

**STUDIES ON THE PREVALENCE AND EPIDEMIOLOGY OF
APPLE POWDERY MILDEW IN HIMACHAL PRADESH**

Thesis

by

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(H-2019-71-M)**

submitted to



**Dr. YASHWANT SINGH PARMAR UNIVERSITY
OF HORTICULTURE AND FORESTRY
SOLAN (NAUNI) HP- 173 230 INDIA**

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CERTIFICATE- I

This is to certify that the thesis titled, “**Studies on the prevalence and epidemiology of apple powdery mildew in Himachal Pradesh**” submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE) PLANT PATHOLOGY** in the discipline of **PLANT PROTECTION** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 India is a bonafide research work carried out by **Ms. Renu Negi (H-2019-71-M)** daughter of Shri Jagat Singh Negi under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

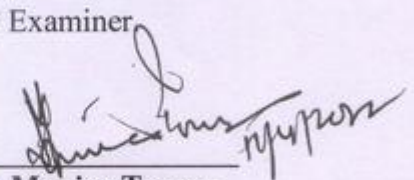
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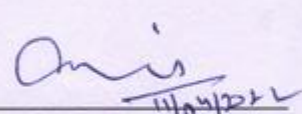
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CERTIFICATE- II

This is to certify that the thesis titled, "Studies on the prevalence and epidemiology of apple powdery mildew in Himachal Pradesh" submitted by Ms. Renu Negi (H-2019-71-M) daughter of Shri Jagat Singh Negi to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173230 India in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE) PLANT PATHOLOGY** in the discipline of **PLANT PROTECTION** has been approved by the Advisory Committee after an oral examination of the student in collaboration with the Internal Examiner

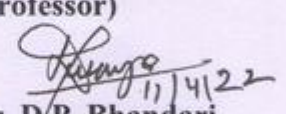

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LIST OF ABBREVIATIONS

%	:	Per cent
/	:	Per
@	:	At the rate
°C	:	Degree Celcius
µm	:	Micrometer
APEDA	:	Agriculture and Processed Food Products Export Development Authority
CD	:	Critical Difference
cm	:	Centimeter
cv.	:	Cultivar
DMI	:	Dimethylase Inhibiting
EC	:	Emulsifiable concentration
<i>et al.</i>	:	<i>et alii</i> (and others)
Fig.	:	Figure
GOI	:	Government of India
H.P.	:	Himachal Pradesh
Ha	:	Hectare
HDP	:	High Density Planting
i.e.	:	<i>Id est</i> (that is)
in vitro	:	Under control condition
J & K	:	Jammu and Kashmir
KVK	:	Krishi Vigyan Kendra
lt	:	Litre
m	:	Meter
MT	:	Metric tones
NHB	:	National Horticulture Board
pH	:	Potential of Hydrogens
ppm	:	Parts per million
RH	:	Relative Humidity
RHR&TS	:	Regional Horticulture Research and Training Station
Sr.No.	:	Serial Number
UHF	:	University of Horticulture and Forestry
var	:	Variety
viz	:	<i>vi delicet</i> (namely)
VPD	:	Vapour Pressure Deficits

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Chapter-1

INTRODUCTION

Apple (*Malus × domestica* Borkh.) is a deciduous plant of the Rosaceae family that produces pomaceous fruits, suitable for human consumption. Apple, a global table fruit, is high in lipids, carbohydrates, calcium, phosphorus, and iron (Boyer and Liu, 2004). The plant is cultivated worldwide, especially in New Zealand, Asia, USA, Europe and southern parts of America and Africa. India produces all deciduous fruits including pome fruits (apple and pear) and stone fruits (peach, plum, apricot and cherry) in a considerable quantity. In India apple is mostly grown in the states of Jammu & Kashmir, Himachal Pradesh, Uttarakhand and Arunachal Pradesh (figure 1).



Figure 1 Major Apple producing states of India

According to Department of Agriculture and farmer's welfare, GOI, north eastern states of India viz., Arunachal Pradesh, Nagaland, Meghalaya, Manipur and Sikkim also grow apples on a low scale. China is in the top list of apple producing countries of the world. The United States of America is the second largest apple producer with more than 6 per cent of the global output. In H.P. total area under Horticulture (2018-19) is 232139 ha. Apple is grown on an area of 113154 ha with a production of 368603 MT according to Department of Horticulture, Shimla (NHB, 2019). Area under apple cultivation in India has increased tremendously from 241.8 thousand ha in 2001-02 to 306.0 thousand ha in 2017-18. Total area under Apple cultivation in India (2019-20) is 308 thousand ha and production are 2734000 MT (<http://www.nhb.gov.in>). Himachal Pradesh plays an important part in the apple production. According to Agriculture and Processed Food Products Export Development Authority (APEDA), Himachal Pradesh is also known as the "Fruit Bowl of The Nation".

Unfavourable climatic conditions, unsuitable varieties, insufficient pollinizers, lack of pollinators, insufficient nutrition, poor soil conditions, poor canopy management, old orchards, low planting density, and pathological and entomological problems are all factors that contribute to low apple productivity (Awasthi *et al.* 2001). Entomological and pathological factors are the most important, as they cover insect pest attacks and pathogens that cause diseases, as well as a variety of other issues that lead to lower yields and economic losses.

Apple powdery mildew, which infects apple trees worldwide (Biggs *et al.* 2009), is caused by *Podosphaera leucotricha* (Ell. and Ev.) (Grove *et al.* 2003; Holb, 2009). Powdery Mildew disease is one of the most important diseases of Apple, causing severe economic loss to farmers. Powdery mildew can be found in all of the world's major apple-growing regions, but alarming in semiarid areas and in nursery conditions. The most vulnerable tissues to pathogen attack are the young expanding tissues. Apple powdery mildew causes noticeable effects on the developing temperate fruits and extensive crop losses in all apple producing areas (Blazek, 2004).

Apple powdery mildew can easily develop under the congenial weather conditions of apple-producing areas (Jones and Aldwinckle, 1990; Biggs *et al.* 2009). The disease can result in fruit russeting, losses of tree growth as well as yield. Moreover, the fungus may survive for many years in a plant material. This makes it so difficult to control (Yoder, 2000). Because of the long-lasting problem of apple powdery mildew, more efforts are required

regarding the cultivar susceptibility (Biggs *et al.* 2009). Blooms, petals, sepals, receptacles, and peduncles all are susceptible to infection. Infected blossoms either fail to set fruit or yield undersized, stunted, or russeted fruits. Losses are due to its chronic effect on tree vigour and yield in addition to poor fruit finish. Susceptible apple cultivars include Braeburn, Granny Smith, Gravenstein, Honey Crisp, Jonathan, Newtown and Rome. Less susceptible apple cultivars are Fuji, Golden Delicious, Red Delicious, and Delicious strains. Also, the pear orchards are at a higher risk of disease development if planted next to apple orchards (Hofer *et al.* 2019).

Powdery mildew, caused by the obligate biotrophic ascomycete fungus *Podosphaera leucotricha* (Ell. and Ev.) (Grove *et al.* 2003; Holb, 2009) is one of the major diseases of cultivated apple (*Malus × domestica*) throughout the world and is present in all apple growing countries. Powdery mildew occurs when relative humidity (RH) is greater than 70% and the temperature is between 55 and 77°F (10 and 25°C) (Turechek *et al.* 2004). Unlike other foliar diseases leaf wetness is not required for powdery mildew infection. Powdery mildew is visible usually 98 hours after the infection begins, and fresh infections develop spores in around 5 days. Infected plants are characterised by reduced photosynthesis and transpiration, resulting in suboptimal carbohydrate assimilation and reduced growth (Ellis *et al.* 1981). In some countries, as many as 18 fungicidal sprays are required to control the disease (Yoder, 2000). The pathogen may cause the death of vegetative shoots or flower buds, and russetting of fruit (Jones and Aldwinckle, 1990). The grower's primary concern with mildew is the russet symptoms that markedly reduce fruit quality (Spotts and Cervantes, 1986). Infected young trees of susceptible cultivars are seriously damaged or poorly shaped because of retarded vegetative growth or terminal bud loss which ultimately lead to economic losses.

Powdery mildew of apple caused by *Podosphaera leucotricha* is a serious nursery disease in Himachal Pradesh and is fast spreading in the orchards under warm climatic conditions. This disease poses a serious threat to the production of apple in Himachal Pradesh. Keeping in view the importance of the disease in the state, the present studies were formulated with the following objectives:

OBJECTIVES

- i) To assess the prevalence of powdery mildew disease in major apple-growing regions of district Kinnaur
- ii) To evaluate the efficacy of different fungi-toxicants against the powdery mildew disease of apple

Chapter-2

REVIEW OF LITERATURE

India produces a large number of deciduous fruits, including pome fruits (apple and pear) and stone fruits (peach, plum, apricot, and cherry). Apples are mostly farmed in Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Arunachal Pradesh in India. Arunachal Pradesh, Nagaland, Meghalaya, Manipur and Sikkim, all in India's north-eastern states, cultivate apples on a small scale. India has seen an increase in the area, production and productivity of crops in the horticulture sector during the last decade. Apple production is critical in raising the level of living, increasing per capita income and creating jobs. Over the last decade, India's horticulture sector has grown at a rate of roughly 2.7 percent per year, with yearly production increasing by about 2.7 per cent (www.nhb.gov.in).

The British originally introduced apples to India in 1865 in the Kullu district of HP, while Samuel Stokes introduced the colourful delicious cultivars of apple in the Shimla hills in 1917. During the previous 50 years, over 700 apple cultivars from the United States, Russia, the United Kingdom, Canada, Germany, Israel, the Netherlands, Australia, Switzerland, Italy and Denmark have been tried and tested (Stokes, 2010). The apple market is dominated by the delicious group of varieties. In HP, Delicious varieties span 83 percent of the apple-growing area, while in J&K they cover 45 percent area (Islam and Shrivastav, 2017).

According to Pattanaya (2017), the area under apple cultivation in India has expanded dramatically from 241.88 million hectares in 2001-02 to 306.0 million hectares in 2017-18, with production rising from 1158.4 million MT in 2001-02 to 2371.0 million MTs in 2017-18. According to the report, between 2001-02 and 2017-18, the average area under apple cultivation was 271.1 thousand hectares, with a minimum production of 1986.3 thousand MT. India is currently the world's fifth greatest apple producer, with 25.21 lakh metric tonnes produce, 7.77 metric tonnes of which are produced in Himachal Pradesh (NHB, 2017).

Apples have grown in popularity over the last few decades, and diverse kinds of apples imported from other nations have now been planted across apple-growing districts in Himachal Pradesh, but production has so far not increased in lockstep. H.P. is not just the

leading producer, but also one of the leading importers. The country's annual apple imports are estimated to be over \$238 million, while exports are only \$9 million (Wallace and Mishra, 2017; Anonymous, 2016). Large-scale introduction, multiplication and cultivation of new and old varieties on various kinds of rootstocks are expanding indiscriminately across the State's apple-growing regions. High Density Planting (HDP) was pioneered for apple in Europe in the early 1960s by planting a larger number of plants than is optimal through tree size manipulation to achieve productivity gains and fruit quality while maintaining a balance between vegetative and reproductive load without compromising plant health (Sharma, 2019).

In H.P. standard apple plants on seedling rootstocks are planted at a spacing of 7.5 X 7.5 m with a planting density of 178 trees per hectare, while spur varieties are planted at a spacing of 5.0 X 5.0 m with a planting density of 400 plants per hectare (Sharma, 2019). Traditional orchards produce roughly 6 to 8 MT per hectare on average, which is significantly less than high-density orchards (Kafle *et al.* 2021; Goswami *et al.* 2014). Farmers in Himachal Pradesh are battling climate change to safeguard their apple plantations. They're employing a new high-density apple plantation technology promoted by the state government. 1034 crores of World Bank-funded mega project in Himachal Pradesh, has introduced new high density cultivars produced on clonal rootstocks with the goal of increasing apple yield in less time.

The reasons for low apple productivity could be many but one of the reasons is the incidence of a variety to fungal diseases. Fungal diseases are of utmost economic importance and are responsible for causing huge losses to the apple growers. In Himachal Pradesh Powdery mildew of apple caused by *Podosphaera leucotricha* (Ell. and Ev.) Salm. is a destructive disease that spreads swiftly in orchards when the weather is warm.

According to Imre (2013), apple powdery mildew (*Podosphaera leucotricha*) occurs wherever apples are grown and is one of the most significant fungal diseases impacting apple cultivars, causing considerable economic losses. In the last 100 years, the biology of the pathogen has been extensively studied all over the world, and a summary of this massive research has been produced in the following aspects: geographical distribution, morphology, taxonomy of the causal agent, symptoms, host susceptibility, resistance durability, and disease cycle.

Disease

Apple powdery mildew (*Podosphaera leucotricha* Ell. and Ev.) has a negative impact on apple productivity and quality (Grove *et al.* 2003 and Holb, 2009). Powdery mildew is a disease that attacks buds, young shoots, and leaves. The disease manifests itself in dry climates. This disease affects nursery plants the most (NHB, 2019). Losses are a result of the disease's long-term effects on tree vigour and productivity, as well as poor fruit finish in highly sensitive varieties. Braeburn, Granny Smith, Gravenstein, Golden delicious, Honey crisp, Jonathan, Newtown, and Rome are among the most susceptible apple cultivars. Jonathan and Rome cultivars' fruits may also be severely harmed. Fuji, Red Delicious, and Delicious strains have been described as less sensitive apple varieties (Holb and Kunz, 2016).

Lahlali *et al.* (2020) while working on three most popular cultivars of apple concluded that Powdery mildew was evident in all the three cultivars with Starking Delicious showing 17.1 percent, Golden Delicious 23.5 percent and Gala: 81.1 percent disease incidence respectively. Powdery mildew incidence and severity had a strong positive connection ($r = 0.90$). For ensuring good plant protection practices, they recommended to the farmers to carry out disease scouting and consider the action threshold before applying fungicide sprays.

Symptoms

The disease manifests itself as a white powdery (ash-like) coating on both sides of leaves and young shoots. The leaves of the damaged plants become pale and curl up, while the shoots remain feeble and immature. Leaf fall and early fruit drop may occur in the event of a severe infection. The immature diseased fruit may show indications of russetting (Gupta and Sharma, 2009). Foliage, twigs, blooms, and fruit are all affected. Small grey or white felt-like fungal patches appear on the undersides of leaves. Young diseased leaves grow longer but narrower, twisted and deformed. Infected foliage is brittle, and it may die or stop functioning normally, weakening the tree. With masses of white mycelium and powdery spores, the fungus frequently covers entire terminal branches. Terminal shoots that have been severely infected have shorter internodes and are visible throughout the growing season, and may persist into the dormant season. Blossoms that have been infected appear reddish and withered, and they perish quickly. When fruits become infected, a network of lines, known as russetting, appears on the skin in the infected area (Biggs *et al.* 2009).

Disease Cycle

Podosphaera leucotricha (Ell. and Ev.) Salm. overwinters as mycelium in dormant flower and shoot buds infected the previous year, according to Glawe (2008). The fungus restarts growth after the infected buds break dormancy in the spring, infecting new shoots and young leaf tissue. Asexual conidia are formed on conidiophores and disseminated by wind from these original infections. Conidia germinate at high relative humidity (more than 70%, which is prevalent in the microclimate of the lower leaf surface) and temperatures between 10 and 25°C, he added, whereas leaf wetness is a deterrent to infection in most foliar fungal infections. The youngest leaves are the most vulnerable, but as they age, they become more resistant (Yoder, 2000).

Hickey and Yoder (1990) concluded that mildew colonies generally appear first on the lower leaf surface as white felt-like patches. Conidia germinate to form hyphal outgrowths, which traverse the leaf surface, swell and then flatten to form appressoria. As the mildew colony expands or as secondary infections lead to new colony formation, the infection process (hyphal outgrowth >appressorium> infection peg >haustorium) is repeated until susceptible tissue is no longer available.

Late-season growth resulted in a dramatic increase in mildew activity, according to Pfeiffer *et al.* (2010). Secondary disease cycles are responsible for infecting lateral and terminal buds that carry the fungus over the winter, in addition to contributing to a rapid inoculum build-up. Primary infections in flower buds can produce conidia as early as the tight-cluster stage of apple growth, according to Gupta and Sharma (2009), who were working on Powdery mildew of apple. Infected buds open later than healthy buds, allowing the fungus to colonize sensitive tissue (growing and unfurling leaves, open blooms and immature fruit). However, the sexual spores (ascospores) found in these ascocarps are rarely viable, and there is little evidence that they play a role in survival or infection. According to Brodie and Neufeld (1942), conditions that favour conidia germination may not be optimum for later phases of development since pathogen germ tubes are more vulnerable to moisture stress than their parent conidia.

Carroll and Wilcox (2003) investigated the impact of humidity on the development of powdery mildew on grape seedlings. Humidity levels (RH) between 39 and 98 percent, corresponding to vapour pressure deficits (VPD) between 1,914 and 61 Pa, had a substantial

impact on disease. With rising relative humidity, the incidence and severity of the disease increased until it reached an optimum, around 85 percent relative humidity, after which it appeared to plateau or reduce slightly at higher levels.

Sharma *et al.* (2017) while working on powdery mildew of wheat concluded that Maximum temperature, evening relative humidity and rainfall created a best fit regression model that explained 64 percent of the variation in powdery mildew disease across varieties and locations.

Similarly, Xu and Butt (1998) investigated the effects of four temperatures and nine water vapour pressure deficits in controlled environment cabinets on the early formation of apple powdery mildew colonies on potted apple rootstocks. They conducted that temperature accounted for the majority (61.0–79.0 per cent) of the treatment effects, as indicated by regression analysis, in analyses of variance of these growth parameters.

The effects of constant and varied temperatures on the incubation time of *Podosphaera leucotricha* were investigated by X-M and XU (1996). They found that incubation durations ranged from three to twelve days at temperatures ranging from eight to three hundred degrees Celsius, with no visible lesions appearing at 32 degrees Celsius.

While researching grape powdery mildew, Fathi and Khiavi (2012) discovered that *U. necator* survived the winter seasons as mycelium in the latent buds of grapes. The effect of environmental circumstances on fungus biology revealed that when the temperature reached 16-19°C and the relative humidity was greater than 50%, the fungus initiated pathogenic activity. The ideal temperature and relative humidity for *U. necator* sporulation were found to be 20-25°C and 50-100%, respectively. The disease first surfaced in the first week of May, according to the workers, and the severity of the disease ranged from 0.02 to 12.33 percent.

Gupta and Sharma (2009) while working on Powdery mildew of apples reported that conidia of *P. leucotricha* could germinate throughout a wide temperature range (5-35°C), but the conidial germination increased as temperature increased. It reached epidemic proportions during the months of June and July. Various workers (Monlar, 1971 and Grushin, 1988) reported a high incidence of the disease under high humidity circumstances and reported similar results.

Management

The biggest concern of the grower with mildew is the russet signs, which significantly impair fruit quality (Spotts and Cervantes, 1986). Because of sluggish vegetative growth or even the loss of terminal buds, infected young trees of vulnerable cultivars may be seriously damaged or become poorly structured. Sulphur fungicides are the most popular fungicides used to treat powdery mildew disease, although they have been linked to fruit russetting. Resistance has emerged as a result of the recurrent use of demethylation-inhibiting fungicides to manage apple disease, especially powdery mildew (Gao *et al.* 2009). As a result, novel substances for the management of the disease must be evaluated. In Israel, Reuveni *et al.* (1998) investigated the use of foliar sprays of mono-potassium phosphate fertilizer and sterol inhibiting fungicides to control powdery mildew on apple plants. For treating powdery mildew in apples, they applied foliar sprays of 0.5 per cent commercial sterol inhibiting fungicides and another treatment with an alternating combination of phosphate fertilizer and systemic fungicide. They observed that alternating phosphate fertilizer with systemic fungicide is as effective as or superior than regular fungicide application at half the rate, suggesting that phosphate fertilizer could be a key component in integrated pest management.

In order to derive a simple relationship for estimating density using incidence, Xu and Madden (2002) explored the association between disease incidence and colony density, as well as between leaves and shoot disease incidences for apple powdery mildew. The regression models that used a complementary log-log transformation of incidence were able to accurately predict the incidence of leaf (shoot) infections based on the number of colonies per leaf (or per shoot). The results demonstrated that the shoot incidence could be used to estimate the leaf incidence of the youngest unrolled leaves on a shoot.

Fernandez *et al.* (2006) investigated the use of horticultural mineral oil to prevent powdery mildew and codling moth in apples. Horticultural mineral oil (Orchex 796) was put through its paces in two different treatment scenarios. The first comprised three sprays for powdery mildew in the early season, while the second included a six-spray regimen for codling moth. These treatments were compared to a control group that did not get any oil after bloom. The study's findings revealed that neither treatment regime was successful in managing their respective targets. Both were unable to reduce the damage to a commercially acceptable degree.

Moparthy and Bradshaw (2020) analyzed fungicide efficacy trials on sweet cherry (*Prunus avium*) trees to combat powdery mildew (*Podosphaera cerasi*). They tested two different bio fungicides (*Bacillus subtilis* and *Bacillus pumilus*) and electrolyzed oxidized (EO) water in a greenhouse, nursery, and commercial orchard to see if these could be a viable replacement for four commonly used synthetic fungicides (fluopyram/trifloxystrobin, triflumizole, quinoxyfen, and myclobutanil). In all of the locations tested, electrolyzed oxidised water and fluopyram/trifloxystrobin significantly reduced disease severity and incidence. They also concluded that synthetic fungicides are the best method of managing powdery mildew considering fluopyram/trifloxystrobin was the only fungicide that was successful in lowering disease incidence and severity over the course of the powdery mildew epidemic in both the nursery and greenhouse.

While working on bioefficacy, studies of new fungicide molecules (Proquinazid 20 EC) against powdery mildew of apple in Kashmir, Rather *et al.* (2019) observed that Proquinazid 20EC, even at higher doses (0.04 and 0.08 percent), did not cause any phytotoxicity symptoms and enhanced the fruit yield of the Ambri apple. Similarly, Mitre *et al.* (2018) found that adding potassium bicarbonate with wettable sulphur reduced the degree of scab and powdery mildew attack on leaves and fruits all the while increasing the yield of scab-susceptible and scab-resistant cultivars. Treatment with potassium bicarbonate, potassium silicate, potassium bicarbonate, and copper ammonium phosphate yielded positive results.

Myclobutanil (0.05%), penconazole (0.05%), and hexaconazole (0.05%) were found to be efficient in reducing Powdery mildew incidence in apple by Gupta and Sharma (2005). They concluded that myclobutanil provided 97.12 percent control over check in apple nurseries, followed by penconazole (92.49 percent) and hexaconazole (82.90 percent).

Similarly, Gupta and Sharma (2009) reported successful management of powdery mildew of apple in Himachal Pradesh nurseries using Sulphur-based fungicides and Bavistin. Heidarian and Shahri (2014) further reported that 0.3 mL/lit tetraconazole effectively controlled powdery mildew of apple. The effectiveness of bicarbonate salts in controlling apple scab has been reported by several researchers (Schulze and Schonherr 2003, Ilhan *et al.* 2006, Jamar and Lateur 2007 and Jamar *et al.* 2010), and it has been proposed that this compound could be used in Powdery mildew disease management, with the caveat that it should be used in conjunction with other active compounds.

Byaurgaba *et al.* (2013) found that fungicides containing bupirimate (25 percent a.i), tebuconazole (43 percent a.i), and propineb (58 percent a.i) + cymoxanil (4.8 percent a.i) were effective in the management of powdery mildew in south western Uganda, with the potential to reduce infection by 55.95, 39.12, and 20.84 percent, respectively. Similarly, Holb (2014) focused on unique features of non-chemical techniques, such as agronomic measures, mechanical and biological control, and the use of resistant cultivars, while working on chemicals against powdery mildew of apples.

Binapacryl (0.1 percent) and carbendazim (0.05 percent) both reduced disease on Granny Smith and Red June apple cultivars, according to Gupta (1981). When combined with 0.01 percent bayleton, Baycor 25 was found to be effective (Borovinova 1984). Srivastava and Roy (1984) used Topsin M 0.1 percent, Saprol EC 0.05 percent, and Bavistin 0.1 percent to effectively prevent powdery mildew infection in apples.

Triazoles are effective against the powdery mildew pathogen. Five sprays of tetraconazole (1.0 lt/ha), triadimenol (0.18 lt/ha), and hexaconazole (0.28 and 0.34 lt/ha) applied at 15-day intervals reduced significantly powdery mildew in apples, according to Mandoza *et al.* (1991). Spraying demethylation inhibiting (DMI) fungicides like myclobutanil, flusilazole, triademefon, and propiconazole on McIntosh apple seedlings inoculated with *Podosphaera leucotricha* resulted in significantly fewer powdery mildew colonies, according to Sholberg and Hag (1994). Berrie (1997) reported that DMI fungicides (triadimefon, triadimenol, penconazole, fenarimol, and mycobutanil) were more effective in controlling apple powdery mildew other fungicides. Keeping in view the literature surveyed different fungicides were used in the management studies.

Chapter-3

MATERIALS AND METHODS

The current research was carried out in the laboratories of Department of Plant Pathology, College of Horticulture, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan, India (H.P) and RHR&TS, Sharbo, Kinnaur while the field trials were laid out in the fields of RHR&TS, Sharbo, Kinnaur Himachal Pradesh.

3.1 SURVEY AND SURVEILLANCE

Apple plants in different localities of Kinnaur districts of Himachal Pradesh were surveyed periodically during the year 2020 to 2021 from April to August to record the incidence and severity of powdery mildew under field conditions. The infected plant parts mainly leaves and shoots showing characteristic symptoms were collected in paper bags, brought to the laboratory and preserved for further studies.

3.1.1 Disease incidence and severity

In order to record the incidence and severity of powdery mildew; surveys were conducted between April to August (2020-21) and the disease incidence was calculated by the formula given by Lahlali *et al.* (2020) as under:

$$\text{Disease Incidence } P (\%) = \frac{\text{Number of diseased plants}}{\text{Total number of plants}} \times 100$$

To record disease severity, 25 plants were selected at random and per cent disease severity was scored as percentage plant leaf area affected with powdery mildew, evaluated visually on individual leaflets as the percentage of infected area, using a 0 to 4 scale as per Kim *et al.* 2004.

Rating	Description
0	Disease free no symptoms
1	1to 5 %
2	5.1 to 20 %
3	20.1 to 40%
4	40.1 to 100 %

The disease severity (%) was calculated as under (McKinney, 1923):

$$\text{Disease severity (\%)} = \frac{\text{Sum of all disease ratings}}{\text{Total number of ratings} \times \text{Maximum disease grade}} \times 100$$

The symptoms were photographed and specimens were brought to the laboratory for further analysis.

3.1.2 CULTIVAR SCREENING

Twenty different apple cultivars growing at Krishi Vigyan Kendra (KVK), Sharbo, district Kinnaur, HP were screened against powdery mildew. The KVK lies between 31.05 ° - 32.5 ° north latitude and 77.45° - 79.10° east longitudes. Assessment scale of Hofer *et al.* (2019) with slight modification was used for cultivar screening is as given under.

Assessment scale for apple powdery mildew (Hofer *et al.* 2019, 2021)

Scale	Susceptibility	Mildew
1	No infection	No visible macroscopic symptoms
2	Low susceptibility (LS)	Up to 25% of leaves covered with infection
3	Medium susceptibility (MS)	50% Leaves covered with infection
4	High susceptibility (HS)	75% leaves covered with infection
5	Extreme susceptibility (ES)	100%leaves covered with infection

3.2 PATHOGENICITY

In order to test the pathogenicity of *Podosphaera leucotricha*, apple seedlings were grown in the pots (10 cm dia.) in polyhouse of Department of Plant Pathology. Pathogenicity was confirmed through inoculation tests by gently pressing diseased leaves onto young leaves of five asymptomatic, potted one-year-old Gale Gala seedlings of apple. Five non-inoculated plants were used for a control treatment. The surface was first sterilized with 70 per cent ethanol and then thoroughly washed with sterilized distilled water. After inoculation the plants were lightly sprayed with sterilized distilled water to provide humidity for the germination of conidia. The plants were regularly monitored for symptom appearance. Days after dusting till the first symptom appearance were noted and the conidia were microscopically analysed. The plants were photographed and diseased leaves were detached and preserved in paper bags in refrigerator at 5± 1⁰ C.

3.3 EPIDEMIOLOGICAL STUDIES

3.3.1 Role of epidemiological parameters on Powdery mildew of apple

Sunshine hours, cumulative rainfall, relative humidity, and temperatures were recorded from April to August in the meteorological observatory established at RHR&TS, Sharbo, Kinnaur, H.P for the 2020 and 2021 growing season to ascertain the role of various epidemiological parameters on the development and spread of powdery mildews of apple. Daily observations on epidemiological parameters were expressed as a mean value for the time between the two data recording dates, and the data on disease severity was recorded every 7 days. Statistical analytic approaches were used to find simple, partial, and multiple correlations utilizing meteorological data on weekly temperature, average relative humidity, cumulative rainfall, and sunshine hours (Gomez and Gomez, 1984).

3.4 DISEASE MANAGEMENT

Various fungicides listed below were tested under laboratory and field conditions against powdery mildew. The concentration of the test fungicides as recommended by the university was used.

Sr. No.	Fungicide	Concentration used (g or ml/ 200 L)
1.	Carbendazim	100 g
2.	Hexaconazole	100 ml
3.	Tebuconazole 50% +Trifloxystrobin 25% WG	80 g
4.	Tebuconazole 8% + Captan 32% SC	500 ml
5.	Carbendazim 12% + Mancozeb 63% WP	500 g
6.	Difenoconazole 25% EC	30 ml
7.	Fluxapyroxad 75g/l + Difenoconazole 50g/l SC	60 g
8.	Boscalid 25.2% + Pyraclostrobin 12.8% w/w WG	50 g
9.	Metrafenone 500g/l SC	20 g

3.4.1 *In vitro* evaluation of fungicides

The efficacy of nine different fungicides concentrations viz., Carbendazim, Hexaconazole, Tebuconazole+ Trifloxystrobin, Tebuconazole+ Captan, Carbendazim + Mancozeb, Difenoconazole, Fluxapyroxad + Difenoconazole, Boscalid + Pyraclostrobin, Metrafenone at different concentration (50,75 &100 ppm) were tested against the test pathogen by slide germination method (Ko *et al* 1975; American Phytopathological Society ,1943). One ml each of spore suspension of *Podosphaera leucotricha* and fungicides suspensions of required concentrations were placed in sterilized cavity slides. The cavity

slides were placed inside petri plates on sterilized glass rods by lining the wet blotting paper to maintain humidity. The Petri plates were sealed with plastic films and incubated at 25±1°C for 48 hrs. Five replications were kept for each treatment. Observation on conidial germination and per cent germination inhibition was calculated by using the formula given by Vincent (1947).

$$R = \frac{C - T}{C} \times 100$$

Where,

- R - Per cent reduction
C - Number of conidial germination in control
T - Number of conidial germination in treatment

3.4.2 Evaluation of fungicides against powdery mildew under field condition.

A field trial was laid out both under orchard condition and nursery condition at experiment farm of RHR&TS, Sharbo, Kinnaur (H.P) with nine fungicides concentrations viz., Carbendazim, Hexaconazole, Tebuconazole+ Trifloxystrobin, Tebuconazole+ Captan, Carbendazim + Mancozeb, Difenoconazole, Fluxapyroxad + Difenoconazole, Boscalid + Pyraclostrobin, Metrafenone against powdery mildew of apple in randomized block design and each treatment was replicated thrice. Separate treatment of water spray alone was also kept for comparison. Spray application of fungicides were initiated with the initiation of disease symptom i.e.in the first week of May. In all, three sprays were applied fortnightly intervals and observations on disease severity were recorded ten days after the last spray. The Data on disease index and per cent disease control was also calculated.

3.5 PERPETUATION OF FUNGUS

The purpose of the investigation was to understand more about how fungus survives. Between September and December 2021, twigs and leaves were collected and kept in perforated polybags. Fine sections of leaves and twigs were examined microscopically for the presence of sexual structures or spores. Microscope slide images were captured and archived.

Chapter-4

RESULTS AND DISCUSSION

A survey was conducted to assess the incidence and severity of powdery mildew of apple. Different areas of Kinnaur district of Himachal Pradesh were surveyed during the months of April to July 2020 and 2021. The pooled data has been presented in the table 1.

Table 1. Incidence and severity of powdery mildew in apples under field conditions in District Kinnaur

Location	Disease incidence (%)	Disease severity (%)
Kalpa Block		
Villages		
Kalpa	36.26(37.78) ^c	62.00(55.91) ^a
Roghi	29.64(35.13) ^d	40.49(43.46) ^d
Pangi	53.80(51.15)^a	66.25(59.56)^a
Telang	38.79(39.42) ^c	59.12(53.37) ^b
Kothi	38.71(39.17) ^c	63.94(56.61) ^a
Mean	39.44(40.53)	58.34(53.78)
Nichar Block		
Villages		
Nichar	35.08(41.23) ^{cd}	56.00(60.91) ^b
Sungra	47.44(49.91) ^{ab}	57.24(62.35) ^b
Chagaon	49.36(54.26) ^a	64.75(60.27) ^a
Meeru	47.68(52.21) ^b	52.25(54.57) ^c
Bari	25.42(36.79) ^d	39.75(47.21) ^d
Mean	40.99(46.88)	53.99(57.06)
Overall mean	40.22(43.71)	56.17(55.42)

CD_{0.05}

4.56

5.12

The data presented in table 1 revealed the presence of disease in all the areas surveyed and incidence varied from 25.42 per cent to 53.80 per cent while the severity varied from 39.75 per cent to 66.25 per cent in district Kinnaur.

The data showed that out of two blocks surveyed, Nichar block recorded the highest incidence of 40.99 per cent. However, Pangi village in Kalpa block recorded highest incidence of 53.80 per cent followed by Chagaon (49.36%) and Sungra (47.44%) villages of Nichar block. In case of disease severity, it was seen that Pangi village had highest severity (66.25%) of powdery mildew closely followed by Chagaon (64.75%) and village Kothi (63.94%) which were statistically at par. Overall high disease severity of 58.34 per cent was

recorded in Kalpa Block which was statistically at par with Nichar block with 53.99 per cent severity.

2. Cultivar screening

Twenty different apple cultivars are the plants growing at Krishi Vigyan Kendra (KVK), Sharbo, district Kinnaur, HP were screened against powdery mildew. The KVK lies between 31.05 ° - 32.5 ° north latitude and 77.45° - 79.10° east longitudes. Assessment scale of Hofer *et al.* (2019) was used for cultivar screening.

Assessment scale for apple powdery mildew (Hofer *et al.* 2019, 2021)

Scale	Susceptibility	Mildew
1	NO INFECTION	NO VISIBLE MACROSCOPIC SYMPTOMS
3	LOW SUCEPTIBILTY(LS)	UP TO 25% OF LEAVES COVERED WITH INFECTION
5	MEDIUM SUCEPTIBILTY (MS)	UP TO 50-75% LEAVES COVERED WITH INFECTION
7	HIGH SUCEPTIBILTY (HS)	75% -80%LEAVES COVERED WITH INFECTION
9	EXTREME SUCEPTIBILTY (ES)	>80% LEAVES COVERED WITH INFECTION

The data presented in Table 2 and 3 clearly shows that all the cultivars and pollinizers displayed varied degrees of susceptibility towards the disease.

Table 2 Screening of Apple cultivars against Powdery Mildew under field conditions of district Kinnaur

Sr. No.	Cultivars	Disease reactions	Disease severity (%)
1	Rich-a-Red	MS	56.46
2	Starkrimson Delicious	MS	74.65
3	Vance Delicious	MS	54.66
4	Jeromine	MS	72.43
5	Super Chief	MS	56.89
6	Red Cap Valted	MS	59.78
7	Scarlet Spur II	MS	76.22
8	Top Red	MS	55.78
9	Red Delicious	LS	19.72
10	Royal Delicious	LS	21.76
11	Red Velox	LS	23.56
12	Oregon Spur II	LS	21.78
13	Auvil Early Fuji	LS	24.98

ES-Extreme susceptibility; HS- High susceptibility; MS-Moderate susceptibility; LS-Low susceptibility

Although all the cultivars were found to be susceptible but Red Delicious, Royal Delicious, Red Velox, Auveli Early Fuji and Oregon spur II showed low susceptibility towards Powdery mildew disease. Most of the cultivars were moderately susceptible to the disease. Granny smith and Gale Gala pollinizers were extremely susceptible to the powdery mildew infection whereas Redlum Gala was found to be highly susceptible (Table 3). All the delicious group pollinizers were found to be high and extremely susceptible to disease.

Table 3 Screening of pollinizing varieties against powdery mildew under field conditions of district Kinnaur

Sr. No.	Cultivars	Disease reactions	Disease severity (%)
1	Gale Gala	ES	92.56
2	Granny Smith	ES	88.02
3	Golden Delicious	ES	77.58
4	Golden Spur Delicious	HS	76.44
5	Redlum Gala	HS	88.90
6	Golden Autumn	HS	80.02
7	Red Gold	MS	62.40

ES-Extreme susceptibility; HS- High susceptibility; MS-Moderate susceptibility; LS-Low susceptibility

2. Pathogenicity

In order to test the pathogenicity of *Podosphaera leucotricha*, apple seedlings were grown in the pots (10 cm dia.) in polyhouse of Department of Plant Pathology. Pathogenicity was confirmed through inoculation tests by gently pressing diseased leaves onto young leaves of five asymptomatic, potted one-year-old Gale Gala seedlings of apple. Five non-inoculated plants were used in control. Inoculated leaves developed symptoms after 12 days, whereas the control plants remained symptomless. The fungus present on the inoculated leaves was morphologically identical to that observed on the original diseased leaves, fulfilling Koch's postulates. The observation on incubation period on leaves of apple seedlings were recorded.

It was observed that the symptom development occurred 12 days after inoculation. Small, whitish felt-like patches of fungal growth appeared (Fig 2.) and quickly covered the entire leaf. Diseased leaves became narrow, crinkled, stunted and brittle. Similar results were observed by Kaspers (1967) and Chauhan (2005) while working on powdery mildew of apples.

4. Effect of epidemiological parameters on powdery mildew of apples

During the months of May to August each year, measurements of the daily mean maximum temperature, average relative humidity, cumulative rainfall, and average sunshine hours were recorded at the weather station installed at KVK, Kinnaur. The data on disease severity was recorded at 7 days interval and the daily observation on meteorological factors were expressed as mean value for the period intervening the two data recording dates and are presented in table 4.

The data (fig. 3, Table 4a) on meteorological factors and disease development studies revealed that the disease first appeared in first and second week of May in 2020 and 2021 with maximum temperatures at 12.30 and 17.71°C, relative humidity at 40.00 and 13.84 per cent, cumulative rainfall up to the extent of zero and 0.21 mm and weekly sunshine hours between 10.66 and 11.66hrs during May 2020 and 2021, respectively. The temperatures varied from 12.30°C to 27.81°C in 2020 and 2021. Similarly mean Relative humidity varied from 13.0 to 68 per cent in both years. Highest rainfall of 2.40 mm was observed in the month of July whereas average sunshine varied from 10.66 to 20.74 hrs in both years. However, highest disease severity (83.41%) was recorded in the month of July 2020 followed by 76.18 per cent in the same month in the year 2020. Similarly, highest disease severity (76.86%) was recorded in the month of July in 2021. Very low severity was recorded in the month of May during both years. The data presented in Tables 3a and 3b clearly show that mean temperature between 18-24° C and Relative humidity levels between 50-60 per cent were favourable for disease development. The present study clearly indicated that relative humidity and temperature played a significant role and offered congenial atmospheric condition for the maximum development of powdery mildew of apple in dry temperate agro-climatic conditions of district Kinnaur. The present study also suggested that powdery mildew disease severity and development in apple orchards of Kinnaur can be determined through weather factors. The present results can be used for better decision making well in advance to check the incidence and disease development in accordance with the weather. The present findings are corroborated by the works done by Gupta and Sharma (2009), Gupta and Sharma (2005), Raut *et al.* (2017) Bana *et al.* (2020).



Fig 2 Symptom development in potted apple seedlings

Table 4a. Effect of different metrological factors on disease development during 2020

Data of observation	Weekly mean Temperature (°C)	Mean relative humidity (%)	Cumulative rainfall (mm)	Average sunshine (hours)	Disease Severity (%)
7/5/2020	12.30	40.00	0.00	10.66	1.18
14/5/2020	12.65	43.00	0.00	11.18	3.63
21/5/2020	13.65	34.00	0.70	14.52	7.86
28/5/2020	16.50	49.00	0.80	15.64	15.97
4/6/2020	13.00	56.00	1.70	19.24	21.54
11/6/2020	15.35	57.00	0.20	16.43	35.32
18/6/2020	17.95	45.00	0.20	17.82	43.19
25/6/2020	18.50	54.00	1.10	20.08	54.81
2/7/2020	18.60	56.00	0.20	20.96	66.50
9/7/2020	18.60	63.00	1.70	19.82	76.18
16/7/2020	18.95	54.00	2.40	20.49	83.41
23/7/2020	17.15	68.00	2.30	20.59	58.82
30/7/2020	19.15	64.00	0.00	19.50	46.60
6/8/2020	19.3	59.40	0.20	19.52	31.33
13/8/2020	17.60	20.90	0.25	19.67	23.12

Table 4b. Effect of different meteorological factors on disease development during 2021

Date of observation	Weekly mean Temperature (°C)	Mean relative humidity (%)	Cumulative rainfall (mm)	Average Sunshine (hours)	Disease Severity (%)
15/5/2021	17.71	13.84	0.21	11.66	0.00
22/5/2021	18.40	14.52	0.20	12.11	1.27
29/5/2021	23.17	18.05	0.25	15.52	6.87
5/6/2021	21.52	17.06	0.24	14.64	12.38
12/6/2021	26.22	20.81	0.16	19.24	18.96
19/6/2021	20.50	17.19	1.49	15.43	26.43
26/6/2021	24.39	20.15	0.06	17.72	33.59
3/7/2021	27.04	22.52	0.00	20.04	41.48
10/7/2021	27.81	42.74	1.00	20.74	52.83
17/7/2021	23.16	50.85	1.43	19.92	66.71
24/7/2021	23.73	58.93	2.40	20.49	76.86
31/7/2021	23.86	54.32	1.94	19.79	71.32
7/8/2021	25.08	21.61	0.30	19.62	42.98
14/8/2021	25.60	21.90	0.25	19.67	28.40

5. Correlation of disease severity with meteorological factors

The information on weather parameters and disease development (Fig3&4) revealed that the disease appeared in first and second week of May 2020-21. The disease assumed serious proportions in July. The progress of the disease is dependent on weather parameters such as mean maximum temperature, relative humidity and cumulative rainfall. Therefore, simple, partial and multiple correlations were worked out to establish relative contribution of these dependent variables on disease severity and spread.

Table 5. Simple and partial correlation coefficient between disease severity and weather parameters

Meteorological factors	Disease severity	
	Simple correlation	Partial correlation
Temperature	-0.544	0.412
RH	0.673	0.662*
Cumulative rainfall	0.431	0.459

*Significant at 5% level of significance

The data presented in table 5 revealed that the value of simple correlation coefficient between disease severity and relative humidity (0.673) was highly significant and positive indicating consistent effect of relative humidity on disease severity. However the increase in relative humidity levels above 60 percent was found to be unfavourable for the disease development. The results are in conformity with the work done by Gupta and Sharma (2009). Similarly, correlation coefficient between mean air temperature and disease severity was found significant and negative (-0.544). Temperature between 18-25°C was found to be optimum for the disease development. The temperature above 25°C had deleterious effect on the disease development. The effect of rainfall was found to be non significant and positive (0.431). Temperature and humidity were considered as an important factor for appearance and development of powdery mildew diseases. The results to a greater extent corroborate the findings of various workers (Monlar, 1971, Grushin 1988, Gupta and Sharma, 2009, Tang *et al.* 2017, Korra and Kumar, 2018) who reported high disease development under humidity conditions ranging from 20 to 65 per cent. Data further indicated that partial correlation between disease severity and relative humidity (0.662) was highly significant and positive whereas with temperature and rainfall it was positive but not significant.

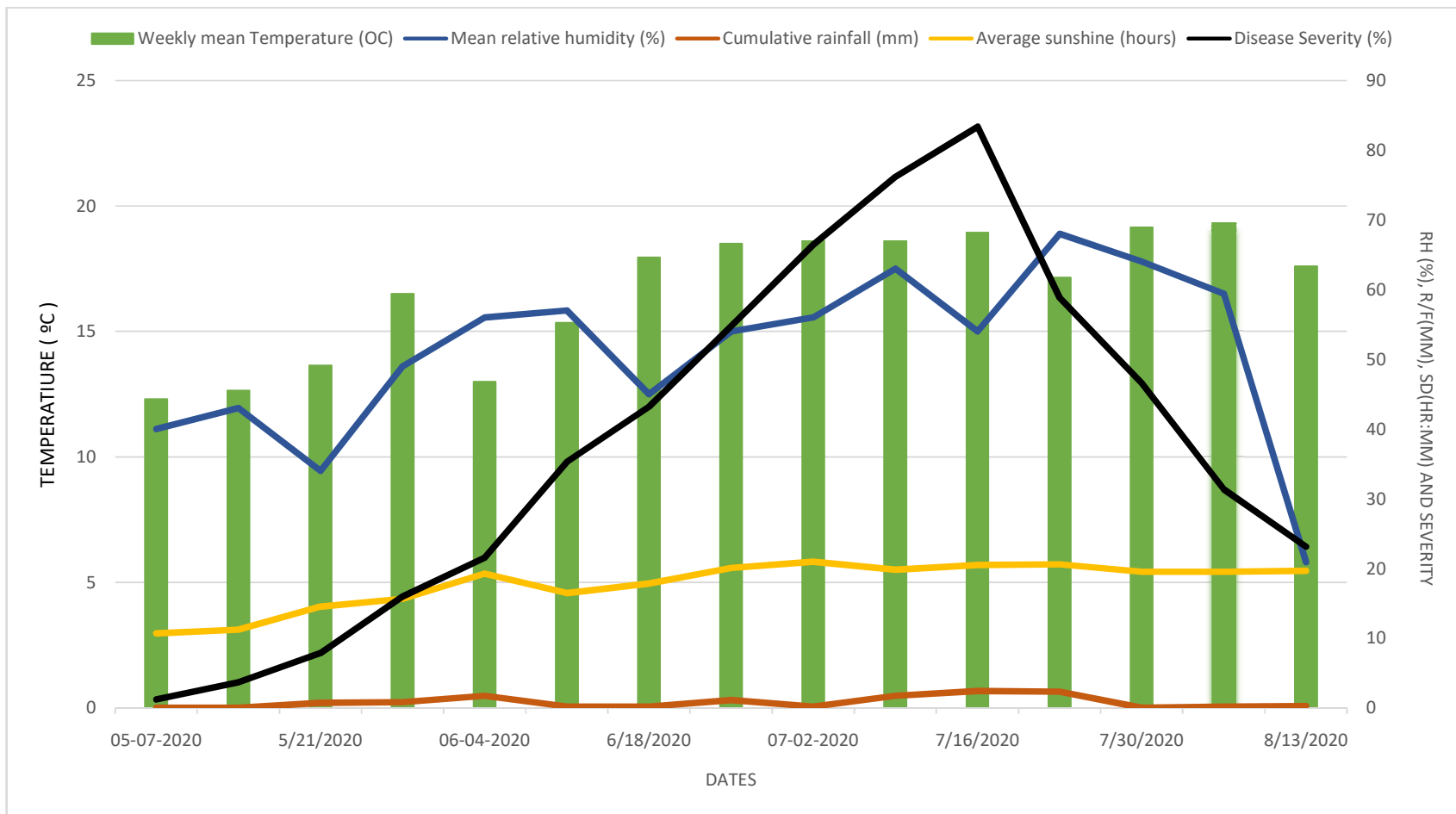


Fig. 3 Effect of different meteorological factors on disease development during 2020

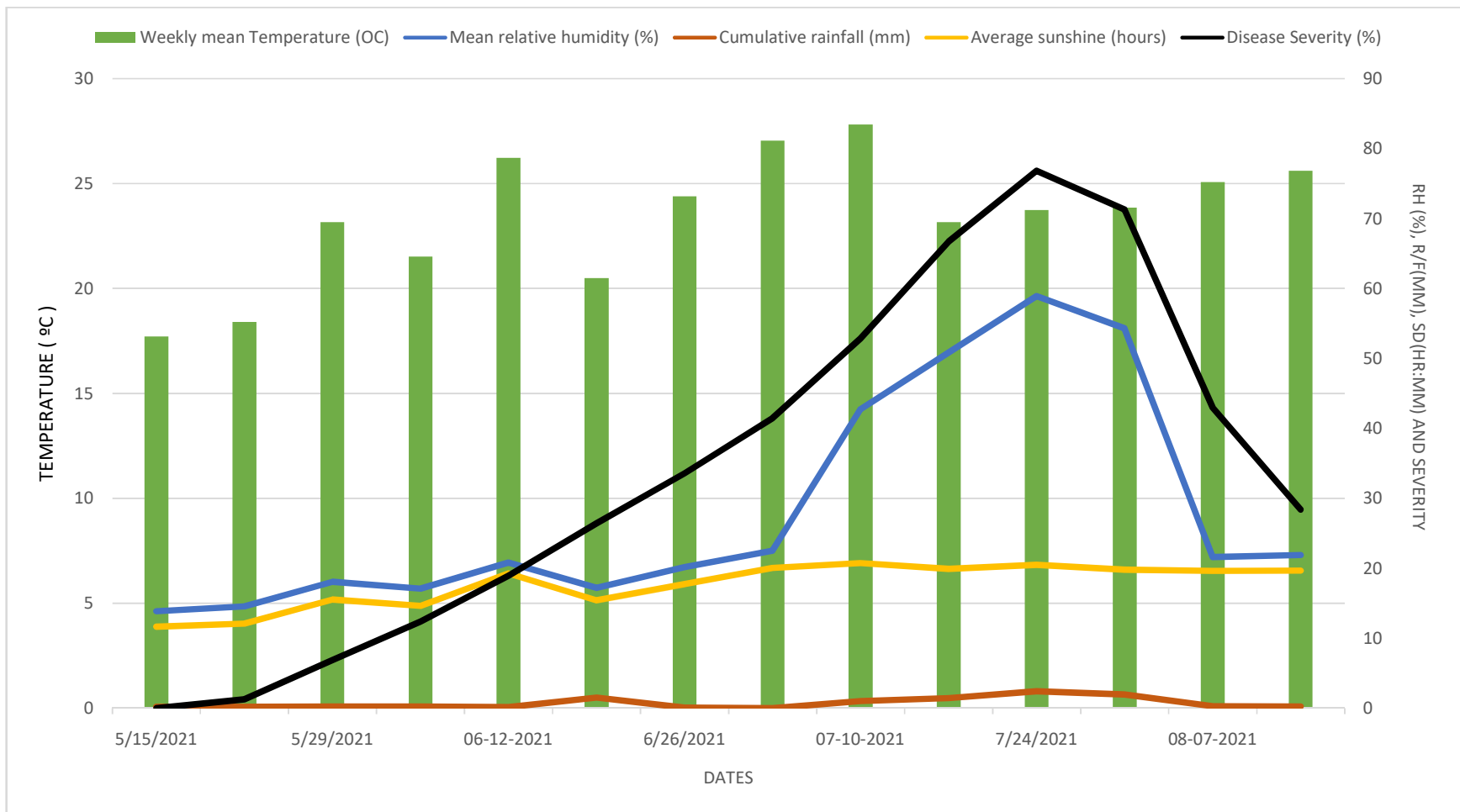


Fig.4 Effect of different meteorological factors on disease development during 2021

Table 6. Multiple correlation and regression equation between disease severity and weather parameters

S.NO	REGRESSION EQUATION	F-VALUE	STANDARD ERROR	R ²
1	- 279.80+0.314 x ₁ *+-0.146x ₂ *+4.3076x ₃	7.290	15.98	Y ₁ =0.693

N =10

*Significant at 5 per cent level of significance

Stepwise multiple regression analysis was performed using the following equation:

$$y =bo + b1x1 + b2x2+ b3x3..... + bnxn$$

Where, Y₁= Disease severity (%), X₁= Mean temperature (°C), X₂= Mean relative humidity (%), X₃= Cumulative rainfall (mm)

Statistical analytic approaches were used to find simple, partial, and multiple correlations utilizing meteorological data on weekly temperature, average relative humidity, cumulative rainfall, and sunshine hours (Gomez and Gomez, 1984). The multiple correlation coefficient (Table 6) between disease severity and group of independent variables viz., Relative humidity, temperature and cumulative rainfall, was found to be 0.693, which indicated that 69.30 per cent change in disease severity could be attributed to the cumulative effect of these independent variables, whereas, the rest of the variation was due to unexplained factors like wind speed, cloud cover and error variations and those factors were not included in the study. It was reported by various workers that at 10–25°C (optimum 20–22 °C) and relative humidity ranged between 70 to 100%. Germination of conidia of powdery mildew was slow at temperatures below 4–10°C and above 28–30°C (Covey, 1969, Hickey & Yoder, 1990, Holb, 2013). The present study is in concurrence with the work done by various workers (Gupta and Sharma, 2009, Tang *et al.* 2017, Korra and Kumar, 2018) who reported that temperature between 18-25° C and relative humidity between 50-70 per cent favoured the disease development but high rainfall and temperatures above 25⁰ C were deterrent to the disease development.

6. Chemical control

Efficacy of different fungicides on conidial germination was evaluated *in vitro*. The data presented in table 7 shows that the per cent conidial germination inhibition *in vitro* was affected by all the chemicals at all the three concentrations tested in the experiment. The maximum germination inhibition (75.89 per cent) occurred at 100 ppm. Individually, Boscalid+Pyraclostrobin (fungicides) showed maximum percent germination inhibition at all the concentrations. This was closely followed by Fluxapyroxad +Difenoconazole (95.91%) and Tebuconazole+Trifloxystrobin (94.78%), respectively at 100 ppm concentration. Per cent

germination inhibition gradually increased with the increase in the fungicidal concentration. Metrafenone and Carbendazim+Mancozeb were found to be least effective at all the concentrations tested.

Table 7. Efficacy of fungicides on conidial germination under *in vitro* conditions

PERCENT GERMINATION INHIBITION AT CONCENTRATIONS			
Fungicides	50 ppm	75ppm	100ppm
Carbendazim	12.23(24.98)	26.79(32.21))	53.12(56.96)
Hexaconazole	26.76(34.78)	59.70 (52.23)	83.89(66.34)
Tebuconazole +Trifloxystrobin	29.95(38.98)	56.78 (60.15)	94.78(71.59)
Fluxapyroxad +Difenoconazole	23.87(35.65)	55.60 (57.42)	95.91(77.29)
Carbendazim+Mancozeb	11.22(23.69)	29.89(37.91)	51.21(54.44)
Difenoconazole	19.56 (27.79)	39.98 (47.83)	90.08(81.96)
Tebuconazole+ captan	21.51(33.44)	53.59(59.09)	79.27(68.96)
Boscalid +Pyraclostrobin	46.73(51.39)	72.59(68.56)	100.00(89.96)
Metrafenone	8.94(16.89)	18.89(25.75)	34.78(45.92)
Mean	20.31(31.95)	45.98(49.02)	75.89(68.16)
CD 0.05	3.87	4.36	3.98

All the fungicides which were tested *in vitro* were also tested under field conditions during May to Aug 2021. The fungicides were sprayed in full grown 10 year old orchard at Kalpa, Kinnaur. In all, three sprays of each fungicide were repeated at 15 days interval starting from May and the data on disease severity was recorded 10 days after the last spray. The data presented in table 8 revealed that all the fungicides were effective in disease management. Maximum per cent disease control (94.04%) was observed in the trees sprayed with Fluxapyroxad +Difenoconazole followed by Boscalid+ Pyraclostrobin (89.92%) both of which were significantly different from each other. However, Tebuconazole +Trifloxystrobin was next best in order and provided high disease control (87.21%) but it was statistically at par with Boscalid+Pyraclostrobin fungicide. Metrafenone and Carbendazim+Mancozeb showed the lowest per cent disease control at 52.06 and 65.75 per cent respectively. Data further proves that minimum disease severity was registered in plants sprayed thrice with Fluxapyroxad +Difenoconazole, Boscalid +Pyraclostrobin and Tebuconazole +Trifloxystrobin at 15 days interval. Reduction in disease severity by spray of fungicides have been reported by Srivastava and Roy, 1984; Mandoza *et al.* 1991, Sharma *et al.*1992 and Strickland *et al.* (2021). Similarly, Vielba *et al.* (2020) also corroborated the present findings while working on fungicide resistance in Powdery mildew fungi.

Table 8. Effect of various fungicidal sprays on disease severity of Powdery mildew of apple in orchards

Fungicide	Concentration (%)	Disease severity (%)	PDC (%)
Carbendazim	0.05	15.46(23.13)	65.75(45.17)
Hexaconazole	0.05	12.71(20.87)	71.84(50.53)
Tebuconazole +Trifloxystrobin	0.04	2.69(9.40)	87.21(67.17)
Tebuconazole +Captan	0.25	6.59(14.83)	85.40(64.84)
Carbendazim+Mancozeb	0.25	13.38(21.44)	70.35(49.18)
Difenoconazole	0.015	12.18(20.41)	73.01(51.62)
Fluxapyroxad +Difenoconazole	0.03	5.77(13.85)	94.04(77.71)
Boscalid +Pyraclostrobin	0.025	4.55(12.29)	89.92(70.87)
Metrafenone	0.010	21.64(29.92)	52.06(29.08)
Control	-	45.14(42.19)	-
CD0.05	3.46		

The same set of fungicides was sprayed on nursery plants. In all three sprays of each fungicides were repeated at 15 days interval starting from May onwards and the data on disease severity was recorded 10 days after the last spray. The data presented in table 9 revealed that all the fungicides were effective in disease management. Maximum per cent disease control (81.09%) was observed with Fluxapyroxad +Difenoconazole followed by Boscalid +Pyraclostrobin (79.51%) and Tebuconazole +Trifloxystrobin (75.37%). The least disease control (26.70%) was observed in Metrafenone.

Table 9. Effect of various fungicidal sprays on disease severity of Powdery mildew of apples in orchards under nursery conditions

Fungicide	Concentration (%)	Disease severity (%)	PDC (%)
Carbendazim	0.05	21.67(27.72)	58.54(40.10)
Hexaconazole	0.05	17.66(24.82)	66.21(46.37)
Tebuconazole +Trifloxystrobin	0.04	10.71(19.04)	75.37(54.67)
Tebuconazole + Captan	0.25	14.24(22.13)	72.75(52.18)
Carbendazim+Mancozeb	0.25	18.97(25.79)	63.70(44.27)
Difenaconazole	0.015	15.71(23.31)	69.94(49.63)
Fluxapyroxad +Difenoconazole	0.03	12.87(20.98)	81.09(58.85)
Boscalid +Pyraclostrobin	0.025	9.88(18.25)	79.51(60.56)
Metrafenone	0.010	38.31(33.29)	26.70(28.06)
Control		52.27(46.28)	-
CD0.05	2.91		

The results were similar to the sprays done in the orchards. However, it was seen that the per cent disease control was higher in case of orchards as compared to the nursery. This can be attributed to the fact that orchards are rainfed and nursery receives regular irrigation at three days interval thus maintaining high relative humidity percentage at levels optimum for the disease development. Strickland *et al.* (2021) hypothesized that differences in DMI efficacy may be due to each fungicides' water solubility and lipophilicity characteristics, and thus their ability to move systemically in the host or more easily penetrate the surface of germinating conidia.

7. Perpetuation of fungus

The investigation was conducted to study the perpetuation of fungus. The twigs and leaves were collected in the month of October-December, 2021 and kept in perforated polybags. The fine sections of the twigs and leaves revealed that the fungus survived in the form of a resting mycelium or encapsulated haustoria in the buds. The microscopic picture (Fig.5&6) revealed the presence of mycelium and conidia. Hyphae were flexuous to straight, branched, septate, 4 to 6 μm wide. Conidia were hyaline, ellipsoid-ovoid, 22 to 32 \times 13.5 to 20 μm and had distinct fibrosin bodies. The Chasmothecia were dark brown; globose to elliptical measuring 80-99 μm having long, light coloured basal and apical appendages. The structures and measurements were compatible with those of the anamorphic state of *Podosphaera leucotricha* (Ellis & Everh.) E.S. Salmon as described by Braun (1987). Chasmothecia (sexual stage) were found in the dormant buds of tree. Similar results were reported by Bharat and Bhardwaj (2000) while working on powdery mildew of apples in Kinnaur.

According to Hickey & Yoder (1990) Fruit buds provide the earliest source of inoculum. Because infected buds usually open a few days later than healthy ones, susceptible tissue is already present when the first conidia are produced. Cunningham (1923) indicated that the abundant chasmothecia played no part in the overwintering of the fungus. It is widely accepted that the sexual stage of *P. leucotricha* do not appear to be important in the disease cycle. Although germination during the winter months has been reported but attempts to germinate ascospores and/or to inoculate foliage with them have been unsuccessful (Hickey & Yoder, 1990). The thorough scanning of literature revealed that powdery mildew of apple is a widespread problem and location specific studies are required to understand the disease incidence and further development of disease.

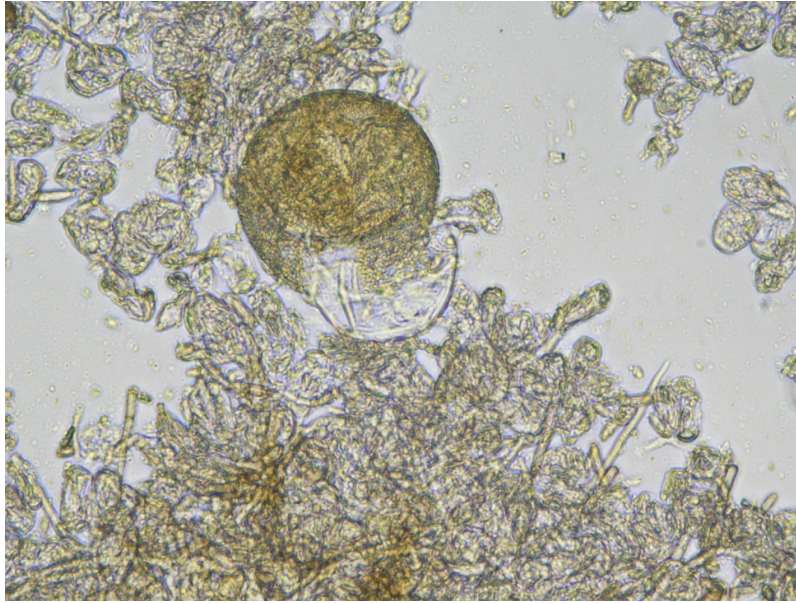


Fig. 5 Immature chasmothecium of *P.leucotricha*



Fig. 6 Conidia of *P.leucotricha*

Chapter-5

SUMMARY AND CONCLUSION

The current research entitled, “**Studies on the prevalence and epidemiology of Apple powdery mildew in Himachal Pradesh**” was carried out at RHR&TS KVK Sharbo in Kinnaur and Dr Y.S Parmar university of Horticulture and Forestry Nauni, Solan H.P. It was undertaken with the objectives

1. To assess the prevalence of powdery mildew disease in major apple-growing regions of district Kinnaur
2. To evaluate the efficacy of different fungi-toxicants against the powdery mildew disease of apple

The salient achievements of the work are summarized as under:

A survey conducted to determine incidence and severity of powdery mildew in apple orchards and nurseries revealed that diseases occurred in moderate to severe form in various parts of Kalpa and Nichar block of Kinnaur district of Himachal Pradesh. The disease incidence ranged from 25.42 per cent to 53.80 per cent and severity from 39.75 per cent to 66.25 per cent. Chagaon village in Nichar block recorded the highest incidence of 49.36 per cent. However, Pangi village in Kalpa block recorded highest incidence of 53.80 per cent.

From a total of 20 cultivars 5 cultivars viz. Red Delicious, Royal Delicious, Red Velox, Auvil Early Fuji and Oregon Spur II, were found to be less susceptible to *Podosphaera leucotricha*, while Granny Smith, Golden Delicious, and Gale Gala were found to be extremely susceptible. The remaining cultivars showed reactions that ranged from mildly to highly sensitive. This study can be used to segregate the varieties according to their susceptibility quotient before distribution of plants to the farmers.

The weather parameters viz. temperature, rainfall, relative humidity and sunshine hours were recorded for two consecutive years to evaluate their effect on the disease severity of powdery mildew of apple. Highest disease severity was recorded in the month of July in 2020 & 2021 and low severity was recorded in the month of May during both these years. The data presented clearly shows that mean temperature between 18-24° C and Relative

humidity levels more than 50 per cent were favourable for disease development and spread. The results on the influence of environmental factors on the disease development under field conditions revealed that the disease initiated in the first week of May and peaked during July in 2020 and 2021. Simple correlation coefficient equation between disease severity and relative humidity was found to be highly significant and positive (0.673) indicating that the disease progression occurred with increasing relative humidity, however the increase in relative humidity levels above 60 percent was found to be unfavourable for the disease development. Temperature showed significant but negative correlation (-0.544) indicating thereby that temperature plays a significant role in disease development increase in temperature above 25⁰ C negatively impacted the disease progression. The multiple correlation coefficients of 0.693 indicated that 69.30 per cent change in disease severity was due to the cumulative effect of these independent variables viz Temperature, relative humidity and rainfall. The impact of weather parameters on disease severity can be used to predict the disease onset and further development in the growing season for effective fungicidal management of this disease.

For the management of the disease, *in vitro* evaluation of fungitoxicants was done against *Podosphaera leucotricha* by slide germination method. Boscalid + Pyraclostrobin (100.00), Fluxapyroxad + Difenconazole (95.91%) and Tebuconazole + Trifloxystrobin (94.78%) were found to be superior over other fungicides in inhibiting the spore germination at all the concentrations tested.

The same set of fungicides evaluated *in vitro* were sprayed under field conditions during May to August during 2020 and 2021. Maximum disease control (94.04%) was reported under Fluxapyroxad + Difenconazole fungicide followed by Boscalid + Pyraclostrobin (89.92%). However, Tebuconazole+Trifloxystrobin were significantly at par with Boscalid + Pyraclostrobin. Metrafenone and Carbendazim + Mancozeb showed the lowest per cent disease control at 52.06 and 65.75 percent respectively.

These fungicides were evaluated under nursery conditions. Here maximum disease control (81.09%) was registered under Fluxapyroxad + Difenconazole fungicide followed by Boscalid + Pyraclostrobin (79.51%). The same set of fungicides performed relatively better in orchard condition as compared to the nursery as the nursery plants are regularly irrigated leading to moisture build up and high humidity levels leading to disease

development. Data further proves that minimum disease severity was registered in plants sprayed thrice with Fluxapyroxad + Difenoconazole, Boscalid + Pyraclostrobin and Tebuconazole + Trifloxystrobin at 15 days intervals.

The studies were conducted to find the perpetuation mode of the fungus *Podosphaera leucotricha* after the leaf fall. It was found that the fungus survived in the form of conidia, mycelium and chasmothecia in the dormant buds and twigs of the tree. The structures and measurements of conidia and chasmothecia were compatible with those of the anamorphic state of *Podosphaera leucotricha* (Ellis & Everh.). The microscopic picture revealed the presence of mycelium, conidia and Chasmothecia (cleistothecium is a former term for this structure that is still widely used) in the buds and leaves of the apple plant. The perpetuation of the fungus occurs in the form of chasmothecia and mycelium.

CONCLUSION

- ❖ The disease is present in moderate to severe form in all the two blocks surveyed of district Kinnaur, Himachal Pradesh
- ❖ Granny Smith, Golden Delicious and Gala pollinizers were extremely susceptible to the powdery mildew infection in district Kinnaur.
- ❖ According to the present study the disease initiates in first week of May and peaks in the month of July in district Kinnaur. Temperatures between 18-24⁰ C and RH between 50-65 per cent were favourable for the disease development.
- ❖ Fluxapyroxad + Difenoconazole, Boscalid + Pyraclostrobin and Tebuconazole + Trifloxystrobin sprayed at 15 days intervals with the initiation of the disease successfully managed the powdery mildew of apples in District Kinnaur, H.P.
- ❖ The fungus survives and perpetuates in the buds and leaves of the apple plant. The Perpetuation of the fungus occurs in the form of chasmothecia, conidia and mycelium.

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ABSTRACT

Powdery mildew of apple was found prevalent in moderate to severe forms in Kalpa and Nichar block of Kinnaur, Himachal Pradesh. Incidence of the disease ranged from 25.42 per cent to 53.80 per cent and severity from 39.75 per cent to 66.25 per cent, respectively. Overall twenty different apple cultivars were screened against powdery mildew planted under field conditions at KVK Sharbo, Kinnaur, H.P. Out of the 20 cultivars 5 cultivars viz. Red Delicious, Royal Delicious, Red Velox, Auvil Early Fuji and Oregon Spur II, were found to be less susceptible to *Podosphaera leucotricha*, while Granny Smith, Golden Delicious, and Gale Gala were found extremely susceptible. In the pathogenicity test of *Podosphaera leucotricha* it was observed that the symptoms developed at 12 days after inoculation. Small whitish felt-like patches of fungal growth appeared and quickly covered the entire leaf. According to the present study the disease initiated during first week of May and peaked in the month of July in district Kinnaur. Temperatures between 18-24⁰ C and RH between 50-65 per cent were favourable for the disease development. For the management of the disease, *in vitro* evaluation of fungitoxicants was done against *Podosphaera leucotricha* by slide germination method. Boscalid + Pyraclostrobin (100.00), Fluxapyroxad + Difenconazole (95.91%) and Tebuconazole + Trifloxystrobin (94.78%) were found to be superior over other fungicides in inhibiting the spore germination at all the tested concentrations. The same set of fungicides evaluated *in vitro* were sprayed under field conditions and maximum disease control (94.04%) was reported in Fluxapyroxad + Difenconazole treated plots followed by Boscalid + Pyraclostrobin (89.92%). These fungicides were further evaluated under nursery conditions. Here maximum disease control (81.09%) was registered in Fluxapyroxad + Difenconazole followed by Boscalid + Pyraclostrobin (79.51%). For the perpetuation of fungus *Podosphaera leucotricha* leaves and twigs were collected from orchards and found that fungus survived and perpetuated in the form of conidia, mycelium and chasmothecia in the dormant buds and twigs of the tree.

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Academic Qualification

Sr. No.	Certificate/Degree	Class/Grade	Board/ University	Marks (%)	Year
1.	Matriculation	First	CBSE	79.8	2012
2.	10+2	First	CBSE	79.8	2014
3.	B.Sc. (Horticulture)	First	Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan	74.5	2019

**Whether sponsored by some state/
Central Govt./Univ./SAARC** : NA

**Scholarship/ Stipend/ Fellowship, any other financial
assistance received during the study period** : University stipend

(Renu Negi)