Studies of potato apical leaf curl virus disease in potato

By

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CERTIFICATE– I

This is to certify that the thesis entitled, **"Studies of potato apical leaf curl virus disease in potato"** submitted for the degree of **Master of Science** in the subject of **Plant Pathology** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** is a bonafide research work carried out by **Mr. Manoj kumar, Admn. No. 2012A76M,** under my supervision and no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, **""Studies of potato apical leaf curl virus disease in potato""** submitted by **Mr. Manoj Kumar**, **Admn. No. 2012A76M** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** in partial fulfilment of the requirement for the degree of **Master of Science** in the subject of **Plant Pathology** has been approved by the Student's Advisory Committee after an oral examination on the same, in collaboration with an **External Examiner.**

MAJOR ADVISOR **EXTERNAL EXAMINER**

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Hisar

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CHAPTER-I

INTRODUCTION

Potato (*Solanum tuberosum L.*) is one of the most important vegetable crops and ranks third among food crops after rice and wheat in the world as well as India from human consumption point of view. Potato belongs to the family Solanaceae and is one of the most important vegetable crops grown throughout India. It is thought to be derived from the Inca name Papa. Potato has been originated from the Andes of Peru and Bolivia in South America where it is found growing wild and the widest diversity of forms, *i.e*., tuber size, shape, colour and taste. Potato also known as white or Irish potato is an annual herbaceous plant and the edible part is an underground modified-stem as tuber. It can be grown under a wide range of climatic conditions with wide flexibility in planting and harvesting time. It is a good source of carbohydrates and is used as staple food in many parts of the world. India is the 3rd largest producer of Potato in the world after China and Russia and during 2012-13 potato crop occupied 19.99 lakh hectares with a production of 45.24 lakh tonnes tubers (Anonymous, 2013b).

Potato is one of the most important vegetable crops grown through Haryana in a wide variety of soil. It ranks first in production and third in area among vegetable crops in Haryana. It shares 7.73% of the total area under vegetables in the state; however, its production share is 12.87% of the total vegetable production. During 2012-13, the area and production of potato were 29473 hectares and 676016 tonne, respectively (Anonymous, 2013a). The productivity (22.94 t/ha) of potato crop in the state is better than the national yield, however, lower than the potential yield (35 t/ha). There are number of factors, which play important role in deciding the productivity and quality of potato tubers, and disease is one of the most important factors. Potato crop is attacked by many diseases, which are widely spread and others are localized, which affect the crop growth and production. In Haryana state, the sporadic incidence of potato apical leaf curl disease was observed first time in early October sown potato crop at Hisar during December 1996, and subsequently, it spread to other parts of the state. Severe yield losses due to this disease have been reported in potato (Lakra, 2002). Further, the fast spread of this disease under high vector population has been noticed in early sown susceptible varieties of potato. There is very high population of whitefly in early October planted potato crop, which leads to high incidence of leaf curl symptoms and it decreases gradually in November and December months when the temperature goes down. Obviously, heavy losses caused by this disease drew attention of scientists and workers dealing with the crop towards its control measures. The disease, a begomovirus disease

transmitted by whitefly (*Bemisia tabaci*), is emerging as a serious threat to potato production. The adults and nymphs of whitefly use their piercing- sucking mouth parts to feed on phloem part of the host plant, which results in direct damage causing localized spotting, yellowing or leaf drop, or sooty mould may occur that adversely affects the photosynthesis process of plants leading to the reduction in yield (Broad and Puri, 1993). The indiscriminate use of insecticide results not only environmental pollutions but also responsible for so many health hazards. Further, the insects have developed resistance to certain insecticides. Therefore, to raise a disease-free crop of potato, the only alternative lies in breeding disease resistant varieties. The genetic resistance is more safe, stable and economical in comparison to pesticide use. The pre-requisite for the development of disease resistant varieties is the availability of efficient and reliable screening techniques and identification of resistance sources. Limited work has been done on evaluation of field resistance and other aspects of potato against potato apical leaf curl disease (PALCVD). Some of the biochemical and morphological attributes, which act as a defense mechanism in the host plant against insects and diseases, are also of considerable importance. The biochemical reaction leading to susceptibility or resistance can be helpful in screening the germplasm at an early stage for potato apical leaf curl disease resistance in potato. Therefore, in view of the importance of the crop and disease in the state, the present study "Studies of potato apical leaf curl virus disease in potato" was planned with the following objective:

- To determine the role of weather variables and whitefly (*Bemisia tabaci*) on the development of PALCVD
- Ascertaining the association of biochemical parameters for potato apical leaf curl virus disease resistance or susceptibility
- To screen potato lines for resistance against potato apical leaf curl virus disease

CHAPTER-II

REVIEW OF LITERATURE

Potato is an important crop grown throughout the world. The literature pertaining to investigation of potato apical leaf curl virus disease of potato has been reviewed as below:

2.1 Viral diseases of potato

According to Horvath and Kazinczi (2000) and Khurana *et al*. (2000), the potato plant may be affected by as many as 45 viruses *viz.*, potato leaf roll luteovirus (PLRV), potato Y potyvirus (PVY) and potato X Potexvirus (PVX) are distributed worldwide, while others *viz*., potato vitivirus (PVT), wild potato mosaic potyvirus (WPMV), Andean potato latent tymovirus (APLV), Andean potato mottle comovirus (APMoV) and potato V potyvirus (PVV) are mainly restricted to tropical zones (Howell, 1981; Hooket, 1981; Salazar, 1996). Galloway (1936) was the first to record the occurrence of potato virus in India. However, authentic records about occurrence of potato viruses X, Y and A were made in the 1940s (Nagaich *et al*., 1974; Khurana, 1992). Potato virus A (PVA) and potato virus M (PVM) are not much common in India as in Europe. Similarly, PVY-N is almost not known in Indian potatoes. Potato mosaic and leaf roll are important and occur widely in almost all cultivars in India (Nagaich et al. 1974; Khurana, 1992). Mosaic and leaf roll are not only most common but also severe in the subtropical/tropical climate (Garg, 1987; Khurana *et al*., 1998). It is mainly due to non-availability of virus free seed, high frequency of the virus sources within and around the crop coupled with early/large population build up and greater activity of aphid vectors (Singh *et al*., 1984). The Acuba and Calico mosaic were common in old Indian and exotic cultivars (Vasudeva and Azad, 1952). However, they have become rare in present day Indian commercial potato cultivars (Singh, 1980; Khurana and Singh, 1986). Many variants of PVX and PVY have been recorded from Indian potatoes, ornamental and weed plant species (kumar *et al*., 1987).

2.2 Geminiviruses

Geminiviruses are plant pathogen of agronomic importance throughout Latin America and Caribbean, the South West United States, Southern Europe, Southern Asia, Africa and Australia. These viruses remained obscure and uncharacterized for a long time due to low titre, phloem inhabitation and poor or no mechanical transmission. The term geminivirus was coined due to the geminate capsid morphology (Harrison *et al*., 1977). These viruses were placed in geminivirus group in 1979 according to the virus classification (Mattews, 1979).

Members of the geminivirus group are viral pathogen that have a characteristic double icosahedral (twin moon) capsid of approaximate dimension of 1830 mm (Esau, 1977). The capsids contain a covalently closed circular single–stranded DNA of 2.5 to 3.0 kb size (Goodman, 1977, 1981; Goodman *et al*., 1977; Harrison et al., 1977; Stanley, 1985; Lazarowitz, 1992). Later, all geminivirus were placed in family Geminiviridae (Mayo, 1996). Geminivirus posses either DNA A as a single genomic component (monopartite) or two genomic components (bipartite) namely DNA A and DNA B. In bipartite viruses, inoculation of both DNA A and DNA B in the same cell is required to cause infection (Hamilton *et al*., 1983).Geminiviruses are transmitted by either leaf hoppers or whiteflies. They infect a wider range of monocotyledonous and dicotyledonous plants (Stanley, 1985; Lazarowitz, 1992).

2.3 Classification of Geminivirus

The family *Geminiviridae* includes one genus each in subgroup-1, subgroup-II and subgroup-III, based on the genomic organization (monopartite or bipartite), insect vector (whiteflies or leafhoppers) and host range of monocotyledonous or dicotyledonous (Stanely, 1985; Lazarowitz, 1992). Recently, three subgroups have been renamed as Mastervirus (subgroup-1), Curtovirus (subgroup-II) and Begomovirus (subgroup-III) (Mayo and Pringle, 1998) and Topucovirus (Fauquetb *et al*., 2000).

Viruses belonging to subgroup-III are transmitted by whiteflies, called as whitefly transmitted geminivirus (WTGs) infect dicots and can have either bipartite or monopartite genome. Subgroup-III genome virus or WTGs are prevalent throughout the world and have been further divided into two subgroups namely old world (OW) and new world (NW). Those belonging to the NW are all bipartite in nature, while those from the OW can have either bipartite or monopartite genome. In typical bipartite or monopartite genome. In typical bipartite group subgroup-III viruses, both DNA A and B are required for infection (Hamilton *et al*., 1983; Stanely, 1985).

2.4 Transmission of Geminivirus

2.4.1 Mechanical Transmission

Marchoux et al. (1970) listed 4 whitefly borne (*Bemisia tabaci*) viruses that had been transmitted by mechanical means, *i.e*., Cassava mosaic virus, Euphorbia prunifolia mosaic virus, sweet potato virus B and tomato rugose mosaic virus. Spread of TYLCV and ToLCV among tomato plants by contact seems unlikely as the disease agents have not mechanically transmitted from tomato to tomato (Yassin and Nour, 1965). Meiners *et al*., (1973) reported that the Salvaoran bean golden yellow mosaic (BGYM) virus is transmitted by mechanical means. Out of the six whitefly transmitted viral diseases affecting tomato in Brazil, only tomato golden yellow mosaic (TGYM) was transmissible by mechanical means. Potato yellow mosaic virus (PYMV) was transmitted mechanically to *Lycopersicon*, *Nicotiana* and *Petunia* spp. but not to potato (Roberts *et al*., 1986).

2.4.2 Graft Transmission

It is assumed that all whitefly-borne viruses are transmissible by grafting. PYMV was successfully transmitted from infected tobacco plants by scion-grafting healthy potato apices (Roberts *et al*., 1986). Varma (1963) listed a number of geminiviruses, which are transmitted by grafting. These include abutilon mosaic virus, yellow–vein mosaic of croton, yellow vein mosaic of *Eclipta alba*, yellow mosaic of mungbean, leaf curl of tobacco and leaf curl of tomato. Yassin and Nour (1965) carried out cross-protection tests between the whitefly-borne tomato leaf curl and tomato vein-thickening viruses using grafting as well as whitefly for inoculation and observed no interference.

2.4.3 Whitefly transmission

The geminiviruses belonging to genus begomovirus are transmitted by whiteflies from infected to healthy plants. The virus-vector relationship has been extensively studied by several workers (Butter and Rataul, 1977; Reddy and Yaraguntaiah, 1981) and information on some of the aspects of his relationship is given below:

2.4.3.1 Acqisition and inoculation thresholds

The only known vector of ToLCV is whitefly, *Bemisia tabaci* Genn. (Vasudeva and Samraj, 1948). *Bemisia tabaci* belongs to order Homoptera and family Aleyrodidae. It has piercing and sucking type of mouthparts. Reddy and Yaraguntaiah (1981) reported that minimum acquisition access feeding perio (AAFP) and inoculation access feeding period (IAFP) were 30 min. each for the transmission of ToLCV. The minimum latent period required by ToLCV was found to be 6 h. Muniyappa *et al*. (2000) reported that minimum AAFP and IAFP were 10 and 20 min, respectively for the transmission of Ban 4. A single whitefly was able to transmit the virus, but five insects were necessary to achieve 100 per cent transmission. In one insect per plant inoculation tests, female whiteflies were more efficient (95%) than male (25%) in transmitting the virus.

Whiteflies transmitted TYLCV after a minimum AAFP, IAFP and latent period of 15 min and 4 h., respectively, was required for the successful transmission of tobacco leaf curl virus by whiteflies (Pruthi, 1944). A minimum AAFP, IAFP an latent period of 3h, 80 min. and 6 h, respectively has been reported for whitefly transmission of African cassava mosaic virus (Dubren, 1994). A single *B. tabaci* is able to transmit CLCuD (Yassin and E1-Nur, 1970) but additional number of *B. tabaci* enhances the transmission efficiency. The minimum AAFP of 3.5 hr and IAFP of 30 min is required for the transmission of this virus. Sharma (2002) reported that a single whitefly was able to transmit CLCuV in cotton plants. He further observed that twenty whiteflies per plant were required for 80 per cent transmission. The minimum accquistion and inoculation access period for CLCuV transmission was found to be 30 and 10 min., respectively.

2.4.3.2 Pre-acquisition starvation periods

ToCLV transmission of up to 36% was obtained when the whiteflies were starved for 1 h. prior to acquisition. Likewise, higher transmission of up to 40 per cent was obtained when viruliferous whiteflies were starved for 1 h. prior to inoculation as compared with infested whiteflies (Reddy and Yaraguntaiah, 1981). The minimum AAFP in case of bhindi yellow mosaic could be reduced appreciably by subjecting the vector to fasting period prior to acquisition (Varma, 1952). Sharma (2002) reported that when pre acquisition starvation period was increased there was a corresponding increase in per cent transmission of CLCuV in starvation period from 0 to 4 h. and there was increase in transmission from 3.4 to 60 per cent.

2.5 Geminivirus of potato

Eight geminiviruses namely beet curly top virus (BCTV), potato deforming mosaic virus (PDMV), mosaic amarilo tomato virus (MATV), Solanum apical leaf curf virus (SALCV), tomato yellow mosaic virus (ToYMV), potato yellow mosaic virus (PYMV), tomato yellow vein streak virus (ToYVSV) and potato apical leaf curl begomovirus (PALCV) have been reported to infect potatoes from different parts of the world.

2.5.1 Potato apical leaf curl virus (PALCV)

Garg et al. (2001 a, b) reported a new disease on potato which produced paracrinkle symptoms. Clarified virus preparation showed presence of a high concentration of geminate virus particles measuring 28×17 nm. Immune electron microscopy (IEM) studies showed very good clumping with Indian cassava mosaic virus (ICMV) antiserum, thereby indicating it to be a begomovirus and tentatively named as potato apical leaf curl virus (PALCV).

Pathogenecity tests and molecular analysis identified the causal organism as tomato leaf curl New Delhi virus (Usharani *et al*., 2004). Twenty-five leaf samples of potato plants showing typical apical leaf curl symptoms were tested by DAS-ELISA using polyclonal IgG against African cassava mosaic virus and monoclonal enzyme conjugate against tomato yellow leaf curl virus. The virus PALCV was detected by nucleic acid spot hybridization (NASH) technique against coat protein gene specific probe to geminivirus. Only six samples proved positive for geminivirus PALCV by DAS-ELISA, whereas, four more samples were found positive indicating higher sensitivity to NASH than the serological method (Venkatasalam *et al*., 2004).

2.5.1.1 Symptomatology

Potato plants infected with PALCV showed cholorotic blotching, crinkling, mosaic, apical leaf curling and stunting (Garg *et al*., 2001b).

2.5.2 Solanum apical leaf curling virus (SLACV)

Potato plants grown from true seeds were infected with the *Solanum* apical leaf curl virus (SALCV) at the high jungle area, San Ramon, Peru. The SALCV was detected by ELISA test. The virus particles in purified preparations as well as those trapped on antiserum

sensitized grids treated with infective sap measured 52×17 nm in size and consisted of three quasi-isometric units in a straight chain. The particle morphology suggested possible affinities with geminiviruses (Hooker and Salazar, 1983).

2.5.2.1Symptomatology

Symptoms in potato plants infected with SALCV consisting of red, purple or pink discoloration, curling, crinkling and dwarfing of apical leaves. Symptoms from tuber-borne infection also include dwarfing and stunting, prolonged dormancy and filiform sprouts producing small plants with very thin stems (Hooker and Salaza, 1983).

2.5.2.2 Transmission of SALCV

The virus is transmissible by grafting but not through seed, aphids leaf hopper or mechanical inoculation of sap (Hooker and Salazar, 1983).

2.5.2.3 Host of SALCV

Host plants of SALCV include *Datura tatula, D. stramonium, Lycopersicon esculentum* (tomato)*, Solanum nigrum, S. basendopogon, Nicandra physaloides, Nicotiana benthamiana* and *Physalis peruviana* (Hooker and Salazar, 1983).

2.6 Epidemiology

Viruses of bacteria, fungi, plants and animals are of diverse structure and composition but they share important features that they cannot replicate outside their hosts, and their survival in nature depends upon an effective means of transmission. Hence, insect vectors are of paramount importance in the epidemiology of plant viruses (Andrews, 1965). The vector *Bemisia tabaci* Gen. is one of the most formidable enemies in tropical and subtropical agriculture (Johnson *et al*., 1982). The cosmopolitan insect has a wide host range extending to more than 300 different host plants (Mishra and Lamba, 1929; Rehman, 1940; Reddy *et al*., 1986).

Lakra (2003b) observed that crops sown after mid November had lower PALCV disease incidence and whitefly infestation. The crops sown in October had higher disease incidence and whitefly infestation.

Sastry *et al*. (1978) observed that the moderately low rainfall, low humidity and warm temperature are congenial for the activities of whiteflies, which in turn is good for the spread of ToLCV in field. A positive and significant correlation has been observed between the tomato leaf curl virus disease incidence and whitefly numbers (Borah and Bordoloi, 1998). There was a positive and significant correlation of disease incidence with rainfall, maximum and minimum temperature. Relative humidity morning and evening showed no significant correlation. Singh et al. (1999) observed rapid spread of ToLCV up to 45 days after transplanting and found a positive correlation with maximum and minimum temperature and maximum and minimum relative humidity. Saikia and Muniyappa (1989) reported a strong correlation between the percent disease incidence of tomato leaf curl virus disease and whitefly population. The disease incidence ranged from 17 to 53per cent in Karnatka, India

from February to May. In sequential sowing 90-100 per cent of plants were infected in plots sown between the end of January and end of May. Saklani and Mathai (1972) reported that October to mid December is the most effective time of planting in delaying the disease incidence of ToLCV followed by January to March.

Chelliah *et al*. (1975) observed negative association of okra yellow vein mosaic (OYMV) virus disease incidence with relative humidity and positive association with maximum temperature in all the three stages of crop growth (*i.e.* 30,45 and 60 days old crop). Singh (1990) from his investigation on epidemiology of OYMV disease stated that dry and hot weather with little and no rainfall was very much congenial for disease development, spread and multiplication of whiteflies. Nath et al. (1992) observed lowest whitefly population (1.05 to 2.51/plant) and OYMV disease incidence (19.09 to 36.51%) in crops sown during the period from 10 February to 10 March. Significant positive correlation was recorded between disease incidence and whitefly population temperature, relative humidity and rainfall. Dhawan et al. (2002) observed a positive and significantly correlation between per cent incidence of chilli leaf curl disease and whitefly population with maximum and minimum temperature.

Ali *et al*. (1995) observed that CLCuV incidence increased from 4.3 to 12.3% during the end of July and first week of August. Simple correlation study revealed that CLCuV percent disease incidence had significant but negative correlation with maximum and mean temperature (Singh *et al*., 2001). Sharma (2002) observed maximum whitefly population and CLCuV disease during August to second fortnight of September when maximum temperature was 35±2ºC, minimum temperature 24±2ºC and relative humidity more than52 per cent. There was positive and significant correlation between per cent disease incidence and whitefly population. The CLCuV per cent disease incidence had significant but negative. Correlation with maximum and minimum temp., while relative humidity (morning) was positively correlated.

2.7 The vector ecology

B. tabaci thrives best under hot and humid conditions. In subtropical area with distinct seasons, these insects survive in small numbers on bushy perennial plants like *Lantana camara* during unfavorable winter and dry summer months. *B. tabaci* are present throughout the year, although their population fluctuates depending on the prevailing weather conditions (Varma, 1986). Under north Indian conditions minimum temperature and minimum relative humidity are most important factors influencing *B. tabaci* population (Varma and Subrahmanyan, 1986; Krishanareddy, 1989), whereas, under south Indian condition, minimum rainfall, minimum relative humidity and maximum temperature are more favourable (Murugesan et al., 1997). Female adults prefer temperature above 30ºC for

oviposition. Activation multiplication of this insect has been observed when the maximum temperature ranged from 33 to 41ºC (Nagpal, 1948).

Mohanty and Basu (1991) studied the flight activity of *B. tabaci* under varying weather conditions. They observed maximum trapped whiteflies during May and June, the period with highest temperature and lowest average relative humidity. Pimple and Summanwar (1983) observed that during October to December, the whitefly population migrates to chillies, tobacco, potato, cotton, mustard and rape-seed, cucurbits and other ornamental and weed plants.

2.8 Effect of viral disease on growth and yield attributes

Accurate estimation of the economic losses caused by different potato viruses is lacking. However, based on rough estimates, they cause losses up to 50 per cent in tuber yield in Indian plains (Pushkarnath, 1976). Incidence of viral disease in potato crop may be as high as cent percent depending upon the virus, variety, location, season and quality of seed stock resulting in heavy losses. Annual losses due to potato viruses with an average of 30-40% incidence causes about 25-30% yield reduction (Khurana, 1999). Greater virus incidence and consequent higher yield losses were observed in the spring season in northeast north and west plains of India than in the autumn/winter seasons crops (Nagaich *et al*., 1969, Pushkarnath, 1976, Singh *et al*., 1984). Several strains of PVY and PLRV may take a heavy toll, *i.e.* up to 60-75% reduction in yield, while the mild ones like PVX, PVS, PVA and PVM can depress the yield up to 10-30% (Nagaich *et al*., 1974; Khurana and Singh, 1988). The economically most important potato viruses can considerably reduce the yield and quality of potato, PLRV and PVY up to 80 per cent, PVM and PVA up to 40 per cent, PVX and PVS up to 20 per cent (HORVATH, 2000).

With 100 per cent disease incidence of PALCV more than 50 per cent losses in yield has been reported in early sown crop of potato cultivar Kufri Ashoka (Lakra, 2002). Potato apical leaf curl virus caused losses in yield and adversely affected plant growth parameters. The most deleterious effect was reported on reduction in leaf area, chlorophyll content, height of plant, and number of stems per plant, number of tubers per plant and weight of tubers per plant (Lakra, 2003b).

2.9 Biochemical basis of disease resistance

2.9.1 Total phenol

The importance of phenolic compounds in disease resistance has been recognized since the on-quoted works of Walker (1923, 1926) who demonstrated the protective role of preformed phenolics in onion against smudge pathogen *Colletotrichum circinans.* The resistant onion variety contains protocatechuic acid and catechol. The phenols are water-soluble and diffuse from the dead cell layers of the scales into the infection drop and due to their high toxicity against *Colletotrichum circinans* inhibit germination and penetration

(Walker and Link, 1935). Since then several reports have indicated the role of phenolic compounds in conferring resistance to plants (Farkas and Kiraly, 1962, Cruickshank and Perrin, 1965, Kosuge, 1969).

An early report of involvement of phenols in disease resistance was made by Lee and Letourneau (1958). By and Large, phenol accumulation is higher in resistant inoculated variety than susceptible ones. The presence of more phenols in resistant inoculated variety has special significance. It appears that there is stimulation of host defense mechanism in the infected plants by formation of phenolics (Sharma *et al.,* 1982). They reported higher contents of chlorogenic acid in the roots of potatoes resistant against *Verticillium* wilt. However, gradual loss of resistance after 4-5 weeks was coincident with reduction in phenol content (Patil *et al.*, 1962) but subsequent studies by Patil and his coworkers (1966) revealed that higher amount of phenols in resistant cultivars was due to greater synthesizing ability for these substances. Vir and Grewal (1974) reported that there was no significant difference in phenolic content in resistant (I-13) and susceptible (Pb-7) varieties of chickpea before inoculation with *Ascochyta rabiei,* but after inoculation, the increase was more pronounced in the resistant variety than in the susceptible ones. Phenolics mostly exist in less toxic (or nontoxic) form of glycosides in healthy plants but following attack by the pathogen, an important host enzyme β-glycosidase is activated, which converts non-toxic glycosides to toxic phenolics, which are inhibitory to pathogens (Hilderbrand and Schroth, 1964). It has also been reported that in pear very little inhibitory phenolics were formed in susceptible parts than in resistant parts after infection with *Erwinia amylovora.*

Several studies have been conducted to quantify the total phenol contents in resistant and susceptible varieties of different crop plants though the precise role of the phenolics compounds remained to be explored. In the study of Khirbat and Jalali (1997) regarding enhancement in total phenol contents in response to both the test pathogen isolates of *Ascochyta rabiei* were recorded in resistant genotype E100 Y, while it was decreased in susceptible genotype H 208 when subjected to inoculation at 2-10 days intervals. Borua and Das (2000) exhibited that total phenol content increased in red chilli fruits of resistant variety Krishna in response to inoculation with *Colletotrichum capsici* as compared to susceptible variety Pusa Jwala. Prasath and Ponnuswami (2008) found that the enhancement in total phenol content in response to *Colletotrichum capsici* was recorded in resistant genotype ACC 18, while it was decreased in susceptible genotype HY 6 when subjected to inoculation. Saraswathi and Reddy (2012) studied response of total phenol content in groundnut on inoculation with *Sclerotium rolfsii* and revealed that the contents of total phenol and *ortho*-dihydroxy phenols increased throughout the sampling period of the disease compared to healthy plants.

Bhullar *et al.* (1972) investigated the role of phenolics in resistance to anthracnose disease of chilli. They observed that the phenolics content was found to be higher in resistant

variety than in the susceptible ones. They reported an increase in the phenolic content in the inoculated plants of both the varieties over control and observed a rapid post inflectional accumulation of phenolics in stem, leaves and fruit of resistant variety. Sharma *et al.* (1983) exhibited that maize inbreed CM-104 resistant against *Drechslera* state *Cochliobolus heterostrophus* cantains slightly higher amount of phenols than the susceptible inbreds CM-600. After inoculation, the increase in phenol content was 1.6 to 11.6 per cent in CM-600. Meena *et al.* (2001) observed changes in total phenol content in groundnut after application of salicylic acid and inoculation with *Cercospora personatum.* It was found that in salicylic acid treated leaves the phenol content was increased one day after inoculation with *Cercospora personatum.* Anand *et al.* (2009) exhibited that the total phenol content increased in ripe and green chilli fruits in response to inoculation with *Colletotrichum capsici* and *Alternaria alternata* as compared with uninoculated. Total phenol content increased in ripe chilli fruits up to 3rd day after inoculation and thereafter the content started to decrease.

Although it is difficult to pin point the cause of increased level of phenol from the expression of the disease symptoms of different growth stages. Accumulation of phenol does occur due to several reasons, principally due to release of phenolic compounds, which exist in the form of glycosides and esters (Saunders *et al.,* 1977) or due to infection activated phenol synthesis *via* shikimic acid pathways (Neish, 1959).

2.9.2 Flavanols

Many infected plant tissues particularly locally infected and resistant tissues show a common shift in metabolism that includes accumulation of secondary metabolites comprising of flavanoids and other compounds. Participation of flavanols in disease resistant reaction has been demonstrated in pigeon pea (Murthy and Bagyaraj, 1980). *Fusarium* resistant cultivars of pigeon pea possess more flavanoid as compared to susceptible cultivars. Similarly, Verticillium resistant terminal leaves of cotton plants possess higher concentration of flavanols and synthesize more flavanols than the susceptible leaves in response to infection (Mahadevan and Sridhar, 1986).

2.9.3 Peroxidase

Peroxidase has been correlated with disease resistance in many plants. It is an important enzyme in the synthesis of lignin. It is known to catalyze the oxidation of mono- and di-phenols and aromatic amines to the highly toxic quinones in the presence of hydrogen oxides (Bonner, 1950). The final step in lignin synthesis, *i.e*., polymerization of the three cinnamyl alcohols is mediated by the peroxidase-H_2O_2 system. The enzyme also catalyses the oxidation of many mono- and diphenols and aromatic amines to highly toxic quinones in the presence of hydrogen peroxide. The enzyme itself has been reported to be toxic to microorganisms. The enzymatic oxidative degradation of IAA is also catalyzed by peroxidase, which constitutes an important regulating mechanism in the control of auxin

concentration. IAA oxidation has been suggested as being responsible for the outcome of several host-parasite interaction and connected symptoms.

As early as 1959, Kedar observed a positive correlation between peroxidase activity and degree of resistance in potato plant to *Phytophthora infestans*. However, Seevers and Daly (1970) found no such correlation to exist in wheat infected with stem rust. Rudolph and Stahmann (1964) showed that peroxidase activity remained unchanged or decreased in susceptible bean leaves infected with virulent strain of *Pseudomonas phaseoli* and increased following infection by a less virulent one. Analogously peroxidase activity in a resistant bean variety exhibited a greater increase following infection with a virulent strain than it did in a susceptible variety. Thus, it seemed that heightened peroxidase activity favours resistance to *Pseudomonas phaseoli.*

Sridhar and Mahadevan (1968) reported an increase in peroxidase activity of rice leaves within 15 minutes of inoculation with *Pyricularia oryzae.* Shishiyama *et al.* (1969) found that in the aspartate rich protein fraction of the rice plants, the peroxidase activity increased about two folds in leaves inoculated with *Cochliobolus miyabeanus* than in healthy plants. Loebenstein and Linsey (1961) working with vein clearing virus of sweet potato observed that infected plants had significantly higher peroxidase activity in roots (1.7) and leaves (3.3) than healthy ones (1.0). They further showed that increase in peroxidase activity following inoculation commenced with the appearance of symptoms in infected plants. The activity varied with age of leaf, timing of daily measurement and age of infection. The relative peroxidase activity kept rising with age of infection and was often high (3.6) in 2-3 months old plants as compared (with 2.0) after 1 month of infection. Vir and Grewal (1974) reported that leaves and stem of chick pea variety I-13 resistant against *Ascochyta* blight showed maximum increase of peroxidase activity 12 days after inoculation, whereas, susceptible variety Pb-7 showed relatively lesser increase at 8 days after inoculation. Several other workers reported increase in peroxidase activity following infection (Fehrmann and Dimond, 1967; Jennings *et al.,* 1969; Gangopadhyay and Lal, 1986; Gupta *et al.,* 1990; Sharma *et al.,* 1982).

Lelyveld and Vuuren (1988) obtained a negative correlation between peroxidase activity in mature leaves of 11 different citrus cultivars and their tolerance towards greening disease, suggesting that peroxidase activity can be used as a parameter for assessing susceptibility. There was no significant difference in peroxidase activity between apparently healthy and affected branches from the same cultivars or species indicating that peroxidase activity was not affected by the presence of disease symptoms. Chandra and Tyagi (1993) determined the PO activity in resistant (Pusa 8972) and susceptible (Pusa 8773) varieties of mung infected with *Macrophomina phaseolina.* Peroxidase levels were similar in stem extracts of uninoculated Pusa 8972 and Pusa 8773, however, uninoculated leaves of Pusa

8972 showed slightly higher peroxidase activity than those of Pusa 8773. After inoculation the enzymatic activity increased in leaves of both the cultivars but the increase was more pronounced in cv. Pusa 8972. Riccardo *et al.* (1993) reported a marked increase in the peroxidase and diamineoxidase activity along with putrescine level in both the susceptible (Calia) and resistant cv. (Sultano) of chick pea on inoculation with *Aschochyta rabiei* but it was to a greater extent in Sultano as compared to Calia. Scott *et al.* (1995) reported accumulation of a cationic peroxidase (PO-C1) in xylem vessels of rice during incompatible interaction with *Xanthomonas oryzae* pv. *oryzae* and suggested that the role of PO-C1 in resistant cultivar might be a consequence of the function in lignin biosynthesis.

Prasath and Ponnuswami (2008) found that the variety ACC 16 resistant against *Colletotrichum capsici* showed highest peroxidase activity as compared to moderately resistant varieties HY-1, HY-2, HY-3, HY-4 and HY-5. Least enzyme activity was observed in susceptible variety P_1, P_2, P_4, P_5 and HY6-10. Anand *et al.,* (2009) observed that peroxidase activity was higher in the inoculated ripe and green chilli fruits compared to uninoculated healthy fruits. In ripe chilli fruits, the peroxidase activity increased up to 3rd day after inoculation and thereafter the activity decreased. However, even on 5th day after inoculation, the activity was higher than the initial level.

Rai *et al.* (2010) exhibited that the variety BS-35 resistant to pepper leaf curl virus showed maximum increase of peroxidase activity as compared to susceptible variety KA-2 after inoculation with viruliferous whitefly. The activity of peroxidase expressed a direct impact for resistance in the host, which could be due to the conversion of enzyme into quinones which are toxic to the pathogen.

2.9.4 Tannin content

Little information is available on the role of tannin in disease resistance. The varieties of sorghum resistant to *Ramulispora sorghicola* contains high content of tannin as compared to susceptible varieties at all the stages of plant growth (Arora and Luthra, 1974; Luthra *et al*., 1990). Tannin content also increased markedly after infection in susceptible varieties. However, in resistant varieties insignificant variation in tannin content after infection was observed.

2.10 Screening of potato germplasm lines against PALCVD

Baswana *et al.* (2009) tested 180 accessions of potato against potato apical leaf curl disease which reported one accession CP-1716 as resistant, while three accessions namely, CP 1813, CP 1818 and CP 1859 exhibited disease incidence <20% and hence moderately resistant. , Lakra (2008) evaluated 266 germplasm lines and 15 cultivars and found that Kufri Bahar and CP 1246 were resistant to PALCVD.

CHAPTER-III

MATERIALS AND METHODS

The present investigation entitled "Studies of potato apical leaf curl virus disease in potato" was carried at Research Area of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar during *Rabi* season of 2012-13 and 2013-14. The details of materials and methods used in the present investigation are as follows:

3.1 Role of weather variables and whitefly (*Bemisia tabaci*) population on the development of potato apical leaf curl virus disease

3.1.1 Field Experiments

The crop was raised in the field keeping row to row and plant to plant spacing 60×20 cm. The plot size was 3.0×2.0 m^2. Potato varieties Kufri Pushkar, Kufri Bahar, Kufri Pukhraj, Kufri Badshah, Kufri Khyati, Kufri Surya, and Kufri Sadabahar were planted in split-plot design on three different dates, *i.e*., 7th October, 16th October and 25th October 2012 and 2013. All the agronomic practices as per the package of the practices were followed during the course of experimentations. There were five replications for each variety. The plots were not given any protective spray and disease was allowed to occur on the plants.

3.1.2 Observations recorded

Observations were recorded on whitefly population per plant, and incidence of potato apical leaf curl virus disease (PALCVD) on potato plants.

3.1.2.1 Whitefly population at weekly interval after plant emergence

In each replication, 10 plants were tagged randomly and whitefly population was counted on these potato plants. The number of whitefly was counted on 10 compound leaves at different positions, *i.e.,* bottom, middle and top of the plant. Counting of whitefly was done in early morning hours because at that time whiteflies were comparatively inactive. Whitefly population was taken from the all seven varieties.

3.1.2.2 Per cent potato apical leaf curl virus disease incidence at weekly interval after plant emergence

The number of plants showing apical leaf curl symptoms along with the total number of plants was counted in each plot and per cent disease incidence was calculated as per the formula given below:

$$\text{Apical leaf curl virus disease (\%)} = \frac{\text{No. of plants affected with apical leaf curl disease per plot}}{\text{Total number of plants per plot}} \times 100$$

3.1.2.3 Meteorological data for development of regression equation

The data on weather variables *viz.,* maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, wind speed, sun shine hour and rainfall were obtained from meteorology laboratory, CCS Haryana Agriculture University, Hisar. The mean of weather variables stated above were calculated at weekly interval and designated as X_1, X_2, X_3, X_4, X_5, X_6 and X_7, respectively.

3.1.2.4 Statistical analysis

Correlation and stepwise multiple regression analysis was done to know the relationship among whitefly population and weather variables. For this mean, the value of whitefly population recorded at weekly interval was calculated and designated as:

Y_1 : Kufri Pushkar

Y_2 : Kufri Bahar

Y_3 : Kufri Pukhraj

Y_4 : Kufri Badshah

Y_5 : Kufri Khyati

Y_6 : Kufri Surya

Y_7 : Kufri Sadabahar

Regression analysis was performed by taking whitefly population as dependent variable and weather parameters as independent variables.

3.2 Evaluation of biochemical parameters in different varieties of potato

For biochemical analysis, leaf samples of resistant variety (Kufri Bahar), moderately resistant (Kufri Pushkar) and susceptible variety (Kufri Khyati) were collected at 20, 40, 60, and 80 day after planting. Leaf samples were taken from healthy and diseased plants sown on 16th October 2013. The following parameters were studied:

3.2.1 Biochemical Parameters

1. Total phenol
2. Flavanols
3. Peroxidase
4. Tannin

3.2.1.1 Extraction and estimation of total phenol

For the extraction and estimation of total phenol, the method of Swain and Hills (1959) was adopted.

Reagents

1. 80% (v/v) ethanol
2. Folin-Ciocalteau reagent (1 N)
3. Saturated solution of Na_2CO_3

4. Stock standard catechol (100 mg/100 ml water): Working standard solution was prepared by diluting the stock solution 10 times.

Procedure

Extraction

One plant was taken randomly from each plot, and its approximately 200 g apical portion of the foliage was taken. All the samples were dried in oven at 50-60ºC. The dried sample of each variety was ground in mortar and pestle and weighed exactly one gram defatted in 10 ml of 80% ethanol, centrifuged to homogenate at 10,000 rpm for 10 minutes, and saved the supernatant. The residue re-extracted twice with 5 ml 80% ethanol, the supernatant was pooled, and final volume was made to 10 ml by adding 80% ethanol.

Estimation

Took 1 ml of the supernatant and evaporated to dryness. Dissolve the residue in 1 ml of distilled water. Then 3 ml of distilled water was added to make final volume of 4 ml. After 3 minutes of addition of 0.5 ml of Folin-Ciocalteau reagent, 2 ml of saturated Na_2CO_3 solution was added to each tube. The contents were mixed thoroughly. Place the tube in boiling water for exactly one minute. Tubes were cooled and absorbance was recorded at 650 nm against a reagent blank. A standard curve prepared by using different concentrations of catechol (0-100 µg/ml) was used to calculate total phenol content. Results were expressed as mg total phenol /1g fresh weight.

3.2.1.2 Estimation of Flavanols

For the estimation of flavanols, the method of Swain and Hills (1959) was adopted.

Reagents

1. Vanillin Reagent (1% Vanillin solution in 70% v/v H_2SO_4)

Estimation

Alcoholic extract (1 ml) was taken in 25 ml measuring flask and 5 ml of vanillin reagent was added during 10-15 seconds. The Flask was shaken in cold water bath to check the rise in temperature. Blank was also prepared with water and absorbance was measured at 725 nm. Flavanols content was calculated with the help of standard curve of tannic acid.

3.2.1.3 Determination of activity of Peroxidase

Peroxidase was extracted and assayed by using the method of Perur (1962).

Reagents

1. 0.1M phosphate buffer (pH 6.1)
2. O-dianisidine (0.1%)
3. 0.2M hydrogen peroxide
4. 0.1M acetate buffer (pH 4.5)

2.26 ml of hydrogen peroxide (30 volumes) was made to 100 ml with distilled water. It was always prepared fresh.

Preparation of enzyme extract

Leaf tissue (1 g) was homogenized in 2 ml of 0.1M phosphate buffer (pH 6.1) by grinding in a pre-cooled mortar and pestle. The homogenate was centrifuged at 10,000 rpm at -4^{o}C for 20 minutes. Supernatant thus obtained was used as enzyme source. The extract was stored in a refrigerator. The activity was estimated within 4 hours of extraction.

Assay

In preliminary studies, it was first established that under the assay conditions employed, the rate of enzyme catalyze reaction was proportional both to the amount of enzyme as well as the reaction time. In a clean dry cuvette 2.5 ml of acetate buffer was taken. In this, 0.5 µl enzyme extract and 0.1 ml O-dianisidine (M.W. 244.3) solution was added. Then, after adding 0.4 ml H_2O_2 in the solution, and the content was mixed thoroughly. The cuvette was place in the spectrophotometer set at 430 nm and immediately the stopwatch was started. The initial absorbance was read and thereafter, at every 15 seconds interval up to 3 minutes. Blank did not contain H_2O_2.

Calculations

The enzyme activity was expressed in terms of specific activity (units/g fresh weight). One unit of activity was defined as the amount of enzyme, which produced a change of 0.1 in absorbance at 430 nm/min of incubation (1 unit = Δ 0.1 O.D/min at 430 nm).

3.2.1.4 Estimation of Tannin

Tannin was estimated by using the method described by Burns (1971).

Reagents

1. Hydrochloric acid (8% v/v) in methanol.
2. Vanillin (4% w/v) in methanol.

These solutions were prepared daily and mixed in 1:1 ratio just before use and avoided use after a trace colour appear.

Estimation

For estimation of total tannin content, 1 ml extract was taken in 50 ml tubes and 25 ml of ethanol was added to each tube, stoppered and swrilled. Mix occasionally by swirling. After 20-28 hours swirl and let settle. Pipette out 1ml of supernatant into each of the two tubes, 5 ml of vanillin reagent were added in each tube, and the blank was prepared with Vanillin–HCl reagent. Absorbance was measured at 525 nm, and the tannin content was calculated with the help of standard curve of tannic acid.

3.3 Screening of germplasm lines against potato apical leaf curl virus disease

Three hundred ten germplasm lines of potato were screened against potato apical leaf curl virus disease under field conditions. Each germplasm was planted in two rows per plot having 3 meter row length and row to row distance was 60 cm and plant to plant 20 cm with five tubers in each row. Planting was done on October 16, 2013. Infector row of Kufri Khyati

after every 5th test row and around the field was maintained to create congenial conditions for whitefly attack. An observation of disease incidence was recorded at 10 days interval as per cent number of plants infected. The final observation was taken up at 80 days.

Disease incidence was calculated by using the following formula:

$$\text{Disease Incidence} = \frac{\text{Total number of diseased plants}}{\text{Total number of plants observed}} \times 100$$

Scale used for screening of resistance

Disease Reaction	**Disease Incidence (%)**
Resistant	<10
Moderately Resistant	10.1-20
Moderately Susceptible	20.1-40
Susceptible	40.1-60
Highly Susceptible	>60

3.3.1 Observations recorded

The observation on per cent plant emergence was recorded at 20 days after planting. The number of infected plants was recorded at 20 days after planting and thereafter at ten days interval until 80 days after planting to identify the source of resistance to potato apical leaf-curl disease. The percent potato apical leaf-curl disease incidence was worked out as follows:

$$\text{Per cent apical leaf curl virus disease} = \frac{\text{Total number of plants affected with apical leaf curl virus disease in both the replications}}{\text{Total number of plants in both the replications}} \text{ x } 100$$

CHAPTER-IV

EXPERIMNETAL RESULTS

The results of the present experiment entitled "Studies of potato apical leaf curl virus disease in potato" conducted during *Rabi* season of 2012-13 and 2013-14 are presented in this chapter with the help of appropriate Tables.

4.1 Symptomatology

First visible symptom of potato apical leaf curl virus disease (PALCVD) was observed as clearing of veins. Infected leaves showed mottling and crinkling symptoms. The younger infected leaves showed notching and indentation of leaf lamina. The infected leaves showed vein thickening and upward curling of leaf margin. Thereafter, curling of leaf margins occurred and leaf margin became wavy. There was development of small yellow patches on leaf lamina. Infected leaves became smaller and distorted in shape. Infected plants remained dwarf with shortened internodes (Plate 1, 2, 3 and 4).

4.2 Role of weather variables and whitefly (*Bemisia tabaci*) population on the development of potato apical leaf curl virus disease

4.2.1 Whitefly population at weekly interval after plant emergence

The data presented in Table 1 reveal that all the seven varieties *viz*., Kufri Pushkar, Kufri Bahar, Kufri Pukhraj, Kufri Badshah, Kufri Khyati, Kufri Surya and Kufri Sadabahar had the attack of whitefly, which is the vector for potato apical leaf curl virus disease (PALCVD) and the observations were taken at weekly interval. All the varieties tested showed that there was maximum whitefly population ranging from 22 to 83 in different varieties in last week of October when the average maximum temperature was 28.6ºC and minimum temperature was 11.7ºC, represented graphically in Fig. 1. The whitefly population was highest in Kufri Khyati (83) and minimum in Kufri Bahar (22) in the year 2012. The population of whitefly decreased gradually with the fall in maximum and minimum temperature (Fig. 1) thus, in 2nd fortnight of December, there were few whiteflies present in the crop.

Table 1: Observations of whitefly population in year 2012

Variety	Date of observations							
	31th Oct.	7th Nov.	14th Nov.	21th Nov.	28th Nov.	5th Dec.	12th Dec.	19th Dec.
K. Pushkar	53	47	39	34	29	18	11	04
K. Bahar	22	15	10	08	05	04	02	00
K. Pukhraj	62	61	58	50	30	20	10	05
K. Badshah	44	36	23	18	15	11	06	02
K. Khyati	83	81	77	68	49	34	18	06
K. Surya	33	32	30	26	17	11	06	00
K. Sadabahr	46	44	36	24	17	10	07	02

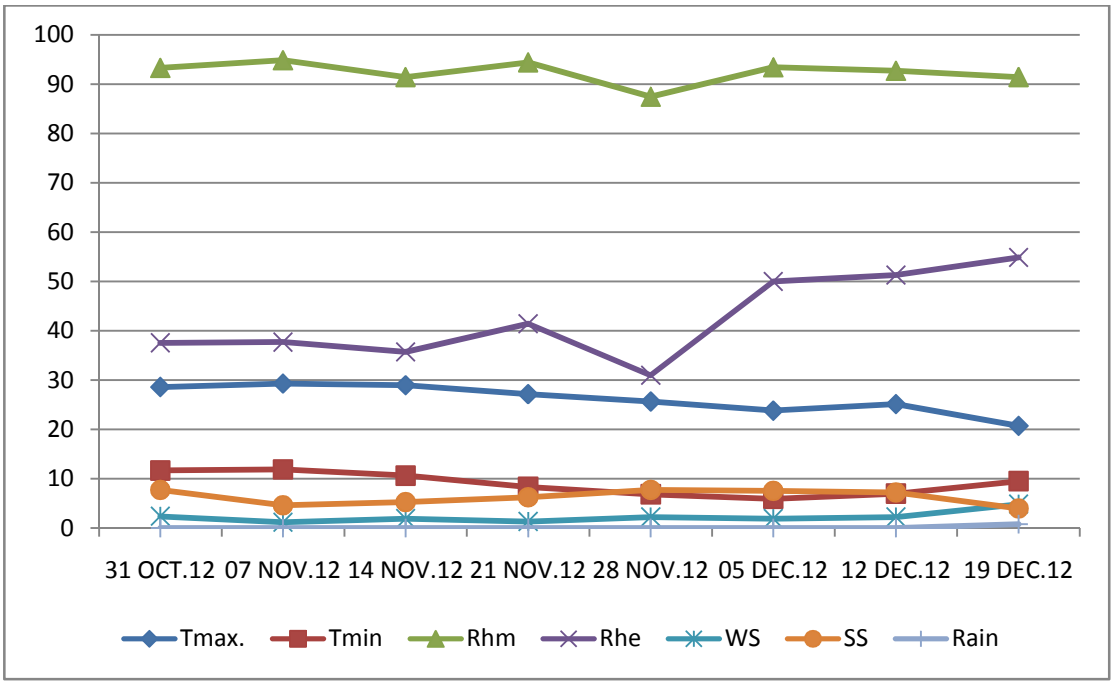

Fig. 1: Effect of weather variables in relation to different observations at weekly interval (2012)

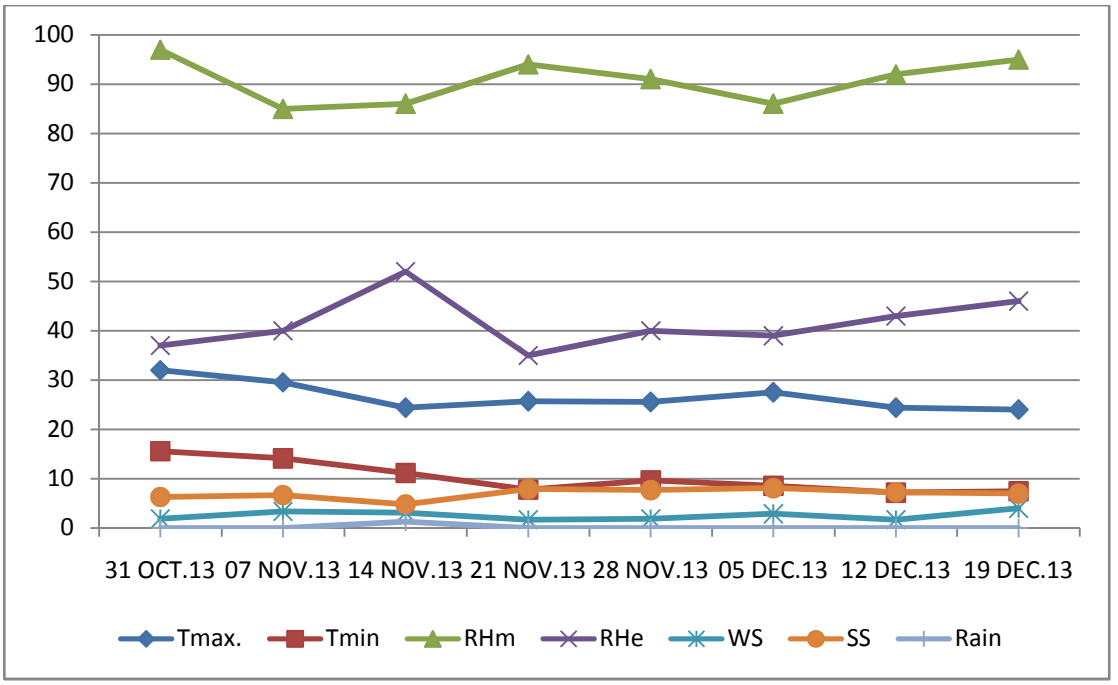

Fig. 2: Effect of weather variables in relation to different observations at weekly interval (2013)

Plate 1: Symptomatology of PALCVD in Potato leaves

Plate 2: Symptomatology of PALCVD in Potato leaves

Plate 3: Symptomatology of PALCVD in leaves of variety Kufri Khyati

Plate 4: Symptomatology of PALCVD in leaves of variety Kufri Badshah

In Table 2 the reaction of different varieties had been given and it was noticed that whitefly population (vector) was directly proportional to potato apical leaf curl virus disease

as Kufri Khyati, which was having maximum number of whitefly (83) in initial stages of the crop growth, had more disease (100%) and lesser in Kufri Pukhraj (60%). Here, it is to be mentioned that although Kufri Bahar had whitefly population (22) which decreased gradually like the other varieties but reduction in number of whitefly was at a faster rate in comparison to other varieties. No visible symptoms of the disease potato apical leaf curl virus (PALCVD) appeared on Kufri Bahar throughout the crop growth.

Table 2: Per cent incidence of PALCVD at different interval/days after emergence in year 2012

Variety	31th Oct.	7th Nov.	14th Nov.	21th Nov.	28th Nov.	5th Dec.	12th Dec.	19th Dec.
K. Pushkar	0	10	20	30	40	40	40	40
K. Bahar	0	0	0	0	0	0	0	0
K. Pukhraj	0	20	30	40	40	50	60	60
K. Badshah	0	10	10	20	20	20	30	30
K. Khayti	10	20	40	60	80	100	100	100
K. Surya	0	10	20	20	20	30	30	30
K. Sadabahar	0	20	40	40	40	40	60	60

A similar type of trend was observed for whitefly population in the year 2013 (Table 3) except whitefly population decreased in mid November 2013 as compared to 2012 because of low maximum temperature of 24.4 and 25.7ºC in 2013 (Fig. 2), whereas, in the corresponding period in 2012, it was 29 and 27.1ºC (Fig. 1).

Table 3: Observations of whitefly population in year 2013

Variety	Date of observations							
	31th Oct.	7th Nov.	14th Nov.	21th Nov.	28th Nov.	5th Dec.	12th Dec.	19th Dec.
K. Pushkar	55	48	31	30	26	16	07	02
K. Bahar	26	18	11	09	06	05	02	00
K. Pukhraj	64	62	56	43	32	18	08	02
K. Badshah	47	39	18	15	12	08	05	01
K. Khyati	87	85	73	60	44	29	11	04
K. Surya	39	36	25	19	13	09	04	00
K. Sadabahar	49	46	34	21	15	09	06	01

From the Table 4, it could be concluded that due to low whitefly population there was less PALCVD in 2013 as compared to PALCVD in 2012 and Kufri Khyati susceptible variety

had only 80% disease infection lesser in Kufri Pukhraj (50%). Likewise 2012, Kufri Bahar had no visible symptoms of PALCVD.

Table 4: Per cent incidence of PALCVD at different interval/days after emergence in year 2013

Variety	31th Oct.	7th Nov.	14th Nov.	21th Nov.	28th Nov.	5th Dec.	12th Dec.	19th Dec.
K. Pushkar	0	10	20	20	30	30	40	40
K. Bahar	0	0	0	0	0	0	0	0
K. Pukhraj	0	20	20	20	30	40	50	50
K. Badshah	0	10	10	20	20	20	30	30
K. Khayti	10	20	30	40	50	60	80	80
K. Surya	0	10	10	20	20	20	20	20
K. Sadabahar	0	20	20	30	30	30	40	50

The correlation coefficient of whitefly population with weather parameters (Table 5) explains that whitefly population was significantly and positively correlated with maximum (X_1) temperature in all the varieties at 5% level except Kufri Bahar (Y_2), which was significantly and positively correlated only at 1% level. Minimum (X_2) temperature was significantly and positively correlated only at 1% level in the varieties Kufri Bahar (Y_2), Kufri Badshah (Y_4) and Kufri Sadabahar (Y_7), whereas, the other varieties Kufri Pushkar (Y_1), Kufri Pukhraj (Y_3), Kufri Khyati (Y_5) and Kufri Surya (Y_6) showed non-significant reaction. Evening relative humidity (X_4) was significant but negatively correlated with the predictability of whitefly population at 1% level in Kufri K.Pushkar (Y_1), Kufri Pukhraj (Y_3), Kufri Khyati (Y_5) and Kufri Surya (Y_6). The other factors morning relative humidity (X_3), wind speed (X_5), sunshine hour (X_6) and rain (X_7) were non-significant in all the varieties.

Table 5: Correlations matrix of whitefly population with weather parameters in relation to different potato varieties in year 2012

Variety	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Y_1	0.92**	0.67	0.25	-0.79*	-0.61	0.12	-0.59
Y_2	0.81*	0.75*	0.36	-0.59	-0.43	0.13	-0.46
Y_3	0.93**	0.70	0.31	-0.75*	-0.63	-0.03	-0.55
Y_4	0.84**	0.75*	0.34	-0.64	-0.48	0.09	-0.49
Y_5	0.94**	0.63	0.26	-0.80*	-0.68	0.06	-0.62
Y_6	0.95**	0.65	0.29	-0.78*	-0.67	0.05	-0.62
Y_7	0.92**	0.79*	0.33	-0.70	-0.54	-0.04	-0.50

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01 level

Based on stepwise regression analysis, whitefly population (vector) was directly proportional to potato apical leaf curl virus disease (PALCVD) in the potato crop. Different

weather variables X_1, X_2, X_3, X_4, X_5, X_6 and X_7 were taken. The multiple regression equation derived is presented in Table (6). From the Table, it could be inferred that X_1, X_2, X_4, X_5 and X_7 were most contributing factors for the predictability of whitefly and correspondingly the disease development (PALCVD). These factors contributed 95, 92, 93, 96, 94, 95 and 98 per cent in the tested seven varieties *viz*., Y_1, Y_2, Y_3, Y_4, Y_5, Y_6 and Y_7, respectively.

Table 6: Multiple Regression equations for the population dynamics of whitefly with different meteorological parameters 2012

Multiple Regression equations	R^2
$Y_1 = 179.19 - 6.67\ X_1 + 9.37\ X_2 - 1.01\ X_4 - 4.55\ X_5 - 61.59\ X_7$	0.95
$Y_2 = 98.93 - 5.02\ X_1 + 6.34\ X_2 - 0.27\ X_4 + 0.16\ X_5 - 52.40\ X_7$	0.92
$Y_3 = 17.31 + 0.87\ X_1 + 5.53\ X_2 - 0.79\ X_4 - 8.62\ X_5 + 2.70\ X_7$	0.93
$Y_4 = 246.13 - 11.35\ X_1 + 13.26\ X_2 - 0.76\ X_4 - 2.91\ X_5 - 100.75\ X_7$	0.96
$Y_5 = 114.41 - 1.84\ X_1 + 8.02\ X_2 - 1.37\ X_4 - 11.62\ X_5 - 19.39\ X_7$	0.94
$Y_6 = 24.94 - 0.17\ X_1 + 3.23\ X_2 - 0.46\ X_4 - 4.20\ X_5 - 7.86\ X_7$	0.95
$Y_7 = 102.84 - 4.75\ X_1 + 9.22\ X_2 - 0.59\ X_4 - 3.26\ X_5 - 52.67\ X_7$	0.98

In the year 2013, the correlation matrix of whitefly population with weather parameter (Table 7) reveled that X_1 was significantly and positively correlated with whitefly population in the varieties Y_2 and Y_4 at 5% level and in the varieties Y_1, Y_6 and Y_7 which was significantly and positively correlated with whitefly population only at 1% level, whereas, Y3 and Y_5 were non-significant. X_2 was significantly and positively correlated with whitefly population in all the varieties at 5% level except Y_4, which was significantly and positively correlated with whitefly population only at 1% level. The other factors X_3, X_4, X_5, X_6 and X_7 were non-significant.

Table 7: Correlations matrix of whitefly population with weather parameters in relation to different potato varieties in year 2013

Variety	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Y_1	0.82*	0.92**	-0.06	-0.35	*-0.20*	-0.37	0.09
Y_2	0.88**	0.95**	0.06	-0.32	*-0.17*	-0.42	0.06
Y_3	0.65	0.85**	-0.18	-0.16	*-0.13*	-0.53	0.34
Y_4	0.89**	0.96*	0.02	-0.33	*-0.11*	-0.39	-0.00
Y_5	0.68	0.86**	-0.19	-0.20	*-0.13*	-0.48	0.29
Y_6	0.79*	0.93**	-0.12	-0.23	*-0.11*	-0.49	0.19
Y_7	0.75*	0.94**	-0.13	-0.14	*-0.06*	-0.56	0.25

Based on stepwise regression in the year 2013, the different weather variables X_1, X_2, X_3, X_4, X_5, X_6 and X_7 responded differently. The multiple regression equation derived is presented in Table 8. From the Table, it could be demonstrated that X_1, X_2, X_4 and X_6 were

most contributing factors, whereas, the other factors, *i.e.*, X_3, X_5 and X_7 had no role for the predictability of whitefly and correspondingly the disease development (PALCVD). These four factors contributed 96, 99, 90, 98, 89, 95 and 96 per cent in the tested seven varieties *viz.*, Y_1, Y_2, Y_3, Y_4, Y_5, Y_6 and Y_7, respectively.

Table 8: Multiple Regression equations for the population dynamics of whitefly with different meteorological parameters 2013

Multiple Regression equations	R^2
$Y_1 = 259.16 - 4.15\ X_1 + 6.34\ X_2 - 3.11\ X_4 - 8.25\ X_6$	0.96
$Y_2 = 79.26 + 0.44\ X_1 + 0.92\ X_2 - 1.16\ X_4 - 6.11\ X_6$	0.99
$Y_3 = 478.82 - 7.89\ X_1 + 8.46\ X_2 - 4.80\ X_4 - 17.20\ X_6$	0.90
$Y_4 = 104.40 - 0.15\ X_1 + 3.51\ X_2 - 1.71\ X_4 - 6.78\ X_6$	0.98
$Y_5 = 602.99 - 9.64\ X_1 + 10.87\ X_2 - 6.23\ X_4 - 21.43\ X_6$	0.89
$Y_6 = 183.76 - 2.01\ X_1 + 3.71\ X_2 - 2.12\ X_4 - 8.73\ X_6$	0.95
$Y_7 = 218.44 - 2.45\ X_1 + 4.77\ X_2 - 2.42\ X_4 - 11.29\ X_6$	0.96

In Table 9, the pooled data for both the years, *i.e.*, 2012 and 2013 were taken and the correlation coefficient of whitefly population with different weather variables showed that X_1 was significantly and positively correlated with whitefly population in all the varieties at 5% level, whereas, X_2 was significantly and positively correlated with whitefly population in all the varieties at 5% level, except in the varieties Y_3 and Y_5, which were significantly and positively, correlated at 1% level. X_4 was significant and negatively correlated with the predictability of whitefly population and correspondingly the disease development at 1% level in all the varieties except Y_2 and Y_7. The remaining weather parameters X_3, X_5, X_6 and X_7 had no significant role in predicting the whitefly population in all the seven varieties.

Table 9: Correlations matrix of whitefly population with weather parameters in relation to different potato varieties in year 2012 and 2013 (pooled)

Variety	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Y_1	0.96**	0.86**	-0.08	-0.80*	-0.51	-0.12	-0.16
Y_2	0.97**	0.91**	0.09	-0.68	-0.40	-0.13	-0.17
Y_3	0.89**	0.83*	-0.13	-0.72*	-0.49	-0.28	0.03
Y_4	0.97**	0.93**	0.06	-0.68*	-0.38	-0.15	-0.20
Y_5	0.91**	0.80*	-0.17	-0.76*	-0.53	-0.21	-0.02
Y_6	0.94**	0.86**	-0.10	-0.72*	-0.50	-0.23	-0.05
Y_7	0.94**	0.93**	-0.06	-0.65	-0.40	-0.31	-0.01

In Table 10, the multiple regression equation for the pooled data of 2012 and 2013 is given. Based on stepwise regression analysis, the whitefly population (vector) was directly proportional to potato apical leaf curl virus disease (PALCVD) in the potato crop. Different

weather variables X_1, X_2, X_3, X_4, X_5, X_6 and X_7 were taken. From the Table, it could be revealed that X_1, X_2, X_4 and X_5 were the contributing factors for the predictability of whitefly. These factors contributed 98, 97, 89, 99, 90, 94 and 97 per cent in the tested seven varieties *viz.*, Y_1, Y_2, Y_3, Y_4, Y_5, Y_6 and Y_7, respectively.

Table 10: Multiple Regression equations for the population dynamics of whitefly with different meteorological parameters 2012 and 2013 (pooled)

Multiple Regression equations	R^2
$Y_1 = 6.33 + 1.37\ X_1 + 3.88\ X_2 – 1.02\ X_4 – 3.49\ X_5$	0.98
$Y_2 = –53.61 + 2.21\ X_1 + 0.92\ X_2 - 0.14\ X_4 + 0.66\ X_5$	0.97
$Y_3 = 123.84 – 4.49\ X_1 + 10.43\ X_2 – 0.69\ X_4 – 16.39\ X_5$	0.89
$Y_4 = – 99.64 + 4.17\ X_1 + 1.93\ X_2 – 0.34\ X_4 + 1.79\ X_5$	0.99
$Y_5 = 119.28 – 3.01\ X_1 + 10.73\ X_2 – 1.19\ X_4 – 17.41\ X_5$	0.90
$Y_6 = 19.47 – 0.64\ X_1 + 4.64\ X_2 – 0.26\ X_4 – 7.03\ X_5$	0.94
$Y_7 = – 3.43 – 1.75\ X_1 + 6.83\ X_2 + 0.02\ X_4 – 8.31\ X_5$	0.97

4.2 Evaluation of biochemical parameters in different varieties of potato

4.2.1 Total phenol content

The study was conducted to evaluate the role of total phenol content in the leaves of potato varieties. Total phenol content was estimated in the leaves of potato on 20, 40, 60 and 80 days after planting and the data are presented in Table 11.

It is clear from the Table 11 that in healthy set, the phenol content was highest in the leaves of resistant (R) variety Kufri Bahar (0.56 mg/g) as compared to the leaves of moderately resistant (MR) variety Kufri Pushkar (0.40 mg/g) and susceptible (S) variety Kufri Khyati (0.23 mg/g). There was no disease symptoms observed in resistant variety of Kufri Bahar, thus, no estimation of phenol content was done. However, in response to whitefly attack, there was significant increase in the total phenol content and it was higher in diseased leaves of moderately resistant variety (0.44 mg/g) as compared to healthy leaves (0.39 mg/g) at 80 days after planting. Similarly, the increased trend in total phenol content was observed in leaves of susceptible variety Kufri Khyati (0.40 mg/g) after whitefly attack at 60 days planting, and thereafter, it decreased and at 80 days, the level was 0.31 mg/g.

4.2.2 Flavanols

The data presented in Table 12 revealed the role of flavanols content in the leaves of potato varieties. Flavanols content was estimated in the leaves of potato on 20, 40, 60 and 80 days after planting. It is showen in the Table 12 that in healthy leaves, the flavanols content was highest in resistant (R) variety Kufri Bahar (0.28 mg/g), less in moderately resistant (MR) variety Kufri Pushkar (0.22 mg/g) and least in susceptible (S) variety Kufri Khyati (0.19 mg/g). In resistant variety of Kufri Bahar there was no appearance of symptoms so no estimation of flavanols was done. However, in response to whitefly attack, there was significant increase in flavanols content and it was higher in both the moderately resistant

(0.34 mg/g) and susceptible variety (0.31 mg/g) after 60 days of planting, whereas, in healthy leaves correspondly it was 0.23 mg/g and 0.20 mg/g. In both the moderately resistant and susceptible varietis, the flavanols content was decreased after 60 days of planting.

4.2.3 Peroxidase

The experiment was conducted to find out the role of peroxidase activity in the leaves of resistant (K.Bahar), moderately resistant (K.Pushkar) and susceptible (K.Khyati) variety of potato after disease incidence. The leaves of varieties were taken at 20, 40, 60, and 80 days after disease incidence and the data are presented in Table 13.

Data in Table 13 indicate that the peroxidase activity was more in healthy leaves of resistant potato variety (0.39 activity/minute/g sample) than in susceptible variety (0.21 activity/minute/g sample). There was no disease symptoms observed in resistant variety of Kufri Bahar, hence, no estimation of peroxidase activity was done. However, a significant increase in peroxidase activity (0.34 activity/minute/g sample) in leaves of moderately resistant variety was recorded at 80 days after infection as compared to leaves of susceptible variety (0.23 activity/minute/g sample). In the leaves of susceptible variety, the significantly increased trend in peroxidase activity (0.30 activity/minute/g sample) was observed particularly at 40 days after infection, and thereafter, the activity decreased.

4.2.4 Tannin

The data presented in Table 14 reveal the role of tannin content in the leaves of potato varieties. Tannin content was estimated in the leaves of potato on 20, 40, 60, and 80 days after planting. From the Table 14, it could be demonstrated that a similar type of trend was observed as there was in total phenol content, flavanols and peroxidase. In healthy set, the tannin content was higher in leaves of resistant variety K.Bahar (0.22 mg/g) as compared to the leaves of moderately resistant variety Kufri Pushkar (0.19 mg/g) and susceptible variety Kufri Khyati (0.16 mg/g). There was no disease symptoms observed in resistant variety of Kufri Bahar, so no tannin was estimated. However, in response to whitefly attack, there was significant increase in the tannin content in the leaves of moderately resistant variety (0.25 mg/g) at 60 days after planting, which decreased afterwards. Significantly increased trend in tannin content was also observed in leaves of susceptible variety (0.22 mg/g) particularly at 60 days planting and thereafter, the tannin (0.18 mg/g) in leaves, which decreased drastically at 80 days after planting.

Table 11: Host–pathogen interaction: Total phenol Content (mg/g fresh wt.) in response to different intervals after planting

Treatments	Kufri Bahar (R)					Kufri Pushkar (M.R)					Kufri Khyati (S)				
	Days after planting					Days after planting					Days after planting				
	20	40	60	80	**Mean**	20	40	60	80	**Mean**	20	40	60	80	**Mean**
Diseased	-	-	-	-	-	0.39	0.47	0.51	0.44	0.45	0.28	0.34	0.40	0.31	0.33
Healthy	0.52	0.58	0.59	0.53	0.56	0.37	0.42	0.40	0.39	0.40	0.22	0.26	0.24	0.21	0.23
Mean	0.52	0.58	0.59	0.53	0.56	0.38	0.45	0.46	0.42	0.42	0.25	0.30	0.32	0.26	0.28
CD at 5%	Varieties (A) 0.012					Days (B) 0.014					Interaction (A×B) NS				

Table 12: Host–pathogen interaction: Flavanols Content (mg/g fresh wt.) in response to different intervals after planting

Treatments	Kufri Bahar (R)					Kufri Pushkar (M.R)					Kufri Khyati (S)				
	Days after planting					Days after planting					Days after planting				
	20	40	60	80	**Mean**	20	40	60	80	**Mean**	20	40	60	80	**Mean**
Diseased	-	-	-	-	-	0.26	0.29	0.34	0.26	0.29	0.22	0.25	0.31	0.24	0.26
Healthy	0.25	0.28	0.31	0.26	0.28	0.20	0.22	0.23	0.21	0.22	0.18	0.20	0.20	0.19	0.19
Mean	0.25	0.28	0.31	0.26	0.28	0.23	0.26	0.29	0.24	0.25	0.20	0.23	0.26	0.22	0.22
CD at 5%	Varieties (A) 0.010					Days (B) 0.011					Interaction (A×B) NS				

Table 13: Host–pathogen interaction: Changes in Peroxidase (activity/minute/g sample) in response to different intervals after planting

Treatments	Kufri Bahar (R)					Kufri Pushkar (M.R)					Kufri Khyati (S)				
	Days after planting					Days after planting					Days after planting				
	20	40	60	80	**Mean**	20	40	60	80	**Mean**	20	40	60	80	**Mean**
Diseased	-	-	-	-	-	0.30	0.35	0.38	0.34	0.34	0.24	0.30	0.24	0.23	0.25
Healthy	0.35	0.38	0.40	0.42	0.39	0.26	0.28	0.29	0.30	0.28	0.20	0.22	0.22	0.20	0.21
Mean	0.35	0.38	0.40	0.42	0.39	0.28	0.32	0.34	0.32	0.31	0.22	0.26	0.23	0.22	0.23
CD at 5%	Varieties (A) 0.009					Days(B) 0.011					Interaction (A×B) 0.018				

Table 14: Host–pathogen interaction: Tannin Content (mg/g fresh wt.) in response to different intervals after planting

Treatments	Kufri Bahar (R)					Kufri Pushkar (M.R)					Kufri Khyati (S)				
	Days after planting					Days after planting					Days after planting				
	20	40	60	80	**Mean**	20	40	60	80	**Mean**	20	40	60	80	**Mean**
Diseased	-	-	-	-	-	0.18	0.23	0.25	0.20	0.22	0.15	0.19	0.22	0.18	0.19
Healthy	0.20	0.22	0.24	0.21	0.22	0.17	0.19	0.20	0.18	0.19	0.14	0.16	0.17	0.15	0.16
Mean	0.20	0.22	0.24	0.21	0.22	0.18	0.21	0.23	0.19	0.20	0.15	0.18	0.20	0.17	0.17
CD at 5%	Varieties (A) 0.009					Days (B) 0.011					Interaction (A×B) NS				

4.3 Screening of potato genotypes to identify the sources of resistance against virus disease screening under field condition

Three hundred ten genotypes were evaluated against potato apical leaf curl disease under field conditions. The cultivars along with per cent disease incidence are presented in Table 15. The disease incidence was recorded 20 days after planting (DAP) at 10 days interval. No disease was recorded at 20 days after planting in all the genotypes under field conditions and the reactions of different genotypes are presented in Table 15.

Table 15: Per cent Incidence of potato apical leaf curl virus disease at different intervals/days after emergence

Sr. No.	Accessions/ cultivars	Percent incidence of PALCVD at different interval /days after emergence						
		20 days	30 days	40 days	50 days	60 days	70 days	80 days
1.	AICRP-C-1	0	20	20	40	40	40	40
2.	AICRP-C-20	0	20	20	20	20	20	20
3.	AICRP-EM-1	0	10	10	40	40	40	40
4.	AICRP-P-1	0	0	20	20	20	20	20
5.	AICRP-P-5	0	10	20	30	30	30	30
6.	AICRP-PH-1	0	10	20	20	20	20	20
7.	AICRP-PH-2	0	10	20	20	20	20	20
8.	AICRP-PH-3	0	10	20	20	20	20	20
9.	AICRP-PH-4	0	10	20	30	60	60	60
10.	CP 116	0	10	10	10	20	20	20
11.	CP 1458	0	0	0	10	10	10	10
12.	CP 2093	0	20	40	60	60	60	60
13.	CP 2332	0	40	60	100	100	100	100
14.	CP 2370	0	10	10	10	10	10	20
15.	CP 2379	0	10	10	20	20	20	30
16.	CP 2385	0	10	20	20	20	20	20
17.	CP 2402	0	10	10	20	20	20	30
18.	CP 2433	0	20	20	40	40	60	60
19.	CP 3050	0	10	10	10	20	20	20
20.	CP 3096	0	10	20	20	30	30	30
21.	CP 3128	0	10	10	20	20	30	30
22.	CP 3130	0	10	10	10	10	20	20
23.	CP 3132	0	10	10	10	20	60	60
24.	CP 3133	0	20	20	30	30	40	40
25.	CP 3136	0	10	10	10	20	20	20
26.	CP 3137	0	10	20	20	20	30	30

27.	CP 3139	0	10	10	20	20	20	30
28.	CP 3140	0	10	10	10	10	20	20
29.	CP 3141	0	10	10	10	20	20	20
30.	CP 3142	0	10	10	20	20	20	20
31.	CP 3143	0	10	10	10	10	10	20
32.	CP 3145	0	10	10	20	20	20	20
33.	CP 3146	0	20	20	20	20	20	20
34.	CP 3147	0	10	20	30	60	80	80
35.	CP 3148	0	10	20	20	30	30	30
36.	CP 3149	0	20	40	40	60	60	100
37.	CP 3150	0	10	10	10	10	10	20
38.	CP 3153	0	10	10	20	20	20	20
39.	CP 3154	0	10	10	20	20	20	20
40.	CP 3156	0	10	20	30	40	60	80
41.	CP 3157	0	10	10	10	20	30	40
42.	CP 3158	0	10	10	20	40	60	80
43.	CP 3159	0	20	20	20	20	20	20
44.	CP 3162	0	10	10	10	10	20	20
45.	CP 3164	0	10	40	60	60	60	60
46.	CP 3165	0	20	30	60	60	60	60
47.	CP 3166	0	10	10	20	40	50	60
48.	CP 3167	0	10	10	10	20	30	60
49.	CP 3169	0	10	10	20	20	20	20
50.	CP 3170	0	10	10	20	20	30	40
51.	CP 3173	0	10	20	30	40	80	80
52.	CP 3174	0	0	0	10	10	20	20
53.	CP 3175	0	10	10	10	10	10	20
54.	CP 3176	0	10	10	20	20	30	30
55.	CP 3177	0	10	10	20	20	20	20
56.	CP 3179	0	10	10	10	10	10	20
57.	CP 3180	0	10	10	10	10	10	20
58.	CP 3181	0	20	30	30	40	40	40
59.	CP 3182	0	10	20	20	30	40	40
60.	CP 3183	0	10	20	20	20	40	40
61.	CP 3185	0	20	30	40	40	40	40
62.	CP 3188	0	20	20	20	20	20	30

63.	CP 3189	0	10	20	20	30	40	40
64.	CP 3191	0	20	20	30	60	100	100
65.	CP 3193	0	20	20	20	20	40	40
66.	CP 3194	0	20	20	40	40	40	40
67.	CP 3195	0	10	10	20	20	40	40
68.	CP 3196	0	10	10	10	20	20	20
69.	CP 3209	0	10	20	20	20	30	40
70.	CP 3210	0	10	10	20	20	20	30
71.	CP 3211	0	10	20	30	40	40	40
72.	CP 3217	0	10	20	30	30	40	40
73.	CP 3222	0	20	60	60	60	80	80
74.	CP 3224	0	20	20	20	30	30	60
75.	CP 3245	0	10	10	20	20	20	20
76.	CP 3246	0	10	10	10	10	10	10
77.	CP 3247	0	10	10	20	20	20	20
78.	CP 3248	0	10	10	30	60	60	60
79.	CP 3250	0	20	30	40	60	60	80
80.	CP 3251	0	10	10	20	20	20	20
81.	CP 3254	0	10	20	30	30	40	80
82.	CP 3255	0	10	10	10	10	20	20
83.	CP 3256	0	10	10	10	20	20	20
84.	CP 3257	0	20	30	40	40	60	60
85.	CP 3258	0	20	20	20	20	20	20
86.	CP 3259	0	10	10	30	60	80	80
87.	CP 3261	0	20	30	60	60	60	60
88.	CP 3262	0	30	40	40	40	40	40
89.	CP 3266	0	20	30	60	60	60	60
90.	CP 3268	0	20	30	40	40	40	40
91.	CP 3269	0	20	20	20	20	20	20
92.	CP 3270	0	20	20	20	40	60	60
93.	CP 3273	0	30	40	100	100	100	100
94.	CP 3275	0	20	40	60	60	60	60
95.	CP 3276	0	10	20	30	30	40	40
96.	CP 3277	0	20	30	40	40	40	40
97.	CP 3279	0	10	10	10	20	20	20
98.	CP 3281	0	10	20	30	60	60	60

99.	CP 3286	0	10	10	20	20	20	20
100.	CP 3288	0	0	0	10	10	10	20
101.	CP 3289	0	10	20	20	20	20	20
102.	CP 3290	0	10	20	20	20	20	20
103.	CP 3291	0	10	10	20	20	20	20
104.	CP 3292	0	10	20	20	20	20	20
105.	CP 3293	0	0	0	10	10	20	20
106.	CP 3294	0	10	10	10	10	20	20
107.	CP 3295	0	30	40	100	100	100	100
108.	CP 3318	0	20	20	20	20	20	20
109.	CP 3322	0	10	10	10	20	20	20
110.	CP 3325	0	10	10	10	10	20	20
111.	CP 3326	0	0	10	20	30	30	40
112.	CP 3328	0	10	20	40	80	80	80
113.	CP 3329	0	10	10	10	20	20	20
114.	CP 3336	0	10	10	10	10	20	20
115.	CP 3338	0	20	30	40	40	40	40
116.	CP 3340	0	10	20	30	40	40	40
117.	CP 3341	0	10	10	10	20	20	20
118.	CP 3342	0	20	40	80	80	80	80
119.	CP 3343	0	20	20	20	20	20	20
120.	CP 3344	0	10	10	10	20	20	20
121.	CP 3346	0	10	10	10	20	20	20
122.	CP 3347	0	10	10	10	20	20	20
123.	CP 3348	0	10	10	10	20	20	20
124.	CP 3350	0	10	10	10	10	20	20
125.	CP 3352	0	10	10	10	10	20	20
126.	CP 3353	0	10	30	40	60	60	60
127.	CP 3354	0	10	20	30	40	40	40
128.	CP 3355	0	10	20	40	40	40	40
129.	CP 3356	0	10	30	30	60	60	60
130.	CP 3358	0	10	20	40	60	60	60
131.	CP 3359	0	10	40	80	80	80	80
132.	CP 3361	0	10	20	20	20	20	20
133.	CP 3362	0	10	20	20	20	20	20
134.	CP 3363	0	10	20	20	20	20	20

135.	CP 3364	0	10	20	30	40	40	40
136.	CP 3365	0	10	20	20	30	40	40
137.	CP 3366	0	10	20	40	60	60	60
138.	CP 3368	0	10	20	40	60	60	60
139.	CP 3370	0	20	30	60	60	60	60
140.	CP 3371	0	20	40	100	100	100	100
141.	CP 3372	0	20	40	40	40	40	40
142.	CP 3376	0	20	20	40	40	40	40
143.	CP 3379	0	10	10	10	10	20	20
144.	CP 3381	0	20	20	40	40	40	40
145.	CP 3382	0	40	40	40	40	40	40
146.	CP 3383	0	10	20	30	40	80	80
147.	CP 3385	0	10	10	20	20	20	20
148.	CP 3388	0	20	20	40	40	40	40
149.	CP 3389	0	10	10	10	10	20	20
150.	CP 3390	0	20	20	40	40	40	40
151.	CP 3391	0	10	20	20	20	20	40
152.	CP 3393	0	10	20	30	40	40	40
153.	CP 3394	0	10	40	40	40	40	40
154.	CP 3395	0	20	20	40	40	40	40
155.	CP 3396	0	10	10	30	40	40	40
156.	CP 3397	0	10	10	10	10	10	20
157.	CP 3407	0	10	20	20	20	20	20
158.	CP 3408	0	10	20	20	20	20	20
159.	CP 3411	0	10	40	40	40	40	40
160.	CP 3412	0	10	30	40	40	40	40
161.	CP 3413	0	20	40	40	40	40	40
162.	CP 3414	0	10	20	20	20	20	20
163.	CP 3415	0	20	40	40	40	40	40
164.	CP 3416	0	10	20	20	20	20	20
165.	CP 3417	0	10	20	30	60	60	60
166.	CP 3419	0	10	30	60	60	60	60
167.	CP 3420	0	10	20	20	20	20	20
168.	CP 3421	0	10	20	20	20	20	20
169.	CP 3422	0	10	20	20	20	20	20
170.	CP 3424	0	10	20	40	40	40	40

171.	CP 3425	0	10	20	50	60	100	100
172.	CP 3426	0	10	39	80	80	80	80
173.	CP 3427	0	20	40	60	80	80	80
174.	CP 3428	0	10	10	10	20	20	20
175.	CP 3429	0	10	10	10	20	20	20
176.	CP 3430	0	10	10	10	20	20	20
177.	CP 3431	0	0	20	20	20	20	20
178.	CP 3432	0	10	10	10	20	20	20
179.	CP 3433	0	20	20	20	20	20	20
180.	CP 3434	0	10	10	10	20	20	20
181.	CP 3435	0	10	20	60	60	60	60
182.	CP 3436	0	20	40	60	60	60	60
183.	CP 3437	0	20	39	60	60	60	60
184.	CP 3438	0	20	20	20	20	20	20
185.	CP 3440	0	10	10	10	20	20	20
186.	CP 3441	0	20	50	100	100	100	100
187.	CP 3442	0	30	80	80	80	80	80
188.	CP 3443	0	30	100	100	100	100	100
189.	CP 3444	0	30	60	60	60	60	60
190.	CP 3445	0	10	20	20	30	30	30
191.	CP 3446	0	20	20	20	20	20	20
192.	CP 3447	0	20	30	40	40	40	40
193.	CP 3448	0	10	10	20	20	20	20
194.	CP 3450	0	20	40	40	40	40	40
195.	CP 3451	0	10	10	20	20	20	20
196.	CP 3452	0	30	60	80	100	100	100
197.	F1C2 109	0	20	20	20	20	40	40
198.	F1C2 112	0	10	20	20	30	30	30
199.	F1C2 116	0	10	20	40	40	40	40
200.	F1C2 121	0	20	30	40	40	40	40
201.	F1C2 137	0	20	30	40	40	40	40
202.	F1C2 146	0	10	20	30	40	40	40
203.	F1C2 206	0	20	30	40	40	40	40
204.	F1C2 212	0	20	30	40	40	40	40
205.	F1C2 234	0	20	40	40	40	40	40
206.	F1C2 248	0	20	20	40	40	40	40

207.	F1C2 251	0	20	30	40	40	40	40
208.	F1C2 253	0	20	20	20	20	20	20
209.	F1C2 282	0	20	60	60	60	60	60
210.	F1C2 297	0	20	30	40	40	40	40
211.	F1C2 306	0	10	20	30	40	40	40
212.	F1C2 343	0	10	10	20	20	20	20
213.	F1C2 348	0	20	30	30	40	40	40
214.	F1C2 349	0	10	30	60	60	60	60
215.	F1C2 353	0	20	30	40	100	100	100
216.	F1C2 365	0	10	10	10	20	20	20
217.	F1C2 378	0	10	10	20	20	20	20
218.	F1C2 390	0	10	20	30	60	80	80
219.	F1C2 422	0	20	30	30	40	40	40
220.	F1C2 426	0	20	20	40	40	40	40
221.	F1C2 427	0	20	20	20	20	20	20
222.	F1C2 429	0	20	20	30	40	40	40
223.	F1C2 434	0	10	40	40	60	60	60
224.	F1C2 436	0	10	40	40	60	60	60
225.	F1C2 443	0	0	10	20	20	20	20
226.	F1C2 450	0	20	30	60	60	80	80
227.	F1C2 452	0	10	30	40	40	40	60
228.	F1C2 47	0	10	30	40	40	60	60
229.	F1C2 62	0	10	20	30	30	60	60
230.	F1C2 68	0	10	30	40	60	60	60
231.	F1C2 98	0	10	20	20	30	30	30
232.	FIC2 121	0	10	40	40	60	60	60
233.	FIC2 422	0	10	40	40	60	60	60
234.	FIC2 68	0	20	20	40	40	40	40
235.	HIS-98-55	0	0	10	10	10	10	10
236.	JEX/A-10	0	20	20	40	40	40	40
237.	JEX/A-1040	0	20	20	20	20	20	20
238.	JEX/A-1061	0	20	40	60	80	100	100
239.	JEX/A-107	0	10	10	10	20	20	20
240.	JEX/A-1081	0	10	20	30	60	60	60
241.	JEX/A-1152	0	20	30	40	60	60	60
242.	JEX/A-122	0	10	10	20	20	20	20

243.	JEX/A-132	0	10	10	20	20	20	20
244.	JEX/A-14	0	10	10	10	20	20	20
245.	JEX/A-15	0	10	10	10	20	20	20
246.	JEX/A-164	0	10	10	20	20	20	20
247.	JEX/A-189	0	10	20	20	20	20	20
248.	JEX/A-19	0	10	20	20	30	30	30
249.	JEX/A-197	0	10	10	20	20	20	20
250.	JEX/A-198	0	10	10	20	20	20	20
251.	JEX/A-199	0	20	20	40	40	60	60
252.	JEX/A-202	0	10	10	20	20	20	20
253.	JEX/A-21	0	20	30	40	60	80	100
254.	JEX/A-215	0	20	20	20	40	40	40
255.	JEX/A-216	0	10	10	20	20	20	20
256.	JEX/A-232	0	10	10	20	20	20	20
257.	JEX/A-24	0	10	10	20	20	20	20
258.	JEX/A-26	0	20	30	40	40	40	80
259.	JEX/A-267	0	10	10	20	20	20	20
260.	JEX/A-274	0	10	20	20	20	20	20
261.	JEX/A-275	0	20	20	40	40	40	40
262.	JEX/A-296	0	10	10	20	20	20	20
263.	JEX/A-298	0	10	10	10	10	10	20
264.	JEX/A-299	0	10	10	20	20	20	20
265.	JEX/A-300	0	20	20	20	20	20	20
266.	JEX/A-316	0	20	30	40	40	40	60
267.	JEX/A-317	0	20	20	20	20	20	20
268.	JEX/A-329	0	10	10	10	10	10	20
269.	JEX/A-368	0	10	10	10	10	10	20
270.	JEX/A-379	0	10	10	10	10	10	20
271.	JEX/A-380	0	10	10	10	10	10	20
272.	JEX/A-390	0	10	20	20	20	20	20
273.	JEX/A-413	0	10	20	20	20	20	20
274.	JEX/A-45	0	20	30	40	40	40	40
275.	JEX/A-457	0	20	30	40	40	40	40
276.	JEX/A-459	0	20	30	40	40	40	40
277.	JEX/A-498	0	10	10	10	10	10	20
278.	JEX/A-506	0	10	10	10	10	10	20

279.	JEX/A-513	0	20	20	20	40	40	40
280.	JEX/A-539	0	10	10	10	10	10	20
281.	JEX/A-58	0	20	20	40	40	40	40
282.	JEX/A-595	0	10	10	10	10	10	20
283.	JEX/A-616	0	20	40	60	80	80	100
284.	JEX/A-617	0	10	10	10	20	20	20
285.	JEX/A-638	0	20	20	30	40	40	40
286.	JEX/A-668	0	10	10	10	10	10	20
287.	JEX/A-683	0	20	40	60	80	80	80
288.	JEX/A-705	0	20	20	20	40	40	40
289.	JEX/A-707	0	10	10	10	10	10	20
290.	JEX/A-708	0	10	10	10	10	10	20
291.	JEX/A-762	0	10	10	10	10	10	20
292.	JEX/A-763	0	20	20	20	20	20	20
293.	JEX/A-801	0	20	40	40	40	40	40
294.	JEX/A-804	0	20	20	20	20	20	20
295.	JEX/A-827	0	10	10	10	30	40	40
296.	JEX/A-865	0	60	80	100	100	100	100
297.	JEX/A-877	0	10	20	20	20	20	20
298.	JEX/A-907	0	20	20	20	20	20	20
299.	JEX/A-912	0	10	10	20	20	20	20
300.	JEX/A-918	0	10	10	10	10	10	20
301.	JEX/A-920	0	10	20	30	40	40	40
302.	JEX/A-935	0	10	20	20	20	20	20
303.	JEX/A-947	0	60	60	60	60	60	60
304.	JEX/A-MISS	0	10	10	60	80	100	100
305.	K. Badshah	0	10	10	20	20	20	30
306.	K. Bahar	0	0	0	0	0	0	0
307.	K. Khayti	0	40	60	60	80	100	100
308.	K. Pushkar	0	40	40	40	40	40	40
309.	K. Sadabahar	0	20	40	60	60	60	100
310.	K. Sutlej	0	10	20	20	30	30	50

Table 16: Diseased reaction of potato genotypes screened under potato apical leaf curl virus disease condition during 2013

Disease Reaction	Disease Incidence	No. of Germplasm Lines
Resistant	<10	3
Moderately Resistant	10.1-20	137
Moderately Susceptible	20.1-40	96
Susceptible	40.1-60	42
Highly Susceptible	>60	32

Three hundred ten potato germplasm lines were evaluated for their resistance to potato apical leaf curl virus disease (PALCVD) under field conditions. Infector row of variety Kufri Khyati at every five test cultivars and all around the plot was sown to create congenial conditions after whitefly attack in the crop. The incidence of potato apical leaf curl virus disease was recorded at 20, 30, 40, 50, 60, 70 and 80 days after planting. Three Lines namely, Kufri Bahar, CP 1458, and HIS 98-55 were resistant to the disease and 137 genotypes were moderately resident, while 32 were categorized under highly susceptible group.

CHAPTER-V

DISCUSSION

Potato is an important staple food of the world and has the potential of much needed nutritious food. Outbreak of potato apical leaf curl virus disease (PALCVD) caused by a whitefly-transmitted geminivirus has been observed to be a serious threat to the production of potato in northern India. PALCVD has been reported for the first time in India from Hisar, Haryana (Garg *et al*., 2001a). The virus is a member of genus begomovirus belonging to the family *Geminiviridae*. The disease is emerging as a major problem for potato cultivation in Haryana and other adjoining states.

In the present study, all the seven varieties *viz*., Kufri Pushkar, Kufri Bahar, Kufri Pukhraj, Kufri Badshah, Kufri Khyati, Kufri Surya and Kufri Sadabahar were vectored by whitefly attack, for potato apical leaf curl virus disease (PALCVD) incidence.

It has been observed that all the varieties tested and sown in first week of October had maximum whitefly population ranging from 22 to 83 in 2012 and 26 to 87 in 2013 in last week of October. The results are in accordance with the results of Lakra (2003b), in which, it was indicated that potato apical leaf curl virus disease incidence had positive incidence with whitefly population and infection was highest in October sown crop. The whitefly population was highest in Kufri Khyati (83) and in the year 2012 and correspondingly the PALCVD was 100% in Kufri Khyati. Lakra (2003b) also demonstrated the same type of trend, *i.e*., more the whitefly population more was the PALCVD. The whitefly population decreased gradually with the fall in temperature in November and December in both the years and low population of whitefly in the crop was recorded. Biswas *et al.* (2004) reported the same trend that sharp decrease in temperature after mid November decreased the whitefly population in potato crop. From the finding, it could be inferred that whitefly population decreased in mid November in 2013 as compared to 2012 because of low temperature of 24.4 and 25.7°C in 2013, whereas, in the corresponding period, in 2012 it was 29 and 27.1°C. Lakra (2003b) reported that sharp decreased in temperature after mid November decreased the whitefly population drastically and subsequently low level of leaf curl incidence occurred. The temperature in the range of 26-32°C and relative humidity of 60-70% are optimal for whitefly development (Traboulsi, 1995).

In reaction of the varieties for PALCVD had been recorded and it was found that whitefly population was directly proportional to the disease development. Kufri Khyati which was having the maximum whitefly population had more disease e.g., 100 and 80% in the year 2012 and 2013 respectively, whereas, in Kufri Pukhraj lesser number of whitefly was observed and hence, less PALCVD was recorded. Lakra (2010) reported the same trend, in

which different varieties had different reaction in potato apical leaf curl virus disease depending upon the whitefly population in that variety.

The present finding is in conformity with the result demonstrated by Lakra (2008) in which it was concluded that transmission of virus was not influenced by inoculation but was highly influenced by the age of crop. Nagaich *et al.* (1974) reported that potato leaf curl virus and mosaic virus are important and occur widely in almost all cultivars in India. The geminivirus belonging to genus begomovirus is transmitted by whiteflies from infected to healthy plants.

In present study, there was a strong positive correlation between whitefly population and PALCVD incidence. Lakra (2003b) also indicated that potato leaf curl incidence had positive correlation with whitefly population and whitefly infestation period on potato crop. Saikia and Muniyappa (1989) made similar kind of observations where they found strong positive correlation between ToLCV disease incidence and its vector whitefly. Borah and Bordoloi (1998) also found a strong positive correlation between whitefly population and tomato yellow leaf curl disease incidence in tomato crop. Sharma (2002) observed that CLCuV disease incidence increased with the increase in whitefly population in cotton crop.

In the present study, whitefly population showed a positive and significant relationship with maximum temperature (X_1), minimum temperature (X_2) and negative significant relationship with evening relative humidity (X_4), whereas, non-significant with morning relative humidity (X_3), wind speed (X_5), sun shine hour (X_6) and rain (X_7) during 2012. During 2013, whitefly population showed significant positive relationship with maximum temperature (X_1) and minimum temperature (X_2), whereas, other factors were non-significant. The pooled data of whitefly population (2012 and 2013) showed positive and significant relationship with maximum temperature (X_1) and minimum temperature (X_2), whereas, negative and significant relationship with evening relative humidity (X_4), while non-significant relationship with all weather variables. The results are in accordance with the findings of Rashmi *et al.* (2008) who had indicated that maximum and minimum temperature were positively correlated, while relative humidity had significantly negatively correlated with whitefly population in the variety Kufri Badshah. The positive correlation of whitefly with temperature and negative correlation with humidity in potato crop had also been reported by Bhatnagar (2007). The present findings are in conformity with the results demonstrated by Bashir *et al*. (2001) who concluded that the whitefly population was negatively correlated with rainfall.

Multiple regression equation on pooled basis maximum (X_1) and minimum (X_2) temperature, evening relative humidity (X4) and wind speed (X_5) could explain whitefly population buildup 89 to 99% in different varieties tested, and suggesting that more precise

information needs to be collected on weather parameters and whitefly population for improving the efficiency of the multiple regression models.

The present study reveals that the role of total phenol plays an important role in defense mechanism in the host plants for disease resistance. Total phenol content was estimated in the leaves of potato on 20, 40, 60 and 80 days after planting in resistant (Kufri Bahar), moderately resistant (Kufri Pushkar) and susceptible (Kufri Khyati) variety. It has been observed that in all the varieties tested, higher total phenol content was found in resistant variety, less in moderately resistant and least in susceptible variety. These findings are in close agreement of earlier studies by a number of workers, where it has been shown that a resistant variety had a higher level of phenols than in susceptible ones in response to tomato leaf curl virus in tomato crop (Banerjee and Kalloo, 1989). Total phenol content was significantly higher in diseased leaves as compared to healthy leaves. The increased quantity of total phenol content might be attributed to defense mechanism. The present finding is in conformity with the result demonstrated by Meena *et al*. (2008) who concluded that total phenol content was high in diseased as compared to healthy leaves when attacked by chilli leaf curl virus disease in *Capsicum annuum*. The total phenol content was significantly increased gradually in moderately resistant (Kufri Pushkar) and susceptible cultivar (Kufri Khyati) up to 60 days after then it decreased down, which might be due to oxidative polymerization of phenolics into melanin in necrotic tissues or incorporation of phenols into lignin. Rai *et al*. (2010) also indicated that phenolic content decreased from 4th day after inoculation in pepper leaf curl virus disease in chilli crop.

The present investigation healthy set the flavanols content was higher in leaves of resistant variety Kufri Bahar as compared to leaves of susceptible variety Kufri Khyati. However, in response to whitefly attack vector for PALCVD, there was significant increase in the flavanols content in the leaves of moderately resistant variety and susceptible variety at 60 days after planting and thereafter the flavanols in leaves decreased at 80 days after planting. Similar to this, Murthy and Bhagyaraj (1980) found that resistant variety possesses higher flavonols content as compared to susceptible variety upon infection in *Fusarium udum* of pigeon pea cultivars. Mahadevan and Sridhar (1986) also found that resistant variety had more flavanols content than the susceptible variety due to pathogen attack.

In the present study, peroxidase (PO) is an important enzyme system found in plants and play measurable role in the biosynthesis of plant cell wall components *viz*., lignin, suberin. The peroxidase activity was assayed in the leaf samples of all the three cultivars and it was noticed that PO activity was significantly higher in the resistant cultivars as compared to susceptible ones, *i.e*., higher in healthy leaves of resistant (Kufri Bahar) as compared to the leaves of moderately resistant(Kufri Pushkar) and susceptible (Kufri Khyati) variety. Similar results had shown by Singh *et al.* (2003) who had concluded that higher PO activity was

found in resistant variety than susceptible ones infected with chilli cucumber mosaic virus, and similarly with Yellow Vein Mosaic Virus in okra (Ahmed *et al*., 1992). The increased PO activity immediately after whitefly (vector of PALCVD) attack was a normal response in the host plant and higher PO activity was observed in diseased leaves as compared to healthy leaves. Similar finding was reported by Meena *et al.* (2008) for chilli leaf curl disease in chilli crop and Devanathen *et al.* (2005) in bunchy top banana virus infection. However, increased peroxidase activity in the leaves of susceptible variety Kufri Khyati was observed at 40 days after whitefly attack and thereafter the activity of enzyme was decreased particularly at 80 days. Similar changes in peroxidase activity as a consequence of pathogen infection were reported by other investigators in leaf blight of mung bean in *Vigna radiata* crop (Chandra and Tyagi, 1993) and in chilli genotypes against *Colletotrichum capsici* (Prasath and Ponnuswami, 2008).

A separate group of compounds *viz.*, tannin has been implicated sometimes in disease resistance. In present study, the tannin was higher in resistant than in the susceptible variety upon diseased than healthy. The present finding indicated that tannin may play little role in disease resistance. Tannin content increased markedly after infection in susceptible variety but not much variation in resistant variety for *Ramulispora sorghicola* disease in sorghum crop (Arora and Luthra, 1974; Lutra *et al.,* 1990).

In present study, three hundred ten potato germplasm lines were evaluated for their resistance to potato apical leaf curl virus disease (PALCVD) under field conditions. Three Lines Kufri Bahar, CP 1458 and HIS 98-55 were resistant to the disease. Similarly, Lakra (2008) evaluated 266 germplasm lines and 15 cultivars and found that Kufri Bahar and CP 1246 were resistant to PALCVD. Baswana *et al.* (2009) conducted a similar trend on screening of 180 accessions of potato against potato apical leaf curl disease, which reported one accession CP-1716 and cultivar Kufri Bahar as resistant, while three accessions namely, CP 1813, CP 1818 and CP 1859 exhibited disease incidence <20% and were categorized under moderately resistant group.

CHAPTER-VI

SUMMARY AND CONCLUSION

The experiment entitled "Studies of potato apical leaf curl virus disease in potato" was conducted at Research Area Department of Vegetable Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar during winter (*Rabi*) season of 2012-13 and 2013-14 with seven cultivars of potato (Kufri Pushkar, Kufri Bahar, Kufri Pukhraj, Kufri Badshah, Kufri Khyati, Kufri Surya and Kufri Sadabahar) planted. The salient findings are summarized below:

The results indicated that the appearance and buildup of whitefly vector for potato apical leaf curl virus disease (PALCVD) were influenced by varieties, crop seasons, and weather. The development of whitefly population showed highest in last week of October and decreased gradually with the fall in maximum and minimum temperature so much so that in 2nd fortnight of December there were few whitefly present in the crop. The whitefly population was highest in Kufri Khyati and minimum in Kufri Bahar variety in both of the year 2012 and 2013. Whitefly population (vector) is directly proportional to potato apical leaf curl virus disease (PALCVD) as Kufri Khyati, which was having maximum number of whitefly (83) in the initial stages of the crop growth, had more disease (100%), whereas, in Kufri Pukhraj the vector population was less and the PALCVD was (60 %). Here, it is to be mentioned that although Kufri Bahar whitefly population and it decreased gradually like the other varieties but reduction was at a faster rate in comparison. In year 2013, the same trend of vector population was noticed in different varieties but the population was less because of low maximum and minimum temperature.

On the basis of stepwise regression analysis for whitefly population (vector) directly proportional to potato apical leaf curl virus disease on pooled data showed that maximum (X_1) temperature, minimum (X_2) temperature, evening relative humidity (X_4) and wind speed (X_5) were the more contributing weather variables which predicted the vector populations more than 89 per cent .

Biochemical studies indicated that the roles of biochemicals total phenol, flavanols, peroxidase, and tannin play an important role in defence mechanism in potato crop for PALCVD. All the biochemical parameters showed that the content were more in resistant variety (Kufri Bahar) less in moderately resistant variety (Kufri Pushkar) and least in susceptible variety (Kufri Khyati). It was also inferred from the study that within the variety the diseased leaves had more biochemical content than healthy leaves except in Kufri Bahar (resistant) variety, which had no visible symptoms hence, no estimation was done for the diseased leaves. It was also noticed that all the biochemical constituents increased initially

after vectored by whitefly for potato apical leaf curl virus disease (PALCVD) incidence up to 60 days and therefore, it decreased.

Three hundred ten potato germplasm lines were screened in the field under artificial disease stress conditions against PALCVD of potato. Three lines Kufri Bahar,CP 1458 and HIS 98-55 were found resistant to the disease while 137 entries was categorized under moderately resistant group.

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ABSTRACT

Title of Thesis	: **Studies of potato apical leaf curl virus disease in potato.**
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Title of degree	: Master of Science
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Keywords: Potato, Kufri, Whitefly, Temperature, Relative Humidity, PALCVD, Biochemical, Grermplasm Lines.

The experiment entitled "**Studies of potato apical leaf curl virus disease in potato**" was conducted at Research Area Department of Vegetable Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar during *Rabi* season of 2012-13 and 2013-14. Potato is an important staple food of the world and has potential of much needed nutritious food. The potato apical leaf curl virus disease (PALCVD) infected plants exhibited symptoms such as vein clearing, crinkling, vein thickening, upward curling of leaf margin and leaf margin became wavy. In the present study, all the seven varieties *viz*., Kufri Pushkar, Kufri Bahar, Kufri Pukhraj, Kufri Badshah, Kufri Khyati, Kufri Surya and Kufri Sadabahar were vectored by whitefly attack, for potato apical leaf curl virus disease (PALCVD) incidence. The correlation between whitefly population on all varieties and weather parameters like maximum and minimum temperature and evening relative humidity and wind speed were the more contributing which predicted the vector populations. Per cent incidence of PALCVD differ from variety to variety. Per cent disease incidence was found to range to 0.00 to 100% depending upon the varieties. Variety Kufri Khyati showed maximum disease incidence up to 100% followed by Kufri Pukhraj (60%). There was no disease incidence in Kufri Bahar variety. In biochemical analysis it was found that the roles of biochemicals total phenol, flavanols, peroxidase, and tannin play an important role in defence mechanism in potato crop for PALCVD. All the biochemical parameters showed that the content were more in resistant variety (Kufri Bahar) less in moderately resistant variety (Kufri Pushkar) and least in susceptible variety (Kufri Khyati). It was also inferred from the study that within the variety the diseased leaves had more biochemical content than healthy leaves except in Kufri Bahar (resistant) variety, which had no visible symptoms. Three hundred ten potato germplasm lines were screened in the field under artificial disease stress conditions against PALCVD of potato. Three lines Kufri Bahar,CP 1458 and HIS 98-55 were found resistant to the disease while 137 entries was categorized under moderately resistant group.

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I hereby, declare that all the information provided in the resume is true to best of my knowledge.

(Manoj Kumar)

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