Biocontrol in Selected Crops Number 2: Tomato

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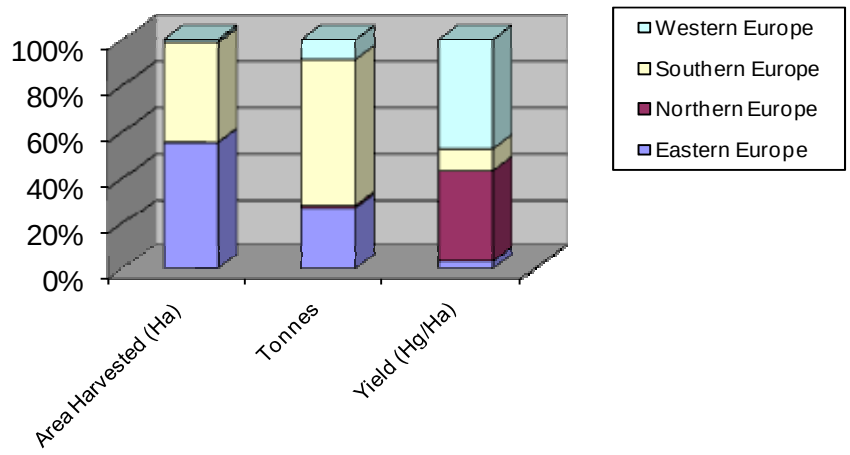
Tomato in European agriculture

Tomatoes are one of the most popular and widely grown vegetables in the world and can be grown either in the field or under greenhouse conditions. Greenhouse production in Europe is extremely intensive and can produce very high yields (up to 700 tonnes/ha). Field production is much less intensive.

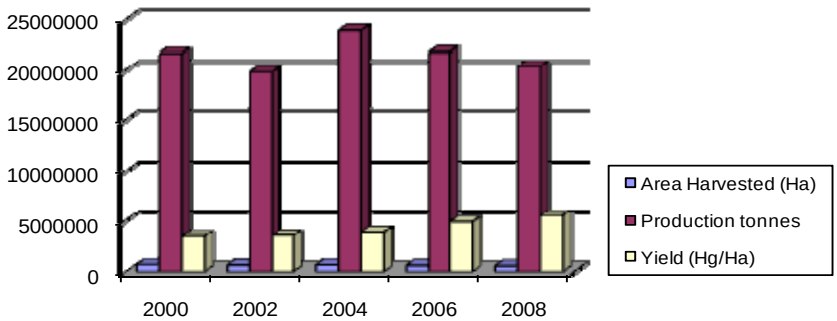
In 2008 the European Union (EU) was the third largest tomato producer with an annual production of 20 million tonnes (China was the leading producer with 33 million tonnes) (FAOSTAT, 2008). The main European producing countries are: Italy (6 million tonnes) followed by Spain (3.8 million tonnes), Russian Federation (1.8 million tonnes), Greece (1.3 million tonnes) and Portugal (1.1 million tonnes). Between them, Southern European countries contribute a total production of 13 million tonnes, which corresponds to 70% of the total production. But in terms of yield (Hg/Ha), Western Europe and Northern Europe have the best performances (see Figure 1 below).

Figure 1: Tomato production in Europe



During the past eight years there has been a positive trend in tomato yields, while the production and harvested area remained essentially the same (see Figure 2 below).

Figure 2: European tomato production during the last 8 years



Pesticides are widely used by tomato growers. More sustainable production methods are readily available but, unfortunately, not widely disseminated. We strongly believe that biological control methods and improved cultural practices can reduce pesticide use dramatically.

Diseases more frequently found in open field production

Many diseases and pests can affect tomatoes during the growing season:

> **Septoria leaf spot**: caused by the fungus *Septoria lycopersici* appears as small, water-soaked spots that soon become circular spots. Infection can occur at any stage of plant development but appears most frequently after plants have begun to set fruit. The fungus survives the winter in tomato debris.

> **Early blight**: caused by the fungus *Alternaria solani*, and is also known as Alternaria leaf spot or target spot. Brown to black spots appear on lower leaves Spots frequently merge, forming irregular blotches. Dark, concentric rings often appear in leaf spots, resulting in the 'target' appearance suggested by the common name. The fungus occasionally attacks fruit at the stem end, causing large, sunken areas with concentric rings and a black, velvety appearance. Warm, wet weather favours the rapid spread of early blight.

> **Anthracnose:** caused by the fungus *Colletotrichum coccodes*. Symptoms first become visibile on ripe or ripening fruit as small, circular, indented spots in the skin. As these spots expand, they develop dark centres or concentric rings of dark specks, which are the spore-producing bodies of the fungus.

> **Fusarium wilt:** caused by the fungus *Fusarium oxysporum* f. sp. *lycopersici*. The fungus attacks only certain tomato cultivars Plants infected by this soil-dwelling fungus show leaf yellowing and wilting that progress upward from the base of the stem. Initially, only one side of a leaf midrib, one branch, or one side of a plant will be affected. The symptoms soon spread to the remainder of the plant.

> **Verticillium wilt:** caused by *Verticillium albo-atrum* and *Verticillium dahliae*. Like Fusarium wilt, this disease appears first on the lower leaves and progresses upward. Unlike Fusarium wilt, symptoms of Verticillium wilt do not progress along one side of a leaflet, branch, or plant.

> **Late blight:** caused by the fungus *Phytophthora infestans*. It can devastate tomato plantings during periods of cool, rainy weather. Late blight may infect either young (upper) or old (lower) leaves. It first appears as water-soaked areas that enlarge rapidly, forming irregular, greenish black blotches, giving the plant a frost-damaged appearance. The undersides of the leaves often show a downy white growth in moist weather.

> **Southern blight:** a fungal disease caused by *Sclerotium rolfsii*, which mainly attacks mature plants, attacking roots, leaves and fruit. It can survive in the soil for many years.

> **Damping-off diseases:** can be caused by several soil-borne pathogens, including *Rhizoctonia solani*, *Pythium spp*. and *Fusarium oxysporum* fungi, and will kill seedlings.

> **Bacterial spot:** caused by the bacterium *Xanthomonas campestris* pv. *vesicatoria*. It appears as small circular to irregular spots on leaves and stems. The bacterium overwinters on the surface of seeds, in infected debris and in soil. It is commonly brought into fields on infected transplants. Warm, rainy weather favours rapid spread of bacterial spot.

> **Bacterial speck:** caused by the bacterium *Pseudomonas syringae* pv. *tomato*. Although bacterial speck seldom reduces yields greatly, it can harm fruit quality. Tiny, dark spots appear on leaves, surrounded by yellow halos. However, as with bacterial spot and bacterial canker, the fruit symptoms are most characteristic. The specks are considerably smaller than the spots caused by bacterial spot, do not penetrate the fruit deeply, and can be scraped off with a fingernail. Infection is favoured by cool (less than 20°C), wet conditions. Epidemics often follow rainstorms that cause abrasion of leaves and splash soil onto the foliage.

> **Bacterial canker:** caused by the bacterium *Clavibacter michiganensis* subsp. *michiganensis*, can cause serious losses in some tomato plantings. Spots on fruit are quite distinctive: white and slightly raised at first, then raised, dark-colored centres with white halos. These spots are sometimes termed 'bird's-eye' lesions. The white halo turns brown as the spot becomes older.

> **Bacterial wilt:** caused by *Ralstonia solanacearum*, a soil borne bacterium that spreads most quickly in warm, wet climates. The infection disrupts water intake. Younger plants wilt in heat but recover, while the wilting is permanent in older plants.

> **Viral diseases:** a number of viruses cause mottling or mosaic symptoms on the leaves. Tomato mosaic virus (TMV) and pepino mosaic virus (PepMV) can be transmitted mechanically, while others are transmitted mainly by aphids, thrips and whiteflies.

Diseases more frequently found in greenhouse production

High humidity and warm temperatures in greenhouses provide a favorable environment for the development of certain diseases. The diseases listed below are much more likely to occur inside greenhouses than outdoors.

> **Gray mould:** caused by the fungus *Botrytis cinerea*. This is a common disease of greenhouse-grown tomatoes. This disease is characterised by a light-gray fuzzy growth that appears on stems and leaves. Soft rot of the stem end of the fruit can also occur. Botrytis infections are most severe in greenhouses with moderate temperatures, high humidity and stagnant air.

> **Leaf mould:** caused by the fungus *Fulvia fulva* and can cause problems in humid greenhouses with poor air circulation. This fungal disease appears on lower leaves as yellow spots on the upper surface and fuzzy masses of buff-colored spores on the underside.

> **Powdery mildew:** caused by the fungus *Oidium neolycopersici* and is common in all types of greenhouses. Characterised in the early stages by white patches on the upper surface of leaves, this disease can cause defoliation as the spots develop into brown lesions. A type of powdery mildew, caused by *Leveillula taurica*, is mostly found in unheated tunnels.

Available biocontrol solutions

Pathogen / Biocontrol agent	Micro-BCA	Macro-BCA	Semiochemicals	Natural products
Alternaria solani				
Botrytis cinerea	***Trichoderma harzianum; Bacillus subtillis***			
Clavibacter michiganensis* subsp. *michiganensis				
Colletotrichum coccodes				
Fulvia fulva				
Fusarium oxysporum f.* sp. *lycopersici	***Trichoderma harzianum; Streptomyces griseoviridis Strain K61***			
***Oidium* spp.**	***Ampelomyces quisqualis strain AQ10***			***Potassium iodide and potassium thiocyanate lactoperoxidase; enzyme extracted from milk (Koppert's Enzycure),***

				extracts from Fallopia sachalinensis (Milsana in Germany)
Phytophthora infestans				
Pseudomonas syringae pv. tomato				
***Pythium* spp.**	***Trichoderma harzianum; Streptomyces griseoviridis* Strain K61**			
Ralstonia solanacearum				
Rhizoctonia solani	***Trichoderma harzianum;* Streptomyces griseoviridis Strain K61**			
Sclerotium rolfsii	***Trichoderma harzianum; Coniothyrium minitans***			
Septoria lycopersici	***Trichoderma harzianum***			
***Verticillium* spp.**	**Streptomyces griseoviridis Strain K61**			
Viral Diseases				
Xanthomonas campestris pv. vesicatoria				

Insect and mite pests frequently found in open field and greenhouse production

> **Aphids (Hemiptera: Aphididae): green peach aphid (*Myzus persicae*), potato aphid (*Macrosiphum euphorbiae*), glasshouse and potato aphid (*Aulacorthum solani*), cotton aphid (*Aphis gossypii*), black bean aphid (*Aphis fabae*).**

Aphids extract nutrients from the plant and secrete a large amount of honeydew that promotes the development of sooty mould on leaves and fruits, and can introduce toxic substances in the plant. High populations can reduce plant growth and distort leaves and stems, delay fruit maturity, and reduce yield quantity and quality. More importantly, they transmit virus diseases (i.e. cucumber mosaic virus (CMV) and alfalfa mosaic virus (AMV)).

> **Thrips (Thysanoptera: Thripidae): western flower thrips (*Frankliniella occidentalis*, *Frankliniella* spp.), onion thrips (*Thrips tabaci*).**

Thrips feed on plant cell fluids. During early development, nymphs eat pollen inside the flowers and then feed on the new fruits. The plant is wounded by feeding, and the empty cells fill with air and appear silvery. Plant tissue is also wounded by the adults during oviposition. Thrips are vectors of the tomato spotted wilt virus (TSWV) and other Tospoviruses.

> **Stink bugs (Rhynchota: Pentatomidae): southern green stink bug (*Nezara viridula*) and other species.**

Stems, leaves, blossoms and fruits are attacked but the latter are preferred. On green fruit, damage appears as dark pinpricks, surrounded by a light discoloured area that turns yellow or remains light green on ripe fruit. As the feeding site heals it become hard and darkened. Stink bugs may also carry bacteria and yeast that may cause decay when introduced into fruit on the bugs' mouth parts.

> **Whiteflies (Hemiptera: Aleyrodidae): sweet potato whitefly (*Bemisia tabaci*, biotypes B and Q), greenhouse whitefly (*Trialeurodes vaporariorum*).**

Both species of insects cause large economic losses, as a consequence of whiteflies feeding on phloem, deposition of honeydew and the development of sooty mould. Fruits cannot be sold and the sooty mould inhibits photosynthesis and respiration of the plant. Also, biotype B of *B. tabaci* injects toxic saliva inducing plant physiological disorders. Moreover, they are vectors of plant viruses. Whitefly-transmitted viruses are among the most severe diseases in several European tomato growing areas. *B. tabaci* transmits Geminivirus causing epidemic diseases, like tomato yellow leaf curl caused by TYLCV and TYLCSV viruses. *T. vaporariorum* transmits tomato infectious chlorosis virus (TICV). Both species transmit Crinivirus, like the tomato chlorosis virus (ToCV). Furthermore, both species of whitefly have been implicated in transmission of an emergent quarantine picorna-like virus, the tomato torrado virus (ToTV). Further information on relationships between tomato and whiteflies, and control methods are available from the ENDURE website: Deliverable DR1.10 Map of EU tomato growing areas and Tomato Case Study Guide Number 1: Evaluation of tools to manage whiteflies in Europe.

> **Cut worms (Lepidoptera: Noctuidae): turnip moth (*Agrotis segetum*), black cutworm (*Agrotis ipsilon*) and *Agrotis* spp.**

Cutworms chop off seedlings or recently transplanted tomato plants at the soil plane. Subsequently, worms can also injure fruits by eating the surface, especially of the fruits next to the ground.

> **Armyworms (Lepidoptera: Noctuidae): cotton bollworm (*Helicoverpa armigera*), beet armyworm (*Spodoptera exigua*), African cotton leafworm (*Spodoptera littoralis*), other noctuid moths.**

Worms eat leaves and fruits and can complete larval development inside fruits. The young larvae enter a fruit at the stem end and during development can emerge from one fruit and enter another. Damaged fruits show superficial wounds or are chewed internally and filled with faeces; they ripen prematurely and will be subject to rot. Young larvae are difficult to detect and are a serious problem for canned tomatoes.

> **Tomato leafminer (Lepidoptera: Gelechiidae, *Tuta absoluta*).**

Tuta absoluta is a devastating invasive pest which originated in South America, was recently introduced to the Mediterranean region and is now widespread in other European countries. Larvae feed on mesophyll tissues and make irregular large mines on the leaf surface. Larve also penetrate into the fruits, which become unsellable, and stems. Bored seedlings may stunt and die. Damage can reach 100% in protected as well as open field crops.

> **Leafminer flies (Diptera: Agromyzidae): American serpentine leafminer (*Liriomyza trifolii*), South American leafminer (*L. huidobrensis*), *L. bryoniae*.**

Leafminer feeding results in serpentine mines. Injured leaves drop prematurely and heavily infested plants may lose most of their leaves. Photosynthesis can be reduced enormously. Consequently, yield, fruit size and quality (fruits exposed to sunburn) decrease.

> **Wireworms (Coleoptera: Elateridae): *Agriotes brevis*, *A. lineatus*, *A. litigiusus*, *A. obscurus*, *A. sputator*, *A. ustulatus*.**

Early in the season cutworms may cause stand loss by cutting off seedlings or recently transplanted tomato plants at the soil line. Later in the season these pests can also injure tomatoes by eating irregular holes in the surface of fruits. Fruits close to the soil plane are generally the most seriously injured.

> **Two-spotted spider mite (*Tetranychus urticae*, Acari: Tetranychidae).**

Mites suck cell contents from the leaves. Plant cells turn yellow, which can be seen on the upper surface of the leaf as small yellow spots. This reduces the photosynthetic area of the leaf and causes physiological disorders. A high density of mites can kill the plants. Yield is reduced and fruits bearing feeding spots are unsellable.

> **Broad mite (*Polyphagotarsonemus latus*, Acari: Tarsonemidae).**

Mites cause apical leaves and flower buds to become malformed. The mite's toxic saliva causes twisted, hardened and distorted growth in the terminal of the plant. Leaves turn downward and turn coppery or purplish. Internodes shorten and the lateral buds break more than normal. The blooms abort and plant growth is stunted when large populations are present.

> **Tomato russet mite (*Aculops lycopersici*, Acari: Eryophyidae).**

Mites remove cell contents from leaves, stems and fruits. The colour of the stems and leaves frequently becomes bronze or russet coloured. Leaves dry and heavily infested plants can die.

Main available biocontrol solutions (OF and GH refer to the use in open field and greenhouse cultivations respectively)

Pest / Biocontrol agent	Macroorganisms	Microorganisms	Natural products	Semiochemicals
Aphids	**Predators:** **- *Aphidoletes aphidimyza* (midge) [OF, GH]** **- *Chrysoperla carnea* (lacewing) [OF, GH]** **Parasitoid wasps:** **- *Aphelinus abdominalis* [GH]** **- *Aphidius colemani* [GH]** **- *Aphidius matricariae:* [GH]** **- *Aphidius ervi* [OF, GH]**	**- *Verticillium lecanii* (fungus)** **- *Beauveria bassiana* (fungus)**	**- Potassium salts of fatty acids** **- Pyrethrins** **- Azadirachtin**	
Thrips	**Predators:** **- *Amblyseius cucumeris* (mite) [OF, GH]**	**- *Steinernema feltiae* (nematode)** **- *Verticillium lecanii* (fungus)** **- *Beauveria bassiana* (fungus)**	**- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadirachtin**	
Stink bugs			**- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadirachtin**	

Biocontrol in Selected Crops
Number 2: Tomato

Whiteflies	**Predators:** **- *Macrolophus pygmaeus* (bug) [GH]** **Parasitoid wasps:** **- *Eretmocerus mundus* [GH] (specific to *B. tabaci*)** **- *Eretmocerus eremicus* [GH]** **- *Encarsia formosa* [GH]**	**- *Verticillium lecanii* (fungus)** **- *Paecilomyces fumosoroseus* (fungus)** **- *Beauveria bassiana* (fungus)**	**- Potassium salts of fatty acids** **- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadiractin**	
Noctuid worms: cut worms, armyworms	**Predators:** **- *Macrolophus pygmaeus* (bug) [GH]** **- *Spodoptera exigua* nuclear polyhedrosis virus [OF, GH]** **Parasitoid wasps:** **- *Trichogramma brassicae* [OF, GH]** **- *Trichogramma evanescens* [OF, GH]**	**- *Bacillus thuringiensis* var. *kurstaki* (bacterium)** **- *Bacillus thuringiensis* var. *aizawaii* (bacterium)** **- *Steinernema carpocapsae* (nematode) [OF, GH]**	**- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadiractin**	**Species-specific sex pheromone:** **- monitoring** **- mass trapping**
Tomato leafminer *Tuta absoluta*	**Parasitoid wasps:** **- *Trichogramma pretiosum* [GH]*** **- *Trichogramma achaeae* [GH]*** **Predators:** **- *Nesidiocoris tenuis* (bug) [GH]** **- *Macrolophus pygmaeus* (bug) [GH]** **- *Nabis pseudoferus* (bug) [GH]*** ***candidate biocontrol agents**	**- *Bacillus thuringiensis* var. *kurstaki*** 	**- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadiractin**	**Sex pheromone:** **- monitoring** **- mass trapping** **- lure & kill**
Leafminer flies	**Parasitoid wasps:** **- *Dacnusa sibirica* [OF, GH]** **- *Diglyphus isaea* [OF, GH]**		**- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadiractin**	
Wireworms			**- Pyrethrins** **- Abamectin** **- Milbemectin** **- Spinosad** **- Azadiractin**	

Two-spotted spider mite	**Predators:** **- *Phytoseiulus persimilis* (mite) [OF, GH]** **- *Amblyseius californicus* (mite) [OF, GH]** **- *Feltiella acarisuga* (midge) [GH]** **- *Macrolophus pygmaeus* (bug) [GH]**	**- *Beauveria bassiana* (fungus)**	**- Abamectin** **- Milbemectin** **- Azadiractin**	
Broad mite	**Predators:** **- *Amblyseius californicus* (mite) [OF, GH]**		**- Abamectin** **- Milbemectin** **- Azadiractin**	
Russet mite			**- Abamectin** **- Milbemectin** **- Azadiractin**	

Not all natural products meet the expectation of low non-target toxicity and low environmental impact. The spraying of natural insecticides and acaricides is in general incompatible with contemporary use of biocontrol agents due to the toxic effects to predators and parasitoids. Introduction of biocontrol agents in a cultivation previously treated with a natural product is possible only after waiting for the time necessary to make pesticide residues safe to beneficials. The persistence of natural products varies (0-15 days) according to the compound and beneficial. Milbemectin and abamectin are not authorised in organic crop protection.

Nematodes

Small, worm-like plant parasitic nematodes mainly attack roots. The most significant for tomato are from the Meloidogyne family. Infected plants are less vigorous with fewer fruits. Root-knot nematodes interact with bacterial and fungal wilts, increasing the damage.

Weeds

Weeds reduce yields by competing for space, light, water and nutrients, weakening the crop stand, and by reducing harvest efficiency. Some weeds can also increase pest problems by serving as alternate hosts for insects, diseases or nematodes. Weeds are most competitive if they emerge from planting until about six to eight weeks after crop emergence. After six to eight weeks, tomatoes become more competitive and they are usually less affected by late germinating weeds. However, even late germinating weeds can produce seed and, in some instances, interfere with harvest.

SWOT analysis

> Strengths: biocontrol products are usually user and environment friendly.

> Weaknesses: however, used alone, their efficacy is considered lower than competitive chemicals. They need to be used at a lower level of infestation (threshold).

> Opportunities: easier registration.

> Threats: high cost and complicated to use.

Recommendations for biocontrol in tomato

Research and development

Technical institutes should look deeper into integrating biological and chemical control.

> Weed control is a big gap to be explored, both on the plantation row and in the control of invasive weeds.

> Develop the concept of integrating pheromones and insecticides in order to protect tomato when heavy pest infestations occur.

> Develop the concept of integrating prevention methods with bacterial antagonists associated later with curative fungicide treatments.

> Reinforce research on alternatives to copper and sulphur.

> Set up 'new application thresholds' adapted to the use of biologicals.

> There is a need to identify native natural enemies for new invasive pests such as *Tuta absoluta*.

> There is a need to develop biocontrol solutions for pests such as russet mite.

> For more information on gaps and needs, download the booklet produced by ENDURE's tomato case study team, in particular pages 8 and 36-38.

Policy makers and regulation

> Reinforce the trend towards zero pesticide residues.

Education, training, communication

> Involve farmers' organisations in the promotion of alternative protection systems.

> Demonstration plots, especially on reputable tomato farms.

> Training courses.

Industry and distribution

> Development of more user friendly biological products.

> Make available application 'kits', including decision support tools.

> Active promotion (demonstrations, lectures, training etc).

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About ENDURE

ENDURE is the European Network for the Durable Exploitation of Crop Protection Strategies. ENDURE is a Network of Excellence (NoE) with two key objectives: restructuring European research and development on the use of plant protection products, and establishing ENDURE as a world leader in the development and implementation of sustainable pest control strategies through:

> Building a lasting crop protection research community
> Providing end-users with a broader range of short-term solutions
> Developing a holistic approach to sustainable pest management
> Taking stock of and informing plant protection policy changes.

Eighteen organisations in 10 European countries are committed to ENDURE for four years (2007-2010), with financial support from the European Commission's Sixth Framework Programme, priority 5: Food Quality and Security.

Website and ENDURE Information Centre:

www.endure-network.eu

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