Food and Agriculture Organization of the United Nations

Integrated pest management of major pests and diseases of grapevine, pepper and tomato in North Macedonia

Support for the enhancement of national plant pest surveillance and phytosanitary certification systems (TCP/RER/3705)

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This document was developed in the context of the implementation of the activities of the project dedicated to strengthening the national capacities to protect from plant pests some of the most economically important crops in North Macedonia, under the overall coordination of Mr Piotr Wlodarczyk, REU Agricultural Officer, Lead Technical Officer for the project.

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Acronyms

AT	Action threshold
CSNV	Chrysanthemum stem necrosis virus
ED	Economic damage
EIL	Economic injury level
EPA	United States Environmental Protection Agency
ET	Economic threshold
FAO	Food and Agriculture Organization of the United Nations
INSV	Impatiens necrotic spot virus
IPM	Integrated pest management
PMI	Powdery mildew index
PHI	Pre-harvest interval
REU	Regional Office for Europe and Central Asia
TSWV	Tomato spotted wilt virus
WHO	World Health Organization

Introduction

Integrated pest management (IPM) has been known for some decades but is often used and understood in different ways by different people.

The FAO definition of IPM:

"Integrated pest management (IPM) means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human and animal health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms."

In other words, all available control options (e.g. cultural, physical, biological, chemical) should be considered and applied reasonably by farmers. Nevertheless, IPM is not simply a toolbox and integration of control options. It also involves measures (e.g. prevention, monitoring, forecasting, early diagnosis) which help slow the development of pest populations. An important aspect in IPM is adequate decision-making for any interventions. All decisions should be justified both economically and ecologically. Therefore, management programmes with the regular application of chemicals are not acceptable in IPM. Instead, priority should be given to prevention and alternative control tactics. Principles and more detailed examples in IPM implementations are discussed below:

Putting IPM into context

IPM has been implemented in various regions and countries that are different in terms of their natural and socio-economic conditions as well as their level of agricultural development. However, progression in plant production and protection may be achieved in any existing situations by implementing IPM. The application of IPM is not a simple and strict compliance with rules and regulations, but rather it means actions taken with an environmental approach including principles, strategies and tactics that contribute to the reduced use of chemicals as well as to higher food security for sustainable production. In order to make IPM as effective as possible, it should be adapted to local/regional conditions.

IPM in a spatial scale: thinking of landscapes instead of individual farms

Various types of habitats (e.g. agricultural areas, semi-natural environments) may be identified on a spatial level (i.e. farms, landscapes). They serve as spaces for living, reproduction and overwintering for many living organisms, including pests. Pests can invade newly established crops, spread among different habitats, and build up significant populations therein. The same is true for their natural enemies and antagonists. Thus, the occurrence and distribution of different species, including pests and beneficial organisms, at a given site will be affected by the surrounding habitats and the management practices applied in these habitats

IPM in a temporal scale: thinking of cropping systems instead of one single season

Cultivated annual and perennial plants host various pests and diseases and allow the emergence of weeds in the field. In the case of arable crops, the alternation of plant species over time at the same site (crop rotation) may break the life cycle of pests resulting in reduced pest pressure in the subsequent crop. In perennial crops, including orchards, the density of pests in a given year is a major determining factor in the initial infestation level in the subsequent year. Both crop rotation and/or other pest management measures will thus have an impact on the occurrence of pests in any cultivated plants in a temporal scale. In this context, IPM is the rational regulation of pests, present at the same site, not only in one plant species grown in a given year but also in cropping systems over several years. This approach is also valid and applicable for beneficial organisms. Therefore, IPM should be considered in a spatio-temporal context.

General principles for the implementation of IPM

1. Prevention and/or suppression of harmful organisms should be targeted and achieved by combining various options such as:

- Crop rotation and intercropping;
- Use of adequate cultivation techniques (e.g. seedbed sanitation, sowing/planting time and plant densities, under-sowing, conservation tillage, pruning and direct sowing);
- Where appropriate, the use of resistant/tolerant cultivars and standard/certified seed and planting material;
- Providing balanced nutrient supply and optimal water management;
- Preventing the spread of harmful organisms through field sanitation and hygiene measures (e.g. removal of infected plants, plant parts and plant debris and regular cleaning of machinery and equipment); and
- Protecting and enhancing beneficial organisms (e.g. utilization of "ecological services" inside and outside production sites).

2. Monitoring

Harmful organisms should be monitored with adequate methods and tools, where available. These should include observations in the field (e.g. occurrence of pests, appearance of symptoms) and, where feasible, scientifically-sound warning, forecasting and early diagnosis systems (consisting of traps, weather stations etc.). Regular consultation with professionals is also recommended. For further information on monitoring see the next chapter.

3. Adequate decision-making

Based on the results of the monitoring and the consideration of local conditions (e.g. cropping system, weather) proper decisions should be made about the need for, timing and methods of pest management. Where feasible, threshold values for harmful organisms should be defined and considered, taking into account the given growing conditions before any treatments.

4. Non-chemical plant protection measures

Sustainable physical, biological and other non-chemical methods should be preferred to chemical ones especially if they can also provide satisfactory pest control. As chemical pesticides are designed to be toxic to living organisms, are dispersed in the environment and are applied to food crops, their use should only be a last resort; used only if there are no adequate non-chemical alternatives and if it is economically justified. If the application of pesticides is foreseen, a pest management plan needs to be prepared.

5. Specific pesticides

If, after consideration of available IPM approaches the use of chemical pesticides is deemed to be justified, then careful and informed consideration should be given to the selection of pesticide products. Factors to be taken into account include hazards and risks to users, selectiveness and risks to non-target species, persistence in the environment, efficacy and the likelihood of development or presence of resistance in the target organism. The pesticides to be applied should be as specific to the target agent as possible and should have minimal effects on human health, non-target organisms (e.g. predators, parasitoids, pollinating insects) and the abiotic elements of the environment (i.e. water and soil). Their use should be kept to a minimum, e.g. by reducing the application frequency or using partial applications. If repeated application of chemicals is justified and required, pesticides with different modes of action (see WHO and EPA toxicity classification schemes) should be applied as part of an anti-resistance strategy to maintain the effectiveness of the available products.

The products to be applied should be registered in the country of use, or specifically permitted by the relevant national regulatory authority if no registration exists. The use of any pesticides should comply with all the registration requirements including the crop and pest combination for which it is intended.

6. Evaluation

The efficacy of the applied plant protection measures should be checked and evaluated based on the records on the use of pesticides and on the monitoring of harmful organisms. This will help farmers improve future pest management methods by making use of their knowledge and experience gained.

In addition to the principles above, key factors for the implementation and development of IPM are the knowledge and capacity of farming communities. Without understanding the local agro-ecosystems, mechanisms, biology of pests and their natural enemies etc., IPM cannot be successfully implemented. Farmers should improve their knowledge by participating in training courses and through professional consultancies, and they should be involved in the development process. Communication, discussion of problems as well as sharing experiences with each other (community-based learning) are also important, and all contribute to proper decision-making.

Key benefits of using IPM:

1. Lower risks to human health and the environment (e.g. water resources, pollinating insects).
2. Delayed development of pesticide resistance.
3. Money can be saved on plant protection.
4. Improved public image of agricultural production.

Monitoring in integrated pest management

Any decisions about pest management tactics to apply should be preceded by the proper identification of the organisms and conditions occurring in the field. Moreover, careful consideration is required to classify the organisms, and determine any of them as a pest.

The FAO definition of a pest

"Pest means any species, strain or biotype of plant, animal or pathogenic agent injurious to plants and plant products, materials or environments and includes vectors of parasites or pathogens of human and animal disease and animals causing public health nuisance"

Complete control of all pests is neither necessary in most cases nor appropriate for IPM. Almost all crops can tolerate a certain amount of damage without appreciable effects on vigour and yield. In light of this, it is necessary to estimate the pest densities that can be tolerated. A number of economic concepts are helpful in determining the point at which it pays to apply certain control methods:

- Economic Damage (ED): begins at the point at which the cost of crop damage equals the cost of control.
- Economic Injury Level (EIL): the lowest pest population density that will cause ED.
- Economic Threshold (ET) or Action Threshold (AT): the population density at which control action should be determined (initiated) to prevent an increasing pest population (injury) from reaching the EIL. To make a control practice profitable, or at least break even, it is necessary to set ET below EIL.

A pest can be non-economic (consistently remaining below economic levels), occasional (normally remaining below EIL but sporadically exceeding the threshold levels), and severe (occurring at high levels regularly and causing major damage without control). Most actual thresholds used in IPM today are more complicated and dynamic than a simple fixed level. Action thresholds can be expressed as the number of pest stages in the crop, damage, or a relative measure of pest activity by trapping or other indirect sampling methods.

Monitoring

Once precautions have been taken to prevent infestations, it is important to regularly check the occurrence of species identified properly and considered to be pests or beneficial organisms, the damage caused by the pests, the crop characteristics, and the environmental factors. This monitoring procedure is a key element of IPM programmes. It helps early detection, ranking of the severity of infestations and estimation of future populations. Therefore, it provides a better chance to avoid economic losses. In addition, regular monitoring works well for evaluating the results of a control strategy used. However, the methods of monitoring vary depending on the pest and the situation. These methods, developed for several species, should thus be adapted to local conditions. If monitoring has been carried out carefully, it should provide sufficient basis for decision-making about any pest control tactics to be applied (or not) or for the evaluation of pest management actions taken formerly.

Upon entering any fields, there are certain general procedures that must always be followed:

- Identify the field on the scouting report form properly indicating all available data;
- Record date and time of the day;
- Record weather conditions;
- Record crop growth stage;
- Record general soil and crop conditions;
- Sample the field using the method and pattern recommended for the particular pest(s), and, if necessary, collect samples of (potential) pests and/or damaged (parts of) cultivated plants for later identification; and
- Record the scouting results using the recording units for the particular pest(s).

Nowadays, there are many tools and techniques available for the scout carrying out field monitoring – from rather simple to more complex ones. It is very important to be aware that the equipment and the method to be used depends on the context. Therefore, specific knowledge and the choice of adequate devices are required to monitor effectively and reliably.

In practice, for example, traps (light, coloured, pheromone etc.) are widely used to help monitor certain pests. If they are applied properly, they will be suitable tools for checking population activity and getting information for setting the action threshold.

This brochure frequently mentions pheromone traps as the recommended trap types in monitoring. In light of this, the most important instructions in connection with their use are summarized as follows:

- Carefully choose the target species that should be trapped in your field;
- Search for information (literature, local data etc.) about the time of emergence of the species, and set the traps in the field 1–2 weeks prior to the expected start of emergence;
- Use original traps and lures (and keep the lures in a deep freezer before use);
- Assemble the traps on the spot;
- Read the specific instructions for setting the pheromone trap (e.g. crop height);
- Consider the size of the area when determining the number of traps to be set (at least two traps for the same species located at min. 10–15 m apart are recommended in a given crop);
- Check and record the catches at regular intervals and as frequently as possible (at least once a week);
- Change traps and/or their components (e.g. sticky insert, lure) according to the specific instructions, and do not reuse them later; and
- Remove all traps from the field when the period of observation (trapping) is finished.

Integrated pest management of major diseases and pests in grapevine

Disease: Downy mildew of grapevine

Pathogen: *Plasmopara viticola*

Downy mildew of grapevine, caused by fungal-like oomycete *Plasmopara viticola*, occurs in most parts of the world, where grapes are grown. It is native to North America, but its introduction in Europe around 1875 caused severe damage all over Europe, destroying all the vineyards in its path. Downy mildew is a highly destructive disease of grapevines in all grape-growing areas of the world where there is spring and summer rainfall at temperatures above 10^{0} C. Crop losses in individual years can be 100 percent if the disease is not controlled during favourable weather. Early infection of young bunches can lead to significant crop loss, whereas, severe leaf infection affects the source-sink relationship in the vine and may lead to defoliation and possible sunburn or lack of fruit ripening.

Hosts: All cultivars of grapes in the species *Vitis vinifera* and many *Vitis* intraspecific hybrid cultivars. Susceptibility within the North American species *Vitis labrusca*, varies from highly susceptible to resistant.

Symptoms and signs:

Downy mildew attacks all green parts of the grapevine (leaves, inflorescence, bunches, berries and shoots).

Leaves

The symptoms on leaves vary with leaf age. On young leaves (in spring), the disease will appear on the upper surface as small yellow spots known as oil spots. These spots are about 10 mm diameter, with a brownish-yellow halo. Spots tend to grow as they mature and the halo fades. As they enlarge they may appear to cover most of the leaf, especially if there is more than one spot on the leaf. After warm humid nights, a dense, raised, white cottony growth develops on the underside of the yellow oil spots. This is commonly referred to as 'white down'. As the spots age naturally, or after a sporulation event or hot weather, their centres dry out and become a reddish brown leaving an outer ring of yellow. The fungus in this yellow ring remains active and given favourable conditions at night can produce a ring of 'white down' on this outer active edge.

Later in the growing season (late summer and autumn) on mature leaves, leaf infections will appear as small, angular, yellow spots that are limited in growth by veins. These form a tapestry-like (mosaic) pattern that soon turn reddish brown. Defoliation can occur in severely affected vines.

Shoots

Infections on young shoots, stems and tendrils usually appear as oily brown areas. These oily patches may spread into leaf stalks, which turn brown and may die. After warm humid nights, these oily patches may be fully covered with white cottony growth ('white down').

Inflorescences, bunches and berries

Infection on inflorescences, young berries and bunches are also seen as oily brown areas. After suitable warm humid nights, they may be fully covered with white down. Infected inflorescences and young bunches rapidly turn brown and decline. Infected young berries stop growing, harden and may later develop a purple hue. They turn dark brown, shrivel and fall from bunches.

Berries become resistant to infection when they are pea size (5–6 mm diameter). However, they may still be killed if the berry or bunch stems become infected. They may also be prone to sunburn and fail to ripen if defoliation occurs from leaf infection.

Pathogen biology:

The pathogen survives the winter period as oospores embedded in dead leaves and other host tissue on the vineyard floor. Oospores may be released from the decaying plant material onto the soil surface. Oospores represent the primary inoculum and may overwinter in leaf litter or may be released into the soil as leaves decay. They generally begin to germinate in significant numbers shortly after bud break of grape, and populations of oospores may continue to germinate for the entire growing season in some regions. The conditions necessary for oospore germination are wet soils with temperatures above 10 °C. An additional rule of thumb in most regions includes rainfall of at least 10 mm in a 24-hour period to satisfy the requirement of soil wetness.

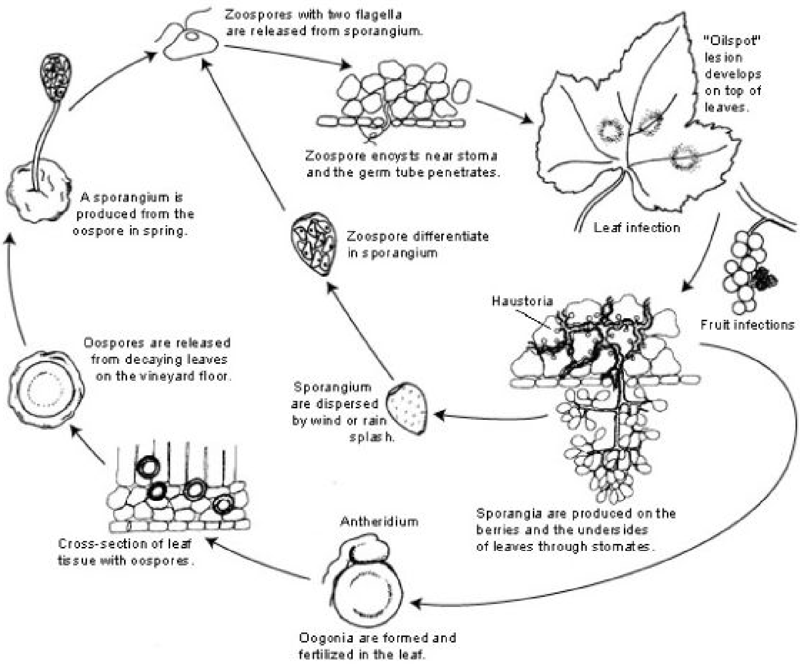


Figure 1. Disease cycle of *Plasmopara viticola*

(Drawing courtesy of Gavin Ash, Charles Sturt University, Wagga Wagga, New South Wales, Australia).

Oospores form a single germ tube terminating in a sporangium. Zoospores form within the sporangia and are then released. Zoospores germinate and penetrate the plant only through functioning stomata, i.e. only on green host tissue. Sporangia and zoospores are easily desiccated. They die within 5 to 7 hours of exposure to low humidity and sunlight, so most infection occurs in the morning, soon after their release. However, they may survive on leaf surfaces for more than 24 hours under cool humid conditions. Sporangia also serve as a means of secondary spread of the pathogen. Sporangia are produced on sporangiophores that emerge through stomata of infected leaves and other grapevine tissues (e.g. bunches). Production of sporangiophores and sporangia requires 95 to 100 percent relative humidity and at least 4 hours of darkness at temperatures initially exceeding 12 ^{o}C. Sporangia are dispersed to new infection sites by rain splash and/or wind. Zoospores released from the sporangia swim in free water on the grapevine surface and encyst near a stoma. Zoospores then germinate and penetrate through a stoma by means of a germ tube. Sexual reproduction occurs towards the end of the season. The resulting oospores are thick-walled and serve as survival spores.

The incubation period (the time from infection to appearance of new symptoms) varies from 5 to 21 days depending on temperature, humidity and variety susceptibility. The incubation period is shortest (~5 days) at mean temperatures from 20–25 ^{o}C. At mean temperatures of 12 ^{o}C or lower, the incubation period is 14 days or longer.

Monitoring:

Good management of downy mildew is reliant on good monitoring of favourable weather conditions for primary and secondary infection events and of the disease progress in the vineyard. Automatic weather stations can be used wherever possible for monitoring and predicting weather events. Weather stations collect information on temperature, rainfall, leaf wetness and humidity (suitable for downy mildew) and process the data for the likelihood of a primary or secondary infection event.

In regions where weather stations are not available, farmers can use the 3–10 rule (10:10:10) to predict possible primary infections. The 3–10 rule is based on three conditions that have to be met during the 24 hours: at least 10 cm of shoot growth, 10 mm rainfall and temperatures of 10 . If 10:10:10 conditions are not detected, it is very unlikely that a primary infection has occurred in the vineyards. If 10:10:10

conditions are met, then a primary infection may have occurred. This can only be confirmed by the appearance of oil spots. For this reason, monitoring in the vineyards should start 3–4 weeks after budburst (when shoots are approximately 10 cm long) and should be repeated every 7–14 days when weather conditions are favourable for downy mildew development. Secondary infection conditions are quite different to primary infections. For a secondary infection to occur there must be existing oil spots in the vineyard or located nearby. Secondary infections occur when existing oil spots sporulate to release new spores into the vineyard. The disease spreads through secondary infections on warm, wet nights, when the temperature is 13 ^{o}C or more, and several hours of leaf wetness occurs around dawn.

Some general guidelines on vineyard monitoring include:

- Monitor for possible source areas of downy mildew infection such as wetter, more sheltered parts of the vineyard (for example near windbreaks and sheds), vines with dense canopies or areas that have previously been infected.
- Inspect both sides of 200 vines per hectare by scanning the foliage between mid-morning and mid-afternoon.
- Spend about 30 seconds per vine. Less time will be required early in the season when vine canopies are small. Focus on the canopy near the ground in lower lying areas where the soil may remain wet for extended periods. The disease is difficult to detect in dense shaded canopies. The foliage may need to be parted to scan the inner leaves. Use a hand lens to check suspect spots on leaves for evidence of the fungus.
- More than two oil spots per 50 vines would be considered a risk to the vineyard.

Disease management:

Cultural practices

When establishing vineyards, the location, drainage, type of irrigation and trellising system should all be selected to reduce the risk of disease. Because moisture favours the development of downy mildew, grapevines should be established in well-drained sites with good air movement. Canopy management practices that encourage air movement will help to dry out the leaves and improve sunlight and spray penetration. This will help to prevent infection. Such practices include:

- Lower planting density
- Trellising and pruning to open the canopy
- Shoot training to open the canopy
- Vine trimming and hedging
- Lateral shoot thinning
- Leaf plucking (removing leaves from the vine in the area around the fruit clusters)

Vegetative growth may also be managed by the selection of appropriate rootstocks prior to planting and by careful application of fertilizers (for example nitrogen). Excessive growth leads to dense shaded canopies that may encourage the development of downy mildew. Reducing leaf litter may reduce the amount of overwintering inoculum.

Genetic resistance

All cultivars of *Vitis vinifera* (the European species) are considered susceptible to downy mildew, although cultivars such as Chardonnay, Pinot Noir, and Sultana are considered more susceptible than Cabernet Sauvignon and Semillon. Several North American species show resistance to downy mildew (e.g. *V. labrusca* and *V. rotundifolia*), although the *V. labrusca* cultivars Niagara and Catawba are highly susceptible.

Biological control

In North Macedonia, a biological pesticide based on orange oil was recently registered for the control of wide range of insects, mites and fungal diseases, including for the control of *Plasmopara viticola* in grapevine (see table below).

Table 1. Biological pesticide based on orange oil for control of insects, mites and fungal diseases in grapevine

Active ingredient	Rate of application	PHI* (days)	Comments
Orange oil	1.6 litres/ha	1	Maximum 6 sprays/season

* PHI – Pre-harvest interval

Chemical control

Both pre-infection (protective) and post-infection (systemic or penetrant) fungicides are widely used for the control of downy mildew. Pre-infection (protectant) fungicides help to prevent downy mildew zoospores from entering the green vine tissue. Pre-infection fungicides have limited movement from the areas where they are deposited and any new growth after the spray has been applied will not be protected. Spray coverage needs to be excellent to adequately protect all green tissue. In particular, sprays need to be applied to the underside of leaves and to the back of bunches. Post-infection fungicides are systemic and penetrate the vine tissue killing the downy mildew fungus from within the vine tissue. Relying on post-infection fungicides requires careful monitoring of infections and has a greater risk of downy mildew becoming established. Post-infection fungicides work best when applied as soon as possible after an infection event – within five days of infection and before oil spots appear. No additional spraying should be required until weather conditions favour another possible infection event. In this situation, pre-infection fungicides may be used again. These fungicides are best used in conjunction with a forecasting programme, which assesses the likelihood of infection from canopy micro-climate data.

In North Macedonia, there are many fungicides registered for the control of downy mildew in grapevine, based on different active ingredients or a combination of active ingredients such as: copper hydroxide, copper oxide, copper oxychloride, methiram, dithianon, dithianon + potassium phosphonate, dimethomorph + mancozeb, ametoctradin, dimethomorph + folpet, dimethomorph + ametoctradin, mancozeb + mandipropamid, mandipropamid + zoxamide, metalaxyl-m + mancozeb, metalaxyl-m + folpet, metalaxyl-m + copper oxychloride, benalaxyl + folpet, benalaxyl + mancozeb, cymoxanil + mancozeb, iprovalicarb + copper oxychloride, fluopicolide + fosetyl aluminium, disodium phosphonate + cyazofamid, fosetyl aluminium + folpet, fosetyl aluminium + folpet + iprovalicarb, cymoxanil + famoxadone, valifenalate + mancozeb, valifenalate + folpet, azoxystrobin + folpet, azoxystrobin.

Plasmopara viticola is considered as a high risk pathogen for the development of resistance. The frequent use of one fungicide or one group of fungicides increases the risk of resistance developing to that fungicide or that group of fungicides. To reduce the risk of resistance, always read the chemical label thoroughly prior to use.

Disease: Powdery mildew of grapevine

Pathogen: *Erysiphe necator* (syn. *Uncinula necator*)

Powdery mildew of grape, caused by the fungus *Erysiphe necator*, is an important disease of grapes worldwide. If uncontrolled, the disease can be devastating on susceptible varieties under the proper environmental conditions. Diseased vines show a reduction in vine size, grape yield and winter hardiness compared with healthy plants.

Hosts: The pathogen is an obligate parasite on genera within the family Vitaceae, including *Vitis*, *Cissus*, *Parthenocissus* and *Ampelopsis*. The most economically important host is grapevine (*Vitis*), particularly the European grape, *V. vinifera*, which is highly susceptible to powdery mildew.

Symptoms and signs:

Powdery mildew can infect all green parts of the grapevine (leaves, shoots, canes and berries).

Leaves

On leaves, initial symptoms appear as chlorotic spots on the upper leaf surface that soon become whitish lesions. As spores are produced, the infected areas take on a white, powdery or dusty appearance. Late in the season, small black round structures (chasmothecia) begin to appear on the white powdery lesions. Severe leaf infections can cause distortion, drying, and premature drop.

Shoots and canes

Symptoms of infection on green shoots appear as dark brown to black lesions. On the canes, an old infection appears as reddish brown areas.

Berries

An infection on the berries can appear as white and powdery, or dark and dusty. Powdery mildew can result in shrivelling or cracking of berries, which then dry up, or never get ripen. Berry infection may lead to further infection by spoilage microorganisms that reduce the quality of wine, even if the powdery mildew infection is mild.

During the summer and autumn, the fungus produces small black round structures (chasmothecia) on all infected parts of the grape, to overwinter.

Symptoms of powdery mildew in grapevine

Pathogen biology:

The powdery mildew fungus overwinters as hyphae inside dormant buds, or as chasmothecia (spore-bearing structures) in bark or on canes, leftover fruit, and leaves on the ground. Chasmothecia are the most important sources of overwintering inoculum in most production areas. In the spring, ascospores are released from the chasmothecia and are carried by rain or wind to susceptible grape tissues. The spores germinate on any green surface of the developing vine, resulting in primary infections. After infection, the fungus colonizes the plant tissue and produces another type of spore (conidia) on the surface. The conidia and fungal mycelium give a powdery or dusty appearance to the infected plant parts. Conidia serve as secondary inoculum for new infections during the remainder of the growing season. During the summer, chasmothecia form on infected plant surfaces.

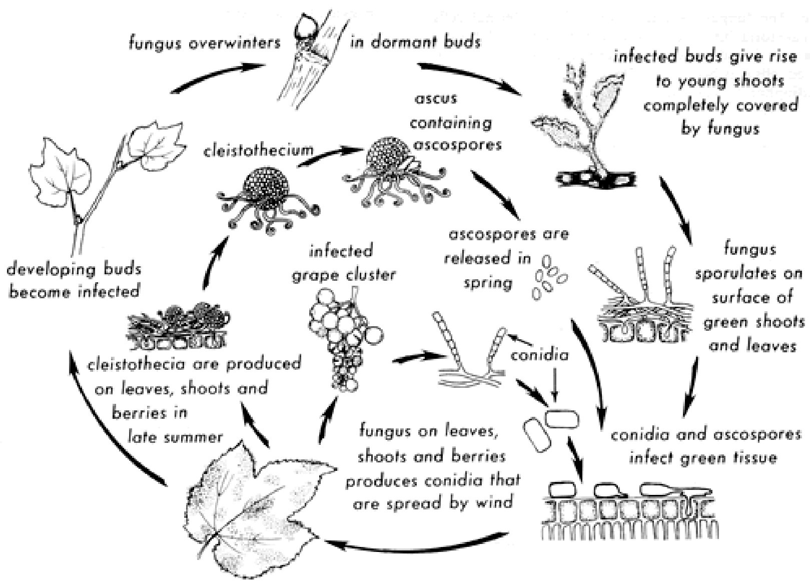


Figure 2. Disease cycle of *Erysiphe necator*

(©Albury Organic Vineyard)

When hyphae from dormant buds serve as the primary inoculum, the new tissue is infected when the bud breaks dormancy. These are called “flag shoots” that will produce conidia that will spread to adjacent shoots. The powdery mildew fungus, unlike downy mildew, does not require free moisture for its infection and disease development, but relative humidity between 40 and 100 percent and temperatures between 6 and 32 °C. Higher temperatures inhibit the development of the powdery mildew fungus. A relative humidity of 40 to 100 percent is conducive to spore germination and infection. This means that powdery mildew can become a serious problem even when it is too dry for other diseases to develop. Low, diffuse light also favours powdery mildew development.

Monitoring:

Without careful monitoring in place in the vineyard, it is possible for several cycles of powdery mildew infection to occur before symptoms are first detected, as the life cycle from spore germination to spore production is short (five days) under optimum conditions. However, if no disease is found by careful monitoring, the need for pesticide spraying can be reduced or eliminated.

Farmers should look for powdery mildew symptoms principally in blocks where the disease has previously been a problem, and in areas where vines may be dense or sheltered. This is especially important after mild cloudy weather with low to moderate light levels.

Monitoring should start from budburst and should continue at approximately two-week intervals for symptoms detection. Early in the season, farmers should look for flag shoots and powdery mildew leaf spots, which are most readily detected between 3–8 weeks after budburst, before the canopy closes. Flowering and fruit set is a critical period in the management of powdery mildew, and for that reason monitoring should occur on a weekly basis during these stages.

Some general guidelines on vineyard monitoring include:

- Inspect 200 vines per hectare for an accurate assessment of infection levels. Briefly examine as many leaves and later bunches as possible spending about 30 seconds per vine.
- Check outer leaves as well as inside the canopy where less light penetrates;
- Use a hand lens to check suspect patches on leaves for signs of fungal growth and resting spores (chasmothecia);
- Orientate leaves at an angle to the sun to make powdery mildew easier to identify on the surface of leaves; and
- Mark infection sites to allow later assessments of disease spread and the effectiveness of control treatments.

Disease management:

Cultivar selection

Cultivars of *Vitis vinifera* and its hybrids (French hybrids) are generally much more susceptible to powdery mildew than are native American cultivars, such as Concord. Cultivars that are highly susceptible to powdery mildew include: Cabernet Franc, Cabernet Sauvignon, Chancellor, Chardonnay, Chelois, Einsett Seedless, Gewurtztraminer, Jupiter, Leon Millot, Limberger, Merlot, Moore's Diamond, Muscat Ottonel, Pinot Gris, Pinot Meunier, Pinot Blanc, Pinot Noir, Riesling, Rosette, Rougeon, Sauvignon Blanc, Seyval, Vidal Blanc, Vignoles, and Villard Noir. Cultivars that are only slightly susceptible to powdery mildew include: Canadice, Cayuga White, Chambourcin, Cynthiana/ Norton, Ives, Marquis, Mars, Melody, Steuben and Traminette.

Cultural practices

Planting locations with good airflow are preferable, because the canopies at these locations will dry faster. Avoid planting grapevines in low or shady areas. There are also several different management practices that can help reduce or prevent powdery mildew. Such practices increase light penetration and reduce relative humidity in the plant canopy. Do not crowd the plants together when planting or training vines. A high canopy designed with air ventilation will be preferable to a canopy that has low ventilation and high leaf density. Airflow and ventilation will discourage mildew growth. Selective pruning of overcrowded plantings and removing leaves are the recommended cultural practices to increase light penetration and the circulation of air; this also decreases relative humidity and infection. Do not compost infected plant debris. Avoid nitrogen fertilizer applications in late summer to limit the production of succulent tissue. Water early in the morning to let the tissue and soil dry as quickly as possible. Avoid overhead watering to reduce relative humidity.

Biological control

There are several registered biofungicides for control of *Erysiphe necator*, available on the market in North Macedonia, based on different active ingredients (see table below).

Table 2. Registered biofungicides for control of Erysiphe necator in North Macedonia

Active ingredient	Rate of application	PHI* (days)	Comments
Bacillus subtilis QST 713	8 litres/ha	0	Maximum 6 sprays/season
Bacillus pumilis QST 2808	5 litres/ha	0	Maximum 6 sprays/season
Laminarin	2 litres/ha	0	Maximum 7 sprays/season
Orange oil	1.6 litres/ha	1	Maximum 6 sprays/season

* PHI – Pre-harvest interval

Chemical control

There are many fungicides on the market that can be used for managing powdery mildew. For best results, fungicide treatments should begin before the overwintering fungus can infect new growth. The first few treatments are the most important and should be applied at appropriate intervals, starting at bud break or early shoot growth. A powdery mildew index (PMI) model may be used to determine appropriate treatment intervals because frequency will depend upon weather conditions and the choice of fungicide. Alternating fungicides with different modes of action is essential to prevent pathogen populations from developing resistance to classes of fungicides. This resistance management strategy should not include alternating or tank mixing with products to which resistance has already developed.

In North Macedonia, there are many fungicides registered for the control of powdery mildew in grapevine, based on different active ingredients or a combination of active ingredients such as: sulphur, meptyldinocap, myclobutanil, penconazole, tebuconazole, fenbuconazole, tetraconazole, pyriofenone, difenoconazole + cyflufenamid, azoxystrobin, azoxystrobin + folpet, fluxapyroxad, metrafenone, proquinazid, boscalid + kresoxim-methyl, tebuconazole + fluopyram, spiroxamine + fluopyram, tebuconazole + spiroxamine + triadimenol, trifloxystrobin + tebuconazole, spiroxamine.

Disease: **Botrytis bunch rot (Grey mould of grape)**

Pathogen: ***Botrytis cinerea***

Botrytis bunch rot, caused by the fungus *Botrytis cinerea*, is a major disease of wine and table grapes worldwide. It can cause a serious reduction of yield and quality of table and wine grapes, with high economic losses in some locations or years. In wine grape production, the most serious damage results from modified chemical composition of diseased berries resulting in wines that have off-flavours, are fragile, and are more sensitive to oxidation and bacterial contamination. Moreover, the disease can develop on grapes after harvest, during long-distance transport, cold storage and shelf-life.

Hosts: *Botrytis cinerea* is a non-specific pathogen, which can infect more than 200 hosts including many cultivated crops, but also many horticultural and wild plants.

Symptoms and signs:

Bunch rot often begins when blossoms become infected during rainfall. The pathogen invades the flower parts and becomes dormant until veraison. At veraison, individually infected berries in the cluster turn brown on white cultivars or reddish on red and black cultivars due to enzymes produced by the fungus. If temperatures are moderate and moisture is high, epidermal cracks will form, in which fungal growth produces mycelium and spores, resulting in the characteristic grey, velvety appearance of infected berries. The fungus can then spread from berry to berry causing a nested appearance of infected berries. If conditions remain favourable, the disease can result in a high percentage of berries being rotten. Berries may shrivel and become mummified if hot conditions occur after infection. Symptoms of grey mould can appear also on the leaves, as dull green spots which turn brown and necrotic. Infection on pedicel and rachis appear as brown spots that turn black and cause shrivelling and drop off the cluster.

Symptoms of Botrytis bunch rot

Pathogen biology:

Botrytis cinerea overwinters in plant debris and mummified fruit as sclerotia and mycelium, both on the ground and on canes.

Early season infection

In the spring, sclerotia and mycelium produce conidia (spores) which can infect flowers, shoots, leaves and fruit. The overwintered debris with the highest sporulation potential is the mummified fruit, followed by the fruit rachis, canes and leaf litter.

There are two types of early season infection:

1. Latent infection of flower parts leads to fruit infections that remain dormant in early summer. As fruit ripens and berries begin to soften, the fungus becomes active again, causing rot. Flowers can become infected through the stigma and scar tissue on the receptacle (tip of the pedicel) left by the detachment of the calyptra during bloom.

2. *Botrytis cinerea* is a necrotrophic fungus, which means that is a very good colonizer of dead and dying plant tissue. Infected flower remnants and aborted fruit that become trapped in clusters become sources of fruit infection as bunches close and ripen.

Late season infection

Fruit infection usually begins in berries with five to eight percent sugar content (at veraison), with berries remaining susceptible up to harvest, as well as post-harvest. Fruit become increasingly susceptible as they mature. Abundant conidia are produced on infected fruit, leading to secondary spread to adjacent berries in a cluster and to nearby clusters. Rot spreads quickly in compact clusters where maturing berries are compressed together. Spread of the spores is supported by wind, summer rains, overhead irrigation, heavy dew and juice from cracked berries. Fruit damage caused by birds, insects, hail, sunscald and powdery mildew creates entry points for the fungus and can greatly increase losses due to bunch rot. Although *Botrytis cinerea* conidia can germinate and infect between 1–30 °C, optimal temperatures for infection are between 15 and 20 °C, in presence of free moisture or high humidity (above 90 percent).

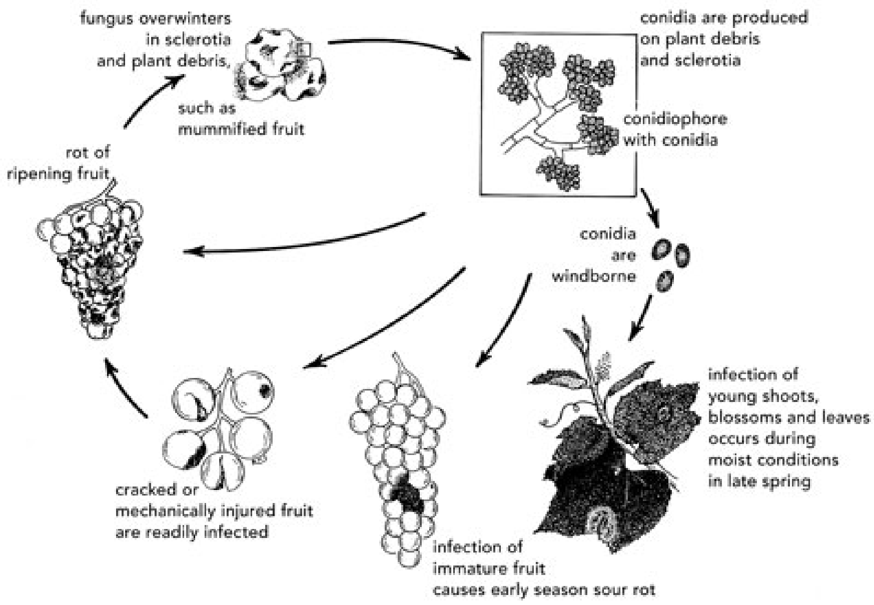


Figure 3. Disease cycle of *Botrytis cinerea* in grapes

(©Gulp Mag)

Disease management:

Control of Botrytis bunch rot is best achieved through an integrated approach that considers the management options listed below.

Cultural practices

Sanitation

Sanitation is an important foundation for all effective disease control. Clusters left on vines or on the soil from the previous season can be a source of inoculum for the following spring. Removing the clusters from vines at pruning and placing them out of vineyard or into the row middles where they can be incorporated deeply into the soil can significantly reduce the inoculum.

Canopy management

Since *Botrytis cinerea* spores have rigid environmental requirements (free moisture or high humidity) for germination and growth, control can be obtained by creating a canopy microclimate that is less conducive to disease development. The objective is to expose the grape clusters to increased air and light penetration so that they dry out more quickly after being wet.

Canopy management can be directed to the canopy or to overall growth of the vine. Vineyard design decisions such as rootstock and cultivar selection, trellis type, training or pruning method, and plant spacing can affect canopy density. Row orientation can influence the fruit microclimatic parameters of wind speed, humidity, and temperature, which can alter the evaporative potential of the canopy and fruit. Careful planning to match a vineyard with the anticipated vigour of the site conditions will produce balanced canopies with moderate shoot vigour that optimizes leaf and cluster exposure to light and air. Vineyard design decisions generally have long-term effects on vine canopies that are not easily changed for the lifetime of the vineyard. Other growing practices, such as irrigation and nutrition, can be altered annually. These practices can influence canopy density by increasing or decreasing the rate and amount of shoot and lateral growth. In general, the denser the canopy is (more layers of leaves surrounding the clusters), the more optimal the conditions for development of Botrytis bunch rot will be. With careful management, it is often possible to reduce the density of the canopy, which in turn helps alleviate disease pressure. Shoot thinning, shoot positioning, leaf removal, and hedging can increase air and light penetration to the clusters when canopies are too dense. Shoot thinning is a common practice for table and wine grape production. It can reduce the density temporarily. The lateral shoot growth promoted by this practice can often increase canopy density at bloom to a level similar of a non-thinned vine.

Removal of leaves and laterals around the clusters creates a microclimate within the canopy that is less conducive to development of Botrytis bunch rot. In many cases, the level of disease control obtained can equal or exceed the level of control from fungicide applications. When conducted immediately after fruit set, this practice can also physically shake off some of the floral debris that can be infected with Botrytis, reducing this source of inoculum. Leaf removal should be done on the side of the canopy that receives morning sun (east or north side) to reduce fruit damage from sunburn. In warmer areas, do not remove excessive numbers of leaves. If leaves are removed in the period after fruit set to when berries are pea-size, the berries acclimatize readily to the sunlight and develop a thick cuticle and epicuticular wax that help prevent sunburn as well as Botrytis infection. The microclimatic conditions in the canopy that most affect development of Botrytis are those that affect the duration of free water on the berries. When leaves around the clusters are removed, the air circulation around the clusters is increased. This contributes to the drying of the clusters after they have become wet.

In an unusually wet year, the benefits of microclimate modifications are reduced because of the impact of the macroclimate, and it may be necessary to increase applications of fungicides. If fungicide applications are necessary, however, proper canopy management will continue to be of benefit because more fungicide will be deposited on the more-exposed clusters.

Irrigation

Choosing the right type, timing, or level of irrigation can help control bunch rots. For example, overhead sprinkler irrigations near harvest can increase Botrytis levels of infestation. If this is the only type of irrigation available, vary the time of day or length of application to accelerate drying of the clusters. The length of time when free moisture is on the clusters should not be greater than 15 hours, including the time it takes to dry the clusters completely. Other types of irrigation should also be used judiciously. High levels of drip or furrow irrigation encourage dense canopy growth and provide moist conditions through increased relative humidity, which is favourable to sporulation. Growers should determine the optimal levels of irrigation at each vineyard site that will result in canopy development that produces desirable yields without excessive shoot or lateral growth.

Prevent berry damage

Reducing feeding wounds caused by birds, grape moths or other berry-feeding insects can significantly reduce Botrytis bunch rots. Controlling powdery mildew also reduces berry scarring that can result in cracking during later growth stages, leading to increased levels of bunch rot. Careful monitoring and management of injuries caused by insects and diseases are key components in reducing bunch rot infections. Also, avoid any physical damage to the berries during canopy and cluster management operations.

Genetic resistance and cultivar selection

Several factors are involved in a grape berries' resistance to *B. cinerea* infection. Many red cultivars contain compounds that inhibit the fungus. Also, the berry skin provides a mechanical barrier to infection, as does the epicuticular wax on the surface of the berry. Wax formation is inhibited when berries grow in contact with other berries or when the environment is shady and relative humidity is high. These contact areas have been shown to be more susceptible to infection by *B. cinerea*. Research has shown that cultivars with very tight clusters have more severe Botrytis bunch rot symptoms, so choose cultivars with open clusters and avoid tightly clustered ones.

Biological control

Several biofungicides are registered for control of Botrytis bunch rot in North Macedonia, based on different active ingredients (see table below).

Table 3. Biofungicides registered for control of Botrytis bunch rot in North Macedonia

Active ingredient	Rate of application	PHI* (days)	Comments
Bacillus subtilis QST 713	8 litres/ha	0	Maximum 6 sprays/season
Trichoderma atroviride SC1	0.2 kg/ha	0	No restrictions
Pythium oligandrum M1	0.25 kg/ha	0	No restrictions
Oil extract of *Melaleuca alternifolia*	2 litres/ha	0	No restrictions
Laminarin	1–2 litres/ha	0	Maximum 7 sprays/season
Eugenol + Geraniol + Thy-mol	4 litres/ha	7/3**	Maximum 4 sprays/season

* PHI – Pre-harvest interval

Chemical control

Key timings (growth stages) for fungicide applications against Botrytis are bloom, just before bunch closing, veraison and pre-harvest. Sprayings in bloom and at bunch closing limit the establishment of primary infections, while veraison and pre-harvest sprays limit the spread of the disease. If fungicide use is necessary near harvest, remember to check the pre-harvest interval (PHI) of that fungicide to be sure it can be used close to harvest.

The number of spray applications necessary to control bunch rot depends upon disease pressure in the vineyard and on weather conditions, as well as on other factors such as cultivar susceptibility. Fewer applications may be needed if weather is very dry and/or disease pressure is low. Use a full programme in vineyards where bunch rot was a serious problem in the previous year, and where sanitation measures were not taken after harvest. The number of sprays can be reduced in vineyards with a history of low disease levels and for all vineyards in dry years.

In North Macedonia, there are several fungicides registered for the control of Botrytis bunch rot, based on different active ingredients or a combination of active ingredients such as: boscalid, cyprodinil, fenhexamid, isofetamid, pyrimethanil, cyprodinil +fludioxonil and boscalid + pyraclostrobin.

Disease: Phomopsis cane and leaf spot

Pathogen: *Phomopsis viticola*

Phomopsis cane and leaf spot is a widely recognized grape fungal disease around the world, caused by the fungus *Phomopsis viticola*. The disease is favoured by extended periods of rainfall during or shortly after budburst that can lead to yield losses of up to 30 percent. Yield loss can occur through reduction of viable canes, reduced budburst and bunch infection. This leads to reduced production of bunches, lower quality of fruit and reduced yields.

Hosts: *Vitis vinifera* is the primary host of this pathogen. Secondary hosts are other *Vitis* spp. including sand grape (*Vitis rupestris*), fox grape (*Vitis labrusca*) and Virginia creeper (*Parthenocissus quinquefolia*).

Symptoms and signs:

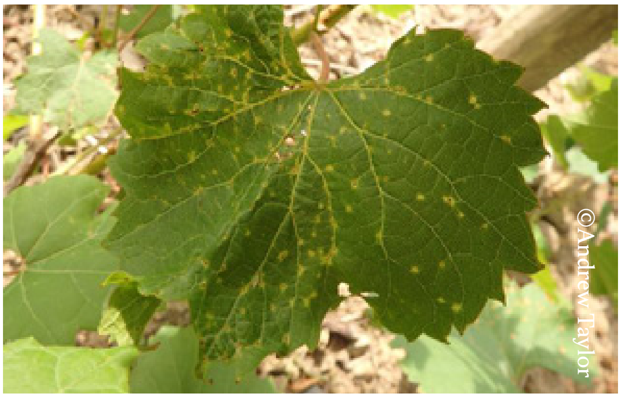
Phomopsis viticola can infect most parts of the grapevine (leaves, stems, inflorescences, canes, rachis and berries), but the most common symptoms appear on the leaves and shoots.

Leaves

In spring, small dark spots (about 1 mm in diameter) surrounded by 2–3 mm yellow halos develop on the lower leaves of the shoots. Leaf spots remain small and can become numerous. If too many spots develop on one leaf, the leaf will turn yellow and fall off. Leaf petioles can also have black spots and lesions.

Green shoots

First symptoms on green shoots appear as small spots with black centres, usually on the lower internodes. Spots gradually expand and elongate to form black crack-like lesions up to 5–6 mm long. Lesions can coalesce, deepen and become large cracks that cause shoots to become girdled. Girdled shoots can fail to mature or become stunted and die. Severe infections can lead to dwarfing, deformation and death of infected shoots, which break off near the base. Weakened older shoots (30–60 cm long) can break under a heavy crop load or in strong winds.



Berries

Phomopsis viticola can infect berries throughout the entire growing season. Symptoms of the infection are not visible until close to the harvest. Infected berries start to rot – they become light brown and in the end shrivel – when spores break through the berry skin.

Canes

In winter, infected canes develop bleached white areas. Bleached areas, particularly those around the nodes, become speckled with small black spots (the resting structures of the fungus). These small black spots (pycnidia) contain spores.

Pathogen biology:

The fungus overwinters in the buds, bark and canes of infected vines. Spores are produced in black spots (pycnidia) on bleached canes. In spring, spores are spread by water and rain-splashed onto young, newly developed green shoots. Fungus infection depends on duration of wetness and temperature (1–32 °C). The possibility of infection increases when there is 100 percent relative humidity and an optimal temperature of 23 °C. Symptoms of Phomopsis cane and leaf spots infection on canes appear 21 to 30 days after the infection. During summer, the fungus is relatively inactive (when temperatures are above 30 °C). The fungus can persist for several seasons in the vine and, if left untreated, infected canes and spurs may produce spores for around three years.

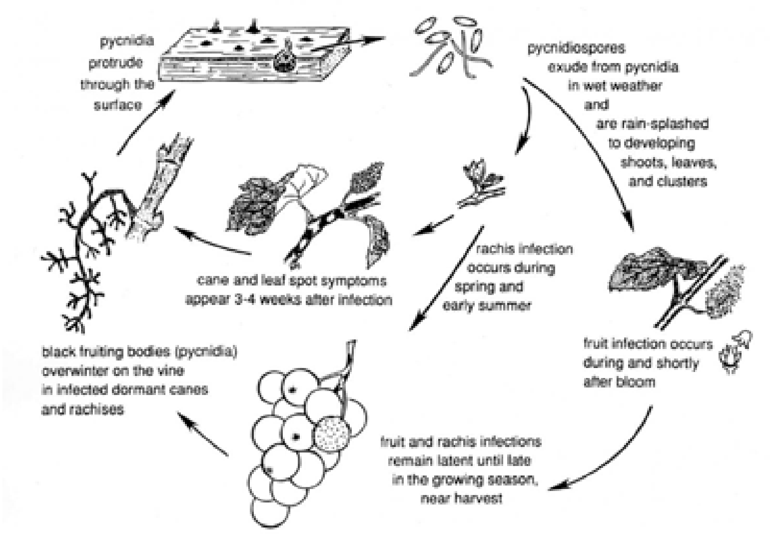


Figure 4. Disease cycle of *Phomopsis viticola*

(©Ohio State University Extension)

Monitoring:

Monitoring is critical to determining whether *Phomopsis viticola* is present in the vineyard. The majority of infection occurs during or shortly after budburst. Early detection and knowledge of any previous infections are critical for the control of the disease, as first chemical sprays are required at 50 percent budburst to avoid infection of newly emerged shoots.

Sheltered or low-lying parts of the vineyard and/or vines with dense canopies should be closely monitored. Vines showing symptoms of the disease should be monitored for several years after the last recorded infection.

In winter, look for bleached canes and spurs, with and without scarring. In the growing season, symptoms can be seen from budburst onwards. Inspect 200 shoots per hectare, particularly in parts of the vineyard where disease has occurred in previous seasons, and in low-lying areas. Briefly examine leaves and lower internodes on shoots. Later in the season, inspect rachis and bunches if long wet periods (20–30 hours) occur at flowering.

Begin monitoring for bleached and cracked canes around four weeks before budburst, particularly in areas where leaf and shoot symptoms were observed in the previous season. Infection occurs following ten hours of rainfall at optimum temperatures of 16–20 °C and prolonged leaf wetness, so monitor vines every 1–2 weeks starting from three weeks after budburst. Leaf spots usually appear about three weeks after infection; stem symptoms can take four weeks or more to appear.

Disease management:

Control of Phomopsis cane and leaf spot is best achieved through an integrated approach that considers the management options listed below.

Cultural practices

Always use grafting and planting material that is free from *Phomopsis viticola*. Consider removal of any infected canes or mummified bunches during pruning where practical. Prune off the diseased and dead wood from vines, remove from the vineyard (where practical) and bury or burn to reduce the amount of inoculum.

Canopy management practices can be used to encourage air movement, reduce humidity within the canopy, and improve the penetration of sunlight and access for fungicide application, thereby reducing the risk of disease. This may include reducing vine vigour by pruning to reduce bud numbers, using foliage wires to lift and hold shoots, or removing excessive shoots or foliage. Large numbers of unpruned canes (e.g. as a result of mechanical hedge pruning) can provide a significant source of inoculum for the following season.

Chemical control

If Phomopsis spot is detected or has previously been a problem, appropriate registered fungicides must be applied before the fungus produces spores and has the chance to infect new growth.

One application during dormancy (3–4 weeks before budburst) inhibits spore production. If the disease has been a problem in the previous one or two seasons, a protectant fungicide should be applied at 50 percent budburst and two weeks after budburst. If wet conditions persist after budburst, further fungicide applications may be required to prevent further infection. Note that fungicides registered for *Phomopsis viticola* are protectants only and do not have an effect if applied after disease symptoms appear.

In North Macedonia, there are several fungicides registered for the control of Phomopsis cane and leaf spot in grapevine, based on different active ingredients or a combination of active ingredients such as: copper hydroxide, copper oxide, copper oxychloride, dithianon, azoxystrobin + folpet, fosetyl aluminium+folpet, dithianon + potassium phosphonate.

Disease: Esca disease complex

Pathogen: Esca is caused by a complex of several different fungi such as *Phaeoacremonium aleophilum*, *Phaeomoniella chlamydospora* and *Fomitiporia mediterranea*.

Esca disease has become increasingly devastating during the past three decades in most grapevine production areas around the world. In the past, this disease manifested itself mainly in adult plants but currently it is frequently found in young plants. The spread of the fungal agents is mainly linked to the dissemination of spores both in winter and during the vegetative phase. In both periods, infections are aided along by the presence of wounds.

Hosts: All species of *Vitis* spp. and varieties of *V. vinifera* are susceptible to Esca but vary in degree of susceptibility. Varieties such as Cabernet Sauvignon, Sangiovese, Trebbiano Toscano, Thompson Seedless, Sauvignon blanc, Mourvèdre, Ugni blanc, Cinsault, Trousseau or Temperanillo (sin. Tinta Roriz or Aragonez) are more prone to express both foliar and wood Esca internal symptoms in comparison to Merlot, Pinot Noir, Carignan, Roussane, Montepulciano.

Symptoms and signs:

Grapevines can display two types of Esca forms, acute or chronic, in unpredictable periods and ways.

<u>The acute form</u>, which is common in Europe, is apoplexy where the plant, in the space of a day, passes from full and healthy growth (totally or just parts of the vine) to being completely withered or dry. Green, healthy-looking leaves turn pale green, then grey-green, and quickly wither, drying up completely in a few days. Apoplexy is thought to be favoured by hot summers, in particular, when rainfall is followed by dry, hot weather. It may be connected with a rapid rise in the concentration and activity of toxic metabolites in the canopy when the rate of transpiration is high.

<u>The chronic form</u> comprises symptoms inside the trunk and larger branches, on the shoots and smaller branches, on the leaves, and on the berries. Symptoms on leaves consist of light green or chlorotic, rounded or irregular spots between the veins or along the leaf margins that usually spread outward to the distal parts of the shoots. The spots, initially small and scattered over the lamina, gradually expand and coalesce, become partly necrotic, and ultimately leave only a narrow strip of unaffected green tissue along the main veins. As the chlorotic tissue turns yellow-brown or red-brown, the diseased leaves assume a "tiger-stripes" pattern. Foliar symptoms may occur at any time during the growing season but are most prevalent during July and August. This form strikes new leaves and in many cases progresses throughout the season, until the entire plant dries out and results in partial or total production loss. On berries, small, round, dark spots (black measles) each bordered by a brown-purple ring, may occur. These fruit spots, which are better viewed on white cultivars, may appear at any time between fruit set and ripening. In severely affected vines, the berries often crack and dry. Symptomatic fruit is found only on shoots with symptomatic leaves, but you can find shoots with symptomatic leaves and no symptomatic fruit. On adult plants (eight to ten years and older), the most common internal symptom is white rot, which gradually changes the hard wood to a soft, friable, spongy mass. Rotted tissues appear creamy yellow or whitish, and in cross section are often bordered by a thick black or dark brown line separating rotted from non-decayed wood. The decay usually starts from a large pruning wound on the trunk extending into the woody tissue and either remains restricted to the older part of the wood or spreads along a sector in the woody cylinder.

It has been scientifically proven that Esca is caused by the production of mycotoxins by fungi that are responsible for the disease, linked with other abiotic factors such as the physiological state of the vine, weather, water conditions (excess or lack of water), nutritional imbalances (for example C/N ratio) and agronomic anomalies.

©Mia Cloete, 2015. Symptoms of Esca disease complex: a. Tiger stripe leaf symptoms; b. "Black measles" on berries; c. & d. White rot and internal wood symptoms; e. Leaf symptoms and decline; f. Apoplexy (acute form).

Pathogen biology:

Symptoms first become apparent in vineyards five to seven or more years old, but the infections actually occur in younger vines. The overwintering structures that produce spores (perithecia or pycnidia, depending on the pathogen) are embedded in diseased woody parts of vines. During autumn to spring rainfall, spores are released and wounds made by dormant pruning provide infection sites. Wounds may remain susceptible to infection for several weeks after pruning with susceptibility declining over time. After a pruning wound is infected, the pathogen establishes a permanent, localized wood infection, which cannot be eradicated by fungicide applications.

Vines are predisposed to the pathogens by stress, in particular water stress. Blocked xylem vessels aggravate water stress, leading to insufficient water and nutrient supply within the vine. This results in symptom expression, which usually becomes acute during periods of high-water demand. Symptom severity on leaves is directly related to the symptom severity in the trunk. Environmental factors and host stress such as malnutrition, poor drainage, soil compaction, heavy crop loads on young plants, planting of vines in poorly prepared soil, and improper plant holes also play an important part in the development of disease. The production of fungal toxins that are then translocated to the leaves and berries may also be involved.

Vines derived from infected mother plants are considered a significant source of plants infected with young Esca. Esca is considered to be the result of unprotected pruning wounds. In general, pruning wounds made early in the dormant period are much more susceptible than wounds made late in the dormant period.

Monitoring:

Monitoring in the vineyards should start in spring, when farmers should look for dead spurs or stunted shoots. During the summer, farmers should look for tiger stripe symptoms on leaves or completely dried vines.

Disease management:

Management starts with preventive practices in nursery mother blocks and propagation beds. Good management techniques, which include proper planting, irrigation, and fertility for young vines while avoiding devigourating stresses, both before and after planting, are very important for establishing a healthy and productive vineyard.

Cultural practices in the nursery:

- Strict sanitation and protection of all wounds from pruning to grafting will help protect vines during nursery production. Frequently disinfect pruning shears, hydration tanks, grafting machines, and callusing rooms.
- Grow mother vines in well-drained soil or on raised beds. Use drip irrigation that does not over-wet the root crown.
- Immediately after grafting, nurseries should dip vines into specialized waxes containing plant growth regulators or fungicide-impregnated formulations, which encourage graft union callus development while inhibiting fungal contamination.
- Soak dormant cuttings for 30 min. in hot water (50 °C). This has not always been effective and must be combined with other methods.

Cultural practices in the vineyard:

- Plant new vineyards in spring or autumn when water is not a limiting factor. Irrigate new plantings for a few years before switching to dryland production.
- When planting, sort out vines of poor quality. Do not plant vines that have weak or spindly growth or obvious problems such as crown gall.
- Avoid large pruning cuts when possible and avoid pruning during and before wet weather. Prune later in the dormant period. If delayed pruning is not feasible, for additional protection consider treating pruning wounds with a protectant. Keep in mind that all wounds made in the dormant season are susceptible to trunk diseases, including Esca.
- When making large cuts during wet weather, leave a stub several centimetres long to be pruned off later during dry weather (double pruning). Remove prunings from the vineyard and destroy them.

Biological control

Biological control in conjunction with other control tactics such as sanitation is the most current approach in the fight against Esca disease. *Trichoderma* sp. have been shown to help protect pruning wounds, basal ends of propagation material, and graft unions before infection. Recently, in North Macedonia, biological fungicide, based on *Trichoderma atroviride* was registered for control of *Botrytis cinerea*, as well as for control of Esca disease complex. This product contains spores of *Trichoderma atroviride* strain SC1. Following the application of this biofungicide directly on the pruning wounds or in the nursery during the production of young plants, the exposed wood will be rapidly colonized by *T. atroviride* SC1. As a result, the plant is protected against the entry of the pathogens. The application of this biofungicide is recommended during the whole life cycle of grape plants: in the nursery while processing the plant material and in the vineyard every year after pruning.

Chemical control

Chemical control is based on the protection of exposed wounds using fungicides in order to prevent grapevine infection. Sodium arsenite was considered the only effective fungicide available to reduce the impact of Esca complex disease. This fungicide was banned worldwide in 2003 because of its potent toxicity to all live forms, its carcinogenic effects on human lung and skin, high toxicity to environment and accumulation in the food chain. Alternative chemicals are the focus of researchers, in order to find an effective substitute product. Still, there are no registered chemical solutions for mitigating this disease. Its complexity makes it hard to study and to find adequate solutions.

Pest: *Lobesia botrana*

Common name: European grapevine moth

Lobesia (=*Polychrosis*) *botrana*, known as the European grapevine moth, is traditionally a major vineyard pest throughout Europe. *L. botrana* is a major cause of economic damage in grapes. Harvest losses of up to 40 percent can occur as a result of direct damage to fruit and subsequent fungal infections.

Hosts: Grape (*Vitis vinifera*) is the preferred host, but it has also been reported on blackberry, gooseberry, black and red currant, olive, kiwi, pomegranate and a number of other wild hosts.

Symptoms and damage:

In May and June, first generation larvae penetrate and feed on the flower clusters. Symptoms are not evident initially, because larvae remain protected by the top bud. Later, when larval size increases, each larva agglomerates several flower buds with silk threads forming nests visible to the naked eye, and the larvae continue feeding while protected inside. Second generation larvae (July–August) feed on green berries. Young larvae penetrate the berry and hollow them out, leaving the skin and seeds. Larvae secure the pierced berries to surrounding ones by silk threads to avoid falling. Frass (excrement) may also be visible. Each larva is capable of damaging between two and ten berries, and up to 20–30 larvae per cluster may occur in heavily-attacked vineyards. Third generation larvae (August–September) cause the greatest damage by webbing and feeding inside berries and within bunches, which become contaminated with frass. Additionally, feeding damage to berries after veraison exposes them to infection by Botrytis and other secondary fungi such as *Aspergillus*, *Alternaria*, *Rhizopus*, *Cladosporium* and *Penicillium*.

Moreover, damage is variety-dependent. Generally, damage is more severe on grapevine varieties with dense clusters, because this increases both larval installation and rot development.

Damage on berries (left) and inflorescence (right)

Description of the pest:

The adult moth is about 6 to 8 mm long. The forewings are a light, creamy white to tannish colour, with black, brown and grey mottling. The hind wings are a greyish colour. The wingspan is 10–13 mm. Females tend to be larger than males.

The pupae are a dark brown colour and usually 6 mm long.

Larvae are about 1 mm when hatched and can grow to about 15 mm long. The larvae are a pale, yellowish/whitish colour when newly hatched and usually become light green to light brown in colour.

The eggs are typically laid singly on the host plant and have a rounded, flat shape.

Adult (left) and larva (right) of *Lobesia botrana*

Pest biology:

Depending on the environmental temperature, the European grapevine moth can have up to four generations in its life cycle. In the climate conditions of North Macedonia it has three generations per year.

Pupae overwinter in diapause (a resting state) inside silken cocoons, found under the bark on the underside of cordons and arms, in soil cracks, or in hidden places on trellis posts. In the climate conditions of North Macedonia, adults of the first generation emerge from the end of March and can fly till the end of May (the flight peak is from the middle of April until the middle of May). Adult males emerge about a week before females. Adults remain hidden during the day, emerging to fly at dusk. Mating occurs in flight. Egg laying begins one or two days after mating. Eggs of the first generation are glued singly on flat surfaces on or near the flower cluster (e.g. on the bunch peduncle or on the flower calyptra). One female can lay approximately 100 eggs. Eggs hatch after ten days. The first generation larvae web flower parts together and feed on individual flowers and pedicels; they may enter the peduncle and cause the bunch to dry up. Larval development is completed in 20 to 30 days depending on temperature. Pupation occurs inside a webbed cocoon that may be found on the flower cluster, under the bark on cordons, or in soil cracks. Adults emerge 6 to 14 days after pupation. The flight of the adults from the second generation in our climate conditions begins from the middle or end of June and lasts until the middle of July. Eggs of the second generation are laid individually on shaded developing green berries. When berries are pea size, each larva ties several berries together with webbing and feeds on berry surfaces. Larvae penetrate mid-size berries where two berries touch or where the pedicel attaches, and feed internally. Around early veraison, pupae form as described for the first generation. The flight of the adults of the third generation occurs at the end of July or beginning of August and can last up to the beginning of October. Eggs of the third generation are laid on single berries around veraison. Shortly after hatching, larvae penetrate the berries where the berries touch each other and feed internally on ripening fruit. Larvae can be found inside one or more berries. Infested clusters contain webbing and excrement. A larva can fully excavate the berry leaving the seeds and somewhat intact berry "skin" full of excrement and loosely attached to the pedicel.

Monitoring:

Successful control of the grape moth requires constant monitoring of the vineyards. Monitoring is usually performed through:

- Visual checks

Visual checks should be conducted for each generation separately (egg laying, egg hatching, larvae emergence, infested clusters with webbing, berry damage etc.).

- Pheromone traps

One to two traps per hectare should be placed at the same height as the crops, in vineyards or on specific supports. Sex pheromones attract males and are used to monitor male flights. Place pheromone traps before bud break. Check traps weekly, recording the number of moths caught and removing trapped moths from the sticky trap bottom. Plot the weekly catches to determine initiation and peak of male flights in each generation. Continue monitoring with traps until the peak of the third flight.

Economic thresholds:

75 adults per pheromone in one week;

10–15 larvae on flower clusters in 100 randomly-checked flower clusters (for first generation);

5 larvae in 100 randomly-checked clusters (for second and third generation).

Pest management:

Integrated pest management is the best approach for managing *L. botrana*. This includes use of insecticides, bioinsecticides and sex pheromone-based strategies that disrupt mating. The latter is considered a more environmentally safe management approach.

Mating disruption (MD) technique is a biotechnical method that aims at preventing males from finding unmated females by saturating the atmosphere with artificial pheromone of the species through the use of sexual pheromone loaded dispensers. Thus, the method leaves the females unfertilized and incapable of laying viable eggs. Many studies have shown that the use of sexual pheromones (MD technique) can provide complete protection in varieties with short vegetation (ex. Cardinal variety) against European grape moth.

Insecticides should be applied ten days after the peak of the flight for every generation. One to two treatments should be performed for every generation.

In North Macedonia, there are many registered insecticides based on different active ingredients such as: delthamethrin, spinosad, chloranthraniliprole, chlorpiryfos-methyl, emamectin benzoate, abamectin, methoxyfenozide, indoxacarb, spinetoram.

There is also one registered bioinsecticide in North Macedonia for control of *Lobesia botrana*, based on *Bacillus thuringiensis* ssp. *kurstaki* strain PB 54.

Pest: *Eupoecilia ambiguella*

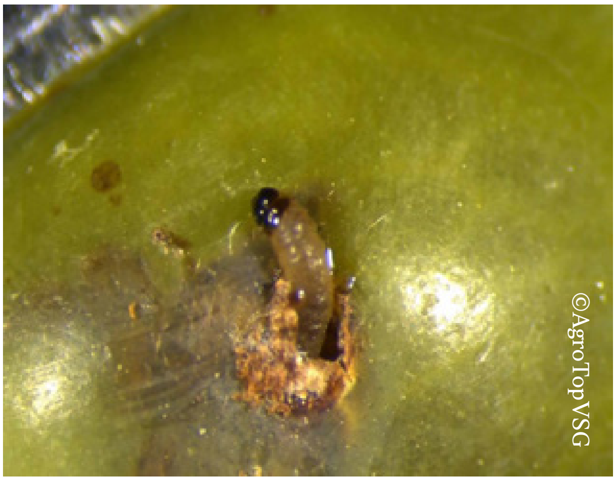
Common name: European grape-berry moth

The grape-berry moth may cause considerable damage. It is considered as one of the most destructive insect pest in many wine-producing areas. *Eupoecilia ambiguella* is found throughout the vine-growing countries of Europe and Asia. It seems to prefer cultivars that have green, yellow green or yellow skins as they are more heavily attacked than cultivars that are wine red or dark blue.

Hosts: The main host of this pest is genus *Vitis*, especially *Vitis vinifera*, but larvae are considered polyphagous.

Symptoms and damage:

Larval damage is similar to damage caused by *Lobesia botrana*. Larvae damage flowers, immature berries, and parts of the seed through direct feeding damage and secondary infections, caused by Botrytis bunch rot. Larvae of the first generation cause minor damage by feeding on flower buds, while those of the second generation cause the most damage by feeding on grape berries. The most significant losses are due to secondary infection of feeding sites on berries and clusters by *Botrytis cinerea*.



Damage on berries caused by *Eupoecilia ambiguella*

Description of the pest:

Eggs: The eggs are slightly elliptical and light yellow, measuring 0.6–0.7 mm in length.

Larvae: Larvae are approximately 12–15 mm in length. The head and prothoracic shield are dark brown to black. Body colour varies from light yellow to pink.
Pupae: Pupae are 5–8 mm long, with reddish brown colour.

Adults: The forewings are light, with yellow-brown colour and black transversal trapezoidal stripe in the middle. The hind wings are a greyish colour. The wingspan is 12–14 mm.

Adult (left) and larvae (right) of *Eupoecilia ambiguella*

Pest biology:

Eupoecilia ambiguella and *Lobesia botrana* are often confused because of their rather similar biology. In some years, both pests are present, while in others, one is more dominant. However, they have slightly different climatic preferences. *Lobesia botrana* prefers warm and dry conditions, while *Eupoecilia ambiguella* is found in more northern, humid climates because of its preference for cooler weather. As such, it is more of a pest in northern countries.

In the climate conditions of North Macedonia, *Eupoecilia ambiguella* has two generations per year. The first generation appears during April, while the second generations occurs in the middle of July and lasts until the middle of August. In both cases, the time during which adults are found lasts about 2–5 weeks. Flight activity, mating and oviposition mainly occur at dusk. Females deposit eggs (60–100 per female) singly on buds, pedicels and flowers during the first generation, and on grape berries during the second generation. Early instar larvae burrow into the buds or berries and feed internally; later instars web together buds or berries, and a single larva can feed on up to a dozen berries. Pupation occurs in leaves for the first generation and under the bark for the second generation. Overwintering occurs as a second generation pupa.

Pest management:

Control measures are the same as those for European grapevine moth (*Lobesia botrana*).

Integrated pest management of major diseases and pests of pepper and tomato

Disease: Damping-off of tomato and pepper

Pathogen: *Pythium* spp.

Pythium species are fungal-like organisms (Oomycetes), commonly referred to as water moulds, which naturally exist in soil and water as saprophytes, feeding on organic matter. However, some Pythium species can cause serious diseases on greenhouse vegetable crops resulting in significant crop losses. Damping-off disease occurs in all soils where tomatoes and peppers are grown and they infect crops when the soil is wet. Infection is most common under cool conditions. Once tomato and pepper seedlings reach the two- or three-leaf stage, they are no longer susceptible to infection by Pythium.

Hosts: Tomato and pepper seedlings can be affected by several Pythium species, but *Pythium ultimum* and *Pythium debaryanum* are prevalent in North Macedonia.

Symptoms and signs:

Damage to young seedlings appears near the ground level. Initially no external symptoms of the pest's presence are noticeable on the host, but after it has gained a firm hold, the seedlings become pale green and show a weak, shrivelled place of girdle of brown colour on the stem near the surface of the soil. At this point the cortical cells are killed making the tissue weak. The infected tissues appear soft and water soaked. Infected seedlings collapse. The upper part of seedling bends or topples over in a characteristic manner. This peculiar symptom of disease is known as "damping off". Seedlings are extremely susceptible for about two weeks after emergence.

The disease occurs in two stages:

1. Pre-emergence phase:

   Pre-emergence damping-off consists of decay of the germinating seeds or death of seedlings before they can push through the soil. This injury is a common cause of poor stands, which are often attributed to inferior quality of the seed or to the lack of treatment of the seeds.

2. Post-emergence phase:

   Toppling over the infected seedlings after they come out of the soil surface. The roots may be killed, and affected plants show water soaking and shrivelling of the stems at ground level. Soon after, they fall over and die.

Damping-off symptoms on tomato (left) and pepper (right)

Pathogen biology:

Pythium spp. can grow as a saprophyte and survive in the form of resistant resting structures in the soil and in root residues. When conditions are favourable, the pathogen begins to infect the seeds and/or root tips of plants. Vegetative hyphae can directly penetrate plant cells. Mycelial growth and the movement of zoospores can facilitate the spread of *Pythium* spp. to other susceptible plants. *Pythium* spp. can reproduce both sexually and asexually. For asexual reproduction, sack-like sporangia will be formed. Sporangia can directly germinate as hyphae. For sexual reproduction, an oogonium and antheridium will be produced. When they contact each other, the nuclei of these two structures will form a zygote, then a thick-wall oospore will be formed. Both sporangia and zoospores are short-lived in soils, while oospores can survive in the soil for longer periods. For example, sporangia of *P. ultimum* were found to remain viable for 11 months in the soil, while oospores can survive in the soil for nearly 12 years.

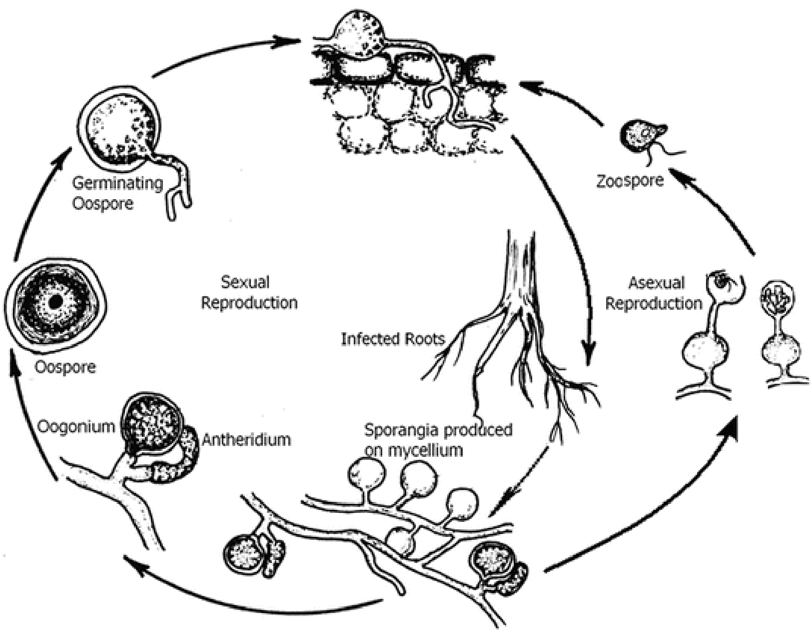


Figure 5. Disease cycle of *Pythium* spp.

(©Ministry of Agriculture, British Columbia)

Disease management:

Disease management consists of a combination of cultural, biological and chemical tools to control and/or manage crop diseases effectively. Cultural controls keep Pythium from reaching the roots while biological and chemical controls inhibit or suppress Pythium in the root zone.

Cultural practices:

- Avoid placing nursery in a shaded, humid place;
- Use only certified disease-free seed from reputable sources;
- Select well-drained nursery sites away from tomato fields;
- Elevate seed beds to improve drainage;
- Transplant only disease-free seedlings;
- Do not overwater because this favours the disease. You may only irrigate early in the day to allow rapid drying of leaves;
- Disinfect seedling pots and trays with sodium hypochlorite (NaOCl) before storage; and
- Uproot diseased seedlings and bury deep or burn.

Biological control:

Biological control of soilborne plant pathogens offers environmentally-safe and cost-effective alternatives to chemicals. Trichoderma fungi generally grow in their natural habitat on plant root surfaces and help control root diseases. *Trichoderma harzianum* is widely recognized as a powerful biocontrol agent against several soilborne plant pathogens. There are several biofungicides based on *Trichoderma harzianum* registered and available for use in North Macedonia. Strain T-22 of *Trichoderma harzianum* protects the roots of vegetable crops against several soilborne pests such as *Pythium*, *Fusarium*, *Rhizoctonia* and *Sclerotinia*.

Chemical control:

There are several registered fungicides in North Macedonia for the control of damping-off disease in tomato and pepper, based on several active ingredients or combination of active ingredients, such as: propamocarb hydrochloride, propamocarb hydrochloride + fosetyl, dimethomorph + ametoctradin.

Disease: Late blight of tomato

Pathogen: ***Phytophthora infestans***

Phytophthora infestans is the plant pathogen that destroyed the potato crop in Ireland during the 1840s, causing the Irish potato famine. This fungal disease can spread rapidly during cool, rainy weather, killing plants within a few days and causing total crop loss. Effects on the plant include extensive defoliation, reduced photosynthetic leaf area, loss of plant vigour, plant death, loss of fruit and reproductive capacity, and loss of seeds.

Hosts: The host range of *P. infestans* is mainly limited to solanaceous crops, including tomato, nightshade (*Solanum nigrum*) and potato.

Symptoms and signs:

On tomato leaves

Lesions begin as indefinite, water-soaked spots that enlarge rapidly into pale green to brownish black lesions and can cover large areas of the upper surface of the leaf. During wet weather, lesions on the under surface of the leaf may be covered with a grey to white mouldy growth (not to be confused with powdery mildew disease). On the undersides of larger lesions, a ring of mouldy growth of the pathogen is often visible during humid weather. As the disease progresses, the foliage turns yellow and then brown, curls, shrivels, and dies. The late blight symptoms are distinct from and should not be confused with symptoms of powdery mildew disease, the spores of which appear usually on the upper leaf surface of tomato.

Symptoms on upper surface (left) and under surface (right) on tomato leaves

On tomato petioles and stems

Lesions begin as indefinite, water-soaked spots that enlarge rapidly into brown to black lesions that cover large areas of the petioles and stems. During wet weather, lesions may be covered with a grey to white mouldy growth of the pathogen. Affected stems and petioles may eventually collapse at the point of infection, leading to death of all distal parts of the plant.

On tomato fruit

Dark or olive-coloured greasy spots develop on green fruit; a thin layer of white to grey mycelium may be present during wet weather.

Symptoms on stem (left) and tomato fruit (right)

Pathogen biology:

P. infestans survives in plant debris or on volunteer tomato plants and on perennial weeds such as *S. nigrum*. In the regions where both mating types of *P. infestans* are present (A1 and A2), the fungus develops thick-walled oospores that are long-term survival propagules. Sexual reproduction is rare in nature. More commonly, asexual reproduction occurs. Sporangiophores bearing asexually produced zoosporangia form on diseased tissues at a relative humidity of 91–100 percent and a temperature range of approximately 3–26 °C, with an optimum temperature between 18 and 22 °C. Dispersal of the pathogen is by wind, rain, or is human assisted via the movement of infested or contaminated materials such as seed or tools. Sporangia germinate directly via germ tubes and penetrate a plant organ, or they release motile zoospores, which in turn encyst on host organs and penetrate the tissues via a penetration peg. Mycelium of the pathogen penetrates cell walls directly and spreads intercellularly throughout host tissues, rapidly destroying them and leading to the development of the characteristic necrotic late blight symptoms.

Monitoring:

Check tomato plants regularly for infections, especially when the days are cool and wet, or overcast with heavy dews. When the crop is growing, lesions can appear on any part of the tomato plant. Typically, lesions are most likely to occur on plants in the wettest locations. These could be in a low spot in a field, or in locations that are shaded or likely to remain wet longer than others. Look for spots and patches on the leaves which grow rapidly and produce a furry white growth on the underside. Look for the white growth after putting the suspected leaves in a plastic bag overnight.

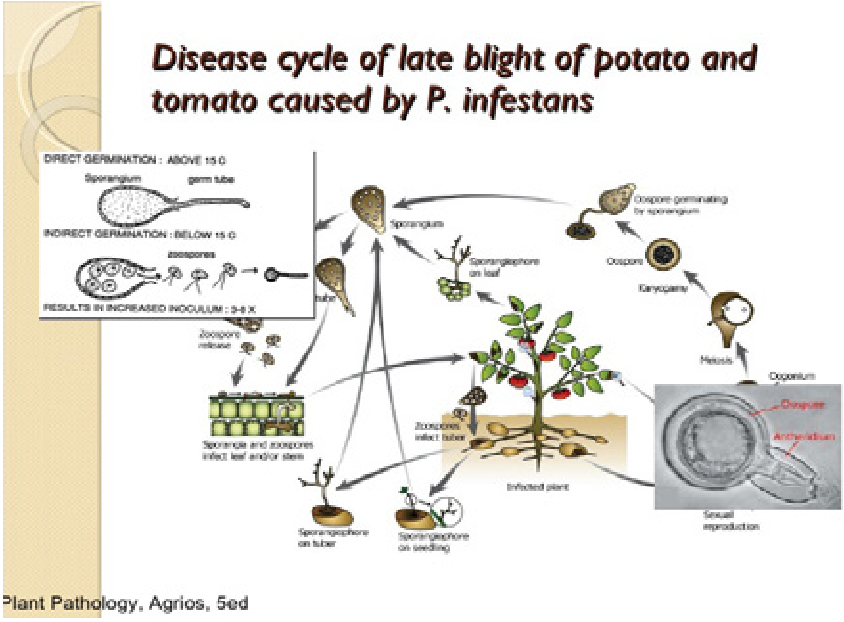


Figure 6. Disease cycle of late blight of tomato

(©George Agrios, Plant Pathology 5th Edition)

Disease management:

Cultural practices before planting:

- Check plants in the nursery for late blight infections before taking them to the field. Destroy diseased plants.
- If unsure of symptoms, spray plants with a fungicide before transplanting in the field.
- Do not plant tomatoes next to older plantings of either tomatoes or potatoes, otherwise spores will spread by wind or windblown rain.
- Use spacing between plants that allows air movement through the plantation so that foliage dries as quickly as possible after morning dews or rains. For the same reason, orient the rows parallel to the direction of wind.
- If using your own seed collected from a crop which had late blight, dry the seed for three days at 22 °C.

Cultural practices during growth:

- Do not use overhead irrigation, as it will create conditions for spore production and infection.
- Remove a few branches from the lower part of the plants to allow better airflow at the base.
- Prune any diseased leaves from the bottom of the plants as they become infected.
- If practical, grow tomatoes intercropped with non-hosts, e.g. beans or maize; this will increase the spacing between plants and reduce the spread of spores.
- Stake the plants to keep foliage off the ground; it will improve air movement around the plants.
- Remove self-grown tomatoes, potatoes and Solanum weeds (i.e. volunteer plants) as they may have late blight infections.

Cultural practices after harvest:

- Rotations of two to three years to non-host crops are recommended to control late blight. Besides potato and tomato, several weeds and ornamental plants in the Solanaceae family are known to be susceptible to late blight.

Chemical control:

There are many registered fungicides in North Macedonia for the control of late blight in tomato, based on different active ingredients or combination of active ingredients, such as: copper oxide, propamocarb hydrochloride, cyazofamid, propamocarb hydrochloride + cymoxanil, metalaxyl-M + mancozeb, metalaxyl-M + copper oxychloride, azoxystrobin + difenoconazole, benalaxyl + mancozeb, mancozeb + mandipropamid, dimethomorph + mancozeb, cymoxanil + famoxadone, valifenalate + mancozeb, benthiavalicarb isopropyl + mancozeb.

Disease: Phytophthora blight of pepper

Pathogen: ***Phytophthora capsici***

Phytophthora blight, caused by *Phytophthora capsici*, is one of the major diseases of peppers. *P. capsici* can infect pepper plants at all growth stages, causing seedling death, root rot, crown rot, stem blight, leaf spot, and fruit rot.

Hosts: *Phytophthora capsici* is a highly dynamic and destructive pathogen of vegetables. It attacks all cucurbits, pepper, tomato and eggplant, and, more recently, snap and lima beans.

Symptoms and signs:

On pepper

On pepper, infection of the stem near the soil line is common. Stem lesions start as dark, water-soaked areas which become brown to black and result in girdling, wilting and plant death. *Phytophthora capsici* may also cause root rot and foliar blight on pepper. On leaves, small water-soaked lesions expand and turn to a light tan colour. White mouldy growth may be seen on leaves during wet periods. Rapid blighting of leaves and shoots may occur. Pepper fruit can also be infected through the fruit stalk. Fruit symptoms appear as dark green, water-soaked areas that become covered with a white cottony growth under humid conditions. Infected fruit dry, become shrunken and wrinkled, and remain attached to the stem.

Symptoms on pepper plants

(©Cornell University, Long Island Horticultural Research & Extension Center)

On tomato

Phytophthora blight can cause crown rot, leaf spot, foliar blight and fruit rot in tomatoes. Fruit rot begins as dark, water-soaked spots, which rapidly expand during warm weather to cover most of the fruit surface with a brown, watery discolouration that may appear as concentric rings. Under humid conditions, infected fruit may be covered with white cottony growth and rot entirely following secondary infections by other microorganisms. Similar symptoms can also be caused by the late blight pathogen, *P. infestans*.

Symptoms on tomato plants

(©Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org)

Pathogen biology:

Phytophthora capsici is a soilborne pathogen which overwinters as oospores (thick-walled resting spores) in the soil or in plant debris. Oospores are resistant to dry conditions and cold temperature and can survive in the soil for many years. In the spring, oospores germinate to produce sporangia and zoospores (asexual spores) when soil humidity is at full field capacity. Sporangia are spread by wind and water through the air and are carried with water movements in soil. Sporangia germinate to directly infect host tissues, or if conditions are wet, they can also germinate to release zoospores. Zoospores are motile and swim to invade host tissues. *Phytophthora capsici* can also be spread with infected transplants or seed, and through contaminated soil and equipment. Abundant sporangia are produced on infected tissues, particularly on fruit. Sporangia are spread with water, by rain-splash, or with air currents. Windborne sporangia can be carried over long distances. If the environmental conditions are favourable, the disease develops very rapidly. Phytophthora blight is favoured by high soil moisture, frequent rains or irrigation, and warm temperatures (optimum 24–33 °C). The disease is usually associated with heavy rainfall, excessive irrigation, or poorly drained soil.

Water and movements of infested soil with transplants, farm equipment, or tools are the main contributors to the pathogen dissemination. Infested irrigation water is a significant source of inoculum and *P. capsici* zoospores can easily be carried via run-offs from rivers, creeks, ditches, streams, and ponds fed by canals.

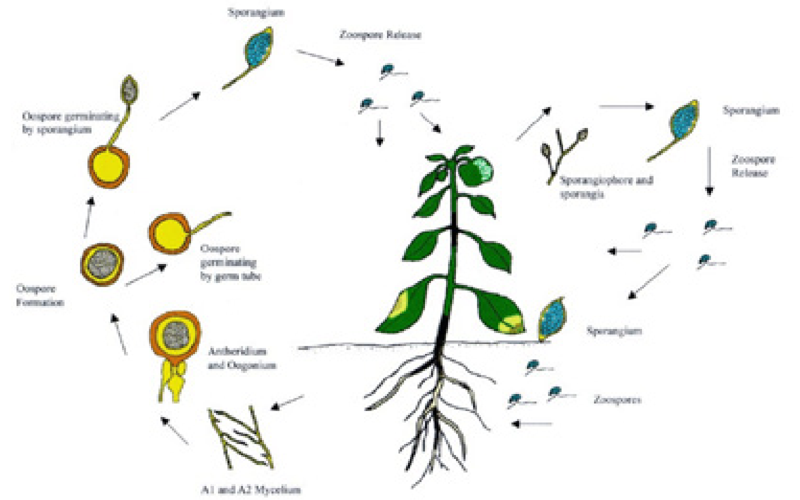


Figure 7. Disease cycle of *Phytophthora capsici*

(©Jean Beagle Ristaino, 1999)

Monitoring:

Early detection of the disease may help avert serious losses. Inspect your field regularly for disease symptoms. Pay particular attention to low areas of the field where the soil remains wet for longer periods.

Disease management:

Phytophthora blight cannot be managed by fungicide applications alone; successful disease control in infested fields is achieved only by a season-long effort to manage the water and to utilize other cultural practices.

Water management

Phytophthora capsici requires saturated soils for infection. Use the following methods to encourage drainage and avoid prolonged soil saturation:

- Do not use surface water (ponds, creeks) for irrigation since it may be infested. Irrigate moderately from a well via drip, and avoid overhead irrigation, especially once the fruit are present.
- Be careful to not overwater.
- Check irrigation system regularly for leaks and fix them.
- Avoid soil compaction. Use farm machinery as little as possible throughout the season and never work in fields when the soil is wet.
- Make sure water can flow out of the field. Create breaks in raised beds and clear away soil at the ends of rows to prevent damming.
- Mulch between rows and on bare soil with straw or leave cover crop stubble to reduce splash dispersal of inoculum. Inoculum can move rapidly across black polyethylene mulch and bare soil.

Cultural practices

- Keep records of contaminated fields. Do not rent land for susceptible crops without investigating the history of disease problems.
- Avoid planting susceptible crops in Phytophthora-infested soil. Rotate with corn, small grains, brassicas, alliums, or other non-hosts.
- Separate susceptible crops (if possible) so that there is no opportunity for water to move from one planting to another.
- Do not plant low areas with susceptible crops – plant a cover crop, maize or another non-susceptible crop or leave it bare.
- Rotations of at least three years to non-host crops are recommended to control Phytophthora blight.
- Remove diseased fruit or plants away from the field. Do not leave culls in the field or near surface irrigation water sources (ponds, creeks).
- Sanitize farm equipment after working on an infested field.

Physical control methods

Soil solarization involves the heating of soil under clear polyethylene mulch during the hottest months of the summer and has been demonstrated to reduce levels of many soilborne pathogens, including *Phytophthora capsici*. Still, keep in mind that soil solarization only kills pathogen propagules at shallow depths in soil (up to 15 cm).

Biological control:

In North Macedonia there is one registered broad-spectrum biofungicide based on spores of *Trichoderma harzianum* T22, which can be applied in the soil through drip-lines or to foliage.

Chemical control:

Fungicide programmes for managing Phytophthora blight in pepper should be preventive and usually recommend several applications, especially during early growth stages, when pepper plants are most susceptible to this disease. During early growth stages, at least two fungicidal treatments should be performed, i.e. one before transplanting and another one immediately after transplanting.

There are several fungicides registered for control of *Phytophthora capsici* in pepper in North Macedonia, based on several active ingredients or combination of active ingredients such as: propamocarb hydrochloride, 8-hydroxyquinoline sulphate and propamocarb hydrochloride + fosetyl.

Disease: Grey mould of tomato and pepper

Pathogen: *Botrytis cinerea*

Botrytis cinerea is a significant necrotrophic plant pathogen that causes grey mould disease in over 200 plant species. This pathogen has a disastrous economic impact on various economically-important crops including grape, strawberry, tomato etc., and can be present in stems, leaves, flowers, fruit and seeds. It may cause obvious disease symptoms in the pre-harvest period or remain latent until the post-harvest period. Moreover, it is considered as one of the most important post-harvest pathogens in fresh fruit and vegetables. The annual economic losses caused by *B. cinerea* easily exceed USD ten billion worldwide.

Hosts: *Botrytis cinerea* has a very wide host range with more than 200 reported hosts, including vegetable crops, such as tomato, pepper, beans, potato, crucifers and cucurbits.

Symptoms and signs:

Botrytis cinerea usually develops on fading flowers and subsequently infects the fruit calyx. Flower petals are very susceptible and can initiate infection of pedicels and developing fruit. The lesions on fruit appear as light brown to grey spots, up to 3 cm in diameter, and irregular in shape. Later, a dark grey, velvety growth develops on the fruit surface, followed by a watery, soft rot. Green fruit can also become infected directly by airborne spores instead of by contact with other infections. White circular (halo) spots appear on the fruit and have been named "ghost spots". These spots persist and can appear on green, breaker, and mature fruit. As fruit ripen, the colour of the halos changes from white to yellow. The "ghost-spot" symptom results from spore germination and penetration in young fruit, as they are only susceptible to the attack up to cherry size. Penetration of the mycelium of Botrytis into the fruit produces a host reaction preventing any further mycelial growth and results in localization of the pathogen. The halo forms around the point of entry. Foliar symptoms are also common under humid greenhouse conditions. Affected leaves show light tan or grey spots, and the infected areas become covered with grey fungal growth. The leaves wither and collapse. The fungus proceeds into the stem producing tan, elliptical cankers with concentric rings. Stem infections occur during periods of high humidity through leaf scars, cracks, and pruning wounds. Stem lesions may expand in concentric rings to girdle the entire stem causing wilting above the infection site.

Pathogen biology:

Botrytis cinerea produces overwintering structures called sclerotia in addition to producing various other types of spores. These allow the fungus to survive in soil, dead plant material or on different host plants. The fungus is easily dispersed on large distances by wind. Small pieces of infected plant tissue or fungal spores from infected plant debris are also disseminated on shorter distances by splashing and windblown rain. Grey mould development, particularly fungus sporulation and infection, is favoured by cool, wet and humid weather. The fungus requires a water film of several hours for spore germination, and a longer period of surface wetness for symptom development. Optimum relative humidity for spore production is around 90 percent, and most spores are produced during the night when the temperature is lower and the relative humidity is higher than during the day. Temperatures of 17–23 °C are ideal for disease development. The length of the surface wetness period needs to be longer at lower temperatures for development of the disease. Although fading flowers are a favourable site for infection, the fungus generally infects plants through wounds. Penetration of intact tissue is rare. Plants approaching maturity are more susceptible.

Symptoms of *Botrytis cinerea* in tomato on fruit, stem and leaves

Monitoring:

Inspect the crop for grey mould symptoms regularly so that the initial infection, or a sudden increase of the disease, is detected at an early stage, because once *Botrytis cinerea* becomes well established in a crop it is much more difficult to control. Look for leaf spots and tan stem cankers. *Botrytis cinerea* produces characteristic grey fuzzy appearing spores on the surface of infected tissues during humid conditions. Pay particular attention to areas where plants are spaced close together and where condensation may occur. Once symptoms of grey mould are found, identify the infection points, then review and adjust the control measures to minimize the spread of the infection at these points.

Disease management:

Cultural practices:

It is almost impossible to exclude Botrytis from crops as the pathogen is very common in the environment. The most appropriate and cost-effective course of action is to take measures to prevent stem and fruit infection, the most damaging forms of the disease. The key preventive measures are glasshouse humidity control, inoculum reduction and good crop management. Reliable control of grey mould requires careful attention to all these aspects.

Humidity control

The aim is to prevent frequent long periods of high humidity in the crop canopy and condensation on plant surfaces. As a guide, seek to avoid successive days with relative humidity above 85 percent for more than six hours. Although rapid spore germination generally does not occur until the humidity is above 90 percent, the humidity in the microclimate close to plant surfaces will be greater than that in the measuring box. Use heat and ventilation to reduce humidity in the glasshouse. Do not allow the air temperature to rise too quickly in the morning, i.e. no more than 2 °C per hour, to reduce the risk of condensation on cool plant surfaces (e.g. fruit, stems). It is more effective to use ventilation to limit temperature rise and avoid dew point temperatures being reached than to boost heat input. Using computer settings which increase ventilation set points in line with increasing solar radiation levels during this period can aggravate the problem.

Inoculum reduction

The aim is to reduce the quantity of *Botrytis cinerea* in the crop that could lead to further disease development through production of airborne dispersal spores, growth into the stem through a leaf petiole or fruit truss, or by contact spread from infected tissue to healthy tissue. Elimination or reduction of Botrytis inoculum early in the season is particularly important. It will have more effect when the infection levels are low, it will be easier to achieve, and it will delay the disease as several cycles of infection are required for uncontrolled development. Where practicable, pick off all Botrytis-affected leaves. Cut out small Botrytis lesions from the stem with a sharp knife. Cut beyond the lesion edge by 5–10 mm, as fungal growth is likely to extend beyond the visible rot. Where a stem lesion has girdled the stem sufficiently to cause wilting, remove the plant. Do not leave stem bases to die back; they are susceptible to Botrytis infection and can provide a continual source of spores. *Botrytis*-affected leaves, cut out stem lesions and stems killed by Botrytis should all be removed from the greenhouse. Ideally, remove them before Botrytis sporulation is obvious.

Crop management

The aim is to grow and manage the crop from the moment it is introduced to the greenhouse in a way that reduces its susceptibility to Botrytis infection. In particular, seek to maintain balanced growth and avoid fleshy, soft stem and leaf growth, ragged de-leafing wounds and senescent leaves. Methods for avoiding soft lush growth include avoiding excess water application, maintaining adequate solution conductivity and balanced nutrition, with adequate potassium but limited nitrogen supplies. Stem wounds are most susceptible to infection by Botrytis in the first few days after de-leafing, before a wound response layer has formed. Seek to avoid prolonged exudation of sap from the de-leafing wounds. De-leaf a little and often, rather than removing many leaves at once. De-leaf in the morning, to allow time for stem wounds to dry, but not too early, before the plant has become active, or while the humidity deficit is still very low. Stop irrigation early on overcast days so that the slab is not overly wet during the night, which can enhance guttation by root pressure, especially at low night temperatures, which also increases the risk of fruit splitting. The standard of crop work can have a tremendous impact on Botrytis levels. Make sure that leaf debris is removed from the crop canopy, fallen fruit are picked up, leaves and side shoots are not trapped by support strings, and that de-leafing and spent fruit truss removal are done well and in a timely manner.

Biological control

There are several registered biofungicides for control of grey mould of tomato and pepper in North Macedonia, based on several different active ingredients (see table below).

Table 4. Registered biofungicides for control of grey mould of tomato and pepper in North Macedonia

Active ingredient	Rate of application	PHI* (days)	Comments
Bacillus subtilis QST 713	8.0 litres/ha	0	Maximum 6 sprays/season
Trichoderma atroviride SC1	0.2 kg/ha	0	No restrictions
Oil extract of *Melaleuca alternifolia*	2 litres/ha	0	No restrictions
Laminarin	1–2 litres/ha	0	Maximum 7 sprays/season

* PHI – Pre-harvest interval

Chemical control

Fungicide sprays should start before a dense canopy of the tomato plant develops. This is important no matter what type of fungicide is used. In addition, most fungicides registered to control grey mould are only protective which means that they will not suppress an established infection. Fungicide spray intervals may be two weeks initially in early spring, increasing to three or four weeks as the season progresses and the weather generally improves, but should be reduced in persistent wet weather or if Botrytis levels increase.

The grey mould fungus is likely to develop resistance to some groups of chemical products. To help avoid the build-up of resistant strains alternate the use of different groups of chemicals.

There are several registered fungicides for control of grey mould in tomato and pepper in North Macedonia, based on following active ingredients or combination of active ingredients: fenhexamid, boscalid+pyraclostrobin, cyprodinil+fludioxonil.

Disease: Fusarium wilt of tomato and pepper

Pathogen: *Fusarium oxysporum*

Fusarium wilt of tomato and pepper is a highly destructive disease found in tomato and pepper grown in greenhouses or in field conditions. It is caused by a soilborne pathogen – *Fusarium oxysporum*. Fusarium wilt is reported to be one of the major diseases causing the highest pre-harvest losses in tomato and pepper production in many warm regions of the world.

Hosts: *Fusarium oxysporum* is a soilborne pathogen with a wide range of hosts, including tomato and pepper plants.

Symptoms and signs:

Symptoms include yellowing and browning of foliage and stunting and wilting, with some recovery at night. The first symptoms appear when fruit begin to ripen. Lower leaves turn yellow, sometimes on one side of the plant or one side of a branch. This is followed by leaf and stem wilting. When an infected stem is scraped or split lengthwise you will see the browning of the vascular tissue. Blocking of the xylem vessels is the main reason for wilting. The pith (the tissue in the middle of the stem) remains healthy.

Symptoms of Fusarium wilt in tomato (left) and pepper (right)

Pathogen biology:

F. oxysporum has no known sexual stage, but produces three types of asexual spores: microconidia, macroconidia, and chlamydospores. It survives in the soil debris as a mycelium and all spore types but is most commonly recovered from the soil as chlamydospores. Chlamydospores can survive in soil for up to ten years. This pathogen spreads in two basic ways: it spreads short distances by water splash and by planting equipment, and long distances by infected transplants and seeds. *F. oxysporum* infects a healthy plant by means of mycelia or by germinating spores penetrating the plant's root tips, root wounds, or lateral roots. The mycelium advances intracellularly through the root cortex and into the xylem. Once in the xylem, the mycelium remains exclusively in the xylem vessels and produces microconidia (asexual spores). The microconidia are able to enter into the sap stream and are transported upward.

Where sap flow ends, the microconidia germinate. Eventually the spores and the mycelia clog the vascular vessels, which prevents the plant from up-taking and translocating the nutrients. As a result, the plant transpires more than it can transport, the stomata close, the leaves wilt, and the plant dies.

Soil and air temperatures of 28 °C are optimal for disease development. Too warm (34 °C) or too cold (17–20 °C) soils retard the wilt development. In general, factors favouring wilt development are: soil and air temperatures of 28 °C, soil moisture optimum for plant growth, plants preconditioned with low nitrogen and phosphorus and high potassium, low soil pH, short day length, and low light intensity. Virulence of the pathogen is enhanced by micronutrients, phosphorus, and ammonium nitrogen and decreased by nitrate nitrogen. Moreover, infection into the xylem is favoured by wounds to the roots, including those caused by the root-knot nematodes (*Meloidogyne* spp.).

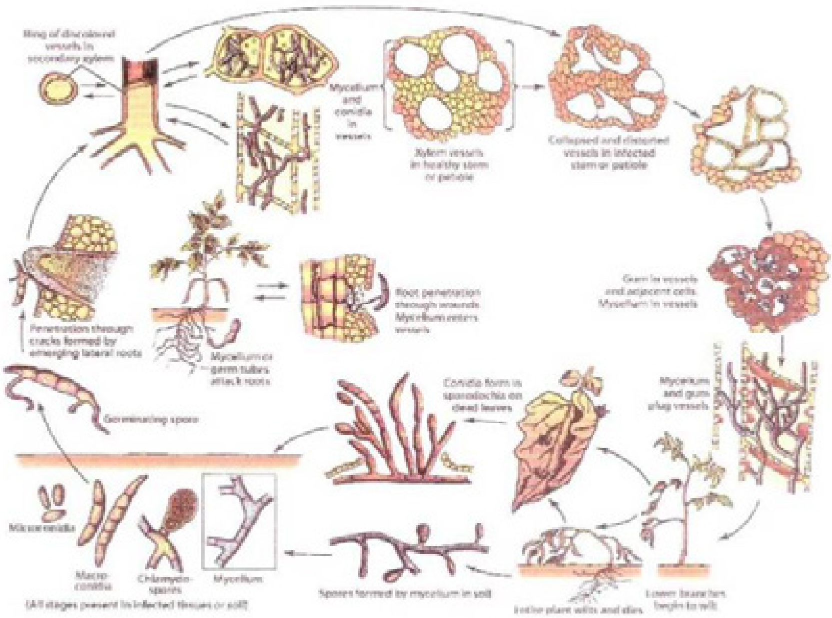


Figure 8. (©George Agrios, Plant Pathology 5th Edition)

Disease management:

There is no cure (chemical control) for Fusarium wilt. Prevention is the only way to avoid the damage from Fusarium wilt in tomato and pepper production. Preventive control measures include:

- Conduct soil sterilization or fumigation to eliminate wilt fungi from the soil. Soil solarization involves the heating of soil under clear polyethylene mulch during the hottest months of the summer and has been demonstrated to reduce levels of many soilborne pathogens, including Fusarium species.
- Disinfect tools and machinery in greenhouses.
- Remove and destroy all infected plants.
- Choose resistant cultivars.
- When planting, avoid all wet spots and build raised beds if drainage is insufficient.
- Avoid over-application of nitrogen fertilizers. High soil nitrogen levels accompanied by low potassium levels can increase susceptibility to the fungus. Use soil tests to determine potassium

and other nutrient levels.

- Avoid activity in wet plantings. Movement of wet soil from place to place via shoes or tools may spread the disease.

- Rotate crops for 5–7 years. Do not plant solanaceous plants in the area where infection occurred. Besides tomato and pepper, potato and eggplant are also susceptible to the disease and may allow its survival year after year in the same planting area.

Biological control

Biological control of soilborne plant pathogens offers an environmentally-safe and cost-effective alternative to chemicals. *Trichoderma* species generally grow in their natural habitat on plant root surfaces and help control root diseases. *Trichoderma harzianum* is widely recognized as a powerful biocontrol agent against several soilborne plant pathogens. There is one biofungicide based on *Trichoderma harzianum* strain T-22, which is registered for use in North Macedonia. This biofungicide contains spores of *Trichoderma harzianum* strain T-22 and protects the roots of vegetable crops against several soilborne diseases caused by species from *Fusarium*, *Pythium*, *Rhizoctonia* and *Sclerotinia* genera.

Biological control of soilborne plant pathogens offers an environmentally-safe and cost-effective alternative to chemicals. *Trichoderma* species generally grow in their natural habitat on plant root surfaces and help control root diseases. *Trichoderma harzianum* is widely recognized as a powerful biocontrol agent against several soilborne plant pathogens. There is one biofungicide based on *Trichoderma harzianum* strain T-22, which is registered for use in North Macedonia. This biofungicide contains spores of *Trichoderma harzianum* strain T-22 and protects the roots of vegetable crops against several soilborne diseases caused by species from *Fusarium*, *Pythium*, *Rhizoctonia* and *Sclerotinia* genera.

Disease: Verticillium wilt of tomato and pepper

Pathogen: ***Verticillium albo-atrum, Verticillium dahliae***

Hosts: Both *Verticillium* species are soilborne fungi that attack a wide range of plants. Over 350 host plants are susceptible to Verticillium wilt including members of the Solanaceae family (tomatoes, potatoes, peppers and eggplant), the Brassicaceae family (Brussels sprouts, cabbage and cauliflower), the Cucurbitaceae family (cucumber and pumpkin), but also Fragaria (strawberry) and many fruit and ornamental trees.

Symptoms and signs:

Affected plants are often scattered sporadically in the field. Disease symptoms on pepper and tomato produced by both fungi are similar. Usually, the symptoms are not visible until several weeks into the growing season. In early stages, the edges of the leaves will roll inward with some foliar wilting. The plant may recover from wilting during the night when temperatures are lower and there is less water stress. Initially, there is some slight stunting and a slight yellowing of the older, lower foliage. The disease symptoms move up the plant. As the disease develops, the leaves show more yellowing and they may drop off, and the plant shows permanent wilting with stunting. There is a dark brown discolouration of the vascular section of the stem that extends from the soil line up the stem into the lower branches of the plant.

Symptoms of Verticillium wilt in tomato (left) and pepper (right)

Pathogen biology:

Verticillium albo-atrum and *Verticillium dahliae* are root invaders. They do not live in soil as saprophytic fungi but can survive in soil for several years in the form of specialized "resting structures". Thus, *V. albo-atrum* survives as dormant (melanized) mycelium, while *V. dahliae* forms special dormant structures, called microsclerotia. While resting, many factors such as soil chemistry, temperature, hydration, micro fauna, and non-host crops have an effect on the viability of the resting structures. Mycelium has been observed to remain viable for at least four years, while microsclerotia have been observed in fields planted with non-host crops for up to 15 years.

When the roots of a host crop come near the resting structures, the root exudate (chemically diverse secretions) triggers the germination of the threadlike fungal structures and they grow towards the plant. Verticillium wilt is a vascular disease and generally requires an opening in the root system to access the vascular structure of the plant. Verticillium produces conidia that are released into the plant xylem tissue and colonize the plant in as little as 24 hours. The pathogen is sensitive to soil moisture and temperature. Tomatoes and peppers must have at least a day of saturated soil before infection occurs. Soil temperatures must be moderate or cool for infection to take place: 24 °C is optimum, with 13 °C minimum and 30 °C maximum.

Once established in a field or landscape, spread of the pathogen occurs primarily by soil cultivation and movement of soil by wind or water. Verticillium propagules occur in highest concentrations in the top 30 cm of the soil profile, but they have been recovered from depths as low as 40 cm. Inoculum densities and disease severity tend to increase from year to year when susceptible crops are planted.

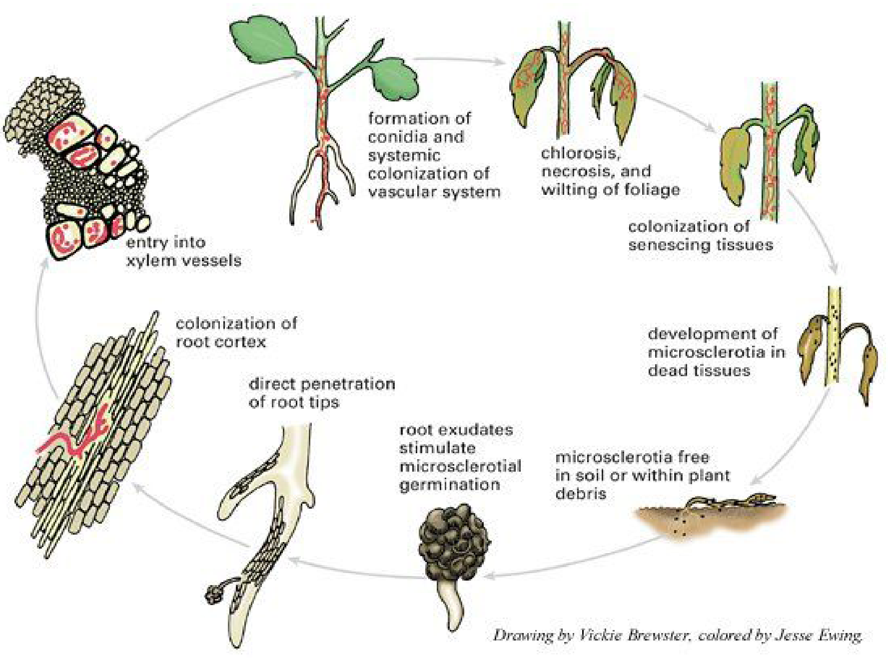


Figure 9. Disease cycle of *Verticillium dahliae*

(©aps.net.org)

Disease management:

There are no effective control methods once the disease has occurred in the field. However, there are a number of preventive control measures that can be taken when dealing with Verticillium wilt:

- Sanitation is crucial, since once the fungus is introduced into the field it may remain indefinitely. If possible, where limited infection occurs, destroy infested plant material (including the roots) after harvest to reduce populations of the fungus. Burn the infected plants.
- Eliminate weeds in the production field that may serve as symptomless hosts for the fungus or other susceptible crops that may contribute to bridging the period between susceptible pepper crops. Clean farm tools and equipment when moving from one field to another. Wash your shoe soles after working in an infested area. Work in healthy fields first, before working in affected fields.
- Use a long rotation of 3–4 years, including rice, broccoli, corn or sorghum, to allow plant residues to decompose in the soil and to reduce fungal populations in the soil. Avoid use of potatoes, eggplant or strawberries in the rotation scheme.
- Pre-plant soil solarization alone or combined with fumigation, especially using fumigants containing metam-sodium, will reduce fungal populations. This is especially effective in greenhouse production. Maintain a high level of plant vigour with appropriate fertilization and irrigation to keep plants less susceptible.
- Avoid contaminated land.
- Keep seedling and crop production fields away from previous fields infested with Verticillium.
- Try to avoid stressing plants, especially the roots. Control root-knot nematodes and root-feeding insects since they may help Verticillium to establish and spread.
- Check for symptoms of Verticillium wilt throughout the fruit development and keep records of infections in order to make decisions for future plantings.
- Maintain/provide proper soil humidity and drainage.
- Avoid high doses of nitrogen fertilizers – use balanced fertilizers or fertilizers with slightly higher phosphorus levels. As soon as possible, remove infected plants with as much of the infected root system as possible.

Disease: Powdery mildew of pepper

Pathogen: ***Leveillula taurica***

Powdery mildew of pepper caused by *Leveillula taurica*, is a common and potentially serious disease during warm and dry weather. It can lead to loss of leaves, and early ripening and sunscalding of the fruit. Yield losses may exceed 50 percent, depending on the age of the crops when the disease occurs, environmental conditions and effectiveness of control methods.

Hosts: Pepper is the main crop affected by this disease, but the same isolates of *L. taurica* may attack tomato, eggplant and cucumber.

Symptoms and signs:

In general, pepper crops become more susceptible to powdery mildew as they ripen. Older plants and lower leaves are the first to show symptoms of powdery mildew infection. The leaf blade is the most attacked organ. Symptoms appear on both the lower and upper sides of the leaf blade. Early symptoms appear on the lower side of the leaf as whitish spots that gradually expand and look "fluffy". As the disease symptoms progress, the top sides of the leaves exhibit yellowish spots opposite the spots on the bottom side. The edges of infected leaves may roll upward exposing white, powdery fungal growth. As the disease develops, the older colonies of the fungus may change their colour to dirty white. Severely affected leaves turn yellow, then brown, and drop from the plant prematurely. This loss of photosynthetic leaf area slows plant growth and fruit development. The defoliation also exposes fruit to direct sunlight, which can lead to sunscalds.

Symptoms of *Leveillula taurica* on pepper leaves

Pathogen biology:

The fungus survives from season to season on living pepper plants or alternative hosts. Cleistothecia (sexual spores) of the Leveillula perfect stage occur rarely, but asexual spores (conidia) are produced more commonly and are disseminated by wind. The powdery mildew disease cycle (life cycle) starts when spores (conidia) land on a pepper leaf. After landing on a leaf, a spore of *L. taurica* germinates, enters a stoma (pore) and then grows within the leaf tissue. After two or three weeks, the fungus grows out of the leaf openings (stomata) on the under surface of the leaf and releases spores into the air, to be carried to other leaves. Under favourable conditions, secondary infections occur every seven to ten days, and disease can spread rapidly. The disease is favoured when large day/night temperature and humidity fluctuations occur, which promote leaf wetness. Development of *L. taurica* is favoured by warm (25 °C) and dry (less than 80 percent relative humidity) days followed by humid (greater than 85 percent relative humidity) nights.

Monitoring:

Once pepper leaves are infected with powdery mildew, it is difficult to control the disease. If left unchecked, the crop can be entirely destroyed. Monitor the crop right from the start (on a weekly basis), since early detection is important for successful powdery mildew control. For closer inspection, target the areas in the greenhouse where powdery mildew first started in the previous year. Hotspots for powdery mildew are areas where the climate fluctuates, air circulation is poor and relative humidity is high. Powdery mildew is likely to start on older, lower leaves. Look for the yellow spots and patches on the leaves somewhat bounded by the main leaf veins. Look on the underside of the leaves for white patches of spores protruding through the surface (keep in mind that there is little cottony growth over the leaf blade with this powdery mildew).

Disease management:

Pepper powdery mildew is different in several ways from the mildews that infect tomato (*Oidium neolycopersici*), or cucumber (*Erysiphe cichoracearum*, *Sphaerotheca fuliginea*). Unlike tomato and cucumber powdery mildew, which can easily be seen on the top side of the leaves, pepper powdery mildew grows on the under surface of leaves, due to the endophytic mycelium, which develops inside the infected leaf tissues.

Therefore, the management of this pathogen can be achieved through an integrated approach that considers the management options listed below.

Cultural practices

Before planting:

- Avoid overcrowding of seedlings in the nursery, and check each for infection before field planting.
- Weed around the nursery, especially removing plants that belong to the Solanaceae family (e.g. nightshade).
- Remove volunteer plants of the previous crop.

During growth:

- Do not apply excessive amounts of nitrogen fertilizers. Abundant leafy growth promotes conditions for disease development.
- Select sites with well-drained soils and good air circulation. Adjust planting densities and row orientations to promote good air circulation and light penetration into the canopy.
- Ensure that plants have adequate amounts of water as moisture stress may increase their susceptibility.
- In greenhouse production, increasing the temperature can lower humidity levels and slow disease development.

After harvest:

- Collect all crop residue and burn or bury it.
- Avoid overlapping crops to prevent spores from older crops infecting newer ones at an early stage.
- Practice crop rotation, choosing a non-host crop, e.g. root crops or those from the cabbage family.

Biological control

There are few registered biofungicides for control of *Leveillula taurica*, which are available for use in pepper and tomato in North Macedonia, based on different active ingredients (see table below).

Table 5. Registered biofungicides for control of Leveillula taurica for use in pepper and tomato in North Macedonia,

Active ingredient	Rate of application	PHI* (days)	Comments
Bacillus pumilis QST 2808	10 litres/ha	0	Maximum 6 sprays/season
Laminarin	1–2 litres/ha	0	Maximum 7 sprays/season
COS-OGA	2–3 litres/ha	0	Maximum 5 sprays/season

* PHI – Pre-harvest interval

Chemical control

The disease can be prevented by early application of fungicides. The effectiveness of fungicide applications depends on early detection of symptoms and thorough coverage of the leaves with the pesticide, particularly on the under surface of the foliage and in the lower part of the plant canopy. Use fungicides with different modes of action (belonging to different groups) to prevent the development of fungicide-resistant strains of the pathogen.

There are many registered fungicides in North Macedonia for control of powdery mildew on pepper, based on different active ingredients or combination of active ingredients, such as: myclobutanil, tetraconazole, boscalid + pyraclostrobin, difenoconazole + cyflufenamid, azoxystrobin + difenoconazole, difenoconazole + fluxapyroxad, trifloxystrobin + tebuconazole.

Disease: Powdery mildew of tomato

Pathogen: *Oidium neolycopersici*

Oidium neolycopersici is an extremely common pathogen in glasshouse tomatoes and increasing in significance in field tomatoes. Severe infections lead to leaf chlorosis, premature senescence and a significant reduction in fruit size and quality.

Hosts: Tomato is the principal host of *O. neolycopersici*, but the fungus is reported to attack over 60 species in 13 plant families, particularly members of the Solanaceae (pepper, eggplant, potato and tobacco) and Curcubitaceae families.

Symptoms and signs:

Powdery mildew is most likely to occur in late summer. First symptoms appear as small, powdery white spots or colonies on the upper surface of the leaves. The spots soon become covered with white spores, which makes the leaves look like they have been dusted with flour. The lower surface of the foliage may also be affected during later stages when the disease is severe. Severely affected leaves turn yellow, then brown, and later become shrivelled. Generally, the lower leaves are affected first and the disease gradually moves up the plant. Plants may become defoliated under severe infections, leading to lower yields and possible sunburn damage to the fruit. No symptoms appear on the fruit, but fruit produced by infected plants often lack flavour.

Symptoms on tomato leaves caused by *Oidium neolycopersici*

Pathogen biology:

O. neolycopersici is not known to reproduce sexually, but it is able to survive on tomato plants in greenhouses in its mycelial form, from one year to another. Moreover, the pathogen has a wide host range and probably survives on other hosts or volunteer tomato plants from season to season.

O. neolycopersici is a prolific producer of spores that are readily dispersed by wind and rain. Many cycles of disease development occur during the plant's growing period. The fungus is also spread by insect pests (thrips, aphids and whiteflies) and, to a lesser extent, by field workers. The fungus is not seed-borne. Spore germination and infection are favoured by wide fluctuations of temperature and humidity during day and night, which create periods of leaf wetness. For *O. neolycopersici*, optimum temperature for development of the disease is 22 °C, especially after 16 or 24 hours of leaf wetness. Symptoms can appear within seven days from the time that the spore lands on the leaf surface. Other factors such as close plant spacing and luxuriant plant growth arising from high nitrogen levels are likely to foster disease development.

Monitoring:

Monitor fields on a weekly basis and search plants for the presence of powdery mildew symptoms on leaves (focus on the upper surface of the leaf). Early detection of the disease is important since early control measures will reduce subsequent disease development and the number of foliar fungicide sprays that are required.

Disease management:

Management strategies for the control of *O. neolycopersici* in tomato should employ combination of cultural, biological and chemical measures.

Cultural practices

Before planting:

- Avoid overcrowding of seedlings in the nursery, and check each for infection before field planting.
- Control weeds around the planting site since this fungus has a wide host range and could persist on these plants during the growing season or during the off season.
- Remove volunteer plants from the previous crop.

During growth:

- Do not apply excessive amounts of nitrogen fertilizers. Abundant leafy growth creates conditions favourable for disease development.
- Select sites with well-drained soils and good air circulation. Adjust planting densities and row orientations to promote good air circulation and light penetration into the canopy.
- Ensure that plants have adequate amounts of water as moisture stress may increase susceptibility.
- In greenhouse production, increasing the temperature in the greenhouse can lower humidity levels and slow disease development.

After harvest:

- Collect and burn or bury all crop residue.
- Avoid overlapping crops to prevent spores from older crops infecting newer ones at an early stage.
- Practice crop rotation, choosing a non-host crop.

Biological control:

There are several biofungicides available in North Macedonia for the control of powdery mildew of tomato, caused by *Oidium neolycopersici*, based on different active ingredients (see table below).

Table 6. Biofungicides available in North Macedonia for the control of powdery mildew of tomato

Active ingredient	Rate of application	PHI* (days)	Comments
Bacillus pumilis QST 2808	10 litres/ha	0	Maximum 6 sprays/season
Laminarin	1–2 litres/ha	0	Maximum 7 sprays/season
COS-OGA	2–3 litres/ha	0	Maximum 5 sprays/season

* PHI – Pre-harvest interval

Chemical control:

There are several registered fungicides for control of *Oidium neolycopersici* in North Macedonia, based on different active ingredients or combination of active ingredients, such as: myclobutanil, boscalid + pyraclostrobin, difenoconazole + cyflufenamid, difenoconazole + fluxapyroxad.

Disease: **Leaf mould of tomato**

Pathogen: ***Passalora fulva*** **(syn. *Fulvia fulva*)**

Leaf mould, caused by the fungus *Passalora fulva* (previously *Fulvia fulva*), is a common and destructive disease worldwide on tomatoes grown under humid conditions. Leaf mould is primarily a problem on greenhouse tomatoes, but it occasionally develops on field and garden-grown tomatoes, if conditions are favourable. The disease is most destructive in the greenhouse during autumn, early winter and spring, when the relative humidity is most likely to be high, and air temperatures are such that heating is not continuous.

Hosts: *Passalora fulva* is known to be pathogenic only on tomato.

Symptoms and signs:

Symptoms usually develop only on foliage, with fruit infections being very rare. Leaf mould symptoms typically appear on older leaves first. The first leaf symptom is the appearance of small, white, pale green, or yellowish spots with indefinite margins on the upper leaf surface. On the corresponding areas of the lower leaf surface the fungus begins to sporulate. The fungus appears as an olive green to greyish purple velvety growth, composed mostly of spores (conidia) of the leaf mould fungus. Infected leaf tissue becomes yellowish brown, and the leaf curls, withers, and drops prematurely. The withering and defoliation progress up the plant until the entire plant may appear dry and dead.

Pathogen biology:

The fungus survives between seasons as conidia (spores), as sclerotia in the soil, and as a saprophyte on infected plant debris. Seed can be also contaminated and serve as the initial source of disease. Conidia are resistant to drying and may survive in the greenhouse at least one year in the absence of a susceptible host, and new conidia can be produced from surviving sclerotia. The conidia act as primary inoculum to infect plants when conditions become favourable. Large numbers of spores are produced on the under surface of infected leaves, and these spores are easily spread from plant to plant by air currents, splashing water, on tools, and clothing of workers, and possibly by insects. Spores germinate in water films or when the humidity is above 85 percent, at temperatures between 4 °C and 34 °C. The optimum temperature for the germination is between 24 °C and 26 °C. Leaves are infected through stomata when the humidity is 85 percent or higher. Infection occurs most rapidly when the humidity at the leaf surface fluctuates between 85 percent (day) and 100 percent (night). Symptoms usually begin to appear approximately ten days after inoculation, with spore formation beginning a few days later.

Monitoring:

Monitor fields on a weekly basis and search plants for the presence of leaf mould symptoms on leaves. Look for yellow spots and rapidly developing irregular patches on the upper surfaces of the lower leaves, with olive green to greyish purple velvety growth on the under surface. Look for plants where leaves dry up and die rapidly.

Disease management:

Cultural practices

- Remove crop residue at the end of the season. Burn it or bury it away from tomato production areas.
- Start with certified, disease-free seed or treat seed with hot water.
- Whenever possible, provide adequate plant and row spacing to avoid excessive shading.
- Use drip irrigation and avoid wetting the foliage.
- Apply appropriate spacing between rows and between individual plants to provide good air movement.
- Circulate air in greenhouses or tunnels with vents and fans to reduce humidity around plants. Keep the relative humidity in the greenhouse below 85 percent and keep free moisture from forming or persisting on leaves. This will inhibit the development and spread of the leaf mould fungus. Provide good ventilation and as much light as possible.
- Keep night temperatures in greenhouses higher than outside temperatures to avoid dew formation on the foliage.
- Sanitize greenhouse thoroughly between crop cycles.

Chemical control

In order to be most effective, pesticides should be applied prior to infection when environmental conditions favour disease. Be sure to thoroughly cover all aboveground parts of every plant, especially the lower surface of the foliage. There are several registered fungicides in North Macedonia, available for the management of leaf mould on tomato, based on the following active ingredients or combination of active ingredients: tetraconazole, boscalid + pyraclostrobin, difenoconazole + cyflufenamid.

Disease: Early blight of tomato

Pathogen: ***Alternaria solani***

Early blight, caused by the fungus *Alternaria solani* is one of the most common tomato diseases, occurring nearly every season wherever tomatoes are grown. It affects leaves, fruit and stems and can be severely yield limiting when susceptible cultivars are used and weather is favourable. Early blight is common in both field and high tunnel tomato production.

Hosts: Tomato and potato are the main hosts of *Alternaria solani*, but the pathogen can also infect eggplant and several solanaceous weeds.

Symptoms and signs:

Symptoms of early blight occur on fruit, stem and foliage of tomatoes.

Leaves

Initial symptoms on leaves appear as small 1–2 mm black or brown lesions and under conducive environmental conditions the lesions will enlarge and are often surrounded by a yellow halo. Lesions greater than 10 mm in diameter often have dark pigmented concentric rings. This so-called "bullseye" type lesion is highly characteristic for early blight. As lesions expand and new lesions develop, entire leaves may turn chlorotic and dehisce, leading to significant defoliation.

Stems

Lesions on stems are often sunken and lens-shaped with a light centre and have the typical concentric rings. On young tomato seedlings, lesions may completely girdle the stem, a phase of the disease known as "collar rot," which may lead to reduced plant vigour or death.

Fruit

Infection of both green and ripe tomato fruit normally occurs through the calyx with lesions sometimes reaching a considerable size. The lesions appear leathery and may have characteristic concentric rings. They generally occur near the stem. Infected fruit frequently drop prematurely.

Symptoms of early blight on leaves and fruit

Symptoms of early blight on stem

Pathogen biology:

A. solani overwinters in infected plant debris and soil in its mycelial form and thick-walled chlamydospores. The dark pigmentation of the mycelium increases resistance to lysis, which extends survival time in the soil to several years. The pathogen also survives on tomato seed or may be introduced on tomato transplants. In mild climates, the pathogen can survive from season to season on volunteer tomato and potato plants as well as other weedy solanaceous hosts such as nightshades. Warm (24–29 °C) and humid environmental conditions are conducive to infection. In the presence of free moisture and at an optimum temperature of 28–30 °C, conidia will germinate in approximately 40 min. Desiccated germ tubes are able to renew growth when re-wetted, and, hence, infection can occur under conditions of alternating wet and dry periods. Germ tubes penetrate the leaf epidermis directly or enter through stomata. The time from initial infection to appearance of foliar symptoms depends on environmental conditions, leaf age, and cultivar susceptibility. Early blight is principally a disease of ageing plant tissue. Lesions generally appear quickly under warm, moist conditions on older foliage and are usually visible within 5–7 days after infection. Secondary spread of the disease results from conidia being dispersed mainly by wind and occasionally by splashing rain or overhead irrigation. Early blight is considered polycyclic with repeating cycles of new infection. In the period of secondary spread, the disease has the potential to spread rapidly and to build up to damaging levels in the crop.

Monitoring:

Monitor fields on a weekly basis and search plants for the presence of early blight symptoms on leaves, stems and fruit. Early detection of the disease is important since early control measures will reduce subsequent disease development and the number of foliar fungicide sprays needed.

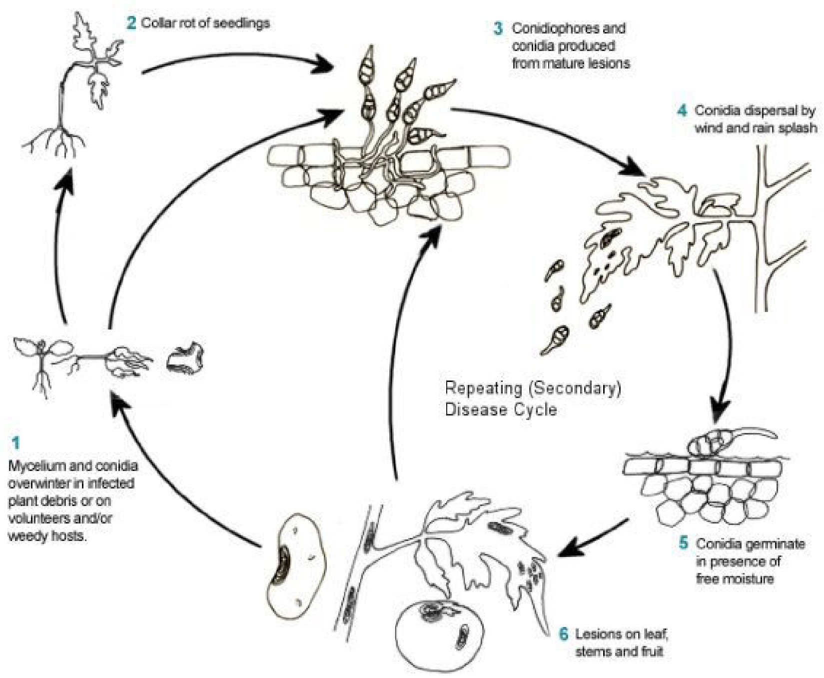


Figure 10. Disease cycle of *Alternaria solani*

(©aps.net.org)

Disease management:

Cultural practices

In many cases employing sound cultural practices that maintain tomato plants in good health will keep early blight losses below economic levels.

- Use pathogen-free seed or collect seed only from disease-free plants.
- Use crop rotation with non-hosts for at least two years.
- Control susceptible weeds such as nightshades and volunteer tomato plants throughout the rotation.
- Fertilize properly to maintain vigorous plant growth. In particular, do not over-fertilize with potassium and maintain adequate levels of both nitrogen and phosphorus.
- Avoid working on plants when they are wet from rain, irrigation or dew.
- Use drip irrigation instead of overhead irrigation to keep foliage dry.
- Stake the plants to increase airflow around the plant and facilitate drying. Staking will also reduce contact between the leaves and spore-contaminated soil.
- Apply plastic or organic mulch to reduce humidity and provide a barrier between contaminated soil and leaves.
- In autumn, remove and bury infected plants to reduce the likelihood of the pathogen surviving to the following year.
- Management of other diseases such as Verticillium or Fusarium wilt will reduce plant stress and hence, early blight severity.

Biological control

There is one biofungicide registered for the control of *Alternaria solani* in tomato, based on *Bacillus subtilis* QST 713 (see table below).

Table 7. Biofungicide registered for the control of Alternaria solani in tomato

Active ingredient	Rate of application	PHI* (days)	Comments
Bacillus subtilis QST 713	8 litres/ha	0	Maximum 6 sprays/season

* PHI – Pre-harvest interval

Chemical control

In order to be most effective, fungicide applications should be made when environmental conditions favour the disease and repeated according to label instructions. It is important to alternate between fungicides with different modes of action to avoid the development of pathogen insensitivity to particular active ingredients. As always, all label recommendations must be followed when applying fungicides to crops. Pay particularly close attention to pre-harvest intervals.

In North Macedonia, there are many registered fungicides for the control of early blight on tomato, based on following active ingredients or combination of active ingredients: copper oxide, boscalid + pyraclostrobin, metalaxyl-m + mancozeb, difenoconazole + cyflufenamid, azoxystrobin + difenoconazole, difenoconazole + fluxapyroxad.

Pest: *Tuta absoluta*

Common name: Tomato leaf miner or Tomato borer

Tuta absoluta is a highly destructive insect pest of tomato plants. Originating from Latin America, *T. absoluta* has recently spread via infested fruit and packaging material to Europe, North Africa and the Middle East. Given its aggressive nature and crop destruction potential, it has quickly become a key pest of concern in these new areas. In tomato, it can attack any part of the plant at any crop stage and can cause up to 100 percent crop destruction. In North Macedonia, this pest was detected for the first time in 2011.

Hosts: *Tuta absoluta* lives on and in the leaves, stems and flowers of plants in the Solanaceae family (tomato, potato, eggplant, *Solanum nigrum*, *Nicotiana* spp., *Datura* spp.) and also in the fruit of tomatoes. Its primary host is tomato. Recently, it has also been found on bean plants (*Phaseolus vulgaris*).

Symptoms and damage:

Infestation of tomato plants occurs throughout the entire crop cycle. Feeding damage is caused by all larval instars and throughout the whole plant. The larvae feed on the mesophyll tissue in leaves, forming irregular leaf mines which may later become necrotic. Larvae can form extensive galleries in the stems, which affects the development of the plants. Fruit are also attacked by the larvae, and the entryways are used by secondary pathogens, leading to fruit rot. The extent of infestation is partly dependent on the variety. Potential yield loss in tomatoes (quantity and quality) is significant and can reach up to 100 percent, if the pest is not managed.

Damage on tomato leaves and fruit caused by *Tuta absoluta*

Pest description:

Eggs

Eggs are oval-cylindrical, creamy to yellow in colour and 0.35 mm long.

Larvae

There are four instars. Early instars are white or cream with a black head and 0.5 mm long. Later they turn pink or green and are 6 mm long.

Pupae
Pupae are brown and up to 9 mm long.

Adults
Adult moths are small with body length from 5 to 7 mm. They are greyish or silver colour with black spots on the wings. The wingspan is 8–10 mm.

Pest biology:

Tuta absoluta has ten to twelve generations per year. It can overwinter in all growth stages (eggs, larvae, pupae and adult), depending on the climate conditions. It reproduces rapidly, with a life cycle of 24–38 days, depending on temperature. The moths are active at night and hide between leaves during the day. The minimum temperature for their activity is 9 °C. The larval stage (caterpillar) does not enter diapause while food is available. During the life of one female, up to 300 eggs may be deposited on above ground parts (on leaves, stems and young fruit). Eggs hatch and larvae bore between the epidermal layers of the leaf creating mines and, when older (at the third to fourth instar or later developmental stage of the larva) they leave these mines and travel to new locations to mine again. The young larvae usually attack the leaves but can be found in growing points and in flowers. Later stage larvae tend to attack the fruit. Pupation happens in the mine, outside the mine, or in the soil.

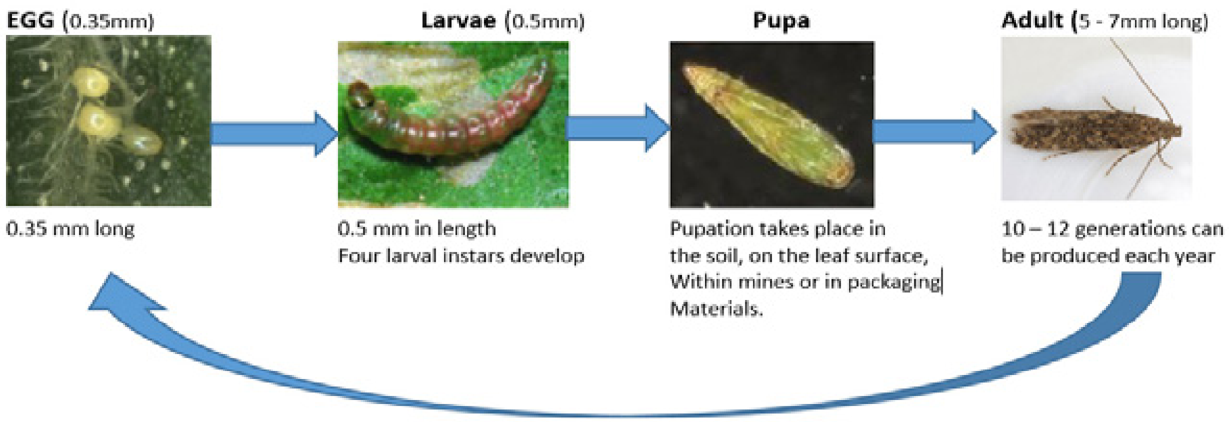


Figure 11. Life cycle of *Tuta absoluta*

(©Greenlife Crop Protection Africa)

Monitoring:

Start monitoring two weeks before planting. Use special traps (water traps or blue light) to detect the first presence of the moth inside and outside the greenhouse. Check plants for the first appearance of mines. Make regular field inspections to look for new or further infestations.

Pest management:

The basis for effective and sustainable management of *Tuta absoluta* is the integration of cultural, mechanical, biological and chemical control.

Cultural practices

- Use crop rotation with non-hosts (crops from other botanical families).
- Destroy previous crop residue right after the last harvest.
- Allow a minimum of six weeks from crop destruction to planting the next crop to prevent carryover of the pest from previous crop.

- Between planting cycles, cultivate the soil and cover with plastic mulch or perform solarization.
- Control weeds to prevent multiplication in alternative weed hosts (especially weeds from the Solanum, Datura and Nicotiana genera).
- Do not grow other host crops around the farm and remove host weeds near the greenhouse.
- Use plastic mulch to help identify and reduce pupation in the soil.
- Use pest-free transplants. Check the seedlings before transplanting to ensure they are free of Tuta eggs and larvae.
- During the growing season, remove and destroy any infected leaves, shoots and fruit immediately.

Mechanical control

- Grow tomato seedlings inside a netted nursery.
- Seal greenhouse with high quality nets suitable for T. absoluta.
- Install a tight and secure door in the greenhouse to prevent moths from entering.
- Before planting, double check the net to make sure it does not have holes or gaps.
- Make provision for ventilation at each end of the greenhouse to remove hot air, especially during hot summers.
- As soon as more than 3–4 moths per trap are captured each week, start mass trapping of moths. For mass trapping of moths, use sticky traps or water + oil traps (30–40 traps/ha) baited with pheromone. Keep using pheromone traps for at least three weeks after removing the crop. This will help to catch the remaining male moths in the greenhouse.

Biological control

Establish populations of effective biological control agents in the greenhouses, such as *Nesidiocoris tenuis*, *Macrolophus pygmaeus*, *Necremnus* sp., *Trichogramma* sp. or *Pseudoapanteles* sp. There are also two bioinsecticides registered for the control of *Tuta absoluta* in North Macedonia, based on *Bacillus thuringiensis* ssp. *kurstaki* and *Bacillus thuringiensis* ssp. *kurstaki* strain PB 54.

Chemical control

Use only insecticides registered for the control of *Tuta absoluta* and always follow the directions for use on the label of each product. Rotate insecticides with different modes of action to avoid resistance.

In North Macedonia, there are several registered insecticides for control of *Tuta absoluta* in tomato, based on following active ingredients or combination of active ingredients: abamectin, emamectin benzoate, chloranthraniliprole, spinosad, indoxacarb, abamectin + chlorantraniliprole.

Pest: ***Liriomyza bryoniae***

Common name: Tomato leaf miner

The principal impact of *Liriomyza bryoniae* is through the larvae mining into leaves and petioles, which leads to reduced photosynthetic ability of the plant and retarded growth of plants. Severe infestations can cause 100 percent yield loss of tomatoes.

Hosts: *Liriomyza bryoniae* is highly polyphagous and has been recorded in many plants belonging to 16 families. It is a major problem on tomatoes, crucifers, cucurbits and lettuces grown under glass in all areas where the pest is present or in open fields, especially in southern Europe. Other hosts of tomato leaf miner include eggplant, capsicum (peppers) and potatoes, as well as solanaceous weeds.

Symptoms and damage:

Leaf miners cause plant damage both directly and indirectly. The most direct damage is caused by the larvae mining the leaf tissue, leading to drying out and premature leaf-fall. In full-grown fruiting-tomato plants, a considerable quantity of foliage can be damaged before the harvest, which can significantly reduce yields. Seedlings and young plants can be completely destroyed as a result of the direct damage caused by leaf miners. Older larvae make wider tunnels. Feeding spots made by adult females can also reduce yield, although this is usually of lesser significance. Indirect damage arises when disease causing fungi or bacteria enter the plant tissue via the feeding spots.

Damage on leaves caused by *Liriomyza bryoniae*

Description of pest:

Eggs

Eggs are white and elongated, about 0.25 mm in size.

Larvae

The larvae are typical, legless, creamy yellow in colour and up to 3 mm long.

Pupae

Pupae are more cylindrical, about 3 mm long, and can vary in colour from yellow to brownish black.

Adults

Adults of *Liriomyza bryoniae* are small (1.7–2.2 mm in length), with a black body and yellow areas on the head and sides.

Liriomyza bryoniae adult (left) and larva (right)

Pest biology:

The life cycle of the leaf miner has the following stages: egg, three larval instars, a pupal instar and the adult. It usually overwinters as pupa in the soil in open fields. In greenhouses, it can continuously develop all year round. After emergence, females are still not mature for copulation and they start to feed on tomato leaves. After copulation, females lay creamy white to yellow eggs on the underside of tomato leaves. Eggs take 4–8 days to hatch, depending on the temperature. When the larva hatches from the egg, it begins to eat into the leaf at once, tunnelling down into the mesophyll tissue, where damage is caused by extensive mines, leaving the outer layers of the leaf and stalk intact. Shortly before pupating, the grown larva cuts a sickle-shaped exit hole in the leaf with its mouth parts. After roughly one hour the larva crawls out of the leaf and falls to the ground. This occurs early in the morning. The larva crawls into the ground to pupate. A small percentage of the larvae remain hanging on the leaf and pupate there, sometimes on the upper surface but more commonly on the underside. The late third instar larva that emerges from its tunnel just prior to pupating, is known as a pre-pupa. This stage lasts only a few hours. Tomato leaf miner has 4–6 generations per year.

Monitoring:

Check plants for the first appearance of feeding spots, which appear as white spots, usually arranged as straight lines along the leaf edges. Make regular field inspections to look for new or further infestations.

Pest management:

The combination of cultural, biological and chemical measures should generally assist in the management of *Liriomyza bryoniae*.

Cultural practices

- Use crop rotation with non-hosts (crops from other botanical families);
- Destroy previous crop residue right after the last harvest; and
- During the growing season, remove leaves or whole plants which are heavily infested.

Biological control

Introduction of natural enemies, such as parasitoids *Dygliphus isaea*, *Dacnusa sibirica* and *Opius pallipes*, as well as predatory bug *Macrolophus pygmaeus*. Further, larvae of *L. bryoniae* can also be successfully controlled with *Bacillus thuringiensis*.

Chemical control

Use only insecticides registered for the control of *Liriomyza bryoniae* and always follow the directions for use on each product label. Rotate insecticides with different modes of action to avoid resistance.

There are several registered insecticides in North Macedonia for the control of *Liriomyza bryoniae* in tomato, based on following active ingredients or combination of active ingredients: abamectin, spinosad, abamectin + chlorantraniliprole.

Pest: *Frankliniella occidentalis*

Common name: Western flower thrips

Frankliniella occidentalis is a relatively new pest in Europe and originates from North America. Since its introduction in 1983, it has become a major pest of vegetables, fruit and ornamental crops across Europe. Due to its wide host range and its importance as a vector of plant viruses, nowadays *F. occidentalis* is considered as one of the world's major pests.

Hosts: *F. occidentalis* is a highly polyphagous species with at least 250 plant species from more than 65 families being listed as hosts. Some examples are: soft fruit (plums, peaches, strawberries, grapes), flowers (gladiolus, impatiens, gerbera, chrysanthemum, poinsettia), vegetables (tomato, cucumber, pepper, cabbages, beans), which can be infested both in the field and in greenhouses. Many species of wild flowers are hosts, too.

Symptoms and damage:

Damage is caused by thrips in two ways. Direct damage results from feeding. Adults and nymphs puncture individual plant cells, mostly in the epidermis, with their mouth parts and suck up the sap. Empty, air-filled tissue causes the plant surface to get a characteristic silvery appearance. Specifically, foliage becomes silvery, while flowers become flecked, spotted and deformed and buds fail to open. Heavier infestations lead to browning and wilting of leaf tips, and in extreme cases, to shoot distortions and dropping of leaves. 'Halo spotting', another symptom of thrips damage, consists of small dark scars surrounded by whitish tissue. In pepper, tomato, cucumber and beans, fruit scarring occurs and the undersides of leaves show small black specks of faecal material. Moreover, in pepper, oviposition causes a reaction of the surrounding plant tissue.

Indirect damage is caused by infection of crops by viruses. At least three important tospoviruses are known to be transmitted by western flower thrips, such as: *Tomato spotted wilt virus* (TSWV), *Impatiens necrotic spot virus (INSV)* and *Chrysanthemum stem necrosis virus* (CSNV). TSWV causes significant damage to vegetables in the Solanaceae family, for example in tomatoes, potatoes and pepper, but also in lettuce.

Feeding scars from thrips, termed 'silver damage' on pepper leaves (left) and tomato fruit (right)

Symptoms of tomato spotted wilt virus on pepper leaves

Description of the pest:

Eggs

The eggs are oval or kidney-shaped, white in colour and about 0.2 mm long.

Nymphs

The nymph is thin and wingless, yellowish in colour with red eyes, up to 1 mm long.

Adults

The adult male is about 1 mm long, while the female is slightly larger, about 1.4 mm in length. Males are rare, and are always pale yellow (almost white), while females vary in colour, often by season, from red to yellow to dark brown. Each adult is elongated and thin, with two pairs of feathery wings.

Adult (top left) and nymphs (bottom right) of Western flower thrips

Pest biology:

Thrips have an unusual form of incomplete metamorphosis. There are four nymphal instars. They are all mobile, but only the first two, actually called larvae, are able to ingest food. The third and fourth are called pre-pupa and pupa, respectively. It can develop quickly, going from egg to adult in two weeks or less at favourable temperatures. Adult females insert eggs into the plant tissue under the epidermis. Hatching occurs about 3–4 days after the egg has been laid. The larval stage lasts about five days. Larvae and adults feed on flowers, buds, terminals, leaves, and fruit. When mature, larvae drop to the soil to go through the pre-pupal and pupal stages, and finally return to the plants as adults. Adults can live around 15 days. In warm regions or in greenhouses, where continuous breeding is possible, it can have up to 12–15 generations per year. Otherwise, adults and pupae can overwinter in sheltered places, such as under lumps of soil, tree bark, weeds etc. and only one or two generations may be completed. Optimal conditions for development are at 25–30 °C, and a cycle can be completed in about three weeks (15–18 days).

Monitoring:

Look for discoloured, deformed new growth and buds – when thrips feed on developing tissues, the cells are unable to expand and mature leaves and petals become distorted. Look for scarring on fruit, particularly noticeable on pepper, and look for leaves which have a silvery appearance. Shake or tap flowers and shoots over white paper. Use yellow or blue sticky traps. Blue traps have the advantage that they are not as attractive to non-thrips species.

Pest management:

The combination of cultural, mechanical, biological and chemical measures should generally assist in the management of *Frankliniella occidentalis*.

Cultural practices:

Before planting:

- Check seedlings to ensure that they are free from the pest.
- Remove weeds from within and around crops. Note that the host range for thrips is very wide and includes many weeds. Grasses, however, are poor hosts and could be used around greenhouses and nurseries to reduce the need for management of other weeds that are hosts. A ten metre-wide strip around greenhouses and nurseries or around crops is sufficient. Bare ground is also effective.
- Do not plant new crops next to those infested by thrips and do not plant new crops downwind from those infested with thrips. These measures are especially important if the “old” crop is infected with TSWV.
- Use plastic mulch to cover the soil.
- Use crop rotation. Do not plant the same crop on the same land without a break.

During growth:

- Monitor routinely for thrips. Use yellow or blue sticky traps placed about 10 cm above the crop and inspect weekly.
- Remove and destroy all plants showing symptoms of infestation by thrips.

After harvest:

- Collect and destroy crop debris by burying or burning.

Mechanical practices:

Perform mass trapping of thrips. For this purpose, numerous sticky traps (yellow and blue) should be placed in greenhouses in order to reduce the Western flower thrips population. Traps should be positioned just above the plant tops.

Biological control

Natural enemies such as predatory thrips (*Aelothrips* spp.), predatory bugs (*Orius* spp., *Anthocoris nemorum*), lacewings (*Chrysoperla* spp.) and predatory mites (*Amblyseius* spp., *Neoseiulus* spp.) can provide significant control of *F. occidentalis* populations in the greenhouses and should be included as a part of an IPM program.

Other antagonists which can be successfully used against the Western flower thrips include predatory nematodes, such as *Steinernema feltiae*, and entomopathogenic fungi, such as *Beauveria bassiana* and *Metarhizium anisopliae*.

Chemical control

If thrips cause physical damage to the crop, the use of insecticides may be needed. However, there are problems using pesticides to control thrips. First, the insects are hidden within flowers and the leaves of shoots; second, the eggs are inserted into the leaves making it difficult for sprays to reach them; and third, thrips rapidly become resistant to insecticides, so much so that there are large differences in the susceptibility of thrips populations to commonly used products. Use only insecticides registered for the control of *Frankliniella occidentalis* and always follow the directions for use on the label of each product. Rotate insecticides with different modes of action, to avoid resistance.

There are several registered insecticides for control of *Frankliniella occidentalis* in tomato and pepper in North Macedonia, based on following active ingredients: abamectin, delthamethrin, spinosad.

Pest: *Trialeurodes vaporiarum*

Common name: Greenhouse whitefly

T. vaporariorum originates from Central America but nowadays is found worldwide. It is originally a subtropical species and although it can even withstand slight frost for a short time, it is only found in glasshouses in cold climates, at least during the winter. It was accidentally introduced to Europe in the middle of the nineteenth century. Nowadays, it is considered as one of the most harmful insect pest in greenhouses.

Hosts: *T. vaporariorum* probably has the most comprehensive host range of all insect pests. It includes about 800 species. Besides vegetables, the most threatened crops in glasshouses are ornamentals.

Symptoms and damage:

Adults and nymphs of *Trialeurodes vaporariorum* cause three types of damage to plants: direct suction of plant sap, honeydew covering plants caused by extensive sugar secretions, and transmission of plant viruses. The nymphs and adults of whitefly suck plant sap from the phloem.

Due to their often very large numbers, the loss of nutrients can lead to growth deformation, yield reduction, wilting of leaves, and in extreme cases to the death of the plant. For instance, tomato plants turn yellow, look mottled and have stunted growth with wilting and defoliation and thereby seriously reducing the crop yield. Heavy feeding by whiteflies can eventually kill plants.

At least the same amount of injury is caused by honeydew. Typically for phloem-feeding insects, whiteflies have to ingest a lot of plant sap, because they need proteins and amino acids that are available in low concentrations only, in contrast to rather large amounts of carbohydrates. They excrete the excess liquid, with most of the sugars still in it, as honeydew. This can be produced in copious amounts (literally dropping from the leaves) and it may cover all plant surfaces beneath the feeding sites with a sticky film, which will serve as a substrate for sooty moulds that interfere with photosynthesis and render fruit unmarketable.

While *T. vaporariorum* is less important as a vector in comparison with *F. occidentalis*, it does transmit some viruses belonging to the family *Closteroviridae* that can cause significant damage, and its importance in this respect has increased during recent years.

Symptoms and damage in tomato caused by whitefly

Description of the pest:

Eggs

When first laid, eggs are transparent to pale cream-yellow, which turn to brown-black (Photo A below).

Nymphal instars

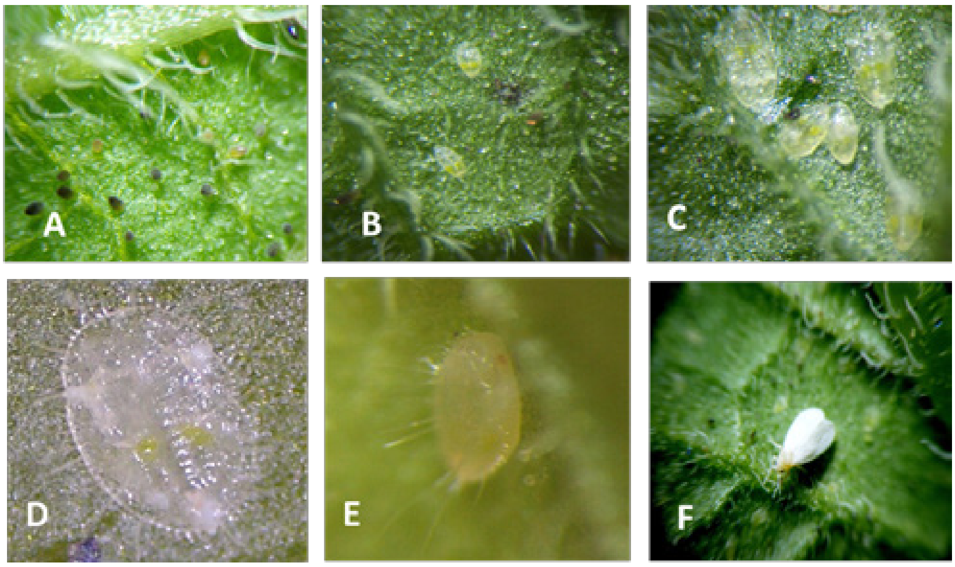
First nymphal instars, called "crawlers," are near-transparent, flat, and oval (Photo B). Second nymphal instars are translucent and oval with wavy edges (Photo C). Third nymphal instars are larger in size but morphologically similar to the second nymphal instar (Photo D).

Pupa (fourth nymphal instar)

Fourth nymphal instar is oval, flat, and almost transparent (Photo E). As development progresses it becomes opaque and is called a pupa. The pupa is elliptical with characteristic long erect threads of wax.

Adults

Adults look like small moths. They are about 1–2 mm long and have pale yellow wings, powdered with white wax (Photo F). At rest, these are held flat, giving the insect a triangular appearance. The female is larger than the male.



The developmental instars of the greenhouse whitefly, *Trialeurodes vaporariorum*: (A) egg, (B) first nymphal instar, (C) second nymphal instar, (D) third nymphal instar, (E) fourth nymphal instar or pupa and (F) adult. ©International Potato Center (CIP)

Pest biology:

The greenhouse whitefly (*Trialeurodes vaporariorum*) goes through six stages: egg, first, second, third and fourth larval stage (the latter often referred to as 'pupa' although strictly spoken this is not true) and adult. The larvae are found on the underside of young leaves and have oval shape. The first instar larvae (crawlers) are mobile, whereas the rest of the larval stages remain flattened on the leaf. The fourth larval stadium develops into a white, oval case encircled by a ring of erect waxy rods. This is called the pupa stage and these pupae are found on the oldest leaves.

The adult emerges from the pupa via a T-shaped fissure. Adult whiteflies can usually be found in the top of the plant and on the underside of young leaves, where they deposit their eggs (100 eggs per female). When shaking infested plants, adults will first fly, then return to the underside of the leaves. The adult greenhouse whitefly (*Trialeurodes vaporariorum*) has well-developed piercing-sucking mouthparts and begins to feed on plant sap very soon after emerging. In greenhouses, *T. vaporiarum* usually develops 10–12 generations per year. Under favourable conditions, one life cycle can be completed in 3–4 weeks.

Monitoring:

Plants should be inspected at least on a weekly basis for the presence of whitefly and data should be recorded. Increase the frequency of monitoring during warmer weather and on host plants which are known to be more susceptible to whitefly. Frequent monitoring will enable infestations to be spotted while they are still light, and thus easier and cheaper to manage. Methods of monitoring include:

Visual inspection

Inspect at least 100 plants per 1 000 m^2. Examine both leaf surfaces of plants that look stunted or are chlorotic using a hand lens. Older nymphs tend to be found on older leaves, eggs and young nymphs tend to be found on young growth. Move through the crop and gently but firmly hit foliage against a beating tray (which can be a folder, bucket or plastic plate). Generally accepted threshold is one adult per 100 plants.

Yellow sticky traps

Yellow sticky traps are useful tools for monitoring whitefly adults. Adults are most attracted to young foliage, so traps should be positioned just above the plant tops. Traps should also be placed near to doors, vents and any susceptible crops. At least one trap per 100 m^2 is recommended for greenhouse crops, and more in varieties that are known to be susceptible to whiteflies. Inspect sticky traps at least weekly and change traps every two to four weeks. A generally acceptable threshold for whiteflies is the average of 0.5 per trap per day when the crop is young, and two per trap per day when the crop reaches maturity.

Pest management:

Management of whitefly can be difficult. The best strategy is to prevent whitefly from developing in greenhouses. In many situations, natural enemies will provide adequate control of whiteflies. Outbreaks often occur when natural enemies are disrupted by insecticide applications. For this reason, the combination of cultural, biological and chemical measures should be included in the management of *Trialeurodes vaporiarum*.

Cultural practices

- Use crop rotation.
- Remove plant debris and weeds after harvest to reduce the numbers of whitefly nymphs and eggs.
- Place fine nets (insect-proof) on the vent openings and on the doors of the greenhouses to prevent entry of adults.
- Control weeds around greenhouses.
- During the growing season, remove leaves or whole plants heavily infested with the non-mobile nymphal and pupal stages. This will reduce populations to levels that natural enemies can contain.
- Always inspect new plants for whiteflies and their nymphs before introducing in the greenhouse.

Biological control

Biological control of *T. vaporiarum* has been widely used in greenhouses, especially since the development of insecticide-resistant whiteflies, and is mainly based on parasitic wasp, *Encarsia formosa*. The wasps kill whitefly nymphs in one of two ways: they either lay an egg inside the nymph, providing food for their offspring, or kill the nymph right away and feed on the fluids inside of it.

The predatory beetle *Delphastus pusillus* is also a very effective biological control agent for *T. vaporiarum* in greenhouses. *Delphastus pusillus* is a very small, black ladybird beetle that attacks all stages of whiteflies, but prefers eggs and nymphs. The females lay their eggs within the clusters of whitefly eggs. Adults can consume 160 eggs or 12 large nymphs per day. A larva consumes 1 000 whitefly eggs during its development. These predators can be used in combination with *Encarsia* sp.

Lacewings (*Chrysoperla* spp.) are also used as general predators in greenhouses as they also consume whiteflies.

Fungal pathogens *Verticillium lecanii* and *Achersonia aleurodes* also attack whiteflies and can be used as useful control agents for this pest.

In North Macedonia, one biological pesticide based on orange oil was recently registered for the control of wide range of insects, mites and fungal diseases, including for the control of *Trialeurodes vaporiarum* in tomato and pepper (see table below).

Table 8. Biological pesticide based on orange oil registered in North Macedonia for control of insects, mites and fungal diseases in tomato and pepper

Active ingredient	Rate of application	PHI* (days)	Comments
Orange oil	2 litres/ha	1	Maximum 6 sprays/season

* PHI – Pre-harvest interval

Chemical control

Whitefly can be difficult to control with insecticides, especially in situations when biological control with natural enemies is introduced in greenhouses. If this is the case, it is necessary to avoid use of insecticides that kill the natural enemies.

Use only the insecticides registered for the control of *Trialeurodes vaporiarum* and always follow the directions for use on the label of each product. Rotate insecticides with different modes of action, to avoid resistance.

In North Macedonia, there are several registered insecticides for the control of *Trialeurodes vaporiarum* in tomato and pepper, based on following active ingredients: abamectin, flonicamid, sulfoxaflor, pyriproxyfen, lambda cyhalothrin.

Pest: ***Tetranychus urticae***

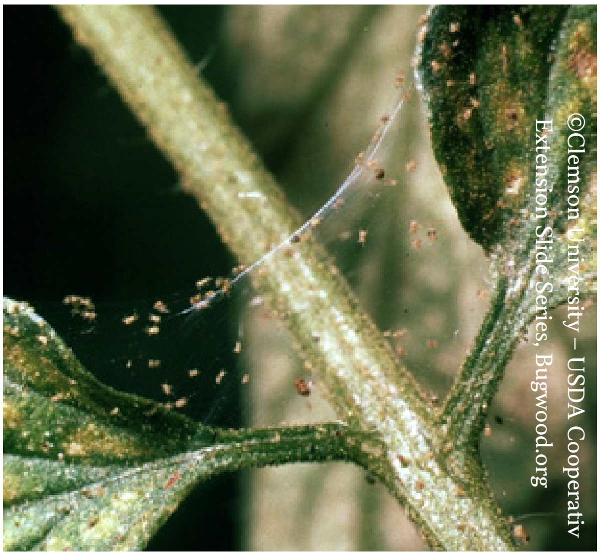
Common name: Two-spotted spider mite; Greenhouse red spider mite

Spider mites are the most common mites attacking woody plants and the two-spotted spider mite is considered to be one of the most economically-important spider mites. This mite has been reported to infest over 200 species of plants, especially in temperate and subtropical regions. It is considered as one of the most economically-important pests in greenhouse production of vegetables.

Hosts: *T. urticae* is an extremely polyphagous species, with at least 200 plant hosts. It is an economically-important pest, especially on beans, peppers, tomatoes, vine, cotton, cucumber, hop, soybean, strawberry, sunflower, and as well as numerous fruit trees and ornamentals. It can also be found on eggplant, broad bean, cowpea, groundnut, lettuce, melon, red and black currant, sorghum, sweet potato, tea and many other hosts.

Symptoms and damage:

In the early stages of infestation, *T. urticae*, like other spider mites, penetrate plant cells on the undersides of leaves. With further spread of the infestation, they can also feed on the upper sides of leaves. It is estimated that 18 to 22 cells are destroyed per minute. The first visible symptoms are small whitish speckles, mainly around the midrib and larger veins. When these spots merge, the empty cells give areas of the leaf a whitish or silvery-transparent appearance. With ongoing infestation, damage will not be restricted to the spongy mesophyll but will include the palisade parenchyma as well, and the leaf tissue may collapse completely. The function of the stomata is affected and transpiration constrained. The leaf will turn yellow, wilt, and finally be shed; sometimes complete defoliation occurs. Often, the whole foliage of attacked plants takes on a yellow or brownish cast. The loss of photosynthetically-active surface along with reduced transpiration leads to reduced yield, and the plant may be stunted or, in severe cases, killed. Moreover, in tomato, the mites feed directly on fruit, causing gold flecks (discolouration of the fruit), which may have a negative impact on marketability of the fruit.



Symptoms on tomato leaves caused by *Tetranychus urticae*

Severely affected tomato plants (left) and symptoms on tomato fruit (right)

Description of the pest:

Eggs
The eggs are spherical and transparent.

Larvae
The larvae are pale green in colour and have six legs.

Nymphal instars
There are two nymphal instars (protonymph and deutonymph). The nymphs are pale green in colour with darker markings and have eight legs.

Adults
The adult female is 0.6 mm long, pale green or greenish-yellow with two darker patches on the body, which is oval with quite long hairs on the dorsal side. Overwintering females are orange-red in colour. The males are smaller (0.3 mm long), with narrower and more pointed body than the female.

Tetranychus urticae female adults (right is an overwintering female)

Pest biology:

Each female of *T. urticae* can lay an average of 100 eggs during its lifetime of about 30 days. Eggs are mostly attached to the silk webbing. The six-legged larvae hatch after 3–15 days. They moult three times within 4–5 days, towards protonymph, then deutonymph and finally the adult. These instars all have eight legs. Before each moult, there is a short quiescent stage. The development of the mite is rapid, especially in favourable conditions. Thus, at 30–32 °C, which is the optimum temperature for development, and a relative humidity about 45–50 percent, the egg stage lasts 3–5 days, the larval/nymphal stages 4–5 days, and with the pre-oviposition period of 1–2 days, the total life cycle takes only 8–12 days. Often, a change towards hot and dry weather leads to a very rapid increase of the population density.

In greenhouses, reproduction can continue all year round. Outdoors, 6–10 overlapping generations per season are possible, depending on climatic conditions. The development of adult females, which are the overwintering stage of *T. urticae*, is initiated by a short photoperiod, decreased temperature and unfavourable food supply. The overwintering females stop feeding and egg laying and leave their host plants to hibernate in cracks and crevices in protected places, such as soil or glasshouse structures. They resume activity in the spring when they start to lay eggs on the leaves on the plant host.

Monitoring:

Plants should be inspected at least on a weekly basis for the presence of the two-spotted spider mite, especially when the climate conditions are favourable for its rapid development. For detection of spider mites, a 10× to 15× magnifying glass is necessary. Examine the undersides of the leaves closely for mites, cast skins and webbing. A more efficient technique is to place a sheet of white typing paper beneath the leaves and strike the foliage sharply. The mites will fall onto the paper and can be more easily observed and identified than on the green foliage.

Pest management:

Management strategies for control of *Tetranychus urticae* should involve a combination of cultural, biological and chemical measures.

Cultural practices

- Remove plant debris and weeds after harvest;
- Control weeds in greenhouses during the growing season;
- Control weeds around greenhouses; and
- Remove and destroy all infested plants during the growing season.

Biological control

The most effective enemies of *T. urticae* are predatory mites from the Phytoseiidae family. These mites, belonging to the number of genera, such as *Phytoseiulus* and *Amblyseius*, have been shown to regulate populations of *T. urticae* on a range of crops.

Phytoseiulus persimilis successfully controls populations of two-spotted spider mites in greenhouses. This predatory mite feeds on all stages of spider mites but has a preference for eggs. The predatory mites pierce the eggs and consume the contents. Adults of *Phytoseiulus persimilis* also attack adult spider mites but the smaller development stages only feed on smaller prey stages. The larvae do not eat. The predatory mite can only survive on two-spotted spider mites (*Tetranychus* spp.). There are commercial products based on *Phytoseiulus persimilis* available on the market.

Predatory mite, *Amblyseius cucumeris* is also very effective in reducing the population of two-spotted spider mite in greenhouses.

Chemical control

Tetranychus urticae is very difficult to control with acaricides, because its populations quickly develop resistance to frequently used chemicals – after a few years of use. Moreover, it is important that pesticides used for other pests are chosen so that they cause minimal disruption to naturally occurring predators or biological agents, such as *Phytoseiulus persimilis*.

Insecticides/acaricides are recommended for use when the population of *Tetranychus urticae* is still low. For example, a selective insecticide/acaricide can be used to reduce a large overwintered population of spider mite in the spring, before a release of *P. persimilis* later in the year.

There are several registered insecticides in North Macedonia for the control of *Tetranychus urticae* in tomato and pepper, based on following active ingredients: abamectin, bifenazate, spiromesifen.

Pest: ***Myzus persicae*** **&** ***Macrosiphum euphorbiae***

Common name: Leaf aphids (green peach aphid & potato aphid)

The green peach aphid, *Myzus persicae* and potato aphid, *Macrosiphum euphorbiae* are the most common aphid species in peppers and tomatoes worldwide, including in North Macedonia. Both species cause direct damage by removing plant fluids with their piercing-sucking mouthparts. The indirect damage caused by aphids is associated with the excretion of honeydew during feeding. Moreover, both species can transmit over 100 plant viruses.

Hosts: The primary host of *M. persicae* is *Prunus persica* (peach), including var. *nectarine*. *M. persicae* is highly polyphagous on summer hosts, which belong to more than 40 plant families, including Solanaceae, Brassicaceae, Poaceae, Fabaceae, Chenopodiaceae, Cucurbitaceae etc.

The primary host of *M. euphorbiae* is *Rosa* spp. This aphid is also highly polyphagous on secondary hosts, feeding on over 200 species which belong to more than 20 plant families. It favours plants from the Solanaceae family, especially potato and tomato, but is also very common on pepper, eggplant, lettuce, sugar beet and many other cultivated plants.

Symptoms and damage:

Aphids feed on buds, leaves, flowers, stems, and fruit with piercing-sucking mouthparts. Feeding causes plant structures to become stunted, yellowed, and distorted. Aphid feeding results in an overall loss of plant vigour. Early in the season, young vegetable plants can suffer loss of productivity and reduced plant health. Aphids excrete a sugary substance called honeydew which can cover plant surfaces and harm crop quality and marketability. Sooty mould fungi may grow on the honeydew, blocking sunlight and reducing plant vigour. Honeydew attracts ants, which can protect aphids by warding off predators to protect their honeydew food source. One of the most serious problems caused by aphids to vegetable crops is the spread of plant viruses. Viruses can dramatically reduce crop yield, and even kill plants. The green peach aphid and potato aphid are known to transmit more than 100 different plant viruses. Winged aphids can spread viruses from infected to healthy plants. Even when aphids are not detected, there is still a risk of virus introduction from virus-infected aphids immigrating into a field.

Aphid infestation on pepper plant

Description of the pest:

Aphids are small, soft-bodied, pear-shaped insects with two tailpipe-like appendages called “cornicles.” Cornicles are unique to aphids and excrete defensive compounds (waxes and alarm pheromones). Aphids vary in colour (green, yellow, brown, red or black), including within species, depending on maturity, food source, genetic lineage, and their environment. Juvenile aphids (nymphs) look like adults, except smaller in size. Adult aphids can be winged or wingless (apterous). Winged forms generally have slimmer bodies and transparent wings.

Although similar in size, these aphids vary in appearance. The potato aphid is pear-shaped and may be solid pink, green and pink mottled, or light green with a dark stripe. It has a long slender pair of tail-like appendages (cornicles). The green peach aphid is pear-shaped and pale yellow to green in colour. The cornicles are much shorter on this species.

Myzus persicae (left) and *Macrosiphum euphorbiae* (right)

Pest biology:

The life cycle varies considerably, depending on the presence of cold winters. Development can be rapid, often 10 to 12 days for a complete generation, and with over ten annual generations reported in mild climates. These aphids require a woody host to complete their life cycle. They overwinter as eggs on woody hosts and hatch in spring, producing only females. These spring aphids feed on the succulent new growth, and when mature, give birth asexually (parthenogenesis) to female offspring. After several generations on the woody hosts, the aphids form wings and migrate to vegetable crops and other hosts for the summer, where they complete many more generations. As temperatures drop in the fall, aphids again form winged offspring (male and female) and return to winter host plants, where sexual mating occurs and eggs are laid for overwintering.

Monitoring:

Check plants regularly for aphids (at least twice a week when plants are growing rapidly), in order to catch infestations early. Many species of aphids cause the greatest damage in late spring when temperatures are warm but not hot (18–27°C). For aphids that cause leaves to curl, once aphid numbers are high and they have begun to distort leaves, it is often difficult to control these pests, because the curled leaves shelter aphids from insecticides and natural enemies. Many aphid species prefer the underside of leaves, so turn leaves over when checking for aphids. Also check for evidence of natural enemies such as lady beetles, lacewings, syrphid fly larvae, and the mummified skins of parasitized aphids. Substantial numbers of any of these natural control factors can mean the aphid population may be reduced rapidly without the need for a treatment.

Pest management:

Cultural practices

- Before planting, remove weeds and volunteer crops that can serve as aphid hosts.
- Always check transplants for aphids and remove them before planting.
- Where aphid populations are localized on a few curled leaves or new shoots, the best control may be to prune out these areas and dispose of them.
- High levels of nitrogen favour aphid reproduction so never use more nitrogen fertilizers than necessary. Use a less soluble form of nitrogen and apply it in small portions throughout the season rather than all at once. Slow-release fertilizers such as organic fertilizers or urea-based time-release formulations are the best.
- Encourage natural enemies. Plant strips of yarrow, alyssum, herbs and other plants with small, attractive flowers that provide nectar and pollen for beneficial insects.

Biological control

Conservation and attraction of native natural enemies is one of the most effective means to prevent aphid outbreaks. In some situations, such as within greenhouse tunnels, purchasing and releasing biocontrol agents for aphid management can be of value. Generalist predators not only control aphid populations, but also feed on other pests such as thrips, leafhoppers, and mites. Low levels of aphids in the environment are desirable in order to maintain healthy populations of beneficial insects. The most well-known aphid predators include lady beetles (*Coccinella septempunctata*, *Propylea quatuordecimpunctata*, *Coccinulla quatuordecimpustulata*, *Hippodamia variegate*, *Rodolia cardinalis*), lacewings (*Chrysoperla carnea*, *Chrysoperla perla*, *Chrysoperla septempunctata*), predatory bugs (*Orius* spp., *Anthocoris nemorum*) and predatory midges (*Aphidoletes aphydimyza*).

Parasitic wasps (*Aphidius matricarie*, *Aphelinus mali*) are specialized natural enemies of aphids. Female wasps lay a single egg inside each of several hundred aphids. The egg hatches into a wasp larva that consumes the body of the aphid. The wasp larva then pupates inside the aphid, turning it into a mummy, and burrows out through a circular exit hole, leaving the mummified aphid behind. Parasitoid wasps can complete a life cycle within a few weeks; aphid populations may decline quickly once aphid mummies are noted.

Chemical control

When considering whether to apply insecticides for aphid control, remember that most larger plants can tolerate light to moderate levels of aphids with little damage. Larger aphid populations often rapidly decline due to biological control or when hot temperatures arrive. Often a forceful spray of water or water-soap solution, when applied with appropriate equipment, will provide sufficient control.

General action thresholds to determine whether and when to treat for aphids in vegetable crops include:

- When plants are young, aphid populations increase and occur on 50–60 percent of the leaves.
- When aphid populations remain at eight to ten or more per leaf for two or more consecutive weeks.

Only use insecticide applications when needed. Rotate among different insecticide classes between applications as aphids are prone to developing resistance. Select insecticides with the least harmful effects to beneficial insects, and high selectivity for the target pest. Always check product labels for registered uses.

There are many registered insecticides in North Macedonia for the control of leaf aphids in tomato and pepper, based on different active ingredients, such as: flonicamid, sulfoxaflor, lambda cyhalothrin, pirimicarb, imidacloprid, thiacloprid, delthamethrin, or flupyradifurone.

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