps-coordinates.net). Chilli plants were initially screened for leaf curling, leaf yellowing, crinkling, puckering, vein banding and stunting symptoms and the symptomatic plants were marked.

2.2 Diagnosis of Leaf Curl Disease

Plants marked based on visual inspection were assessed using AI-based App 'Plantix–your crop doctor'. The Plantix App was downloaded from the 'google play store' and installed on the android phone. Symptomatic plants photographs were captured by the App interface camera and the disease was diagnosed. The Plantix App directly uploaded the captured image to a cloud-based server using the internet where machine learning based algorithms processed the optical patterns, which identify the plant disease with results back to the user within a few seconds.

2.3 Estimation of Disease Incidence and Percent Disease Index

The ChiLCD affected plants were counted along 2 diagonals in an X shape in the field and the disease incidence (percent plant infection) was estimated using the standard formula [18] mentioned below:

> Disease Incidence = Number of plants showing symptoms / Total number of plants examined * 100

The symptom severity data for ChiLCD was recorded based on the severity scale from 0 to 9 proposed by Bhutia et al. [19], where '0' indicates no symptoms, '1' indicates very mild curling of 1–10% leaves, '3' indicates curling and puckering symptoms on nearly 11–25% leaves, '5' indicates curling and puckering symptoms on nearly 26–50% leaves, '7' indicates severe curling and puckering symptoms on nearly 51–75% leaves with small leaves and stunting of plants, and '9' indicates severe symptoms of >75% leaves with bushy appearance, pronounced small leaves and stunting of plants. The percent disease index (PDI) was calculated using the standard formula [18] mentioned below:

$$\mathrm{PDI} = \frac{\sum_{r=1}^{n} \mathrm{RF}}{\mathrm{N}} \times \frac{100}{\mathrm{G}}$$

where R= I^{th} disease grade rating, F= Frequency of plants showing I^{th} disease rating, N= Total number of plants observed for presence of ChiLCD symptoms, G=Highest grade of disease rating scale.

3. RESULTS AND DISCUSSION

3.1 Disease Incidence and Percent Disease Index of ChiLCD

During the survey at Kemwadi village in Osmanabad district and Ranmasle village in Solapur district of Maharashtra (Fig.1); different symptoms of ChiLCD were observed on leaves of chilli plants (Table 1, Fig.2). The ChiLCD affected chilli plants showed typical symptoms of leaf curling (LC), leaf yellowing (LY), crinkling (Cr), puckering (Pu), vein banding (VB) and stunting (St). The LC and Cr symptoms were found common in all the diseased plants observed in the field. The LY symptom was found more frequent in farmers' fields at Ranmasle village. High ChiLCD incidence (DI) of 85-100% was observed at Kemwadi village and 80-90% at Ranmasle village of Osmanabad and Solapur district respectively (Table 1). The percent diseases incidence (PDI) was estimated 53.8-62.7% at Kemwadi village and 42.3-45.7% at Ranmasle village (Table 1). This result indicates that the severity of ChiLCD was high at Kemwadi village. The stunting of chilli plants with complete yield loss was observed at Kemwadi village where 100% ChiLCD incidence was recorded. The ChiLCD is the most destructive disease and it causes 100% losses to the marketable fruits [20-22]. The infected plants at late growth stages showed abscission of flower buds and sterile anthers, which resulted in poor fruit growth and underdeveloped fruits [15]. Earlier it was reported that three begomoviruses, *Chilli leaf curl virus* (ChiLCV), *Pepper leaf curl Bangladesh virus* (PepLCBV) and *Tomato leaf curl New Delhi virus* (ToLCNDV) are commonly found in the ChiLCD complex in India [15]. Mixed infection of ChiLCV and PepLCBV in ChiLCD complex in Nagpur district, and occurrence of ToLCNDV in ChiLCD affected chilli plants in Pune district of Maharashtra were reported [15].

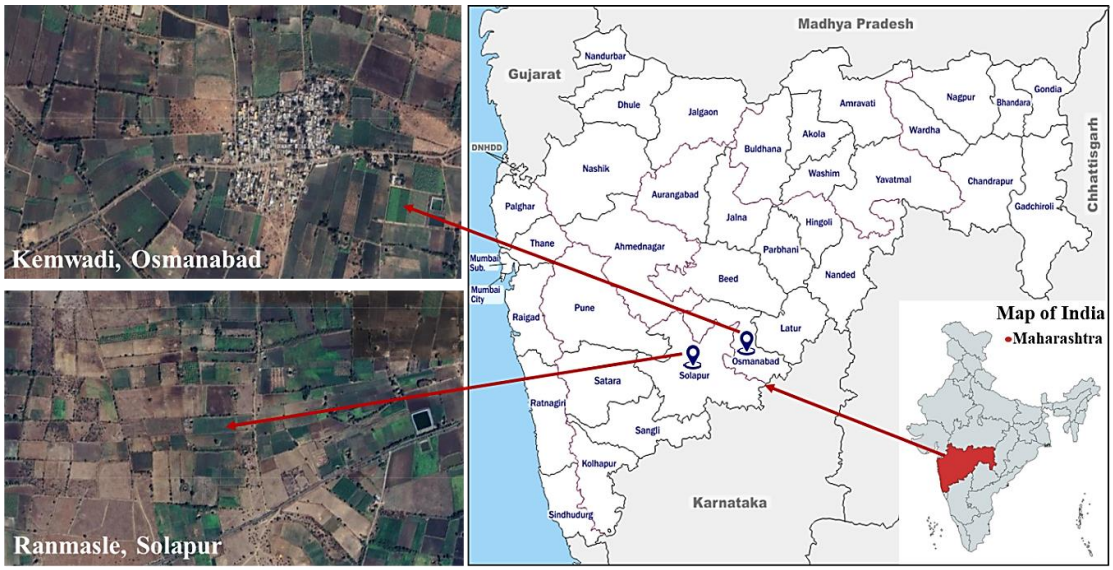

Fig. 1. Satellite map of surveyed locations in Osmanabad and Solapur districts of Maharashtra, India

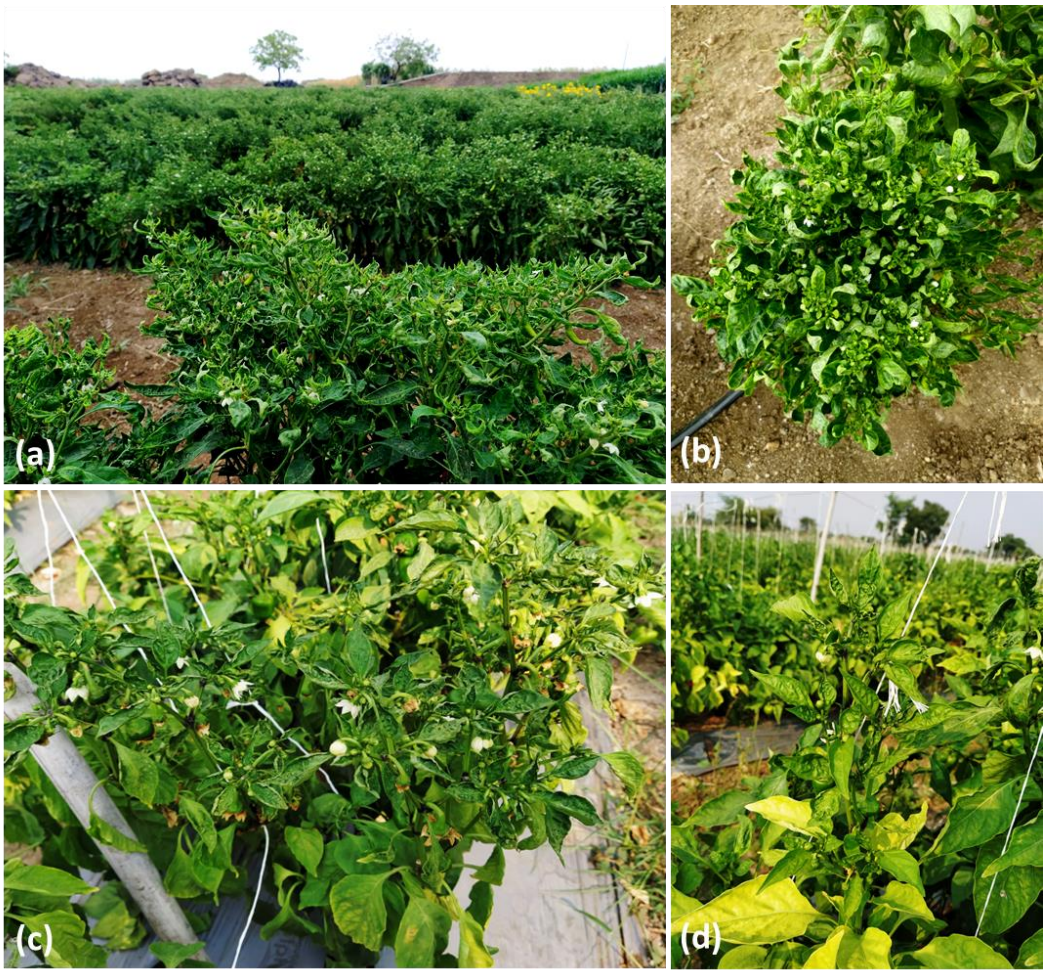

Fig. 2. Chilli plants showing ChiLCD symptoms at Kemwadi village in Osmanabad district (a & b) and Ranmasle village in Solapur district (c & d)

Table 1. Disease incidence and percent disease index of ChiLCD

Location	GPS coordinates	ChiLCD symptoms	Disease incidence (DI)	Percent disease index (PDI)
Field-1 Kemwadi Osmanabad	N17^{0}54'5.06304" E75^{0}51'21.54672"	LC, Cr, Pu, VB	85.0	53.8
Field-2 Kemwadi Osmanabad	N17^{0}54'12.29148" E75^{0}52'20.98308"	LC, Cr, Pu, VB, St	100.0	62.7
Field-1 Ranmasle Solapur	N17^{0}50'3.376" E75^{0}45'31.4"	LC, LY, Cr, VB	90.0	45.7
Field-2 Ranmasle Solapur	N17^{0}50'3.124" E75^{0}45'59.187"	LC, LY, Cr, Pu	80.0	42.3

** Following abbreviation of leaf curl disease symptoms were used in this study, LC (Leaf Curling), LY (Leaf Yellowing), Cr (Crinkling), Pu (Puckering), VB (Vein Banding), St (Stunting)*

3.2 Assessment of AI Technology in Diagnosis of ChiLCD

In the present study, AI-based application 'Plantix–your crop doctor' was used to assess the diagnosis of ChiLCD. The 'Plantix–your crop doctor' App was developed by a German start-up company Progressive Environmental & Agricultural Technologies (PEAT). This App assists in identifying plant disease with the help machine learning and artificial intelligence. In this study 'Plantix–your crop doctor' App efficiently identified the ChiLCD and its pathogen ChiLCV in the field condition (Fig. 3). Recently, Siddiqua et al. [23] assessed the applicability of different AI Apps for plant disease detection. They have reported that out of 17 Apps; only one App 'Plantix–your crop doctor' can accurately identify the plant disease and detect the pathogen. The present study corroborated previous findings and also revealed that the 'Plantix–your crop doctor' App accurately diagnose the ChiLCD. Recent advancement of AI technology revolutionized the plant disease diagnosis by enabling farmers to identify the disease precisely and also suggested potential treatments for the disease management [23,24].

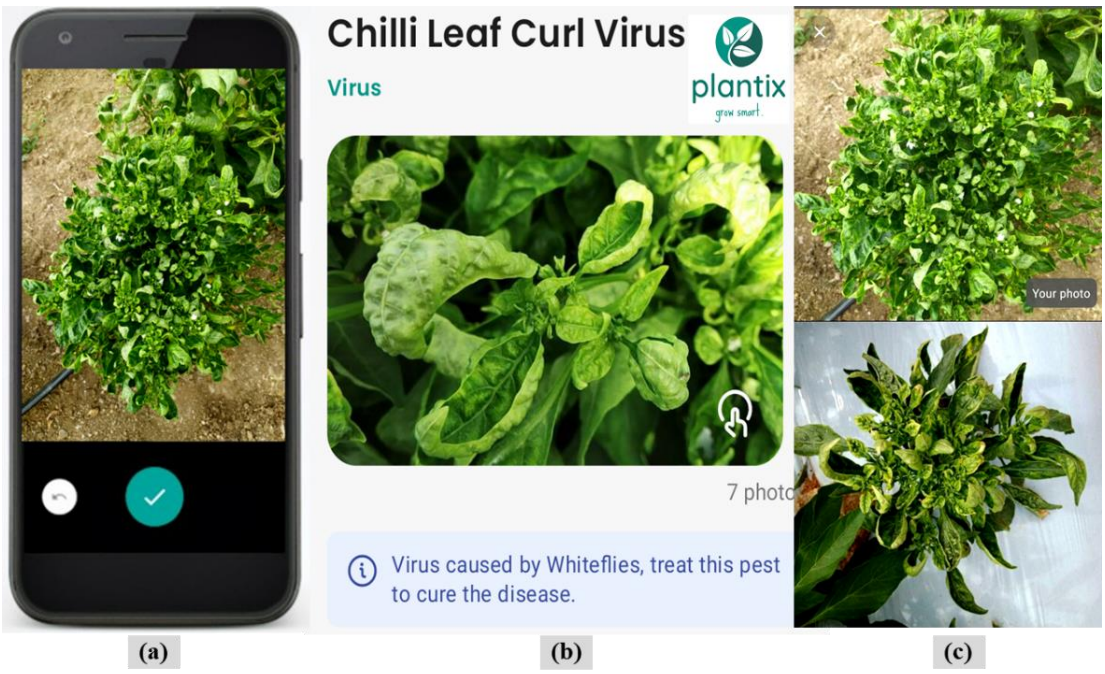

Fig. 3. Detection of ChiLCV using 'Plantix–your crop doctor' App, (a) photograph of diseased plant was captured using the android phone App interface camera, (b) Chilli leaf curl virus was detected by the App, (c) uploaded photograph matched with similar symptom photograph available on the App server

4. CONCLUSION

The present study highlighted the high incidence of ChiLCD in Maharashtra and the accurate diagnosis of ChiLCV by AI-based 'Plantix–your crop doctor' App. Early detection of ChiLCV using the 'Plantix–your crop doctor' App and effective management of insect vector whitefly could prevent ChiLCV spread and minimize the crop yield losses. Agricultural technology needs advanced biotechnological tools to reduce crop losses and feed extra mouths; the global population is estimated to increase by two billion over the next 30 years. The high incidence of ChiLCD in Maharashtra has been taken into consideration and this can be correlated with various factors such as weather conditions, insecticide resistance in whitefly populations, and the appearance of virulent strains of ChiLCV, thus insightful future research is needed to protect the chilli crop from the devastating ChiLCD.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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