Chapter 9
Epidemiology and Forecasting

9.1 Introduction

In epidemics of downy mildews, the pathogen population starts from a low level of initial inoculum which then increases exponentially through successive cycles on the host during the growing season. Therefore, downy mildew of crucifers is a compound interest disease. The seasonal increase of the pathogen population has been investigated much more thoroughly than that of the initial inoculum. Information has been generated on the multiplication phase of the disease which relates to the sequence of events in the life of the pathogen on its host, which are infection, colonization, and sporulation. The studies on forecasting of crucifers downy mildew disease is limited to prediction models.

9.2 Disease Development in Relation to Temperature, Humidity, Rainfall, and Leaf Wetness

The relationship of host-pathogen-environment interaction in case of downy mildew of crucifers is a complex phenomenon which determines the rate of disease development (Fig. 9.1). Among the major environmental factors which markedly influence the development of downy mildew is air temperature and relative humidity Environmental factors effect:Leaf wetness.

The rate of spore germination and host penetration is affected by temperature variations. Chu (1935) found that at 15 °C conidia germinate in 4–6 h, appressoria form in 12 h, and penetration occurs in 18–24 h. According to Eddins (1943), the downy mildew of cabbage is most destructive when the temperature ranges between 10 °C and 15 °C and when the plants remain wet until mid-morning for 4 consecutive days. However, Felton and Walker (1946) reported that on cabbage, germination of the conidia (Fig. 9.2) and subsequent penetration of the host take place most

G. S. Saharan et al., *Downy Mildew Disease of Crucifers: Biology, Ecology and Disease Management*, https://doi.org/10.1007/978-981-10-7500-1_9

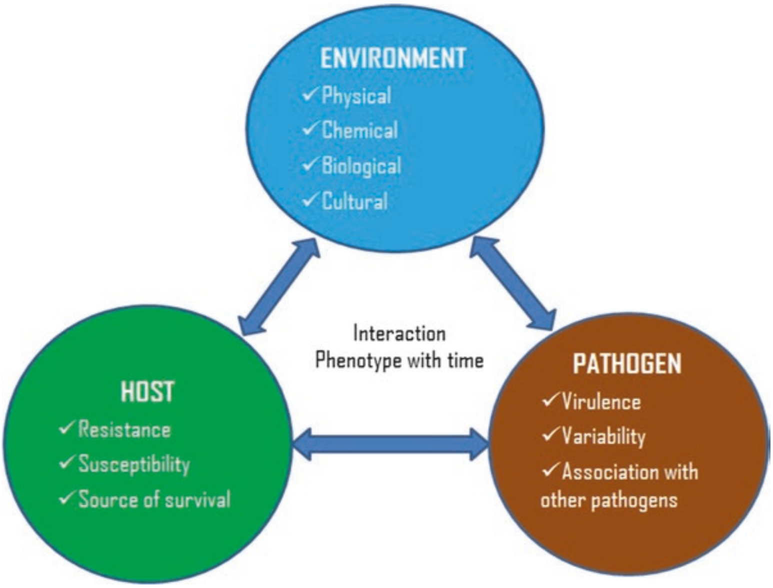

Fig. 9.1 The relationship of host, pathogen, and environment in the interaction phenotype of downy mildew of crucifers

rapidly at 8–12 °C and 16 °C, respectively. Formation of haustoria and growth of the fungus in the host tissues are most rapid at 20–24 °C (Fig. 9.3). Symptoms develop quickly at 24 °C, but sporulation and reinfection is limited at 24 °C and 28 °C. The lower temperature of 16 °C results in slower growth of both the host and the pathogen, less damage, more prolific sporulation, more reinfection, and, consequently, more profuse disease development. The severity of the disease at 10–15 °C seems to be the effect of temperature upon production of inoculum, spore germination, and infection (Figs. 9.4 and 9.5). However, according to Saharan et al. (1997), a temperature of 15 °C seems to be the most favourable for epidemic development as this favours slower growth of both host and pathogen resulting in less drastic damage and hence more profuse disease development. The temperature range for maximum infection of seedlings of a highly susceptible cabbage cv. and subsequent disease development in vitro was 15–25 °C, and 90–100% infection was achieved after 48 h of incubation. At less than 15 °C and 26–30 °C temperature, infection percentage was decreased to 40–50% and 35–40%, respectively. No disease incidence was recorded at temperature above 35 °C. Penetration of cotyledons by germ tube was mostly via stomata and occasionally directly through the cuticle (Achar 1998). In Spain, downy mildew disease intensity on cole crops was positively correlated with RH and negatively with mean temperature and number of hours of daily insolation. A low number of hours of insolation for several consecutive days combined with cool temperature appeared to be determining factors in disease development (Sinobas Alonso and Diaz Alonso 1995).

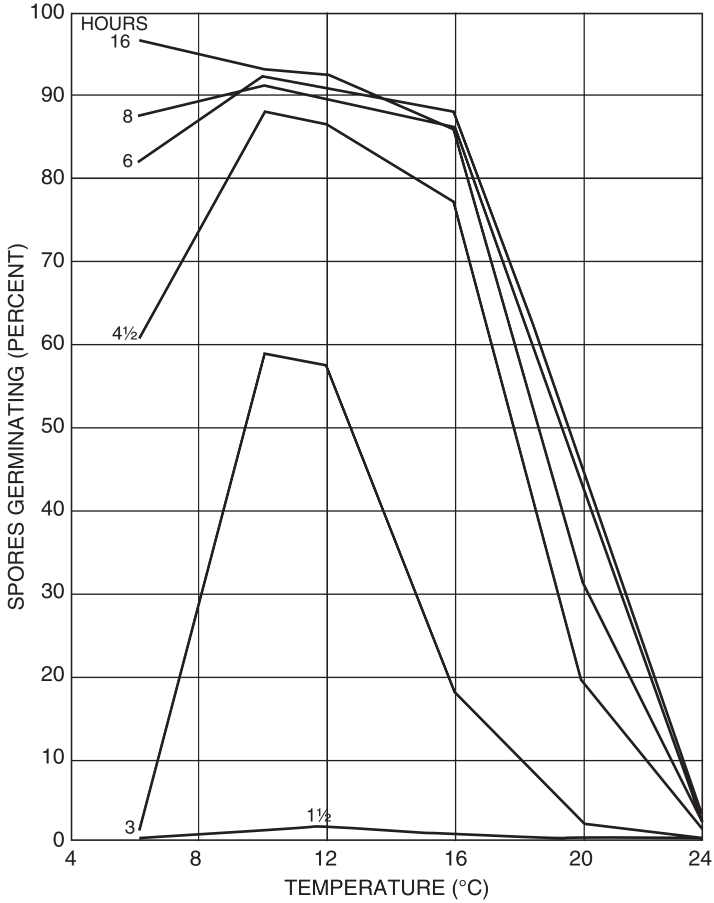

Fig. 9.2 Effect of time and temperature on germination of conidia of *Hyaloperonospora parasitica* (Felton and Walker 1946)

By contrast, Chou (1970) noted 20–25 °C, and Nakov (1972) found 15–20 °C as the most favourable temperature for infection. In temperate coastal regions of Madison, Wisconsin, USA, where Chinese cabbage is grown from late summer through the winter and spring, downy mildew thrives during periods of frequent rains and high humidity. There is an 8–12 h requirement of 100% RH for the production and dissemination of its airborne conidia. Once inside the Chinese cabbage, hyphae spread through the leaves, petioles, and stems, first feeding on the cells without apparent injury then suddenly causing yellowing, collapse, and death of the tissues. Conidiophores and conidia are produced primarily on the lower side of the leaves (Williams and Leung 1981).

On *Brassica* oilseeds, *H. parasitica* is favoured by temperatures of 8–16 °C, moist air, and weak light (Jonsson 1966; D'Ercole 1975). According to Bains and Jhooty (1979), a 17 °C temperature and 51 mm rainfall result in low infection of

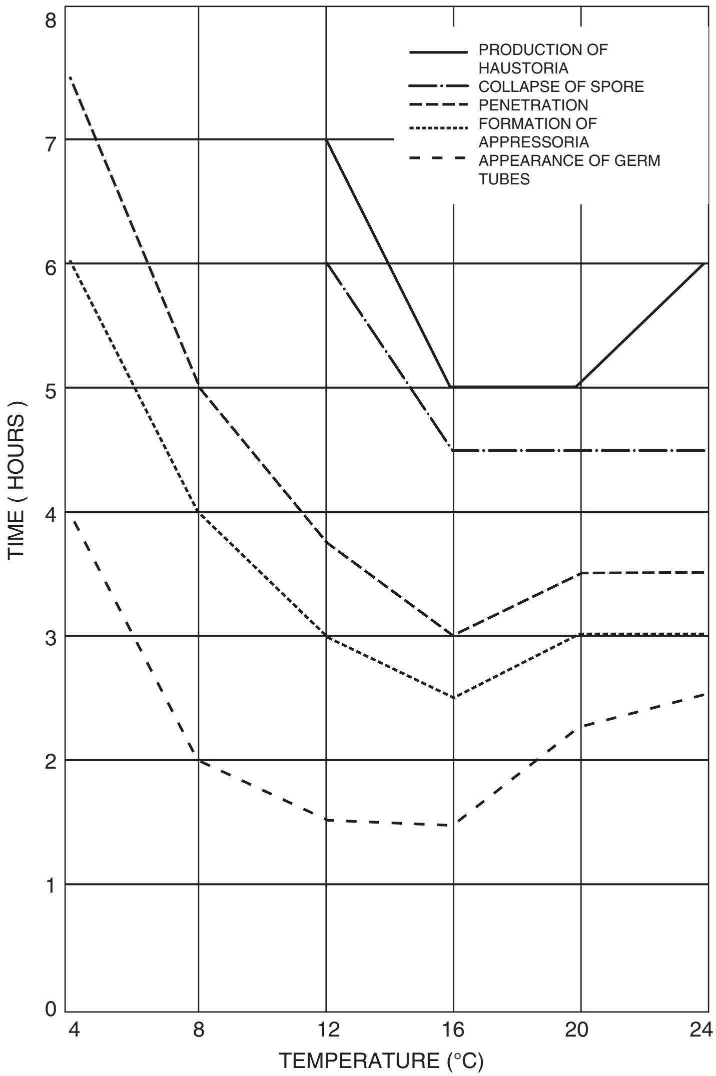

Fig. 9.3 Effect of temperature upon penetration and development of haustoria of *Hyaloperonospora parasitica* (Felton and Walker 1946)

mustard in contrast to high infection at 14 °C temperature and 152 mm rainfall during the crop season. In a subsequent study, 15–20 °C were the best temperatures for infection and development of downy mildew. At this temperature regime, infection occurs within 24 h of inoculation (Table 9.1, Fig. 9.6). The infection frequency is reduced at 25 °C temperature with no infection observed at 30 °C temperature (Table 9.1, Fig. 9.6). The maximum area under disease progress curve occurs at 20 °C temperature (AUDPC-60.54%, Fig. 9.6). Leaf wetness duration of 4–6 h at 20 °C temperature and for 6–8 h at 15 °C temperature is essential for severe infection and disease development on mustard (Tables 9.2 and 9.3 Figs. 9.7 and 9.8).

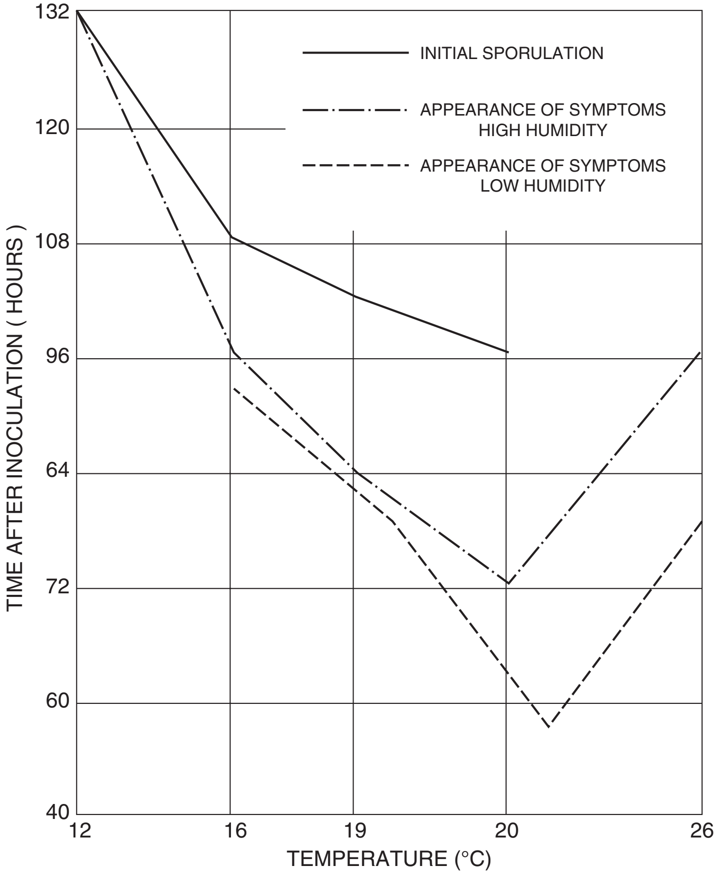

Fig. 9.4 Effect of five different temperatures on the initial sporulation of *Hyaloperonospora parasitica* at high humidity and upon initial appearance of symptoms at low and at high humidity (Felton and Walker 1946)

The infection frequency, and disease development increases significantly with the increase in duration of leaf wetness (Mehta et al. 1995). According to Kolte et al. (1986), sunshine has a significant negative correlation, whereas total rainfall has a significant positive correlation with *A. candida*-induced stag head development on rapeseed-mustard (Table 9.4, Fig. 9.9). The data in Table 9.4 revealed that prediction equations for the development of staghead incidence due to downy mildew and white rust disease complex were up to 68%, whereas staghead severity was up to 62% when all the weather factors were taken into consideration. A reduced period of sunlight (2–6 h/d) and rainfall of up to 161 mm during the flowering period favours severe occurrence of the stag heads.

Maximum temperature was positively correlated with disease index of white rust, downy mildew, and *Alternaria* blight. Maximum temperature from 26 to 29^0 C and average relative humidity of more than 65% (Tables 9.5 and 9.6) favoured the

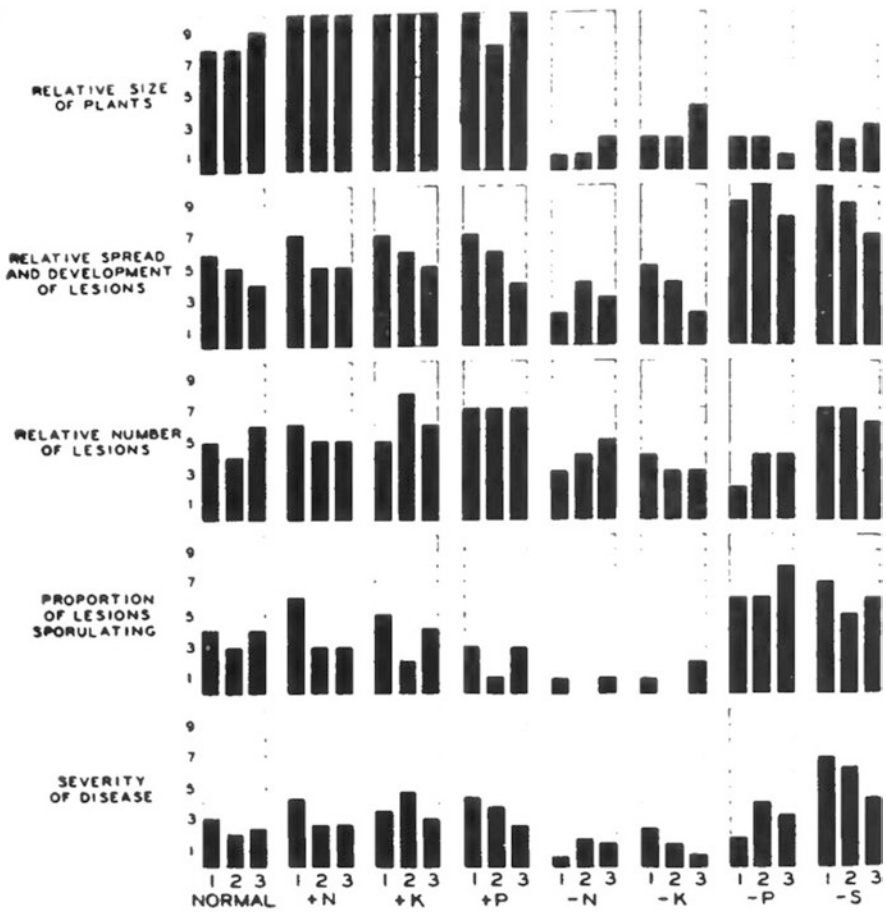

Fig. 9.5 Graphic summary of infection by and development of *Hyaloperonospora parasitica* on cabbage plants grown in sand culture supplied with various nutrient solutions (Felton and Walker 1946)

development of all the three diseases of *B. juncea* (Sangeetha and Siddaramaiah 2007). Under West Bengal conditions, downy mildew of mustard was at its peak when maximum temperature was >27 °C, minimum temperature >10 °C, and relative humidity around 100% in the morning and 50% in the afternoon (Banerjee et al. 2010)

In Ukraine and Russia, downy mildew of white cabbage is more severe with abundant rain (75–100 mm/10 year) and a 14–15 h of day light (Vladimirskaya et al. 1975).

Table 9.1 Effect of temperature on infection by *Hyaloperonospora parasitica* and disease development on mustard seedlings (cv. RH-30) (Mehta et al. 1995)

	Percent disease incidence after inoculation (h)					
Temp. (°C)	24	48	72	96	Mean	AUDPC[a]
10	0.00 (1.8)	54.9 (47.5)	64.192 (53.5)	70.5 (54.5)	47.2 (40.1)	43.8
15	2.91 (6.7)	58.5 (50.3)	73.9 (60.4)	75.6 (62.4)	52.7 (44.9)	45.9
20	34.31 (35.6)	78.3 (62.5)	87. 6 (70.0)	90.3 (75.0)	72.6 (60.8)	60.5
25	0.00 (1.8)	5.1 (9.3)	14.3 (20.9)	19.7 (25.8)	9.8 (14.3)	14.9
30	0.00 (1.8)	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)	0.00 (1.8)	1.8
Mean	9.40 (9.5)	489.0 (34.2)	60.0 (41.5)	64.0 (44.5)		
Correlation coefficient (r)	0.08	0.78	0.82	0.80		

LSD (0.05); temperature (T) = 3.55; observation (O) = 3.55; temp. x observation (TxO) = 7.11
Figures in the parentheses are angular transformed values after adding 0.1
[a]Area under disease progression curve

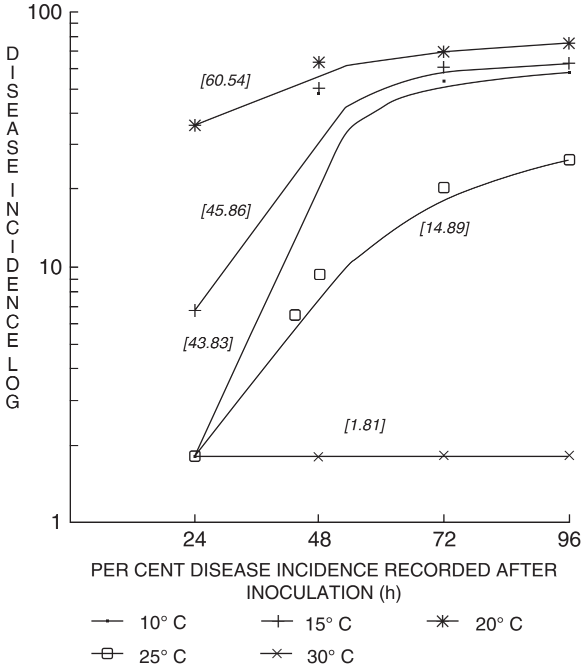

Fig. 9.6 Progression of downy mildew (*Hyaloperonospora parasitica*) of mustard (*Brassica juncea*) in relation to temperature (AUDPC) (Mehta et al. 1995)

Table 9.2 Effect of leaf wetness duration on infection by *Hyaloperonospora parasitica* and disease development on mustard seedlings (cv. RH-30) at 20 °C (Mehta et al. 1995)

	Percent disease incidence after inoculation (h)				
Leaf wetness duration (h)	24	48	72	96	Mean
0	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)	7.1 (15.4)	1.8 (5.2)
2	0.0 (1.8)	0.0 (1.8)	5.2 (13.3)	8.5 (16.6)	3.4 (8.4)
4	0.0 (1.8)	3.1 (8.9)	7.8 (16.1)	29.0 (32.5)	10.0 (14.8)
6	0.0 (1.8)	6.8 (15.1)	22.1 (27.9)	29.4 (32.6)	14.6 (19.3)
8	0.0 (1.8)	21.5 (27.0)	35.8 (36.0)	35.3 (38.7)	24.2 (25.8)
10	0.0 (1.8)	24.6 (29.7)	45.4 (42.4)	44.4 (41.9)	28.6 (28.9)
12	0.0 (1.8)	18.6 (25.3)	53.0 (46.8)	62.3 (52.2)	33.5 (34.1)
14	0.0 (1.8)	25.3 (30.2)	56.5 (48.8)	61.9 (52.0)	35.9 (33.2)
16	0.0 (1.8)	27.9 (31.8)	56.5 (48.8)	62.5 (52.3)	36.7 (33.7)
18	5.0 (8.8)	26.8 (31.2)	59.9 (50.8)	68.3 (55.9)	40.0 (36.7)
20	9.2 (15.2)	34.4 (35.5)	61.6 (51.8)	68.6 (56.1)	43.4 (39.6)
22	26.3 (30.4)	46.1 (42.8)	61.7 (58.0)	69.2 (56.0)	50.8 (45.3)
24	33.0 (35.0)	53.2 (46.9)	67.8 (56.0)	72.8 (58.8)	56.7 (49.2)
Mean	5.6 (8.12)	22.2 (25.2)	41.0 (37.9)	47.9 (48.1)	29.2 (28.6)
Correlation coefficient (r)	0.72	0.95	0.95	0.94	

LSD (0.05); observation (O) = 2.54; leaf wetness duration (W) = 4.59; observation x leaf wetness (O x W) = 9.19

Figures in the parentheses are angular transformed values after adding 0.1

Table 9.3 Effect of leaf wetness duration on infection by *Hyaloperonospora parasitica* and disease development on mustard seedlings (cv. RH-30) at 15 °C (Mehta et al. 1995)

	Percent disease incidence after inoculation (h)				
Leaf wetness duration (h)	24	48	72	96	Mean
0	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)
2	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)	3.8 (9.8)	0.9 (3.8)
4	0.0 (1.8)	0.0 (1.8)	0.0 (1.8)	10.0 (18.2)	2.5 (5.9)
6	0.0 (1.8)	1.7 (5.6)	1.7 (5.6)	20.8 (26.9)	8.5 (10.0)
8	0.0 (1.8)	34.0 (35.7)	47.1 (43.4)	47.1 (43.4)	32.1 (31.1)
10	0.0 (1.8)	49.3 (44.7)	56.4 (48.7)	56.4 (48.7)	40.513 (36.0)
12	0. 0 (1.8)	46.8 (43.3)	58.1 (49.7)	58.5 (50.0)	40.5 (36.2)
14	0.0 (1.8)	53.8 (47.2)	62.7 (52.4)	62.8 (52.5)	44.8 (38.0)
16	0.0 (1.8)	54.0 (47.4)	63.3 (52.8)	63.3 (52.8)	45.2 (38.7)
18	0.0 (1.8)	57.9 (49.6)	64.6 (53.5)	67.0 (54.9)	47.4 (39.5)
20	0.0 (1.8)	65.8 (54.3)	67.5 (55.3)	67.5 (55.3)	50.2 (41.7)
22	0.0 (1.8)	67.5 (55.3)	68.1 (55.7)	68.9 (56.2)	51.1 (42.3)
24	0.0 (1.8)	70.1 (57.1)	70.1 (57.1)	70.1 (57.1)	52.6 (46.5)
Mean	0.0 (1.8)	38.5 (34.3)	43.0 (38.5)	45.9 (42.3)	31.9 (29.2)
Correlation coefficient (r)	0.00	0.91	0.91	0.93	

LSD (0.05); observation (O) = 1.38; leaf wetness duration (W) = 2.49; observation × leaf wetness (O × W) =4.99

Figures in the parentheses are angular transformed values after adding 0.1

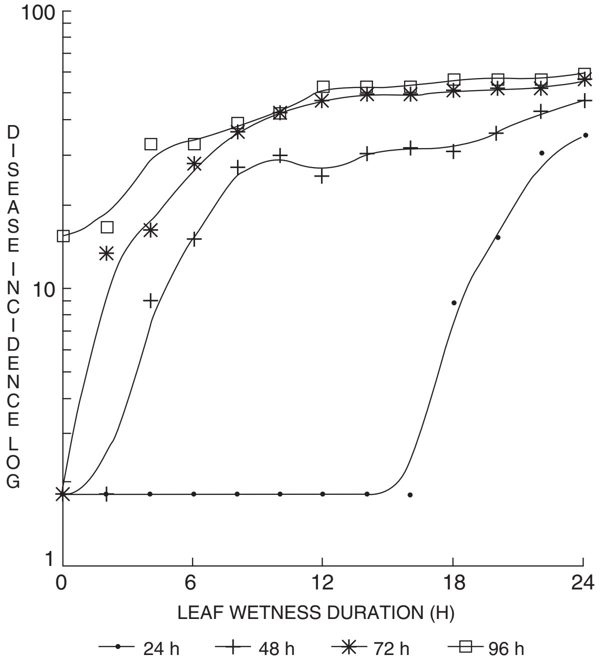

Fig. 9.7 Effect of leaf wetness duration on the development of downy mildew (*Hyaloperonospora parasitica*) infection on mustard (*Brassica juncea*) cultivar RH-30 at 20 °C (Mehta et al. 1995)

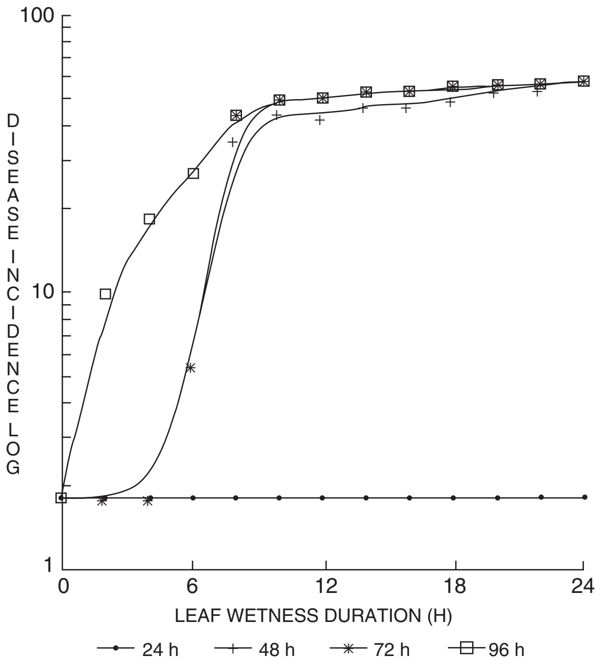

Fig. 9.8 Effect of leaf wetness duration on the development of downy mildew (*Hyaloperonospora parasitica*) on mustard (*Brassica juncea*) seedlings of cultivar RH-30 at 15 °C (Mehta et al. 1995)

Table 9.4 Prediction equations for the progress of downy mildew and white rust complex of rapeseed-mustard using different combinations of weather factors (Kolte et al. 1986)

Equations	b_O	X_1	X_2	X_3	X_4	X_5	X_6	R^{2*}
Stag head incidence (Y_1) (%)	+16.925	+0.019	−0.132	−0.086	+0.158	+0.030	−1.469	0.6849
Stag head severity (Y_2) (%)	+86.169	−1.241	−0.129	−0.503	+0.054	+0.472	−2.125	0.6283
X_1 = mean maximum temperature					X_2 = mean minimum temperature			
X_3 = mean relative humidity					X_4 = total rainfall (mm)			
X_5 = total rainy days					X_6 = mean bright sunshine period (h/day)			

*Significant at 5% level

9.3 Disease Development in Relation to Planting Time

In India, infection of mustard foliage starts by the end of October (cotyledon stage) and progresses up to November (Tables 9.7 and 9.8). The severity of downy mildew and white rust disease complex in relation to planting times has been studied (Saharan 1984) at three different locations, viz., Hisar, Kanpur, and Pantnagar. The results revealed that disease complex intensity increases with the delay in date of planting from October to December during 1978 at Hisar. Similar trend was also observed at Kanpur and Pantnagar (Table 9.7). It is evident from the observations (Table 9.8) that staghead incidence and severity was maximum on yellow sarson and toria during 1977–1978, whereas during 1978–1979 and 1979–1980, it was not consistent. It indicates that probably environmental conditions were not favourable in these years. The crop planted after mid-November may not contract downy mildew. However, downy mildew growth as a mixed infection with white rust on floral parts can be seen up to March (Saharan 1984; Kolte et al. 1986; Mehta 1993). In Lithuania, the severity of downy mildew of winter oilseed rape was higher when sown in the beginning of August in comparison to end of August sown crop (Petraitiene and Brazauskiene 2005).

9.4 Disease Development in Relation to Host Nutrition

Hyaloperonospora parasitica is severe on cauliflower plants which suffer from potash deficiency, while plants with a sufficient quantity of potash are only slightly attacked (Quanjer 1928). Cabbage plants grown in soil fertilized with less potash and more phosphorus are more prone to downy mildew than cabbages grown in unfertilized soil (Townsend 1935). However, according to Butler and Jones (1949), there is no consistent effect of fertilizers on the development of downy mildew of *Brassicas*. Felton and Walker (1946) found no direct relationship between mildew incidence and any excess or deficiency of nitrogen, phosphorus, or potash. On

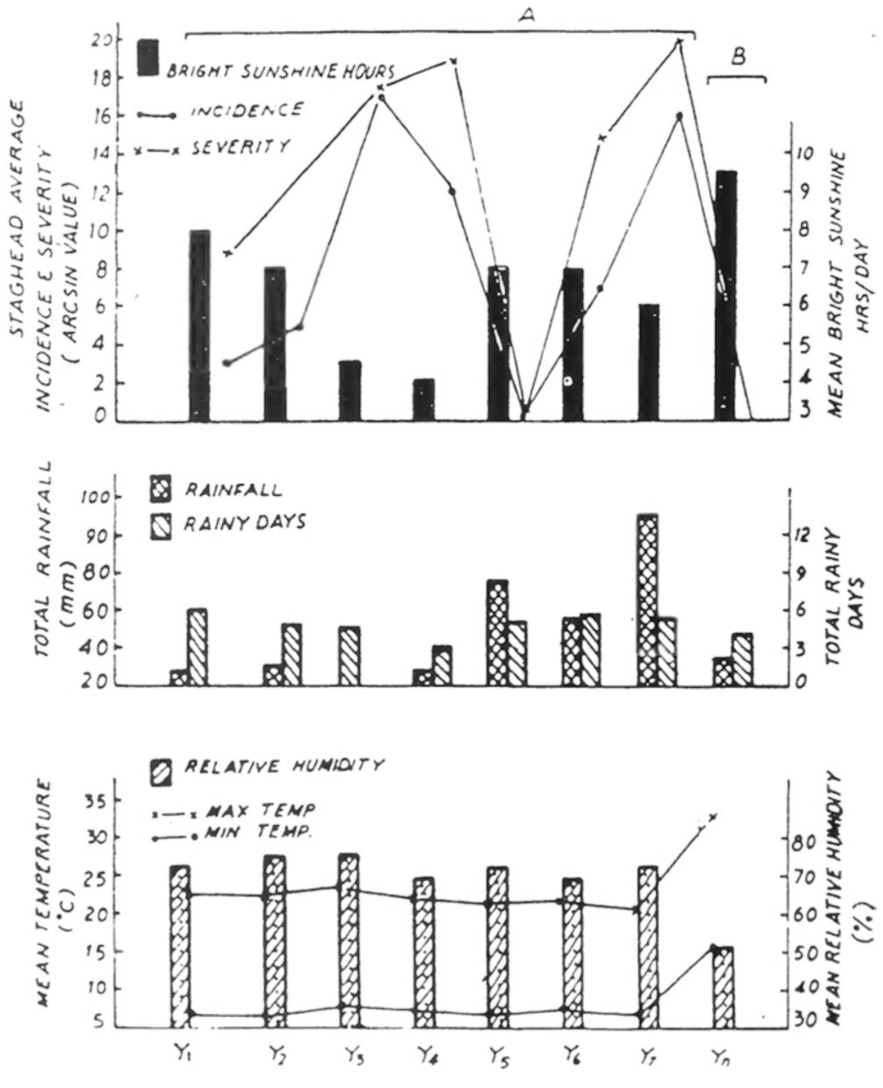

Fig. 9.9 Weather factors associated with occurrence (A) and no occurrence (B) periods of stag head phase of white rust (*Albugo candida*) and downy mildew (*Hyaloperonospora parasitica*) on mustard (*Brassica juncea*) in crop seasons Y_1 (1976–1977), Y_2 (1977–1978), Y_3 (1978–1979), Y_4 (1979–1980), Y_5 (1980–1981), Y_6 (1981–1982), and Y_7 (1982–1983). Symbol Y represents the number of crop seasons covering the period from 1977–1978 to 1982–1983 under no occurrence periods of stag heads (B) (Kolte et al. 1986)

radishes, tubers, conidiophores, and conidia appear to be relatively large, which is probably due to the availability of ample nutrient supply in the tubers (Hammarlund 1931). The incidence and severity of downy mildew on lower leaves of winter oil-seed rape was higher in N-treated plots, compared to N-untreated plots under

Table 9.5 Effect of weather factors on development and severity of white rust, downy mildew, and *Alternaria* blight (Sangeetha and Siddaramaiah 2007)

Observations at 7-day intervals	Temperature^{0}C		Relative humidity (%)		Rainfall (mm)	White rust PDI		Downy mildew PDI		*Alternaria* blight PDI	
	Max.	Min.	I	II		Accumulated	Increase	Accumulated	Increase	Accumulated	Increase
1	27.20	15.91	85.00	60.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	26.02	16.01	87.28	64.28	0.71	0.00	0.00	0.00	0.00	0.00	0.00
3	23.11	16.08	94.00	57.57	1.38	0.00	0.00	0.00	0.00	0.00	0.00
4	26.50	13.90	88.57	51.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	26.48	14.40	90.00	49.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	26.30	13.12	92.00	43.71	0.00	15.77	15.77	0.00	0.00	0.00	0.00
7	26.67	14.40	83.28	36.71	0.00	20.52	4.75	0.00	0.00	0.00	0.00
8	26.54	15.37	86.85	35.57	0.00	21.66	1.14	0.00	0.00	6.52	6.52
9	27.80	11.77	81.57	27.71	0.00	24.86	3.20	0.00	0.00	21.88	15.36
10	28.60	13.20	84.42	42.71	0.00	27.91	3.05	0.00	0.00	23.73	1.85
11	28.51	16.97	83.57	43.57	1.11	40.71	12.80	0.00	0.00	24.85	1.12
12	29.42	14.97	79.85	38.42	0.00	41.36	0.67	1.55	1.55	25.08	0.23
13	29.25	15.54	69.14	43.14	0.00	41.64	0.28	2.39	1.84	26.79	1.71
14	31.41	15.18	80.28	36.00	0.00	45.88	4.24	2.46	0.07	27.50	0.71

Max = maximum; Min = minimum; I = morning; II = evening

Table 9.6 Correlation value between disease index of white rust, downy mildew, and *Alternaria* blight of Indian mustard with environmental factors (Sangeetha and Siddaramaiah 2007)

Weather factors	Correlation coefficient 'R' value		
	White rust	Downy mildew	*Alternaria* blight
Maximum temperature	+0.8245**	+0.7211**	+0.8263**
Minimum temperature	−0.41139	−0.1853	−0.0340
Relative humidity I	−0.3252	−0.2009	0.0983
Relative humidity II	−0.4645	−0.3156	−0.6147
Rainfall	−0.1723	−0.2548	−0.1052

**Indicate positive and significant correlation between maximum temperature and diseases index

Table 9.7 Effect of planting time on the severity of downy mildew and white rust complex of mustard (Saharan 1984)

Planting time	Percent disease intensity		
	Hisar	Kanpur	Pantnagar
06.10.1978	10.0	–	–
21.10.1978	8.6	–	–
28.10.1978	18.6	–	–
06.11.1978	55.4	–	–
18.11.1978	68.5	–	–
02.12.1978	72.8	–	–
01.10.1979	–	24.16	–
10.10.1979	4.6	28.30	–
20.10.1979	10.0	34.34	–
30.10.1979	22.5	36.18	–
09.11.1979	46.8	40.91	–
20.11.1979	57.5	46.15	–
03.10.1981	–	–	15.04
23.10.1981	–	–	19.85
13.10.1981	–	–	32.85

Lithuania conditions (Petraitiene and Brazauskiene 2005). The increase in the N fertilization rate resulted in the increase in infection of downy mildew of oilseed rape under Germany conditions (Sochting and Verret 2004). Jiang and Caldwell (2015) found positive correlation of downy mildew infection in *Camelina* with applied N rates.

Table 9.8 Influence of planting dates on stag head incidence and severity of white rust and downy mildew of rapeseed and mustard in three rabi crop seasons starting from 1977–1978 to 1979–1980 (Kolte et al. 1986)

Date of planting	1977–1978			1978–1979			1979–1980		
	Mustard	Yellow sarson	Toria	Mustard	Yellow sarson	Toria	Mustard	Yellow sarson	Toria
Oct. 1–6	2.7* (11.0)**	0.0 (0.0)	0.0 (0.0)	20.6 (15.6)	24.3 (23.1)	10.2 (20.3)	8.9 (20.3)	4.8 (15.7)	0.7 (4.4)
Oct. 11–14	6.7 (15.6)	1.2 (8.4)	0.0 (0.0)	14.6 (20.4)	23.7 (24.0)	7.7 (21.8)	14.2 (17.7)	8.3 (32.4)	1.8 (6.4)
Oct. 20–22	10.2 (23.4)	4.1 (24.8)	0.0 (0.0)	10.6 (11.3)	17.2 (14.9)	18.2 (16.8)	7.8 (14.6)	3.6 (17.7)	3.6 (16.9)
Oct. 31–Nov. 1	10.2 (20.9)	8.2 (35.2)	10.2 (23.9)	7.8 (9.7)	11.6 (17.2)	24.9 (13.5)	5.3 (11.5)	11.2 (43.4)	9.2 (22.4)
Nov. 1–11	9.3 (22.4)	9.7 (25.8)	10.6 (25.3)	9.6 (11.1)	11.2 (16.5)	9.4 (14.4)	3.1 (5.2)	6.7 (16.3)	18.2 (34.7)
Nov. 20–22	14.2 (22.8)	38.2 (25.7)	22.2 (24.0)	9.1 (10.9)	13.7 (19.0)	8.9 (15.3)	4.3 (8.5)	1.4 (8.8)	15.9 (23.2)

* = Incidence (%plant affected); ** = Figures in parentheses are disease severity (% racemes affected/plant)

CD at 5% for planting dates	1977–1978	1978–1979	1979–1980
Incidence	5.6	2.8	3.6
Severity	5.5	1.7	9.8
Incidence	NS	1.8	2.6
Severity	3.4	1.3	4.2

9.5 Disease Interaction with Insecticidal Sprays

The incidence of downy mildew in plots of broccoli sprayed with emulsifiable insecticide formulations containing a solvent and a wetting agent is significantly greater than in plots sprayed with an insecticide formulation containing no solvent or wetting agent or in unsprayed plots (Natti et al. 1956). It is possible that emulsifiable insecticide formulations remove the bloom from the leaves and dissolve the wax from the cuticle of the leaves creating conditions favourable for the germination of *H. parasitica* spores (Natti et al. 1956).

9.6 Disease Prediction Models

Kolte et al. (1986) developed prediction equations for the stag head severity in relation to planting dates and associated weather factors as under:

$$\text{Stag head incidence}(\%)\ Y = 16.925 + 0.019X_1 - 0.132X_2 - 0.086X_3 + 0.158X_4 + 0.030X_5 - 1.469X_6 - R^2 - 0.68$$

$$\text{Stag heads Severity}(\%)\ Y = 86.169 - 1.241X_1 - 0.129X_2 - 0.503X_3 + 0.054X_4 + 0.472X_5 - 2.125X_6 - R^2 - 0.62$$

where X_1 = mean max. Temp, X_2 = mean min. Temp, X_3 = mean RH, X_4 = total rain fall (mm), X_5 = total rainy days; and X_6 = mean bright sunshine period (h/day).

Mehta and Saharan (1998) developed the prediction models for the progression of downy mildew of rapeseed-mustard as under:

A.	Leaf infection: $Y = -32.7 + 0.09\ X_1 + 0.31\ X_2 + 1.31\ X_3 + 0.12\ X_4 + 0.22\ X_5 - 0.03\ X_6$		($R^2 = 0.36$)
B.	Stag head:		
	i.	Incidence: $Y = -18.6\text{-}2.8\ X_1 + 2.5\ X_2 + 4.5\ X_3 + 0.6\ X_4 - 0.2\ X_5 + 1.0\ X_6$	($R^2 = 0.23$)
	ii.	Length: $Y = -17.4\text{-}1.5\ X_1 + 1.5\ X_2 + 2.6\ X_3 + 0.4\ X_4 - 0.1\ X_5 - 1.0\ X_6$	($R^2 = 0.26$)
		where X_1 = Tmax., X_2 = Tmin., X_3 = Sunshine, X_4 = RHmor, X_5 = RHeve, and X_6 = RF	

References

Achar PN (1998) Effects of temperature on germination of *Peronospora parasitica* conidia and infection of *Brassica oleracea*. J Phytopathol 146:137–141

Bains SS, Jhooty JS (1979) Mixed infections by *Albugo candida* and *Peronospora parasitica* on *Brassica juncea* inflorescence and their control. Indian Phytopath 32:268–271

Banerjee S, Bhattacharya I, Khan SA, Huda AKS (2010) Weather sensitivity of downy mildew and Alternaria blight of mustard in the gangetic west Bengal, India. J Sci Found 8:77–81

Butler EJ, Jones SQ (1949) Plant pathology. McMillan, London

Chou CK (1970) An electron-microscope study of host penetration and early stages of haustorium formation of *Peronospora parasitica* (Fr.) Tul. on cabbage cotyledons. Ann Bot 34:189–204

Chu HT (1935) Notes on the penetration phenomena and haustorium formation of Peronospora brassicae Gaum. Ann Phytopathol Soc Jpn 2:150–157

D'Ercole N (1975) *Peronospora* disease of cauliflower in north central Italy. Informatore Fitopatol 25:21–23

Eddins AH (1943) Control downy mildew of cabbage with Spergon and Fermate. Florida Agric Exp Stn Press Bull 589. 4p

Felton MW, Walker JC (1946) Environmental factors affecting downy mildew of cabbage. Aust J Agric Res 72:69–81

Hammarlund C (1931) Shorter mycological notices II. A giant form of *Peronospora brassicae* Gaumann (=*P. parasitica* (Fries) Tulasne) on *Raphanus sativus f. radicula*. Bot Notiser 5:392–393

Jiang Y, Caldwell CD (2015) Effect of nitrogen fertilization on *Camelina* seed yield, yield components, and downy mildew infection. Can J Plant Sci 96:17–26

Jonsson R (1966) *Peronospora* on oil yielding Brassicas. Methods for testing resistance in winter rape and their results. Sver Utsadestor Tidskr 76:54–62

Kolte SJ, Awasthi RP, Vishwanath (1986) Effect of planting dates and associated weather factors on staghead phase of white rust and downy mildew of rapeseed and mustard. Indian J Mycol Plant Pathol 16:94–102

Mehta N (1993) Epidemiology of white rust and downy mildew disease complex in mustard and residual toxicity of fungitoxicant. Ph.D. Thesis, CCS. Haryana Agricultural University, Hisar, Haryana, India: 154p

Mehta N, Saharan GS (1998) Effect of planting dates on infection and development of white rust and downy mildew disease complex in mustard. J Mycol Plant Pathol 28:259–265

Mehta N, Saharan GS, Sharma OP (1995) Influence of temperature and free moisture on the infection and development of downy mildew on mustard. Plant Dis Res 10:114–121

Nakov B (1972) The effect of ecological factors on the dissemination of *Peronospora parasitica* (Pers.) Fr. on cabbage. Nauch Trudov Vissh Selskostop Inst V Kolarov; Plovdiv 21:109–116

Natti JJ, Harvey GER, Sayre CB (1956) Factors contributing to the increase of downy mildew of broccoli in New York State and its control with fungicides and agrimycin. Plant Dis Report 40:118–124

Petraitiene E, Brazauskiene I (2005) Incidence and severity of Alternaria blight (*Alternaria* spp.) and downy mildew (*Peronospora parasitica*) as affected by winter oilseed rape sowing time and nitrogen fertilizer rate. Agronomijas Vestis (Latvian J Agro) 8:158–162

Quanjer HM (1928) The influence of potash deficiency on the susceptibility of cauliflower to *Peronospora parasitica*. Tijdschr, Over Plantenziekten 34:254–256

Saharan GS (1984) A review of research on rapeseed mustard pathology in India. Annual Workshop AICORPO ICAR, Jaipur, 6–10 August 1984

Saharan GS, Verma PR, Nashaat NI (1997) Monograph of downy mildew of crucifers. Saskatoon Res Cent Tech Bull, Agriculture and Agri-Food Canada, 1997–01, 197 pp

Sangeetha CG, Siddaramaiah AL (2007) Epidemiological studies of white rust, downy mildew and Alternaria blight of Indian mustard [*Brassica juncea* (Linn.) Czern & Coss.] African J Agric Res 2(7):305–308

Sinobas Alonso J, Diaz Alonso M (1995) The mildew of the crucifers in the term of villa del Prado (Madrid): epidemiological notes. Boletín de Sanidad Vegetal Plagas 21:497–506

Sochting HP, Verret JA (2004) Effects of cultivation systems: soil management, nitrogen fertilization on the epidemics of fungal diseases in oil seed rape (*Brassica napus* L. Var. *napus*). J Plant Dis Protect 111:1–29

Townsend GR (1935) Everglades Experimental Station. Report Florida Expt Stn 1933-34, pp. 86–112

Vladimirskaya ME, Ilyina MH, Klinkovskaya IK (1975) Forecasting disease incidence on cabbage crops as influenced with their cultivation practices. Mikol Fitopatol 9:130–132

Williams PH, Leung H (1981) Methods of breeding for multiple disease resistant Chinese cabbage. In: Talekar NS, Griggs TD (eds) Chinese cabbage. Proceedings of the 1st International Symposium. The Asian Vegetable Research and Development Center, Shanhua, Taiwan, pp 393–403