technical leaflet

Leaf diseases

SESVANDERHAVE
sugar beet seed

Introduction

From canopy closure until harvest, sugar beet can potentially be attacked by 4 main leaf diseases, each caused by a different fungus.

Cercospora is the most destructive foliar pathogen of sugar beet. It is widely present in most beet-growing regions and can cause major yield losses if not properly controlled. This disease usually appears early in the season and is most severe in wet and warm areas in case of very early attacks.

Geographically, **powdery mildew** is the most widespread leaf disease of sugar beet. The causal agent is the fungus *Erysiphe betae*. This leaf disease is generally the first to appear in the season. For a long time, powdery mildew was thought to have little or no economic impact on the crop. However, since the 1970s many studies have shown that yield losses are far from negligible.

a/

b/

Figure 1. Cercospora (a) and powdery mildew (b) have a wide geographical distribution and can cause significant yield losses if not adequately controlled.

Rust is caused by the fungus *Uromyces betae*. Despite its wide geographical distribution, its economic impact is often considered to be far less important than powdery mildew or Cercospora. This is mainly explained by the fact that it appears later in the season. In some regions (ex. along sea coasts) it can sometimes cause serious damage.

Ramularia is in many ways (cycle and symptoms of the disease) close to Cercospora. However, it occurs mostly in wet but cooler regions, and appears at the end of the season. Except for northern regions like Scandinavia, Ramularia is usually considered as a low impact disease for sugar beet.

a/

b/

Figure 2. Rust (a) & Ramularia (b) are often considered of secondary importance for sugar beet because they usually have a minor impact on the crop yield. (Source b: IRBAB)

The protection of sugar beet against leaf diseases has gained importance in the last decade. In many areas, fungicides are now commonly used, and have led to a higher yield and profit for the farmer. In regions where Cercospora pressure is very high, it may be necessary to combine these treatments with varieties showing a moderate to high level of resistance. So far, however, such varieties have a key weakness: they show a much reduced productivity compared with susceptible varieties.

Disease infection cycles

For **Cercospora**, the infection cycle begins when a conidial spore - i.e. a multi-segmented dissemination spore of the fungus - falls on the surface of a sugar beet leaf. Under favourable weather conditions, this spore will germinate and produce a germ tube (1). This will grow on the leaf surface until it reaches a stoma (leaf pore). From there, the fungus will develop into a mycelium which will grow in the intercellular space of the leaf (2). Cercospora beticola is a semi-necrotrophic fungus, showing parasitic growth on the infected plant cells which are used for the fungal growth. The intracellular mycelium produces Cercospora-specific toxins (e.g. Cercosporin) which are highly toxic for the plants. The production of these toxins leads to leaf necroses (3) and senescence (4), which are the typical symptoms of the disease.

Under favourable weather conditions the mycelium starts sporulating, forming special structures called conidiophores (5) in the sub-stomatal cavities. These conidiophores bear numerous conidia which are released on the leaf surface and can spread by splashing water or wind (7) to a new plant or leaf. A new cycle can potentially start. The whole cycle can be completed very rapidly and can be repeated many times over a growing season, especially in the case of very early attacks.

However, if the weather conditions are unfavourable to the fungus, it can still survive in the debris of infected plants; two to three months at the conidial stage, and up to one or two years via the conidiophores (6).

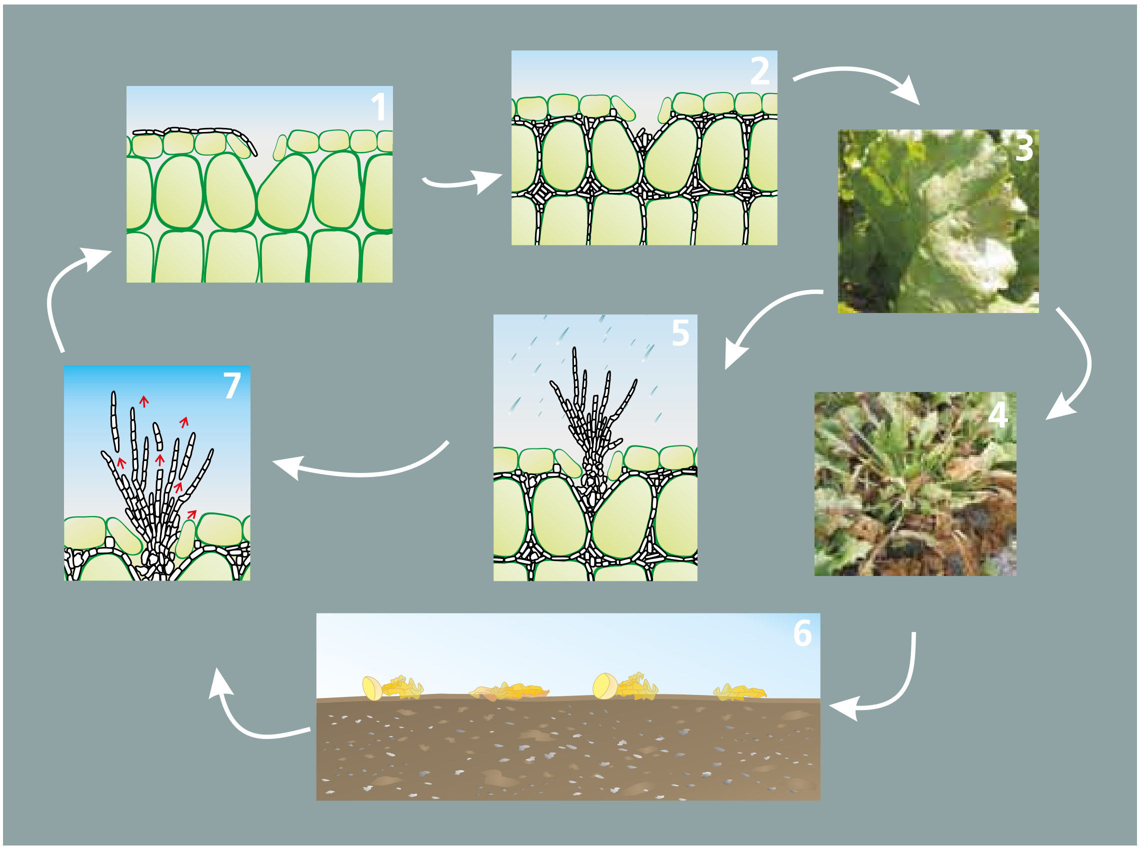


Figure 3. Disease cycle of Cercospora on sugar beet.
Adapted from: Jones, Roger K. & Carol E. Windels (1991)

The details of the disease cycle of *Uromyces betae*, *Erysiphe betae* and *Ramularia beticola* are not given in this leaflet. Due to the very typical morphology of each of these fungi, there are many differences between their disease cycles, but nevertheless the general idea (spore dissemination, mycelium proliferation, and survival structure) is the same. Some key differences are nevertheless highlighted in table 1.

	Growth	Development factors	Dispersion means	Weather	Hosts range
Cercospora	Endophytic (inside the plant)	Needs high temperatures (27-32°C) and moisture (from 60% RH; severe epidemics if >90% RH) for a given period each day (15-20 hrs or 10-15 hrs for very high moisture).	Rain, wind & some insects	Wet & Warm	Includes *Beta*[1] species, spinach and many weeds[2]
Powdery mildew	Epiphytic (on the surface of the plant)	Can start in relatively dry conditions (30-40% RH) and speeds up as moisture increases. Alternating wet and dry conditions (e.g. morning dew) boosts the development. Temperature should be relatively high (25°C is optimum).	Wind & rain	Dew & Warm	Limited to *Beta*[1] species
Rust	Epiphytic (on the surface of the plant)	Requires relatively cool temperature (between 15° and 22°C) for its development but will tolerate warmer temperatures as well. The key factor is moisture for long periods.	Wind & rain	Wet	Limited to *Beta*[1] species
Ramularia	Endophytic (inside the plant)	With low temperatures (optimum 17°C) and wet conditions (> 95% RH).	Wind & rain	Wet & Cool	Limited to *Beta*[1] species

Table 1. Some key differences between the infection cycles of powdery mildew, rust, Cercospora & Ramularia.

(1) *Most cultivated species, B. vulgaris ssp. maritima and other wild beet species.*
(2) *Including Amaranthus, Atriplex, Chenopodium, Plantago, etc.*

Symptoms

Cercospora

Early stage:
Small, round grey spots, well delimited by a reddish-dark brown margin, appear on the leaves. Presence of a grey mycelium with tiny black spots (visible with a magnifying glass).

Later stage:
Large brownish areas causing leaves to look like dried tobacco leaves.

Do not confuse with Ramularia.

Ramularia

Early stage:
Irregular, small light brown spots develop, surrounded by a diffuse dark edge. Presence of grey mycelium with tiny white spots (visible with a magnifying glass).

Later stage:
Large brownish areas causing leaves to look like dried tobacco leaves.

Do not confuse with Cercospora.

Rust

Early stage:
Small circular pustules, red-orange to brown and often surrounded by a yellow halo appear on both sides of the leaves and produce a fine, orange powder.

Later stage:
Leaves dry up.

Powdery mildew

Early stage:
Small, white and star-shaped dots.

Later stage:
Down appears on the leaves, at first white, then greyish (powdery looking) to purplish, dotted with black spots. Then the leaves dry out.

Impact on the yield

One way or another, the development of all leaf diseases will cause a **reduction of the leaf area available to cary out photosynthesis**, thereby reducing **both yield and sucrose content** of the beet. In addition, the **processing quality** may be affected since transport of nutrients and impurities (Na, K, amino-acids) is disturbed by the infection, resulting in a blocking of the root to leaf transport.

For powdery mildew, the reduction of the photosynthetic area is caused mainly by the appearance of the white powder on the leaves. For Cercospora, the impact of the disease on the yield and quality is two-fold. First there will be a reduction of the photosynthetic area due to the progressive increase of the necrotic leaf spots and the drying of leaves. Secondly, the plant will react to the leaf loss by canopy re-growth, which will cause additional yield losses which are more important than those due to necrotic spots.

Figure 5. All leaf diseases will lead to a reduction of the photosynthetic area. For Cercospora and Ramularia, important yield losses can also be caused by canopy re-growth.

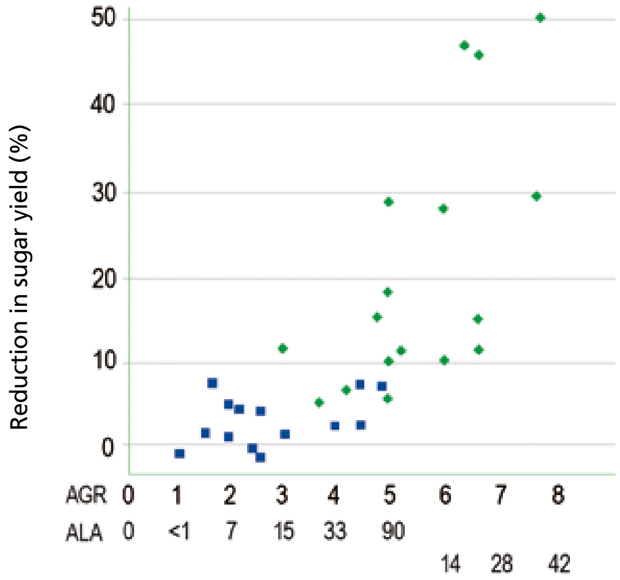


Figure 6. Relationship between sugar yield loss (the ratio between the yield of non treated plots and treated plots, expressed in %) and Cercospora severity (AGR: disease severity rating according to the 'Agronomica' scale; ALA: affected leaf area; time of leaf re-growth).
Adapted from: Rossi et al., 2000.

Cercospora has by far the greatest yield-harming potential. This disease may cause losses up to 50% for root yield and 5 to 10% for sugar content in case of very severe and non treated attacks. Under moderate Cercospora pressure, 30% losses in root yield are fairly common. The earlier the attack of Cercospora, the higher the impact on yield.

Powdery mildew leads to significant losses if the disease is not adequately treated: up to 10-15% in root yield and up to 0.5 % in sugar content. The potential impact on the yield is therefore considered to be less important than for Cercospora.

Because **rust** occurs later in the season, it is usually considered to have little economic importance. In some cases of very severe and early attacks, there may be serious yield losses of up to 10-15%, as was seen a few years ago along the coasts of France.

In most countries, **Ramularia** is considered as a minor pathogen with no or very little impact on crop yields. In Scandinavian countries, however, Ramularia is the main leaf disease and yield losses can be significant, particularly since the use of fungicides there is not as common as in more southern EU countries.

Obviously, for a given disease, the size of the impact on the yield **will vary from one campaign to the other** due to weather conditions and the quality of the management strategy set in place by the farmer.

Geographical distribution

Cercospora

The disease is regularly observed in **2/3 of sugar beet areas worldwide**.
2 different types of region can be identified:

- ✓ Regions with a **low disease incidence**: where 1 to 2 fungicide treatments are applied by farmers, and where sugar yield losses can reach up to 20% in the absence of an efficient fungicide protection. Such regions include countries like the Netherlands and Belgium, the UK, most of France and Germany, Spain, Poland and the Czech Republic, and the Red River Valley Region in the USA.

- ✓ Regions with a **high disease incidence**: where 1 to 2 fungicide treatments are applied by farmers, and where sugar yield losses can reach up to 20% in the absence of an efficient fungicide protection.
  Such regions include countries like the Netherlands and Belgium, the UK, most of France and Germany, Spain, Poland and the Czech Republic, and the Red River Valley Region in the USA.
  Regions with a high disease incidence: where farmers need to spray more than twice to control Cercospora, otherwise they will encounter sugar yield losses greater than 20%.
  This is usually seen in areas where summers are both warm and wet, and where irrigation is a common practice, including in Southern and Central Europe (e.g. Austria, southern Germany, Italy, Hungary and the Balkans) or in the Midwest of the USA (e.g. South Michigan). Severe Cercospora attacks are also frequently observed in China, Japan, North Africa (e.g. Morocco, Tunisia). It is a key disease in Turkey and other Near-East countries as well.

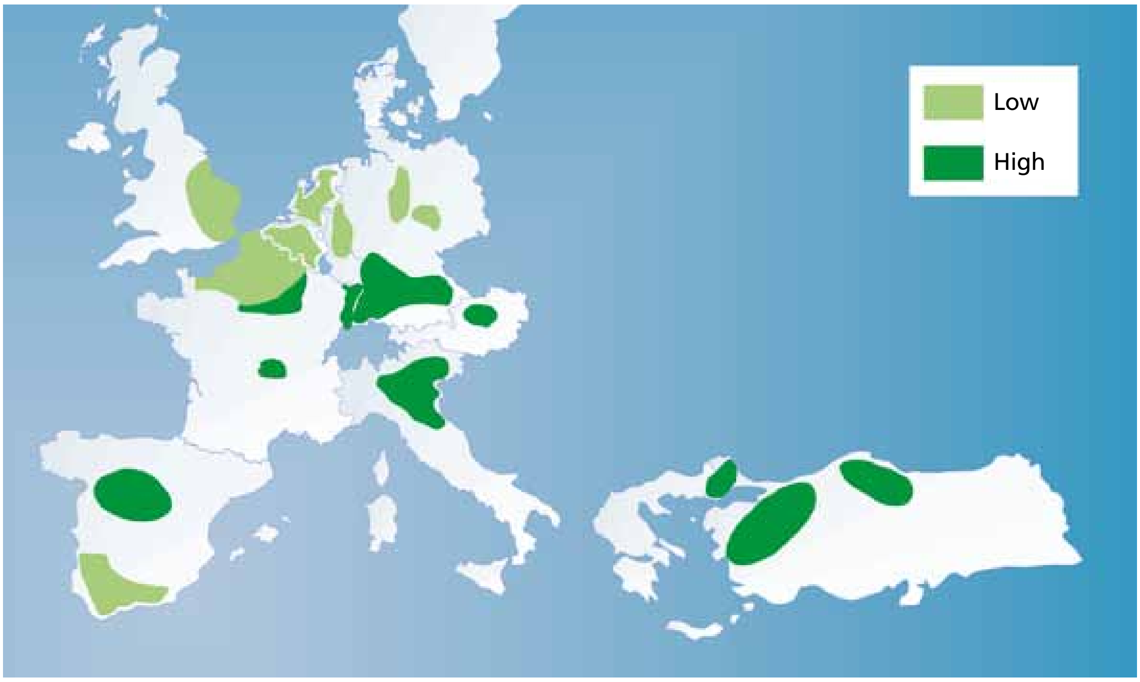


Figure 7. Map of Western Europe representing the regions with a high or low incidence of Cercospora.

Powdery mildew

Powdery mildew is found virtually **anywhere sugar beet is grown**, but with a far less severe yield impact than Cercospora. The most severe attacks occur in warm/arid climates (particularly North Africa & Near East, South-Western USA, and Central Asia). It can also be significant in temperate maritime regions with relatively mild winters, such as the UK.

Rust

Rust is also present **in most beet growing areas** (Northern and Eastern Europe, Russia, Asia and Western USA).

Ramularia

Ramularia may occur in many beet growing areas, but is more frequent and damaging **in regions with a cool & moist climate** such as the north of the USA, Russia and Europe. In Scandinavia, Ramularia is the main leaf disease against which farmers need to spray. In countries like Belgium, the Netherlands, the North of France and Germany, attacks may cause significant damages in some years. This was notably the case in 2007 in France. But most of the time in Western Europe, Ramularia appears late in the growing season and is not considered as economically significant.

Other leaf diseases:
downy mildew, Pseudomonas & Alternaria

Cercospora, powdery mildew, rust & Ramularia are not the only leaf diseases able to attack sugar beet, although they clearly have the biggest impact in terms of acreage and incidence.

Downy mildew (Source: IRBAB)

Alternaria (Source: IRBAB)

Downy mildew on sugar beet is caused by the fungus *Peronospora farinosa*. The typical symptoms are the appearance of gray to violet coloured leaves during cold and wet springs. In general only a few isolated beets are affected in the field, which does not justify a general field treatment.

Alternaria leaf spot is one of the minor leaf diseases caused by 2 different fungi: *Alternaria alternata* and *A. brassicae*. They attack sugar beet leaves without any noticeable effect on yield. Typical symptoms are the appearance of brown spots which can lead to necrosis mostly on leaf edges.

Pseudomonas (Source: IRBAB)

The bacterial pathogen Pseudomonas syringae can occasionally produce symptoms similar to Cercospora and Ramularia. The bacterium is widespread although it rarely produces an economically important loss for sugar beet. No chemical treatment is effective against this disease.

Management of leaf diseases

All 4 leaf diseases are **managed together by growers**, and not separately. In practice however, in most countries the focus will be on Cercospora & powdery mildew, because these diseases have the biggest impact on the final sugar yield.

The protection of sugar beet against leaf diseases is achieved through a **combination of fungicide applications, agronomic measures and - if needed - genetic resistance.**

Chemical control

Over time, the compounds used to control foliar diseases have evolved. Some time ago, farmers used to spray systemic fungicides such as benzimidazoles. But the exclusive use of these pesticides has caused the onset of resistant fungal strains (ex. in Michigan, USA, in the late 90's).

To delay the appearance of such strains, it is now **strongly advised to use fungicides with different modes of action on a same field**. Most current commercial products are already a mix of two types of active ingredients, but alternating commercial products over time is also advised.

In practice, the molecules and therefore the commercial product to be used will depend on the predominant disease present in the field. A product **combining triazoles and another family of fungicides (ex. strobilurins)** will certainly often offer a broad and efficient spectrum of action.

Figure 8. To control beet leaf diseases, it is strongly advised to use on the same field fungicides with different modes of action.

Agronomic measures

- ✓ A rotation of at least 2 years between 2 sugar beet crops (Cercospora and Ramularia spores survive in the soil sometimes more than 2 years)
- ✓ If possible, infected tops & leaves should be removed from the field and the storage area to reduce potential contamination of subsequent sugar beet cultures.
- ✓ Deep ploughing will stimulate fungal development early in the season, before plants are available to infect. This will lead to death of the fungus. No-till techniques should be avoided.
- ✓ Irrigation will speed up the disease development. Giving too much water should be avoided.
- ✓ Avoid an excess of N fertilizers

Resistant varieties

Very schematically, the **level of resistance to leaf diseases** of sugar beet varieties recommended for a given region will change according to the incidence of leaf diseases in that region (cf. geographical distribution).

A difference can be made between beet-growing regions with a low to moderate Cercospora incidence and those where the disease has a high incidence

- ✓ In beet-growing areas where Cercospora has a low to moderate incidence, farmers are able to control leaf diseases efficiently with 1 to 2 fungicide treatments. In these regions, sugar beet only needs a low - sometimes medium - level of resistance to leaf diseases and Cercospora in particular.
- ✓ In regions where Cercospora has a high incidence, it is necessary to combine both fungicides and a resistance in the hybrids.

	Low incidence region		**High incidence region**	
Treatments	1-2		> 2	
Resistance level of the variety	Low	Medium	High	Very high

The use of fungicides to control leaf diseases in France

When to treat?

In France, the national research institute for sugar beet (ITB) has set up observation platforms distributed throughout all sugar beet areas. For each region, a group of farmers and agronomists set up a field observation network to follow the development of leaf disease symptoms from June until harvest. These observations are used to warn growers when a specific leaf disease appears in their region.

When a warning is given, the farmer should start monitoring his fields and observe local symptoms by himself. When a threshold is reached (see the table below), it is strongly advised to spray against the disease.

% contaminated leaves	1st treatment	2nd treatment	3rd treatment
Powdery mildew	15%	30%	30%
Cercospora	5%	20%	25%
Rust	15%	40%	40%
Ramularia	5%	20%	25%

The timing of the first treatment is very important, especially in the case of Cercospora, a disease that can spread very quickly to the entire field and cause very serious damage. In practice, it will very rarely be done before mid-July. Monitoring for the 2nd treatment should start about 2-3 weeks after the 1st spraying. In some cases of very heavy and early attack, a 3rd treatment might be useful. It is strongly recommended not to treat beyond 45 days before harvest (the cost of that treatment will rarely be compensated by an increase of the sugar yield).

With which products?

A first element to consider is to alternate fungicides with different modes of action to prevent or at least delay the development of resistant fungal strains in the long term. This strategy should also be applied for fungicides already containing a mix of two different active ingredients (e.g. triazole and strobilurine).

A second criterion is that not all fungicides are equally efficient to control all diseases. More particularly, if Cercospora is present in the field, care should be taken to select a fungicide which is very effective for its control.

	Triazole	Others	Performance
a	epoxyconazole	fenpropimorph	
b	difenoconazole	fenpropidin	
c	difenoconazole + propiconazole	-	
d	difenoconazole + propiconazole	quinoxyfen	
e	epoxiconazole	kresoxim-methyl	
f	cyproconazole	trifloxystrobine	
g	-	quinoxyfen	
h	futriafol	-	
i	flusilazole	-	
j	tetraconazole	-	

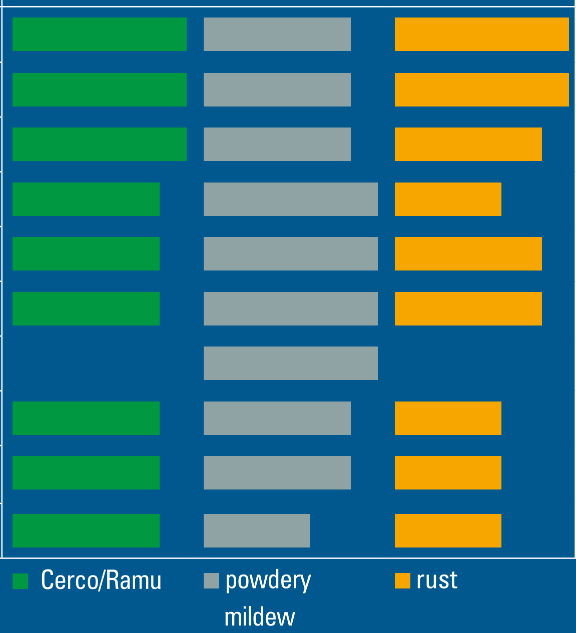


Figure 9. The efficiency of commercial fungicides to control Cercospora, powdery mildew and rust depends on the combination of active ingredients present in the product.
Adapted from: ITB, 2009.

Cercospora-resistant varieties

Genetic control, sources & mechanism

The resistance to Cercospora is **quantitative and polygenic**: it is controlled by several genes and the higher the number of these genes in the hybrid the greater the resistance. Therefore breeders speak of **low, medium, high or very high** levels of Cercospora resistance when breeding sugar beet varieties.

The detailed mechanisms of resistance to Cercospora are not yet fully understood. It appears that some plant defence mechanisms involving the production of antioxidant proteins are able to counter the cercosporin activity at the cellular level - together with molecules able to disturb the chemotropism[3] of the fungus. Anyway, these mechanisms will all result in a **slower infection** of the plant by the fungus.

However, it is very important to understand that, even in very resistant cultivars, there is **no total immunity**: the disease will continue to develop but at a slower pace and fungicide spraying will always be needed in parallel. Therefore scientists find it more appropriate to speak of partial resistance.

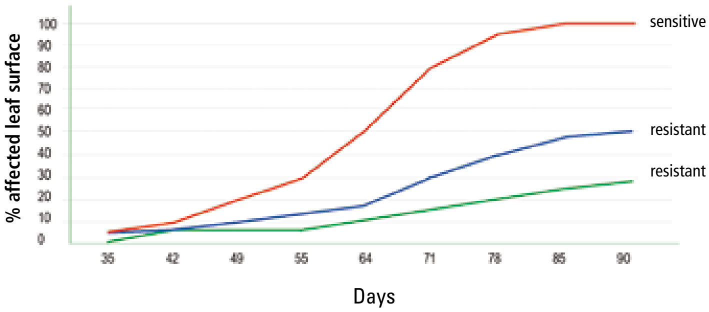


Figure 10. The differences between Cercospora sensitive and Cercospora resistant cultivars can be observed (a) on a disease progression curve (b) in the field.

The majority of sugar beet lines selected world-wide for their Cercospora resistance and used for the development of commercial varieties are derived from early 20th Century Italian breeding programmes performed by Munerati from *Beta maritima*. Based on multiple studies at the Fort Collins USDA station, it appears that genetic resistance in these lines is based on 4 to 5 genes.

In addition to Munerati's lines, SESVanderHave continue to screen several **wild Beta species**. However, such plants are not fully compatible for crosses with sugar beet, which makes it difficult to transfer resistance genes to our elite lines. In addition, they often show many agronomic weaknesses (low bolting tolerance, low productivity, low germination capacity…).

(3) *Chemotropism is a mechanism by which the fungus is attracted by a higher concentration of specific molecules and thereby is able to find the stomatal cavities and infect the plant.*

Figure 11. Wild Beta species often show many agronomic weaknesses, such as a high susceptibility to bolting.

Breeding for resistance

The sugar beet seed drilled by the farmer is what we call a hybrid: it is the result of a crossing between a pollinator (Po or **male line**) and a seed bearer (MS or **female line**). The characteristics of a commercial variety are therefore a mix of both parental characteristics.

Depending on the level of resistance chosen for the male and female parental lines, SESVanderHave breeders can easily **modulate the resistance level of a hybrid**: low, medium, high or very high resistance. On the basis of this concept, SESVanderHave can respond to the differing levels of Cercospora resistance demanded in all sugar beet growing regions of the planet.

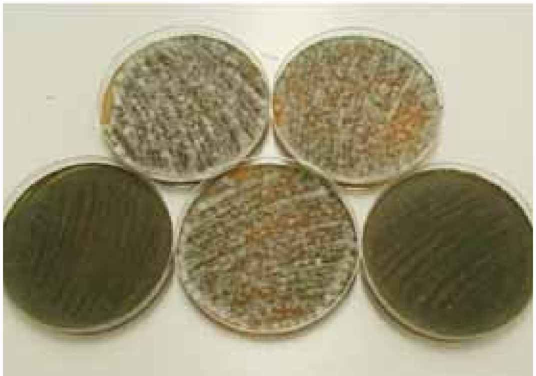
Of course, the choice of the female and male parental lines is in fact the last step of a breeding program. Before reaching that stage, the breeder needs to **develop the different parental lines** - male and female / more or less resistant - that will later form the basis for that final hybrid cross. This work requires a lot of time and talent.

♂	♀	Resistance level
0	0	Sensitive
+	0	Low
+	+	Medium
++	+	High
++	++	Very high

+ resistance gene

In order to introduce resistance genes into a non-resistant elite parental line, the breeder will rely on a common **successive backcrossing** technique. Its general principle is to perform a first cross between an elite line (high sugar content, high root yield, good extractability, etc.) and a resistant 'donor' plant. The result of this initial crossing (F1) is then crossed again with the elite parent: we call this a backcross. This step is repeated many times and, after each backcross, we select the plants that combine the highest proportion of characteristics from the elite parent with the resistance that we are transfering.

This selection is done on the basis of the results of **bio-assays** performed in greenhouses or fields where sugar beet plants are grown, artificially infected by the fungus and their level of resistance assessed. Nowadays, the development of **molecular markers** allows us to know almost instantly if resistance genes are present or not in the genome of a plant. This type of technique is used as a complement to our bio-assays.



a/

b/

c/

d/

e/

Figure 12. SESVanderHave breeders test the Cercospora resistance of their genetic material in bio-assays: fungal strains are grown in Petri dishes (a) and used to artificially infect plants in greenhouses (b & c). After the incubation and infection period (d), the area of leaf infected by the fungus is measured photographically (e).

The grower's dilemma: high resistance or high productivity?

Although the desired level of Cercospora resistance (low, moderate, high or very high) is relatively easy to insert into a hybrid, it is not always the most appropriate thing to do. Indeed, there is a **strong negative correlation between the level of Cercospora resistance and the potential productivity** of a hybrid.

How can we explain this phenomenon? The development of parental lines strongly resistant to Cercospora involves the introduction of several resistance genes in an elite line. However, these resistance genes are often flanked by other genes, some of them coding for poor agronomic performances. This means that, when trying to introduce resistance genes in an elite line, it is difficult to leave these neighbouring and less interesting genes behind.

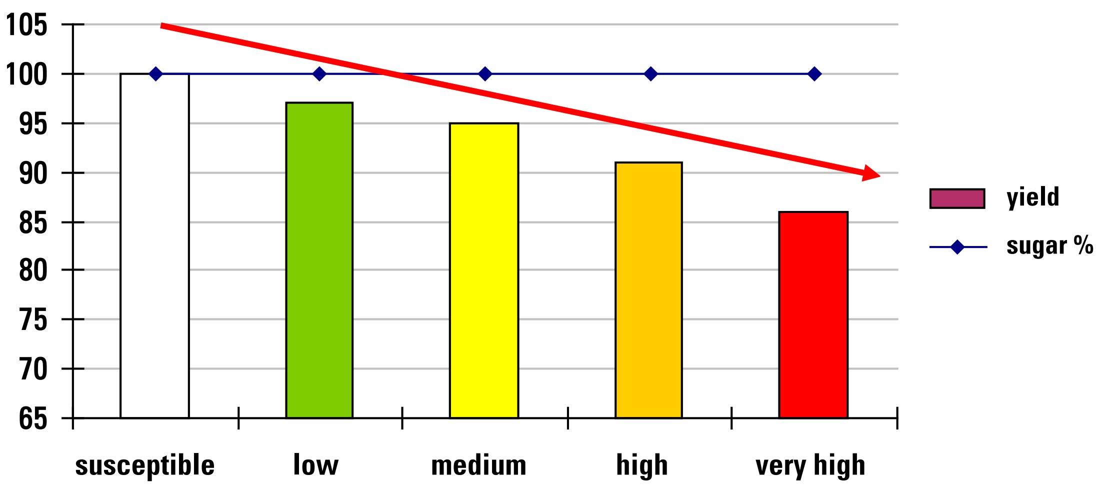


Figure 13. There is a strong negative correlation between the level of Cercospora resistance in a variety and its potential productivity on non-infested field.

The cutting edge

Our breeders have the genetic material needed to provide an **adequate solution to any demand from the grower**, from the lowest to the very highest levels of resistance:

- ✓ In the states of **Michigan and North Dakota** in the US, where Cercospora pressure is very high, SESVanderHave offer their growers sugar beet varieties with a very strong level of Cercospora resistance. Such high levels of Cercospora resistance are also needed in other regions like the North of China where, moreover, the use of fungicides is not yet very common.
- ✓ In the **northern Italy**, where severe Cercospora attacks are frequent but where growers spray several times, 100% of SESVanderHave varieties sown have a medium to high resistance to the disease. This holds true for countries like **Hungary** and **Slovakia**, where the context is similar.
- ✓ In most regions of **Western Europe**, where the pressure of diseases is low, the market does not require disease resistant varieties which, if used systematically, would reduce crop yield. With the benefit of the prediction tools available to him, the farmer will apply one or two fungicides in a reasoned manner on a highly productive cultivar with low to moderate resistance to leaf diseases.

However, this general observation should be **qualified**, i.e. it should take into account the Cercospora risk that is high in some regions (Alsace and Limagnes in France), or increased due to cropping habits (short crop rotations, irrigation, etc.). In these situations, the choice of cultivar must be finely weigh productivity against Cercospora resistance.

This means that the farmer's choice rests on **crop yield** and reduction of **environmental impact**.

This choice is also more and more influenced by regulations that gradually restrict the use of chemical and impose new constraints (e.g. spraying period before harvest).

SESVanderHave is working to cope with these evolutions and offer **productive varieties requiring less spraying**, adapted to the local needs.

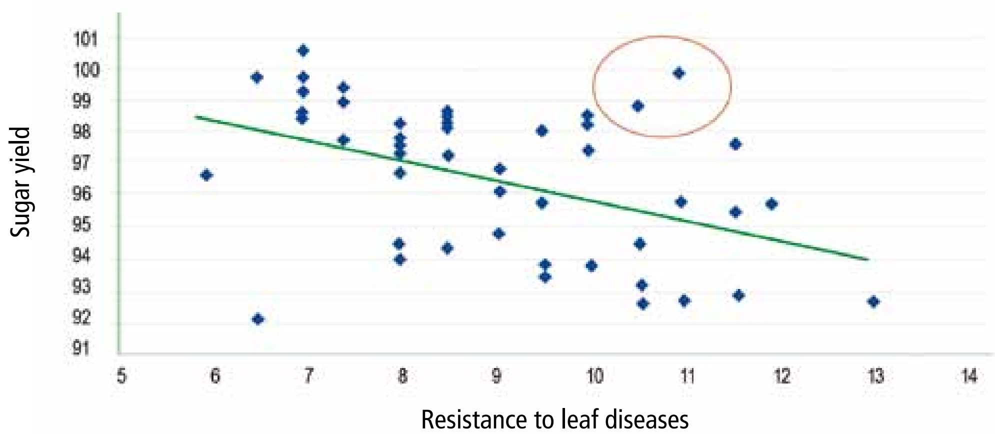


Figure 14. In a near future SESVanderHave expects to start breaking the correlation between productivity and leaf diseases resistance.

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