Cercospora Leaf Spot Disease

27

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Abstract

Cercospora leaf spot, caused by *Cercospora beticola* Sacc., first reported in Italy in 1876, is one of the most devastating and common foliar diseases of sugar beet in the world. The spots of the disease usually appear early in wet and warm areas and are most severe during the vegetation period in case of very early attacks. The disease is common in about 44 percent of sugar beet acreage in the world and the severity of the disease varies between countries and regions in same countries. Because of the disease, beet plants lose their leaves and grow new leaves by using substances stored from roots. During the vegetation season, these activities are repeated. When it cannot cope with the disease, root yield, sugar content, extractable sugar content, and sugar yield decrease up to 26, 13, 18, and 55 percent, respectively. Also, the content of potassium (K), sodium (Na), and alpha-amino nitrogen (α-amino N), having difficulty in getting crystal sugar and reducing sugar production in refining process, increases up to 6, 25, and 40 percent, respectively. Disease is controlled by applying fungicides, besides cultural measures such as planting resistant varieties, crop rotation, use of disease-free seeds, and good agricultural practices. The pathogen forms resistance to fungicides used against it in a very short time. Hence, special combined management strategies must be implemented together safely according to early warning epidemiological models that accurately monitor the onset and progression of the disease.

Keywords

Cercospora beticola Sacc. · *Cercospora* leaf spot · Control · Sugar beet

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Abbreviation

BmJ	*Bacillus Mycoides*
DF	Dry flowables
DIV	Daily Infection Value
EC	Emulsifiable concentrate
IIRB	International Institute for Beet Research
K	Potassium
ME	Microemulsion concentrate
Na	Sodium
Ps	Pseudostromata
SC	Suspension concentrate
SE	Suspoemulsion
WG	Water dispersible granules
WP	Wettable powder
α-amino N	Alpha-amino nitrogen

27.1 Introduction

Cercospora beticola Sacc. brings about spots on leaves and major pathogen of sugar beet worldwide (Holtschulte 2000). Disease symptoms typically appear after row closure. Sugar beet plants lose the leaves due to disease and grow new leaves by using substances in the roots. In this way, the disease causes continuous leaf damage until harvest (Rossi et al. 2000, Franc 2010). Thus, it reduces the root weight and sugar yield and also increases the substances forming molasses such as sodium, potassium, and alpha-amino nitrogen, leading to sugar losses in refinery (Carruthers and Oldfield 1961, Smith and Martin 1978, Oltmann et al. 1984, Adams and Schaufele 1996). The roots of infected plant in storage are disrupted quickly than healthy plants (Graf 1980, Smith and Ruppel 1971).

The disease can be coped by cultural measures such as crop rotation (Pundhir and Mukhopadhyay 1987), planting resistant varieties (Vogel et al. 2018, Kopisch-Obuch et al. 2020), and good farming practices (Skaracis et al. 2010). In addition, fungicide application is the most effective method (Khan and Khan 2010, Ioannidis and Karaoglanidis 2010). Since pathogen creates resistance to fungicides in a short time (Georgopoulos and Dovas 1973, Ruppel and Scott 1974, D'ambra et al. 1974, Pal and Mukhopadhyay 1985, Weiland and Halloin 2001, Giannopolitis 1978, Cerato and Grassi 1983, Bugbee 1996, Karaoglanidis et al. 2000, Köller 1991, Kirk et al. 2012), fungicides with different effect mechanisms should be selected and their different mixtures should be prepared and applied carefully throughout the season within a program (Ioannidis and Karaoglanidis 2010, Secor et al. 2010). Biological control methods are not to be used in practice due to not being satisfactory (Collins and Jacobsen 2003, Galletti et al. 2008). In this review, the information applied from research results into practice on causal agent, symptoms, distribution, economic importance, epidemiology of the disease, and the management strategies that should be put into effect in accordance with the current conditions are presented.

27.2 Causal Agent

The causal agent of leaf spot disease in sugar beet is *Cercospora beticola* Sacc. The fungus is a member of the class Deuteromycetes (Fungi Imperfecti), order Moniliales, family Dematiaceae, and section Phaeophragmosporae (Barnett and Hunter 1972, Chupp 1953). Hyphae are hyaline to pale olivaceous brown, septate, intercellular, 2–4 μm in diameter. They form pseudostromata in substomatal cavities of the host and conidiophores, 10–100 μm × 3–3.5 μm, unbranched, emerge only from host stomata. There are small conspicuous conidial scars at the geniculations and the apex. Conidia are in dimensions of 36–107 μm × 2–3 μm, straight to slightly curved, hyaline, acicular, 3–14 (sometimes more) septa. Teleomorph stage of *C. beticola* is unavailable (Crous and Braun 2003) (Fig. 27.2).

27.3 Symptoms

Leaf spots created by *C. beticola* are circular, in a diameter of 2–5 mm, tan, pale brown, grey or whitish (Ruppel 1986). First spots develop on the older leaves (Fig. 27.1a–c). At the later stages, elongated lesions grow on the petiole (Fig. 27.5). Sometimes, spots can develop on the beet crown (Giannopolitis 1978). As the disease progresses, individual spots coalesce and parts of the leaf where the spots join together turn brown and necrotic (Figs. 27.1, 27.2, 27.3). Pseudostromata which is minute black dot appears in the middle of mature spots (Fig. 27.2). Conidiophores are formed on the pseudostromata when the weather is humid. After producing conidia, the leaf spots become grey and velvety. Followed by blighted and died leaves, eventually they fall to the ground remaining tied to the head of the root (Figs. 27.4, 27.5). The younger leaves usually get spotted and die later than older leaves (Vereijssen 2004). During the later stages of severe epidemics, leaves can be regrown from the plant surrounded by prostrate (Weiland and Koch 2004) (Fig. 27.6).

27.4 Distribution

Saccardo (1876) described first distribution of the disease on *Beta cicla* in Italy, but to date, it has been determined in all sugar beet growing areas worldwide. *Cercospora* leaf spot in warm and humid regions is most damaging to sugar beet (Lartey et al. 2010). Reichert and Palti (1966) and Weltzien (1967) first started to analyse distribution of *C. beticola* affecting sugar beet worldwide. First general

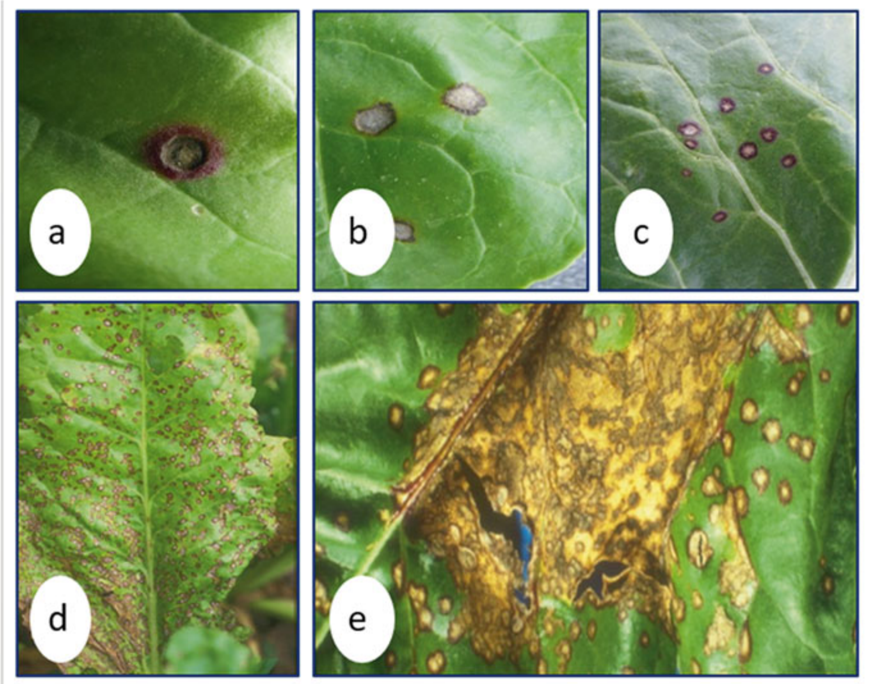

Fig. 27.1 First spots (**a**–**c**), increased and coalesced spots (**d**) and the death of leaf tissue (**e**) on beet leaves infected by *Cercospora beticola*

geographical distribution map of *C. beticola* was published in the sugar beet areas of the northern and southern hemisphere by the Commonwealth Mycological Institute (Anonymous 1969). Bleiholder and Weltzien (1972) developed the first detailed map. And then, in the growing zones of sugar beet, Rossi et al. (1995) drew a detailed map of *C. beticola*. The study group including phytopathologists from the International Institute for Beet Research (IIRB), sugar beet breeders, and the staff of seed companies updated the map in 1998. According to the study, a total sugar beet growing area of 6.95 mio ha was estimated and the incidence of *C. beticola* was reported about 44 percent of beet production acreage (Fig. 27.7, Table 27.1).

The disease affects moderately on the average approximately 50% of sugar beet areas in some parts of Belgium, Chile, China, Croatia, Czech Republic, France, Germany, Moldova, Morocco, Poland, Slovakia, Pakistan, Spain, The Netherlands, The Syrian Arab Republic, Ukraine, and USA. A high incidence of the disease in some parts of Austria, Bosnia and Herzegovina, Greece, Italy, Hungary, Japan, Macedonia, Romania, Slovenia, The Cuban Region of The Russian Federation, Turkey, USA, and Yugoslavia has been estimated. *C. beticola* affects on average approximately 63% of sugar beet areas in these countries. Both moderate and high

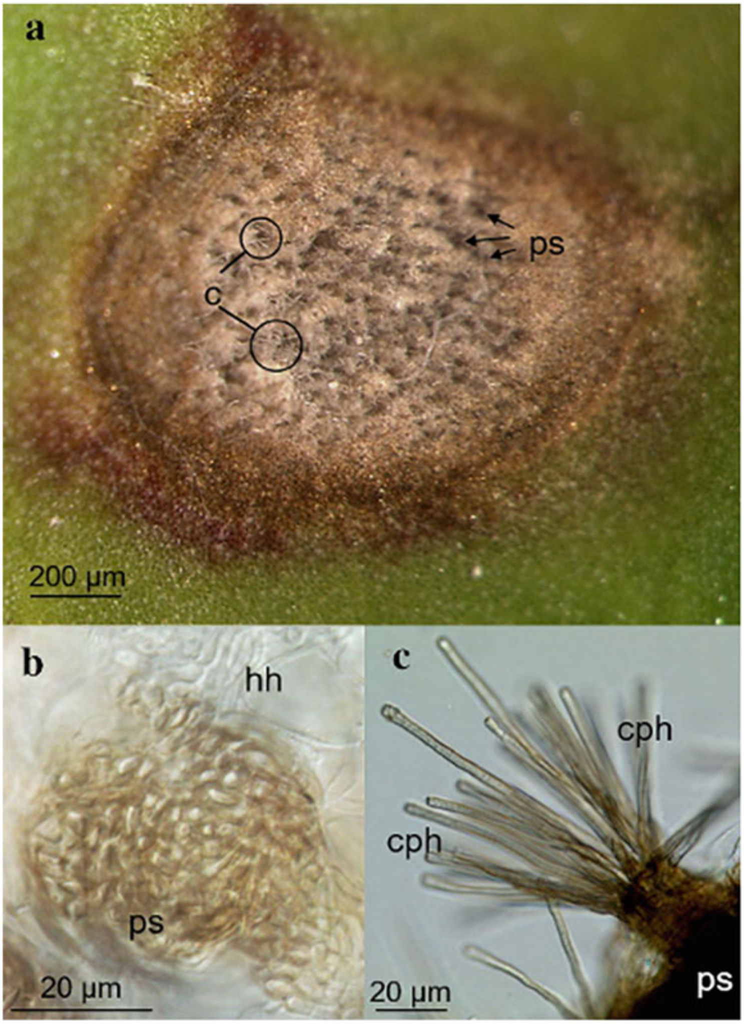

Fig. 27.2 (**a**) Conidia of *Cercospora beticola* on pseudostromata (ps) in the middle of the spot; (**b**) mycelium and pseudostroma; (**c**) conidiophores on the leaf surface (Source: Oerke et al. 2019)

incidence of the disease affecting sugar beet growing areas are more than a third of total acreage worldwide (Holtschulte 2000). The disease occurs severely in Marmora and Black Sea Region in Turkey and it is sometimes seen moderately in the central regions.

Fig. 27.3 Spreading of *Cercospora* leaf spots to neighbouring leaves after initial infection in the field

Fig. 27.4 *Cercospora* leaf spots spreading over all field and killing older leaves

27.5 Epidemiology

Cercospora beticola can infect beet plants between 12–37 °C. Conidia are produced at optimal temperatures between 20–26 °C when the relative humidity prevails in the range of 98–100% (Pool and McKay 1916). Epidemics can severely occur if the relative humidity is above 96% for 10–12 h on a 3–5 succeeding days and the temperature is above 10 °C (Mischke 1960). Although it is rather high temperatures, severe epidemics can develop in Turkey and the Netherlands if the relative humidity is enough. Conidia are disseminated by rain-splash (Pool and McKay 1916, Carlson 1967), wind (McKay and Pool 1918), irrigation water, insects, and mites (McKay and Pool 1918, Meredith 1967). Other potential sources of initial inoculum include the distribution of *C. beticola*-infested plant material via tools or machinery (Knight et al. 2018, Knight et al. 2019) and stromata from other host plants (Khan et al. 2008,

Fig. 27.5 Leaves collapsing and falling to the ground, and regrowth at the head of beet

Fig. 27.6 *Cercospora* disease killing all leaves on the plant and vegetative regrowth

Franc 2010, Skaracis et al. 2010, Tedford et al. 2018, Knight et al. 2020). The most cultivated and wild species of *Beta* are infected by *C. beticola*. The fungus attacks the cultivated plants such as *Spinacia oleracea* (spinach) and *Carthamus tinctorius* (safflower) and weedy species of *Amaranthus, Atriplex, Chenopodium* and *Plantago* (Vestal 1933, Frandsen 1955, El-Kazzaz 1977, Soylu et al. 2003), *Cycloloma, Malva, Limonium*, and Apium (Lartey et al. 2005, Groenewald et al. 2006, Jacobsen and Franc 2009). There have been different races of *C. beticola*, mainly based on cultural and physiological differences in vitro (Schlösser and Koch 1957, Solel and Wahl 1971, Mukhopadhyay and Pal 1981). Conidia of *C. beticola* remain in infected leaf tissues for only 1–4 months (Pool and McKay 1916), but pseudostromata, sources of primary inoculum, can survive for 1–2 years (Pool and McKay 1916, McKay and Pool 1918, Canova 1959b). In the period of 1977–2003, *Cercospora*

Fig. 27.7 Distribution of *Cercospora* leaf spot in the regions of sugar beet growing in the World

leaf spot has increased due to not removing beet leaves and tops from the field. Other sources of inoculum such as infested seed (McKay and Pool 1918, Schürnbrand 1952) and weed hosts (Vestal 1933) were reported. Vereijssen et al. (2005) reported that a soil-born inoculum can infect the roots of sugar beet. The life cycle of *Cercospora beticola* Sacc. has been depicted in Fig. 27.8.

27.6 Effects of Disease on Yield and Growing Traits of Sugar Beet

Due to the disease, beet plants lose their leaves and grow new leaves by using substances stored from roots. During the vegetation season, these activities are repeated. A two-stage of *Cercospora* leaf spot inhibiting beet growth has been described by Rossi et al. (2000). First, the pathogen develops on the first emerging leaves and active leaf area is photosynthetically diminished as spots disseminate and coalesce. Second, photosynthetic potential in the late period (up to harvest) is also decreased and beet plant regrows to consume sugar reserves in roots due to losing leaf severely (Rossi et al. 2000). As a consequence of both root and sucrose loss, sugar yield decreases significantly. A rise in the amount of molassigenic sodium, potassium, alpha-amino nitrogen, and betaine results in a low inferior juice quality (Carruthers and Oldfield 1961, Smith and Martin 1978, Oltmann et al. 1984, Adams and Schaufele 1996, Rossi et al. 2000). The high respiration and decay that result from the disease cause also root losses during storage (Smith and Ruppel 1971). When severe epidemics occur without any control measures, the first leaf spots

Table 27.1 Areas of sugar beet production and incidence of *Cercospora beticola* (Source: Holtschulte 2000)

Continent	Country	Acreage of sugar beet production (in hax1000) KWS and IIRB estimation (1998)	FAO data (1998)	Incidence of Cercospora acreage (in hax1000)
North America	Canada, USA	622	604	432
South America	Chile	50	42,3	10
Western Europe	Austria, Belgium, Denmark, Finland, France, German, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, Switzerland, United Kingdom	2.069,1	1.656,7	1.320,5
Eastern Europe	Albenia, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Macedonia, Latvia, Lithuania, Poland, Romania, Russia, Slovakia, Slovenia, Ukraine, Yugoslavia	2.589,2	2.820,6	770,9
Asia	Afghanistan, China, Georgia, Iran, Japan, Kazakhstan, Kyrgyzstan, Lebanon, Moldova, Pakistan, Turkey, Syrian Arab Republic, Uzbekistan	1.530	1.466,5	451,9
Africa	Egypt, Morocco, Tunisia	99	75,7	34,7
Total	50	6.959,3	6.665,8	3.020

multiply and coalesce, leading to the leaf death early. As a consequence, new leaves regrow. Eventually, root and sugar are lost ranging from 3 to 55 (Rossi et al. 2000) and 25 to 50%, respectively (Smith and Ruppel 1973, Smith and Martin 1978; Shane and Teng 1992, Byford 1996, Verreet et al. 1996, Rossi et al. 2000, Skaracis and Biancardi 2000, Jacobsen and Franc 2009). Storage duration of diseased beets is shorter than that of healthy beets (Smith and Ruppel 1971, Graf 1980).

The consequences of the disease epidemics on the crop depend usually on the interactions among the favourable environmental conditions to the disease, the efficacy of fungicides, the productivity and resistance level of the varieties, and the crop growing dynamics throughout the growing season (Rossi et al. 2000). When it was not treated in the countries with severe disease, sugar yield losses were reported as 55% in Bulgaria, 9–47% in India, 40% in Germany, 30–35% in America, Yugoslavia, Morocco and Romania, 25–50% in Italy, 8% in Japan, and 3% in Georgia (Rossi et al. 2000).

The results of the study conducted in 1990–93 stated that crop losses have occurred 10–50% in Austria, 15–40% in France, 10% in Germany, 20–35% in Greece, 10–25% in Italy, 20% in Morocco, 1–25% in the Netherlands, 15–30% in

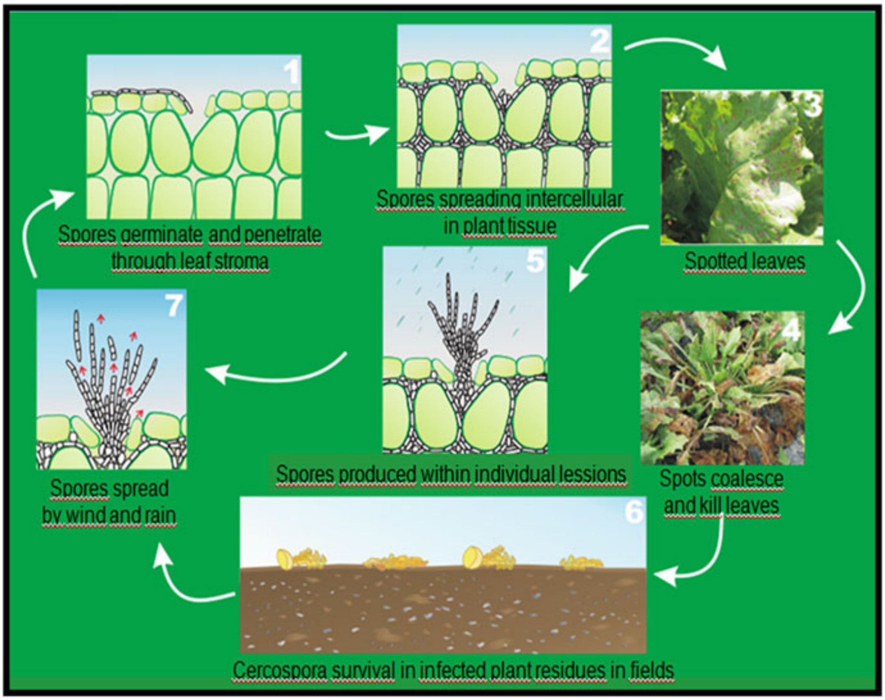

Fig. 27.8 The life cycle of *Cercospora beticola* Sacc. (Modified from Jones, Roger K. and Carol E. Windels)

Spain, and 20–40% in Yugoslavia when fungicides were not applied to the disease. Disease incidence in Belgium, Denmark, England, Ireland, and Sweden remained almost negligible (Byford 1996).

The damage of the disease was estimated about 100 and 29 million Euro due to not spraying and wrong fungicide use each year in Northern Italy (Meriggi et al. 1998, Rossi et al. 2000). Without spraying in Italy, Rossi et al. (2000) have reported that 10.1% of root yield, 4.4% of sugar content, 1.3% of the extractable sugar content, and 16.9% of sugar yield have dropped. On the other hand, the contents of potassium (K), sodium (Na), and alpha-amino nitrogen (α-amino N) which consist of molassigenic compounds have increased by 6.4%, 24.7%, and 16.8%, respectively. Root yield, sugar content, extractable sugar content, and sugar yield of beet decreased by 1–26%, 3–13%, 5–18%, and 6–36%, respectively, while potassium (K), sodium (Na), and alpha-amino nitrogen (α-amino N) content increased by 0–5%, 9–20%, and 1–40%, respectively, depending on the severity of infection by years, without spraying in the province of Sakarya in Turkey (Kaya 2012).

27.7 Disease Management

The integrated management of *Cercospora* leaf spot includes cultural practices, host resistance, and then fungicides application (Pool and McKay 1916, Khan et al. 2007). Cultural practices reduce the level of initial inoculum for the following season through rotation with non-host crops. Burying infested plant materials and avoiding planting next to fields previously sown with sugar beets also decrease the inoculum potential of the pathogen. To predict the occurring of the disease and timing of fungicide application, epidemiological models have been established (Rossi and Battilani 1991, Windels et al. 1998, Pitblado and Nichols 2005, Racca and Jörg 2007). Chemicals should be applied prophylactically early to avoid conidia infecting unprotective leaves. Although there have been studies on biocontrol agents including *Trichoderma* and *Bacillus* for *C. beticola* (Collins and Jacobsen 2003, Galletti et al. 2008), they are not to be used in practice.

27.7.1 Cultural Control

The plants which are non-host should be replanted on the same land after at least 3 years. Sugar beet should be sown in the fields in areas at least 300 ft. from last season's plantings. The soil should be plowed deeply to completely bury infected leaf residues. *Cercospora*-free seeds should be sown. Resistant varieties must be sown. Plants should be irrigated during night so as not to keep leaves wet longer.

27.7.2 Crop Rotation

The pseudostromata of the fungus survive in the soil for 2 years. To effectively eliminate inoculum from a field, sugar beets should be planted in a 3-year rotation with non-hosts. The soil should also be plowed to incorporate beet leaf residues. Deep tillage after sugar beet planting will prevent fungus death (Canova 1959a). At least a three-year rotation should be applied to reduce the inoculum potential of *C. beticola* by ensuring the rotting of infected head and leaf residues, which constitute a new source of the disease infection (Pool and McKay 1916, Pundhir and Mukhopadhyay 1987). Spinach, table beet, and chard plants should not be included in rotation and the host weeds should be removed from the field before infection occurs.

27.7.3 Using Disease-Free Seeds

By using seeds that are not contaminated with *Cercospora* spores, the disease is prevented from moving to new planting areas with seeds.

27.7.4 Good Farming Techniques

In the farming of sugar beet, proper and timely plant growing techniques, implemented from soil preparation to harvest, ensure a strong and rapid plant development. As a result of this, plants gain a little more resistance to diseases. Sprinkler irrigation encourages infection during the day as it prolongs the relative humidity level at a microclimatological leaf area in the field. Therefore, irrigation should be done at night. When sugar beet plants are irrigated by means of sprinkler, the sprinkler irrigation system should be run so that the leaves do not remain wet for more than 24 h.

27.7.5 Sowing Resistant Varieties

Varieties vary considerably in resistance. *Cercospora* usually affects sugar beets planted in fall or spring. The disease affects severely in some regions of Italy, Greece, Turkey, etc. and a more resistant variety must be used. Resistance to the disease in sugar beet decreases the damage at harvest by reducing the disease progression rate during the production season. Therefore, the damage of disease in resistant varieties is lower than susceptible varieties during an epidemic (Rossi 1995, Rossi and Battilani 1990). The occurring and developing of the disease in sugar beet varieties which have different resistance reflects this situation very well (Figs. 27.9, 27.10). The planting of resistant varieties decreases the level of the disease inoculum

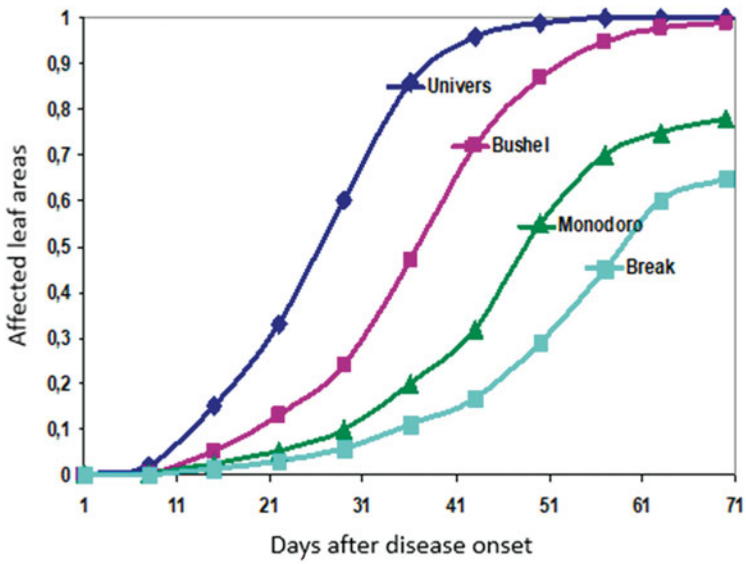

Fig. 27.9 Progress of epidemics on sugar beet varieties having different resistant to *Cercospora* leaf spot in Northern Italy (1995–1998) (Source: Rossi and Battilani 1990)

Fig. 27.10 Disease ratings on older susceptible and resistant sugar beet varieties affected by *C. beticola* in untreated plots in Sakarya, Turkey (2012)

within the field and causes slower disease epidemics. In the event of improving quantitative resistance to the disease, the disease cycle cannot be completed and thus the spore production is inhibited (Parlevliet 1979).

Quantitatively, sugar beet-resistant varieties have been developed against the pathogen. These varieties must be planted in places where the disease prevails and gives important damage every year. Since resistance to disease is not immunity but low resistance (Rossi 2000), sowing resistant varieties must be supported with spraying fungicides. Recently, several new generation sugar beet varieties, resistant to the disease, showed no yield penalty in case of disease absent and performed better compared to susceptible varieties in field trials in Germany (Vogel et al. 2018). Kopisch-Obuch et al. (2020) also stated that new generation varieties gave better performance than classic resistant varieties in Italy and Germany (Figs. 27.11 and 27.12). It has been revealed that these varieties will significantly reduce the use of fungicide in the future. Also, the new generation resistant varieties will decrease the number of applications by delaying the first fungicide application and get rid of the negative effects of the wrong fungicide applications (application time, dosage, and intervals between applications).

27.8 Fungicide Application

The main implementation for *Cercospora* leaf spot management in sugar beet farming is fungicidal application. The fungicides from different chemical classes have been used and inhibited the disease development and sugar yield losses

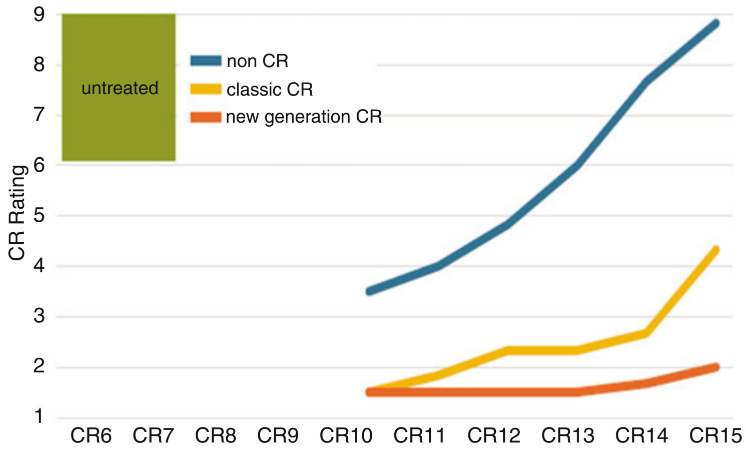

Fig. 27.11 Disease ratings in new generation varieties compared to susceptible and classic resistant ones in untreated plots in Soligenstadt, Frankonia, Germany in 2018 (Source: Kopisch-Obuch et al. 2020)

Fig. 27.12 New generation resistant varieties (right) affected by *C. beticola* compared to susceptible one (left) in untreated plots in lower Bavaria in Germany 2019 (Source: Kopisch-Obuch et al. 2020)

throughout the years (Meriggi et al. 2000). For disease control, a number of fungicides which are protectant and systemic have been registered by different companies and used by the farmers in different countries. Chemical families of available fungicides are as below (Ioannidis and Karaoglanidis 2010):

Table 27.2 Classification of fungicides used in the control of *C. beticola* according to resistance development risk (Source: Ioannidis and Karaoglanidis 2000)

Resistance risk	Fungicides	Chemical group
Low	Maneb Mancozeb	Dithiocarbamats
	Chlorothalonil	Phenolic compounds
	Copper compounds	Copper compounds
Medium	Fentin acetate Fentin hydroxide	Tinned compounds
	Fenpropimorph	Morpholine
	Cyproconazole Difenoconazole Flusilazole Flutriafole	Demethylation inhibitors
High	Benomyl	Benzimidazoles
	Carbendazim	
	Thiophanate-Methyl	

(a) The protective dithiocarbamates, nitriles, and fentin derivatives,
(b) The systemic and curative benzimidazoles,
(c) The systemic, protective, and curative ergosterol inhibitors (DMIs and amines),
(d) The protective, curative, and eradicant quinone outside inhibitors (QoIs) which are relatively new and very effective.

One of the most substantial factors restricting the control of the disease by chemicals is the forming of the resistance to fungicides. Resistance has increased dramatically in the last 40 years. When the same fungicide is used continuously and for many years, fungus *C. beticola* creates resistance. It is the first pathogen to develop resistance to benzimidazole fungicides in some countries, especially Greece, in the early 1970s (Georgopoulos and Dovas 1973, Ruppel and Scott 1974, D'ambra et al. 1974, Pal and Mukhopadhyay 1985, Weiland and Halloin 2001). The pathogen later developed resistance to fentin fungicides (Giannopolitis 1978, Cerato and Grassi 1983, Bugbee 1996). In the 1990s, it developed resistance against demethylation inhibitors (triazoles) in Greece (Karaoglanidis et al. 2000). Since resistance to benzimidazoles is very strong, the efficacy of the fungicide suddenly decreased and disappeared. Resistance to other fungicides developed slowly and was low (Ioannidis and Karaoglanidis 2000) (Table 27.2).

According to the results of the study in Turkey (Maden et al. 2009), *C. beticola* was detected to be resistant to mancozeb and fentin acetate with protecting action and flutriafol with systemic action in all beet growing areas infected by the disease, except Alpullu and Kastamonu regions. The highest resistance to mancozeb was in Susurluk region followed by Adapazarı, Amasya, Kastamonu, and Çarşamba regions. Resistance to fentin acetate was found at the highest rate in the Susurluk factory region, followed by isolates from Amasya and Kastamonu regions.

C. beticola strains resistant to Qo inhibitors including pyraclostrobin, azoxystrobin, and fenamidone were first reported (Malandrakis et al. 2006). The improvement of resistance to strobilurins reduced the leaf spot control in some fields in Michigan and Nebraska, USA (Kirk et al. 2012). Piszczek et al. (2018) declared that there was the *C. beticola* strobilurin resistance and QoI fungicides can be deficient for the suppression of *Cercospora* leaf spot in Poland. They also stated that new disease management implementations must be put into practice since DMI and QoI fungicides are mainly registered in Poland and eventually the choice of fungicides supplying effective crop protection for the leaf spot control is limited.

Rosenzweig et al. (2020) have studied recently fungicide resistance to *C. beticola* in Michigan, USA and Ontario, Canada, and found shifts in fungicide sensitivity phenotypes to DMI and organotin fungicides from 2014 through 2017. They concluded that isolates of *C. beticola* with lower sensitivity to DMI fungicides which are difenoconazole, fenbuconazole, flutriafol, prothioconazole and tetraconazole, and fentin hydroxide have frequently recovered and the frequency of the recovered isolates has increased. The studies of an integrated approach including knowledge of pathogen biology and fungicide efficacy agree with results from sensitivity monitoring. This agreement is a matter of vital importance in improving fungicide resistance and effective disease management strategies.

Ioannidis and Karaoglanidis (2010) declared that according to disease pressure the occurrence of these resistances have decisively given a direction to the current chemical control strategies, based on replacing different fungicide mixtures from different fungicide classes and maintaining a minimum number of applications for a successful disease management (Ioannidis and Karaoglanidis 2010, Secor et al. 2010).

Several strategies have been improved to prevent and delay the emergence of fungicide-resistant populations, limit the distribution of the resistance, and reduce and manage the resistance effect. Factors to consider for managing fungicide resistance and developing strategies need to be adapted as below (Wade 1988, Köller 1991, Meriggi et al. 2000):

- Starting anti-resistant strategies before resistance becomes a big problem.
- Combining chemical control with other methods.
- Spraying fungicide mixtures in different chemical groups with different actions in the beet production season.
- Decreasing the number of applications by applying the fungicide mixtures when necessary in each season spraying program.
- Reducing the using of risky fungicides in spraying programs.
- Biochemical structure of risky fungicides, frequency of resistant subpopulations, epidemiological and biological characteristics of resistant strains.
- The bringing new types of alternative fungicides into practice, as resistance builds up in old fungicides.

There are two fungicide groups with protective action (fentin acetate, fentin hyroxide, maneb, chlorothalonil, copper compounds, etc.) and curative action (triazole, morpholine, and benzimidazole). Owing to prevent the germination of conidia, protective fungicides should be sprayed before the disease occurs. Since these fungicides do not penetrate into the leaf, they should be sprayed on the leaf surface very well. Even when the disease is present, systemic fungicides can move and spread to the untreated areas of the leaf by xylem (Meriggi et al. 2000). Leaf protection might reduce the numbers of fungicide applications during the season, depending on climatic requirements and resistance level of the sugar beet variety (Skaracis et al. 1996, Meriggi et al. 2000). According to weather conditions, disease progress, and threshold, spraying numbers can be decreased, while leaf protection against *Cercospora* is kept quite satisfactory by initiating spray just at occurrence of the disease and going on chemical treatments (Ioannidis and Karaoglanidis 2010, Khan and Khan 2010).

Since the same fungicide is used alone for a long time against the disease, *C. Beticola* Sacc. improves a resistant strain in a short time. Therefore, to get maximum benefit from the different action mechanisms and to prevent the occurrence of the resistant strains of *C. beticola*, in principle, the triazole group fungicides are mixed with one of protective contact effective fungicides such as tin, copper, maneb, mancozeb, and chlorothalonil. The full doses of the triazole group fungicides are mixed with contact and protective ones at 2/3 or 1/2 of the dose (Ioannidis 1994, Menkissoglou-Spiroudi et al. 1998, Meriggi and Rosso 1990). One of the group I fungicides should be mixed with one of those in group II and should be applied 15–20 days intervals in rotation from the beginning of the disease to before harvest in severe epidemic regions by changing each fungicide for next application (Table 27.3).

The main goal of the integrated pest management (IPM) is to decrease the amount of fungicide use and to control fungal diseases by other combined implementations as far as possible (EU 2009). The IPM model is based on the threshold for the epidemiology, where fungicide application thresholds are considered as the main criteria. Fungicides are applied according to threshold values. To decide on the use of fungicide at the first occurrence of the disease, the threshold values of *Cercospora* leaf spot are determined and spraying is started and continued accordingly. Two basic methods are applied in determining threshold values:

(a) Integrated Pest Management model based on threshold-oriented control of *C. beticola* (Verreet et al. 1996, Wolf et al. 2000, Wolf and Verreet 2002): Early warning model based on the principle of the damage threshold values determined by investigating and sampling on the leaves at the canopy closure stage of sugar beet. According to the method, at the beginning of the season, a sample of 100 leaves (1 leaf per plant) are evaluated, while going diagonally through each beet field. Thresholds are when spots occur on 5% of the leaves for the first fungicide applications and then 45% of the leaves for the second spraying. In practice, the model has been used in Germany (Wolf et al. 2000) and was also adapted to the climate conditions of Turkey (Özgür and Kaya 2002). After the first spraying, second and later applications are repeated with

Table 27.3 Fungicides recently used against *Cercospora* leaf spot

Group	Fungicides				
	The name of active ingredient	Percent of a.i. (%)	Formulation	Dose (kg or L/ha)	
Group I (Systemic curative main fungicides)	Flutriafol	12.5	SC	0.50	L
	Flutriafol	25	SC	0.25	L
	Epoxiconazol + Carbendazim	12.5 + 12.5	SC	0.40	L
	Flusilazol	40	EC	0.20	L
	Difenoconazol	25	EC	0.30	L
	Difenoconazol + Propiconazol	15 + 15	EC	0.30	L
	Prochloraz + Propiconazol	40 + 9	EC	1.25	L
	Tetraconazol	12.5	ME	0.75	L
	Epoxiconazol + Pyraclostrobin	6.25 + 8.5	SE	1.50	L
	Tebuconazole + Trifloxystrobin	50 + 25	WG	0.25	kg
	Epoxiconazol + Fenpropimorph	8.4 + 25	SE	0.75	L
	Azoxistrobin + Difenoconazol	12.5 + 12.5	SC	0.50	L
GroupII (Contactprotectant additional fungicides)	Chlorothalonil	75	WP	0.50	kg
	Maneb	80	WP	1.50	kg
	Mancozeb	80	WP	1.50	kg

WP Wettable powder, *WG* Water dispersible granules, *DF* Dry flowables, *EC* Emulsifiable concentrate, *SC* Suspension concentrate, *SE* Suspoemulsion, *ME* Microemulsion concentrate

15–20 day intervals, depending on the period of fungicides remaining and acting in the leaf, until 3–4 weeks before harvest.

(b) Mathematical early warning prediction model based on climate data collected by means of instruments and computer software. Early warning of *Cercospora* leaf spot disease in sugar beet is predicted by climatic data. The used program widely in the world in this context is the method based on Daily Infection Value (DIV) calculated from the temperature and humidity values around the plants in the field to indicate a spray, developed by Shane and Teng (1985), which is *Cercospora* leaf spot model belonging to the University of Minnesota (Windels et al. 1991). The other is software of risk forming based on incubation and sporulation evaluations according to Bleiholder and Weltzien (1972). Here the model gives the infection directly as mild, moderate, and severe. In DIV evaluations, only the DIV of the day is given. According to the Minnesota DIV, mild disease emergence when DIV6 for a day or a total of 2 days occurs and DIV 7 indicates that severe disease will occur when the total of 2 days is 7 or more in a day.

The transition from thresholds to a climatic-based system is depended upon the intensive amount of labour including field observations needed by using thresholds. Weather- and climate-relative systems developed in the combat of *Cercospora* leaf spot are used in Italy (Rossi 1997), The United States (Windels et al. 1998), and Germany (Jörg and Racca 2000). These models consisted of temperature, humidity, and duration length which are suitable for the germination of *C. beticola* conidia (Vereijssen 2004).

The various models, related to the infection process, developed based on the parameters of climate-environment and damages to plant. Some of them consider only climatic data suitable for disease developing (Shane and Teng 1984, Windels et al. 1998, Khan et al. 2007), while the others the resistance level of the variety (Wolf and Verreet 2002, Racca and Jörg 2007). The disease management for the sustainable sugar beet production might be substantially supported by all the models on condition that they are implemented precisely (Windels et al. 1998, Wolf and Verreet 2002, Khan et al. 2007).

27.9 Integrated Management

One or several of implements including resistant variety, fungicide application, crop rotation, good farming practices, and use of disease-free seeds cannot protect sufficiently beet leaves against *Cercospora* leaf spot. For climatic, efficiency, and economic reasons, these should be cautiously employed altogether to minimize the number of fungicide applications and the possibilities of fungicide resistance, and the increasing in pathogen populations. As a result, integrated disease managements are now adopted and widely guided towards achieving sustainable sugar beet production. Integrated disease management (Fig. 27.13) completely consists of a combination of the practices such as crop rotation, good farming techniques, using

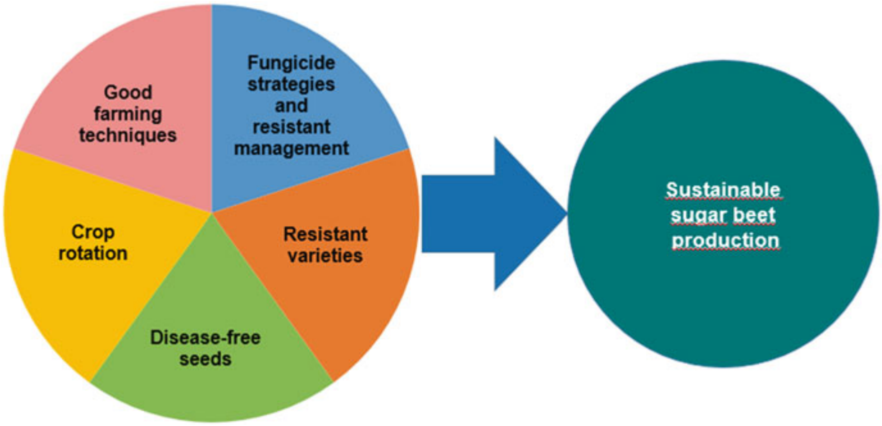

Fig. 27.13 Integrated management of *Cercospora* leaf spot for sustainable sugar beet production

disease-free seeds to decrease inoculum, sowing resistant varieties to make the onset of the disease late and prevent its development, and protecting leaves by fungicides (Jacobsen 2010). The significance of the epidemiological models is that they accurately monitor the onset and progression of the disease. Thus, fungicides are sprayed only when necessary (Skaracis et al. 2010).

27.10 Biocontrol

Biocontrol agents such as *Trichoderma* species and *Bacillus subtilis* were stated for *C. Beticola* in sugar beet (Collins and Jacobsen 2003, Galletti et al. 2008). Unfortunately, they have not been successful in practice. On the other hand, several microbial groups are present together with the disease occurring in the fields of sugar beet and it is supposed that some of microbes may be beneficial to predict the occurrence of disease as biological markers (Kusstatscher et al. 2019). However, biological agents may be used against *Cercospora* leaf spot as a supplementary protection to resistant varieties and fungicides. Bargabus et al. (2002) stated that the systemic resistance caused by *Bacillus mycoides* (BmJ) gave promising result when applied to leaves and also, *Trichoderma* species, a soil-born pathogen (Lartey et al. 2010), can be applied. Galletti et al. (2008) declared that pathogen sporulation and non-competitive or competitive antagonism might be decreased by two *Trichoderma* isolates and also, the incidence of the disease and pathogen sporulation were reduced by repeated sprays of homogenate treated with difenoconazole only once under natural inoculation. Jacobsen (2010) reported that they might contribute to crop protection in times to come. In addition, it was announced that the enzyme laccase gained from a basidiomycete could remove effects of cercosporin and might decrease the cercosporin toxicity when applied to the leaves (Caesar-TonThat et al. 2009). In view of experiments of the troubles owing to the mechanism of resistance, several possible classic and molecular studies to the future improvement are being taken in hand (Skaracis et al. 2010).

27.11 Conclusion

The yield and quality performance of the recent bred varieties resistant to *C. beticola* have reached to that of sensitive ones owing to advances in plant breeding. When disease does not occur, new generation resistant varieties do not cause yield loss and give better performance than sensitive ones. It is supposed that the varieties bred recently will cause a significant reduction in usage of fungicide for an improved integrated pest management. The occurrence of *C. beticola* resistance to the fungicides used should generally be viewed as a big trouble to sustainable sugar beet production. Only obtaining detailed information about the mode of action, method, and time of fungicide usage, the genetics of *C. beticola* and the mechanism of its resistance will identify the risks before fungicide failure. The information gathered will help the resistance management plans and tactics of specific measures for producing sugar beet sustainably, while maintaining yield stability.

Fully comprehending the interaction between *C. beticola* and sugar beet could contribute to new strategies to control disease and thus further reduce yield losses. In this respect, it is the need to research the biology of the pathogen and new developments in its molecular and genetic understanding. Possibly, new biological agents to be discovered in future studies will also contribute to cope with the disease. For advanced integrated *Cercospora* leaf spot management from now onwards, the comprehending of the molecular and genetic characteristics of the pathogen, the properties of the new fungicides to be discovered in detail, the prevention or minimization of resistance improvement, and the exploring of new information on pathogen-beet interaction, especially advances in plant breeding, will allow more competitive and profitable sugar beet production.

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