



ENDURE

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Critical evaluation of tools for diagnosing insecticide resistance, whitefly biotypes and the levels of virus inoculums, and for assessing the risks of TYLCV epidemics and list of 1) recommendations for improving whitefly and TYLCV control (in conjunction with SA4) and 2) key pests that should be taken into account for reducing insecticide use in tomato crops

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Glossary

Whitefly species and biotypes

Bemisia tabaci is considered to be a species complex, with a number of recognized biotypes. *Bemisia tabaci* has been reported from all continents except Antarctica. Over 900 host plants have been recorded and it reportedly transmits 111 virus species. It is believed that *B. tabaci* has been spread throughout the world through the transport of plant products infested with whiteflies. Once established, *B. tabaci* quickly spreads and, through its feeding habits and the transmission of the diseases it carries, causes destruction to crops around the world. This species has been classified as among the 100 "world's worst" invaders (Lowe et al., 2000).

Trialeurodes vaporariorum, is essentially temperate and subtropical. Introduced accidentally into Western Europe, it now constitutes a major pest in protected crops and also transmits plant viruses.

Main viruses species transmitted by whiteflies

TYLCD *Tomato yellow leaf curl disease*. The causing agents of this disease are a complex of virus species of the genus Begomovirus (family Geminiviridae) that are transmitted by the whitefly *B. tabaci*. The most important species that have been reported in Europe are Tomato yellow leaf curl virus (TYLCV) and Tomato yellow leaf curl Sardinia virus (TYLCSV).

TYLCV *Tomato yellow leaf curl virus* (Begomovirus). Insect vector: *B. tabaci*. Crops affected: *Capsicum annuum*, *Solanum lycopersicum*, *Phaseolus vulgaris*. Impact: Severe reduction of yield and heavy economic losses, mainly in tomato.

TYLCSV *Tomato yellow leaf curl Sardinia virus* (Begomovirus). Insect vector: *B. tabaci*. Crop affected: *S. lycopersicum*. Impact: Severe reduction of yield and heavy economic losses.

ToCV *Tomato chlorosis virus* (Crinivirus). Insect vector: *B. tabaci* and *T. vaporariorum*. Crop affected: *S. lycopersicum*. Impact: Yield reduction due to loss of photosynthetic area, reduced fruit growth and delayed ripening.

TICV *Tomato infectious chlorosis virus* (Crinivirus). Insect vector *Trialeurodes vaporariorum*. Crop affected: *S. lycopersicum*. Impact: Yield reduction due to loss of photosynthetic area, reduced fruit growth and delayed ripening.

Main viruses species transmitted by *Frankliniella occidentalis*

TSWV *Tomato spotted wilt virus*. Insect vector: *F. occidentalis*. Crop affected: many species including *S. lycopersicum* and *C. annuum*.

Pest Control Strategies

IPM (Integrated Pest Management) is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means whilst minimising associated hazards to people, property, and the environment.

Pesticides residues

MRL (maximum residue level). All foodstuffs intended for human or animal consumption in the European Union (EU) are subject to an MRL of pesticides in their composition in order to protect animal and human health.

Half-life is the amount of time it takes for one-half the original amount of a pesticide to degrade.

Summary

To achieve TCS objectives, 2 questionnaires were prepared. In the first questionnaire (TCS-Q1), 10 countries were surveyed; the topics covered were: whitefly species, *Bemisia tabaci* biotypes, insecticide resistance, whitefly vectored virus species and hosts, whitefly natural enemies and their use in biological control, other control tools and sampling techniques for decision making. In the second questionnaire (TCS-Q2), 4 scenarios were selected according to their different levels of *B. tabaci* pressure and incidence of whitefly transmitted viruses and, 4 different pest control strategies were defined: Chemical, IPM-Insecticide, IPM-Biological Control (IPM-BC) and Organic production.

Two - whitefly species affect European tomato production: *B. tabaci* which is widely distributed and is a vector of plant viruses causing severe crop losses and, *Trialeurodes vaporariorum* which is ubiquitous. At least 4 biotypes of *B. tabaci* are currently present in Europe, being biotypes B and Q the most widespread and problematic. Other key pests were *Aculops lycopersici*, *Helicoverpa armigera*, *Frankliniella occidentalis* and leafminers. Tomato crops are particularly susceptible to *Tomato yellow leaf curl disease* (TYLCD), a group of viruses causing the most devastating virus disease complex in warm temperate regions of the world. Data from the TCS-Q2 reveals that wherever the pressure of *B. tabaci* is high, viruses responsible of TYLCD are important or very important.

Sampling techniques for decision making are generally based upon whitefly densities and were not related to control strategies or growing area. For population monitoring and control, whitefly species are always identified. Decisions are made on both calendar and threshold basis, although calendar decisions essentially relate to chemical control strategies. Within protected environments IPM-insecticide is the most widely used control strategy followed by IPM-BC and in a lesser extend chemical control. For whitefly control, the number of insecticide applications per month and active ingredients per application are higher in IPM-Insecticide than in IPM-BC. The ranked importance of *B. tabaci* within each of the 4 surveyed regions closely correlated with levels of insecticide use. This showed *B. tabaci* to be one of the principal insect pests driving insecticide use, primarily due to the threat of TYLCD and the resulting low tolerance thresholds that it imposes. Biological control of whiteflies is increasingly applied and is mainly based on inoculative releases of the parasitoids *Eretmocerus mundus* and *Encarsia formosa* and/or the polyphagous predators *Macrolophus caliginosus* and *Nesidiocoris tenuis*. In IPM-BC, selective pesticides are applied for other pests lacking biological solutions or when biological control fails to maintain the target pest under the economic threshold. Important components of IPM strategies are the use of nets in vents and double-door entry systems to reduce the movement of *B. tabaci* into greenhouses, and the use of tomato varieties tolerant to TYLCD in areas of high TYLCD incidence. Moreover, these cultivars need additional protection from viruliferous insects during the first months after planting.

In a sustainable scenario, IPM-BC is the recommended control strategy for improving *B. tabaci* and TYLCD control on tomato greenhouses. However, limitations for uptake of IPM – BC programs were identified. The most extensive limitations were “lack of a biological solution for some pests” and the “cost of the natural enemies”. “Low acceptance of the method on behalf of the farmer” was also reported, especially around the Mediterranean basin. Other limitations listed were the “increase of costs associated with technical advice” and the low “pest injury thresholds” mainly in those areas with high incidence of TYLCD.

To improve plant protection strategies in tomato, research on the following domains were purposed: (i) emergence and invasion of new whitefly-transmitted viruses; (ii) the relevance of *B. tabaci* biotypes regarding insecticide resistance; (iii) biochemistry and genetics of plant resistance; (iv) economic thresholds and sampling techniques of whiteflies for decision

making, and (v) conservation and management of native whitefly natural enemies and improvement of biological control of other tomato pests.

The information gathered within the TCS has permitted to establish a database with up-to-date information on the state of art of *B. tabaci* and whitefly transmitted viruses in EU and neighbouring countries and the tools that are available to manage this pest in tomato. This information will provide valuable input to contribute to the ENDURE Information Centre (SA4), to design innovative cropping systems that include tomato crop (RA2) and a multi-criterion assessment of crop protection methods and cropping systems (RA3). Also the information collected will contribute to the IA2.4 and IA2.5 sub-activities for continuing refinement of decision support systems.

The key information will be collated in a leaflet and disseminated amongst farmers, pest advisors and plant protection services, in conjunction with SA1 activity, to transfer the available techniques and the knowledge on IPM-BC strategy for a wider, efficient and successful implementation.

Preface

ENDURE Sub-activity RA1.2 Tomato Case Study (TCS)

Responsible: UdL (IRTA);

Participants: UdL (IRTA); RRES; CIRAD; INRA; WUR; JKI.

- UdL: Universitat de Lleida; IRTA: Institut de Recerca i Tecnologia Agroalimentàries
- RRES: Rothamsted Research
- CIRAD: Centre de Coopération Internationale en Recherche Agronomique pour le Développement
- INRA: Institut National de la Recherche Agronomique
- WUR: Wageningen University Research centre
- JKI: Julius Kühn-Institut- Bundesforschungsinstitut für Kulturpflanzen

European tomato crops are affected by a diversity of pests among which whiteflies and whitefly-transmitted viruses (mostly a group of virus species causing the Tomato yellow leaf curl disease) are the most harmful in several tomato-growing areas. The complexity of the problem, which includes distinct biotypes of whiteflies, variation within and between virus strains, an increasing higher number of insecticide-resistant populations and difficulties on biological control application has been one of the main subjects of cooperation between researchers and industrialists within the EU funded European Whitefly Studies Network (EWSN) and IOBC/WPRS working groups.

This case study has therefore focused on the next objectives:

- Identify tomato growing areas where whiteflies are the major constraint for tomato production.
- Collect information on the situation and biology of *Bemisia tabaci* and whitefly transmitted viruses in EU and neighbouring countries and the tools that are available to manage this pest on tomato.
- Study of the actual implementation of IPM programs on the different tomato growing areas.

Studies in the framework of ENDURE-TCS were conducted from 2007 until June 2008.

1 Relevance of tomatoes in Europe: tomato production, trading and consumption

In 2005 (FAOSTAT 2007), the total amount of fresh tomato production in the world was around 126 million tonnes, harvested from 4.5 million ha. The major producers of fresh tomato were (in million tonnes): China (31.6), USA (11), Turkey (10) and India (8.6). The EU, considered as an aggregate was the second main producer in the world (15% of fresh tomato harvested). Total tomato production for fresh consumption in EU-27 amounted to around 17 million tonnes with acreage of 0.3 million ha; this accounts for a value share of about 25% of the total vegetables produced in Europe. The production is mainly concentrated around the Mediterranean countries (Figure 1). The seven leading EU producers of fresh tomato were (in million tonnes) Italy (7) and Spain (4.5), followed by Greece (1.7), Portugal (1.1), France (0.8), the Netherlands (0.7) and Poland (0.6). These countries represented a share of 91.5 % of the total EU-27 production.

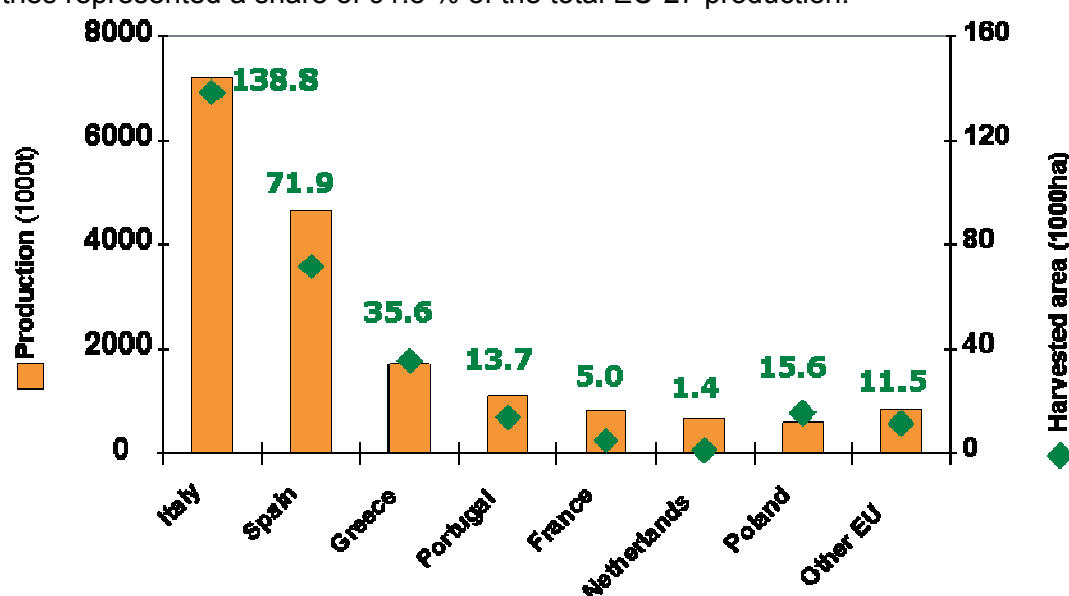


Figure 1: Main fresh tomato producing countries in EU-27 in 2005 (FAOSTAT 2007). Bar graph show tomato production and, the green symbols and numbers indicate the acreage.

Fresh tomato consumption amounted to 15 million tonnes in 2005 (93 g/capita and day), which represented a share of 80% of the vegetables consumed in Europe. The consumption of fresh tomato in the Mediterranean countries was higher than in the Northern countries Italy, Spain, Germany and France, together accounted for around half of total consumption of fresh tomato. Approximately 90 % of the EU tomato consumption came from EU (Figure 2) and only France imported a significant amount of the tomatoes it consumes (47.5 %) from non-EU countries (91% from Morocco, 6% from Israel and 3% from others). The two leading suppliers to the EU were Spain and the Netherlands, together accounting for 60 percent of total supplies in 2005. For example, these two countries together supplied the 78 and 84% of tomato sold in Germany and United Kingdom respectively.

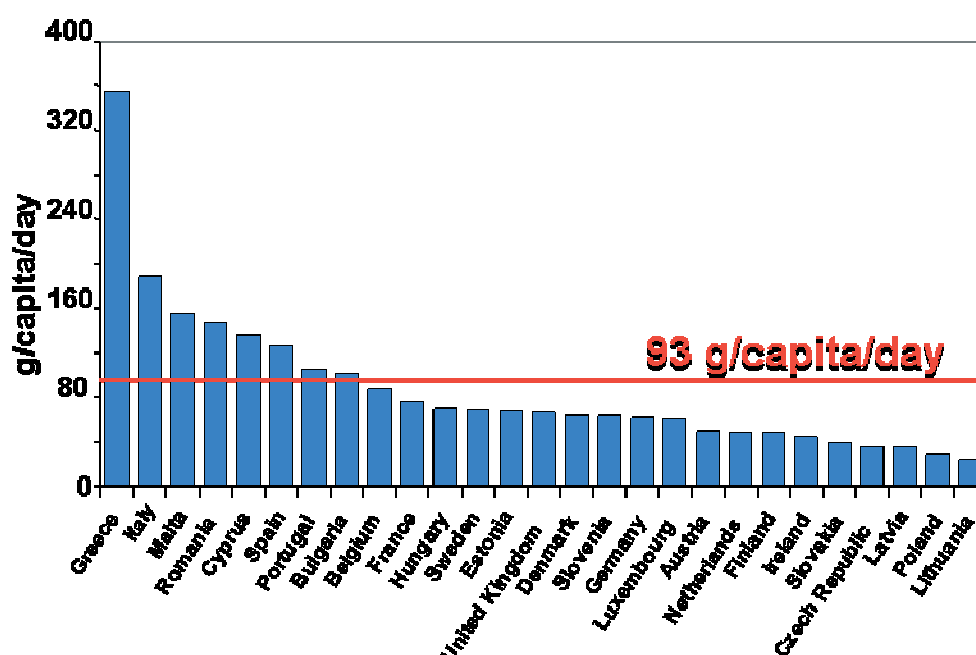


Figure 2: Daily tomato consumption in EU-27 countries in 2005 (FAOSTAT 2007).

From data generated by the EU pesticide residues monitoring report for tomato in 2004 (Commission of the European Communities, 2006) no residues were detected in 64% of tomato samples. Thirty five percent contained residues of pesticides at/or below the MRL (national or EU), which indicates that pesticides have been used in the production process but are at “acceptable” levels, and only 1% of the tomato samples exceeded this legally acceptable level. Pesticide half-lives in soil were reported to be 16 fold slower than in the marketable product (Juraske et al., 2007), suggesting the use of pesticides has a greater impact on the environment than on food quality, therefore pesticide reduction would be a key tool for an environmentally sustainable tomato production.

2 Questionnaires

Two questionnaires were prepared in order to:

- Collect information on the situation and biology of *B. tabaci* and whitefly transmitted viruses in EU and neighbouring countries and the tools that are available to manage this pest on tomato (first questionnaire).
- Study the implementation of IPM programs in tomato growing areas (second questionnaire).

In the **first questionnaire** (TCS-Q1) ten countries were surveyed: Spain, United Kingdom, the Netherlands, France, Germany, Italy, Greece, Morocco, Turkey and Israel. A total of 32 questionnaires were received and processed (Table 1). Data from the questionnaires were representative of surfaces ranging from 5 to 100% of the total tomato harvested area for each country. Topics covered were: whitefly species, *B. tabaci* biotypes, insecticide resistance, whitefly vectored virus species and hosts, whitefly natural enemies and their use in biological control, other control tools and sampling techniques for decision making (ANNEX 1).

Table 1. TCS-Q1 survey data. Percentage of surface was calculated on national area harvested in 2005, according to FAOSTAT (acceded in October 2007). GLH = glasshouse, GRH = greenhouse, NH = nethouse and OF = open field crops. From United Kingdom a questionnaire was received reporting no presence of *B. tabaci*.

Country	Survey characterization			Tomato production		
	No. question.	Surface (ha)	% surface ***	GLH	GRH /NH	OF
France	5	2450	49	▲	▲	▲
Germany	3	368	100	▲	▲	▲
Greece	2	2420	5	▲	▲	▲
Israel	2	20500	100		▲	▲
Italy	3	8500	6	▲	▲	▲
Morocco	2	4600	21		▲	▲
Spain	7	12500	17		▲	▲
Netherlands	3	1400	100	▲	▲	
Turkey	5	No data	No data	▲	▲	▲

In the **second questionnaire** (TCS-Q2) the following four **scenarios or areas** were selected according to their different levels of *B. tabaci* pressure and incidence of whitefly transmitted viruses:

- High *B. tabaci* pressure and whitefly transmitted viruses: **South of Spain** (Almeria)
- Medium *B. tabaci* pressure and whitefly transmitted viruses. Two different areas were selected according to different growing conditions:
 - Short tomato growing cycles: North of Spain (Catalonia).
 - **North of Spain-1**: represents most of the tomato growing production area.
 - **North of Spain-2**: minor area with high *B. tabaci* populations and TYLCD severe problems.
 - Long tomato growing cycles and heated greenhouses. **South of France** (Roussillon).
- Low *B. tabaci* pressure and whitefly transmitted viruses absent: **Germany**

Only surveys referring to greenhouse tomato production were processed. Data coming from one area or scenario were grouped into three **growing cycles** which were defined according to the transplanting date and growing conditions:

- **Cycle A**: Transplant in early spring (mid January to March) and end of the crop by mid July to October.
- **Cycle B**: Transplant in summer (July to August) and end of crop from November to mid January.
- **Cycle C**: Transplant in fall-winter and heating (November to January) and end of crop in October.

Four different **pest control strategies** were defined:

- Chemical: based only on the use of insecticides.
- IPM-Insecticide: integrated pest management strategy based on the rational application of insecticides.
- IPM-Biological control (BC): integrated pest management strategy based on the use of natural enemies and selective pesticides

- Organic production: based on an insecticide-free approach

A single questionnaire was obtained that accounted for each scenario, crop cycle and control strategy by interviewing several advisors operating in each of the four associated geographical regions. Topics covered in this second questionnaire included: main viruses and insect pests, sampling methods used for decision making, use of biological control, insecticides and other control methods, and constraints for a wider implementation of IPM strategies (ANNEX 2). Table 2 summarizes the area covered by each cycle and pest control strategy within these regions.

Table 2. TCS-Q2 survey data. *this data refers to acreage represented in the questionnaires answered by the advisor.

Area	Cycle	Surface (ha) *	Pest control strategies			
			Chemical	IPM-Insct.	IPM-BC	Organic
Germany	A	3			▲	▲
	C	17	▲	▲	▲	▲
South France	A	20		▲	▲	▲
	B	30		▲		
	C	50		▲	▲	
North Spain-1	A	30	▲	▲	▲	▲
	B	18	▲	▲	▲	▲
North Spain-2	A	17	▲	▲	▲	
	B	15	▲	▲	▲	
South Spain	A	3300	▲	▲	▲	
	B	6700		▲	▲	

Following are results and conclusions arisen from questionnaires, personal author's experience and from literature.

3 Main tomato pests

The incidence of pests in the different areas and crop cycles (identified in the TCS-Q2) is shown in Table 3. Some pests are widely distributed and are economically significant whereas others are restricted in their distribution to some areas or crop cycles.

Two primary whitefly pests affect European tomato production. *Bemisia tabaci*, which is capable of causing severe losses even at low densities due to the specific plant viruses it can transmit. These include some of the most damaging viruses affecting tomatoes, such as *Tomato yellow leaf curl virus* (TYLCV). The second, *Trialeurodes vaporariorum*, also transmits plant viruses e.g. *Tomato infectious chlorosis virus* (TICV), although they are of somewhat lesser economic impact. These two species can co-exist within the same crop and correct identification is a pre-requisite to efficient control. *Trialeurodes vaporariorum* is a serious problem in Germany and the South of France and *B. tabaci* in the North of Spain-2, South of Spain and South of France during cycles B and C.

Among other insect pests of tomato, 3 are ranked as key pests in at least one area. *Helicoverpa armigera* is considered a very important pest of tomato production only in the North of Spain during summer. **Leafminers** are ranked as important pests in North of Spain,

Germany and South of France, mainly in the long growing cycles. *Frankliniella occidentalis* is considered an important pest in all the areas except in Germany where it is considered a minor pest.

Mites mainly affect Southern Europe. The mite *Aculops lycopersici*, an increasingly harmful pest in the Mediterranean area, is a key problem in Spain, whereas **spider mites** are considered important pests in the South of France and the South of Spain.

Table 3. Main tomato pests by areas and crop cycles classified according to their importance: 0= absent, 1= not very important, 2= important and 3= very important. See page 9 for cycle description.* T.v.= *Trialeurodes vaporariorum*; B.t.= *Bemisia tabaci*; H.a.= *Helicoverpa armigera*; A.I.= *Aculops lycopersici*.

Area	Cycle	T.v.*	B.t.*	H.a.*	Leaf miners	Thrips	A.I.*	Spider mites
Germany	A	3	1	0	2	1	1	1
	C	3	1	0	2	1	1	1
South France	A	2	1	2	2	1	1	3
	B	3	3	1	2	3	1	2
	C	3	3	1	3	2	1	2
North Spain-1	A	1	1	1	2	2	2	1
	B	2	2	3	1	2	3	1
North Spain-2	A	1	3	3	1	2	3	1
	B	0	3	3	1	2	3	1
South Spain	A	2	3	1	1	2	3	2
	B	1	3	1	1	3	3	2

4 Whiteflies: *Bemisia tabaci* and *Trialeurodes vaporariorum*

4.1. Distribution of whitefly species

Figure 3 collates the information on the distribution of *B. tabaci* as a pest of outdoors and greenhouse crops together with data from TCS-Q1 on the distribution of whitefly species in tomato crops. *Bemisia tabaci* is widely distributed, although outdoors its northerly limit extends across southern France, southern Italy, around the northern coast of the Mediterranean Sea and across Northern Turkey. TCS-Q1 also reports single infestations of *B. tabaci* in some areas of Spain, Greece, Morocco and Turkey and mixed infestations of both whitefly species are common in most of the tomato growing areas including some locations of Morocco and the Canary and Reunion Islands. Single populations of *T. vaporariorum* are usually found in northern locations of Europe (United Kingdom and North of Germany and France) and in an area of Turkey where tomatoes are only grown in open field. The TCS-Q2 confirms that the prevalence of *T. vaporariorum* is low in the south and increases northwards while the prevalence of *B. tabaci* is low in the north and increases southwards.

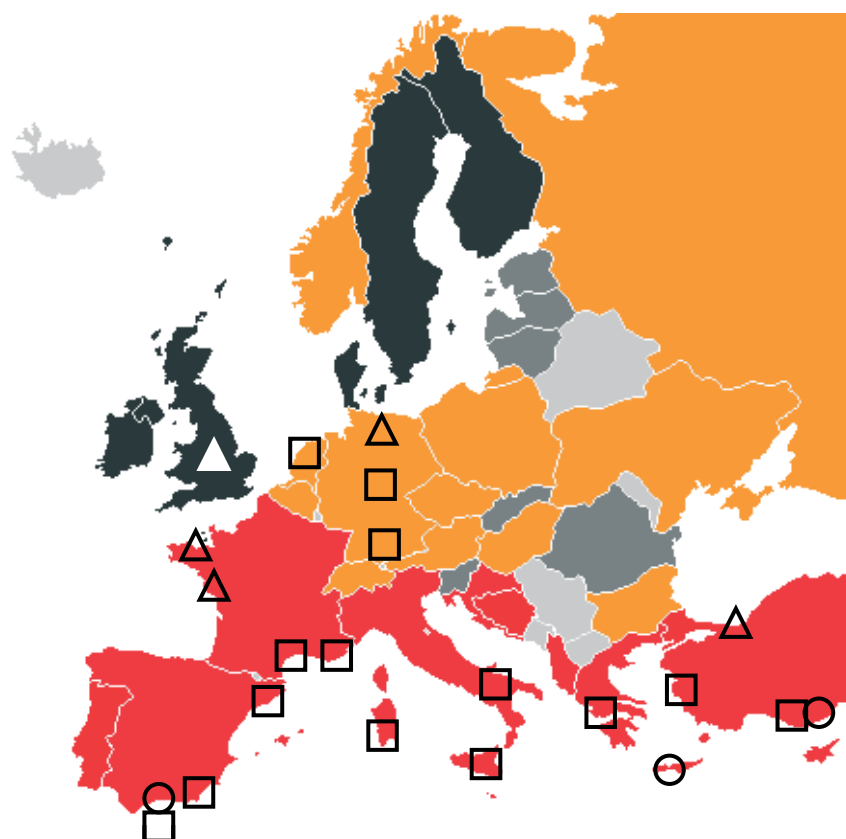


Figure 3: Distribution of whitefly species in tomato growing areas in Europe and Mediterranean partner countries. In colors: ■ = outdoors and protected crops, ■ = primarily protected crops, ■ = absent or non-persistent, ■ = absent or non-persistent (protected zone), ■ = no information (Gorman, personal communication). Symbols represent results from TCS-Q1: ○ = *B. tabaci*, △ = *T. vaporariorum* and □ = mixed populations of *B. tabaci* and *T. vaporariorum*.

4.2. Distribution of *Bemisia tabaci* biotypes

At least four biotypes of *B. tabaci* are currently present in Europe. Due to their invasive and damaging nature, the two most widespread and problematical within agricultural environments are biotypes B and Q and these also prevail within European tomato production. Biotypes B and Q are known to coexist in some areas although they do not interbreed. Minor biotypes reported in Europe are biotype S which has been identified only on *Ipomoea indica* in Spain (Málaga) (Rua et al., 2006) and biotype T identified only on *Euphorbia characias* in Southern Italy and Sicily (Simon et al., 2003).

According to TCS-Q1, biotype Q is the most widespread biotype either on its own (12 locations) or mixed with biotype B (4 locations) (Figure 4). Single infestations of biotype B were reported for 6 locations.

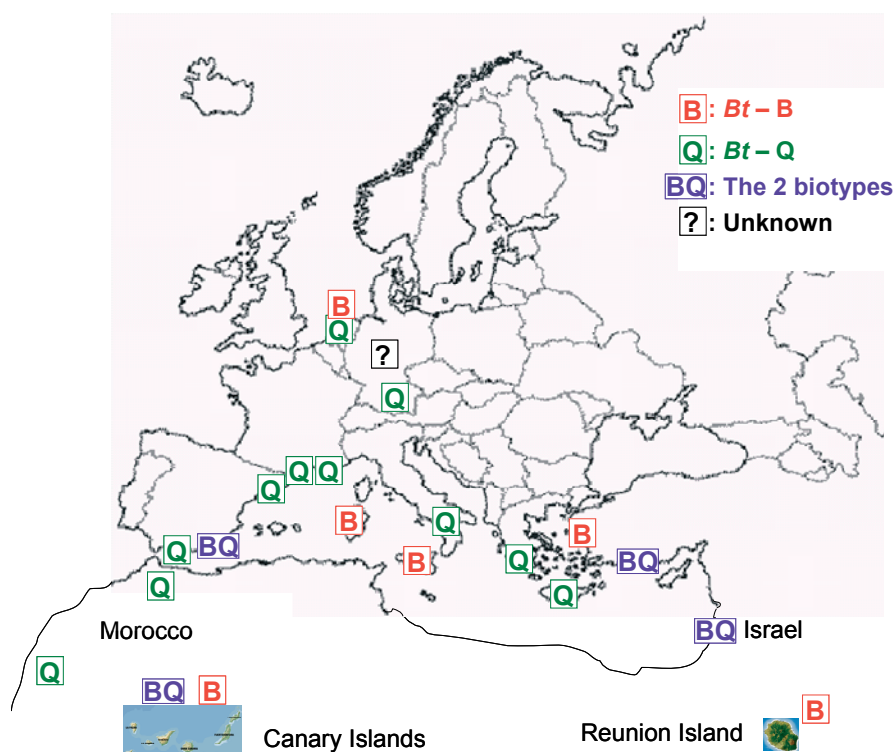


Figure 4: Distribution of *B. tabaci* biotypes in tomato growing areas in Europe and Mediterranean partner countries. Results from TCS-Q1.

5. Viruses transmitted by whiteflies and other insects

5.1 Viruses causing yellow leaf curl of tomato

Tomato crops throughout the world are particularly susceptible to different species of the *Begomovirus* genus, family Geminiviridae, and among them to a group of species, responsible for *Tomato yellow leaf curl disease* (TYLCD). This group of viruses causes the most devastating virus disease complex of tomato in warm temperate regions of the world, being a limiting factor to tomato cultivation worldwide (Cohen and Lapidot, 2007).

Data in Figure 5 shows that TYLCD is present in all growing areas around the Mediterranean basin (OEPP 2006). According to data from TCS-Q1, TYLCD also produces damage to bean crops in some areas of Greece, to peppers in Reunion Island and to ornamentals in Israel and mainland Italy.

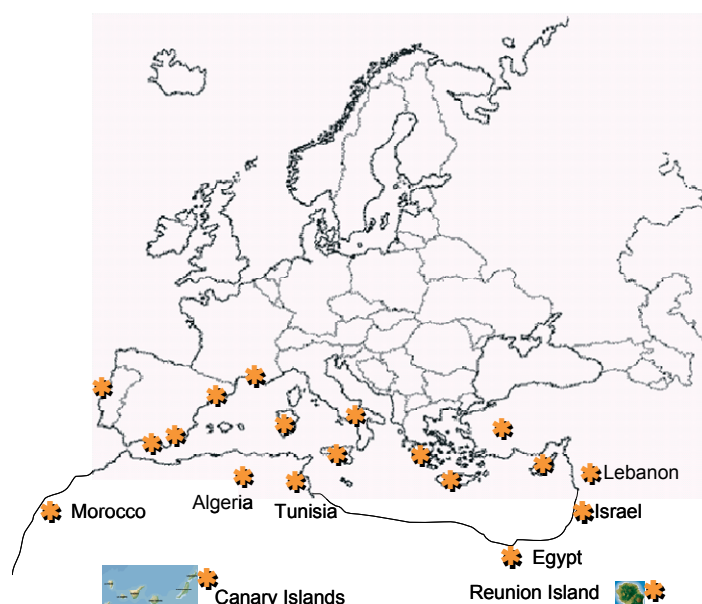


Figure 5. Distribution map of TYLCD (✱) in the EU-countries and the Mediterranean Basin (OEPP 2006).

The symptoms of yellow leaf curl of tomato, that includes leaf curl, yellow mosaics, growth reduction of the plants, stunting and vein thickening (Anonymous, 2001), can be caused by several geminiviruses and not only by the renowned TYLCV. This is not simply a matter of taxonomy of these viruses but may influence their evolution and control. The two recombinant geminiviruses identified in Spain, namely, *Tomato yellow leaf curl Malaga virus* and *Tomato yellow leaf curl Axarquía virus*, result from recombination events between the two geminiviruses that were known to cause TYLCD in Spain which are TYLCV and *Tomato yellow leaf curl Sardinia virus* (Monci et al., 2002, Garcia-Andres et al., 2006). In addition to these four geminiviruses species identified in Europe, there are 50 more distinct geminiviruses around the world that were all identified on tomato (Abhary et al. 2007, and references therein). The risk is not only that some non-European tomato geminiviruses can be introduced into Europe, but that these viruses may recombine with European viruses to produce new species.

Comparison of data from the TCS-Q2 concerning virus importance and insect vector prevalence (Table 4) reveals that wherever the pressure of *B. tabaci* is high, viruses responsible for Tomato yellow leaf curl disease (TYLCD) are important or very important. This was particularly evident from the two surveyed sites in northern Spain where tomatoes were grown in the same seasons according to cycles A and B. North of Spain-1 was under a low *B. tabaci* pressure and TYLCD was not very important, whereas North of Spain-2 was under a high *B. tabaci* pressure and TYLCD was very important.

Table 4: Correlation between importance of insect transmitted viruses and their vector according to TCS-Q2 data. *B.t.*=*B. tabaci*, *T.v.*= *T. vaporariorum*. Importance rank: 0= absent, 1=not very important, 2= important and 3= very important. See page 9 for cycle description and page 4 for virus species names and description.

Area	Cycle	<i>B.t.</i>	TYLCD	ToCV	<i>T.v.</i>	TICV	Thrips	TSWV
Germany	A	1	0	0	3	0	1	1
	C	1	0	0	3	0	1	0
South France	A	1	1	1	2	0	1	2
	B	3	3	2	3	0	3	3
	C	3	3	3	3	0	2	3
North Spain-1	A	1	1	0	1	0	2	2
	B	2	1	0	2	0	2	2
North Spain-2	A	3	3	0	1	0	2	2
	B	3	3	0	0	0	2	2
South Spain	A	3	3	3	2	0	2	2
	B	3	3	2	1	0	3	2

5.2 Tomato chlorosis virus (ToCV) and Tomato infectious chlorosis virus (TICV)

Less important than viruses inducing TYLCD, the other group of whitefly transmitted viruses is the Crinivirus genus, to which belong *Tomato chlorosis virus* (ToCV) and *Tomato infectious chlorosis virus* (TICV) species. ToCV is transmitted by *B. tabaci* and *T. vaporariorum* and TICV is transmitted by *T. vaporariorum*. Symptoms of TICV and ToCV are very similar in tomato and include interveinal yellowing, necrotic flecking, rolling, and thickening, in older leaves while the upper leaf appears normal. Yield reductions occur primarily due to the loss of photosynthetic area. Although no obvious fruit symptoms occur, production is reduced by decreased size and number of fruit.

In the case of ToCV and TICV no strict correlation between virus importance and insect vector prevalence was observed (Table 4). As expected, ToCV is present in the sites of South of France and South of Spain where *B. tabaci* is an important problem, but unexpectedly not in the site North of Spain-2 where *B. tabaci* is an important problem as well. This may be explained by the combination of the recent upsurge of *B. tabaci* in North of Spain-2 and the semi persistence of ToCV in its vector. As ToCV is only retained for a few days after acquisition by its vector, it is less easily transmitted into a new environment than viruses causing TYLCD, which are retained for life by *B. tabaci* (persistent transmission).

TICV is absent in all surveyed sites which in comparison with ToCV, is consistent with its relatively limited distribution (Dalmon 2007, and reference therein). The difference between the geographical distributions of these two criniviruses is apparently because ToCV can be carried by both whitefly species but TICV only by *T. vaporariorum*. The prevalence of *T. vaporariorum* decreases with the increase of temperatures in summer, while the prevalence of *B. tabaci* simultaneously increases. Consequently the period of potentially efficient transmission for TICV is reduced. Finally, difficulties with identification of the symptoms caused by ToCV and TICV, as opposed to those of nutritional deficiency or ageing of the plants, can result in some delays between the outbreak of criniviruses in a new area and their subsequent detection.

Data in Figure 6 shows the geographical distribution of ToCV in Europe and neighbouring countries. As can be observed this *B. tabaci* transmitted virus is present in several countries around the Mediterranean basin.

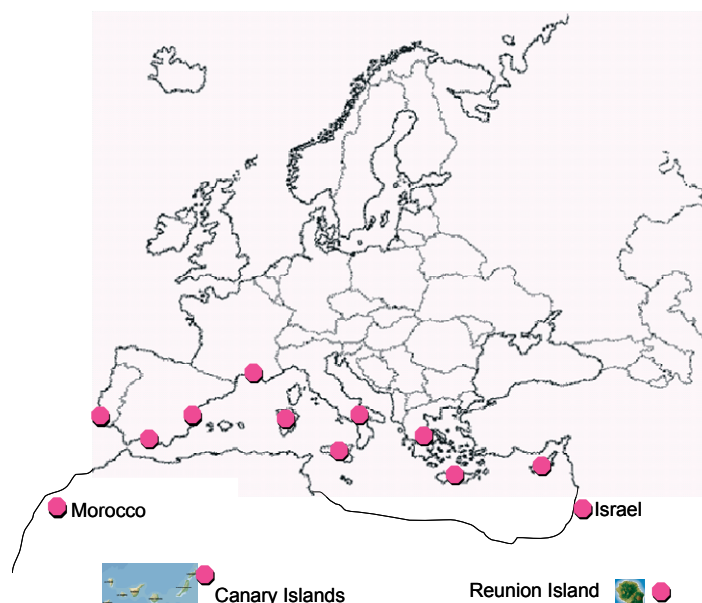


Figure 6. Distribution map of ToCV (●) in the EU-countries and the Mediterranean Basin (OEPP 2005; Segev et al., 2004; Delatte et al., 2006; Papayiannis et al., 2006).

5.3 Other viruses transmitted by insects

Among the insect transmitted viruses, *Tomato spotted wilt virus* (TSWV) was identified as important or very important in crops of France and Spain. Correlation was also detected with this virus and its thrips vector, *Frankliniella occidentalis* (Table 4). Thus, in Germany where *F. occidentalis* was reported as not very important, TSWV is also non problematic. Contrastingly, in the other sites vector as well as virus are reported to be important or very important.

6. Sampling techniques for decision making

Results from TCS-Q1 indicated that in 19 of the surveyed geographical areas decision making on *B. tabaci* control was based on thresholds and in 6 areas was based only on calendar treatments. Frequently, whitefly population sampling was done by counts of adults of both whitefly species on plants or on yellow traps.

Data from TCS-Q2 show that sampling techniques do not depend on control strategies (Chemical, IPM-Insecticide, IPM-BC and Organic) or growing cycle (long or short). Whitefly populations (adults and/or old nymphs) are usually sampled weekly. When the risk of whitefly occurrence is low or its impact presumably less important, samplings are operated fortnightly. There is no common sampling procedure or common sampling unit. Each country or region is using its own procedure for population follow-up and decision making that are generally based upon whitefly densities. Thus 4 sampling techniques relating to 4 different geographical locations were reported. In South of Spain observations consist of 3 leaves (up,

middle and bottom) per plant plus 4 leaflets of 20 plants per hectare. In North of Spain, 3 leaves on 20 to 30 plants are monitored in the greenhouse perimeter when plants are young, and 7 leaves on 14 plants when plants are fully grown. In South of France, at each sampling operation, leaves of 15 entire plants per hectare are observed. At the beginning of the crop, 50 instead of 15 plants are sampled. In Germany 20 to 100 entire plants per hectare are monitored. In the South of Spain, South of France and Germany advisors complement their plant sampling with yellow sticky traps (a mean of 15 traps/ha). For population monitoring and control, whitefly species are always identified. Decisions are made on both calendar and threshold basis, although calendar decisions essentially relate to chemical control strategies.

7. Whitefly control strategies

According to data from TCS-Q1 insecticidal whitefly control is used in all the surveyed countries. However, biological control is increasingly being used in the majority of geographical areas, especially in greenhouse crops. Other control tools such as nets, resistant cultivars and cultural methods were also reported to be used but to a lesser extent.

Data from TCS-Q2 revealed that organic production is the least extensive production strategy in all the surveyed regions. Within protected environments, effective whitefly control is principally achieved through IPM. In terms of acreage, IPM-insecticide is used as a control strategy in 70% of the surveyed area, IPM-BC in 25% and chemical control only in 5%. IPM-BC is the most common strategy in Germany (cycles A and B) in South of France and some areas of North of Spain, whereas IPM -insecticide is the most common strategy used in the South of Spain and North of Spain-2 (Table 5). In North Spain 2 strategies based on insecticide use account for 80% of the surveyed surface whereas in North Spain 1 represent only 15 - 30%. These two areas are very close, less than 50 km apart, and have similar climate conditions and crops cycles. However, *B. tabaci* populations and TYLCD incidence are higher in North Spain 2. This may be explained, at least partially, by a higher use of insecticides. Since higher populations of *B. tabaci* were recorded from crops where whitefly control relied only on insecticides compared to crops where IPM-BC was used (Arnó 2005).

Table 5. Pest control strategies used for different growing cycles in the surveyed regions. See page 9 for cycle description.

Area	Cycle	Total surface (ha)	%Chemical	% IPM-Insec.	%IPM-BC	% Organic
Germany	A	3	-	-	90,5	9,5
	C	17	6	18	70	6
South France	A	20	-	18	72	10
	B	35	-	100	-	-
	C	50	-	20	80	-
North Spain-1	A	31	11	19	69	1
	B	18	7	8	69	16
North Spain-2	A	17	30	50	20	-
	B	15	30	50	20	-
South Spain	A	6700	3	78	19	-
	B	3300	7	58	35	-

7.1. Insecticides

Both *B. tabaci* and *T. vaporariorum* have developed high levels of resistance to the majority of registered insecticides. Data from TCS-Q2 revealed that unlike other pest species of tomatoes, the ranked importance of *B. tabaci* within each of the four surveyed regions closely correlated with levels of insecticide use (Figure 7). This showed *B. tabaci* to be one of the principal insect pests driving insecticide use, primarily due to the threat of TYLCD and the resulting low tolerance thresholds that it imposes. However, even in areas where *B. tabaci* is not of concern, chemical control of whiteflies remains an important component.

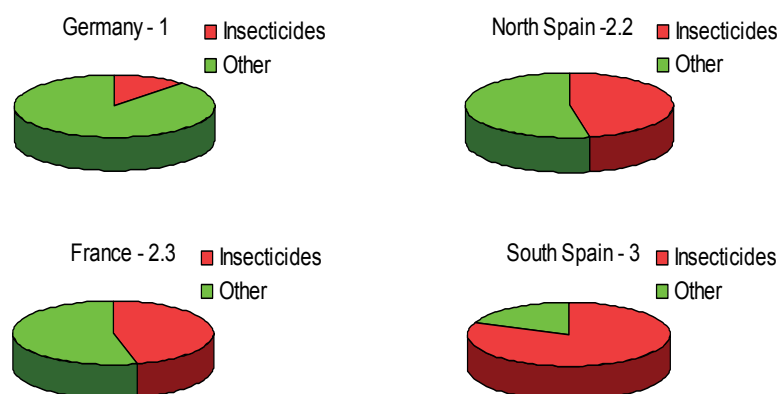


Figure 7. Chemical reliance of control strategies employed within 4 tomato producing regions of Europe. Numbers refer to average rank (0-3) of pest importance from TCS-Q2 (Table 6).

When the average number of insecticide applications per month is analysed, it is apparent that a higher number of applications is used in those areas with high pressure of *B. tabaci* and TYLCD. As expected, the number of insecticide applications per month is higher in IPM-Insecticide than in IPM-BC strategies in all areas except Germany (low whitefly pressure) and North of Spain (same advisors were responsible for recommendations of both strategies). On the other hand, IPM-Insecticide uses 18% less active ingredients (a.i.) per application than the chemical strategy and 17% more a.i. per application than IPM-BC (Table 6). Thus, IPM-BC is the most suitable strategy for a sustainable agriculture.

Table 6. Insecticide applications per month for each crop cycle, pest control strategy and area (data from TCS-Q2): * < 1 application/month; ** from 1 to 2 applications/month and *** > 2 applications/month. See page 9 for cycle description.

Area	Cycle	<i>B.t.</i>	TYLCD	IPM-BC Appl/month	IPM-Ins Appl/month	Chem Appl/month
Germany	A	1	0	*		
	C	1	0	*	*	*
South France	A	1	1	*	*	
	B	3	3		***	
	C	3	3	*	***	
North Spain-1	A	1	1	*	*	*
	B	2	1	*	*	*
North Spain-2	A	3	3	*	*	*
	B	3	3	*	*	**
South Spain	A	3	3	**	***	***
	B	3	3	**	***	***
Average number of a.i./appl				1.5	1.8	2.2

Insecticide resistance. The range of insecticides targeted against whiteflies across the four regions surveyed in TCS-Q2 spans organophosphate, pyrethroid, carbamate and neonicotinoid chemistries, in addition to specific insect growth regulators, pymetrozine and pyridaben. Confirmed cases of resistance have been reported for both whiteflies, especially for *B. tabaci*, to all the compounds listed. Insecticide resistance is a primary constraint, not only to effective chemical based strategies but more importantly as the chemical back-up that supports the performance and sustainability of IPM. With a requirement for IPM compatibility, insecticidal control of whiteflies has increasingly centred on a limited number of selective compounds, many of which are compromised by resistance development. Consequently, some growers that are using control strategies based on insecticides are reverting to broader-spectrum compounds with greater toxicity to both biocontrol agents and insect pollinators. For *B. tabaci*, the lack of genetic introgression between biotypes B and Q can result in different insecticide resistance profiles. This can lead to a competitive advantage when particular insecticides are used, which potentially has a dramatic influence on biotype ratios and distribution patterns.

7.2. Biological control

Natural enemies used in the 9 surveyed countries in TCS-Q1 for biological control of whiteflies are: *Eretmocerus mundus* in 9 countries, *Typhlodromips* (= *Amblyseius*) *swirskii* and *Macrolophus caliginosus* in 7 countries, *Eretmocerus eremicus* and *Nesidiocoris tenuis* in 4 countries, *Encarsia formosa* in 3 countries and *Dicyphus hesperus* in 2 countries. Figure 8 shows the use of these natural enemies in the different locations in tomato, eggplants, pepper, cucurbits and ornamentals. As can be observed, more non-European natural enemies are used in northern locations than in the Mediterranean countries.

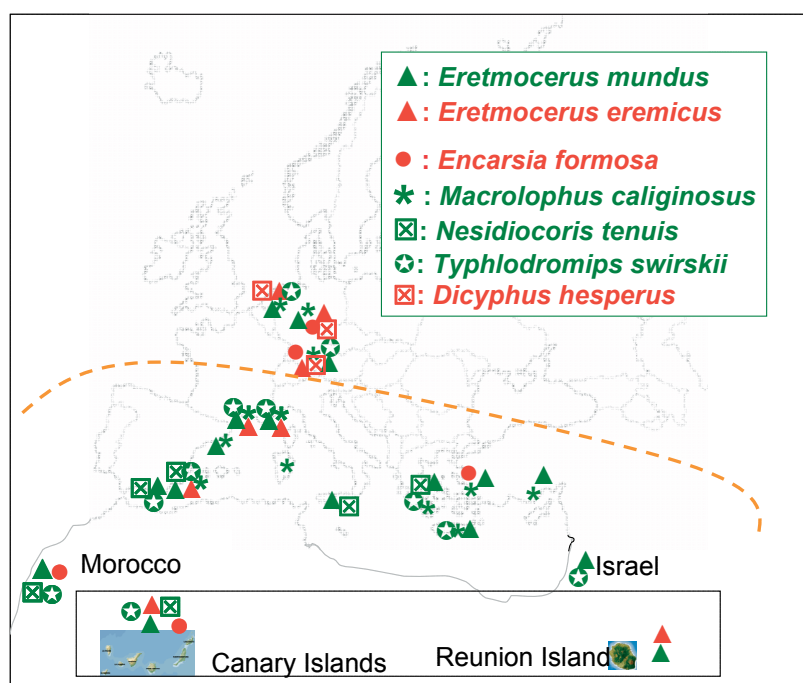


Figure 8. Natural enemies used in biological control of whiteflies in the different countries. Symbols in red are used for beneficials not native of Europe (data from TCS-Q1).

TCS-Q2 reveals that IPM based on BC is applied in the 4 tomato growing areas surveyed, the largest acreage (> 2000 ha) being in the South of Spain. Biological control of whiteflies is mainly based on inoculative releases of the parasitoids *E. mundus* and *E. formosa* and/or the polyphagous predators *M. caliginosus* and *N. tenuis*. Only in the North of Spain, a program based on the conservation of native populations of *M. caliginosus* is also used. Data on the different beneficials used in the different areas at crop cycles is summarized in table 7.

Among the predators, *M. caliginosus* is widely released in Germany, South of France and North of Spain, whereas *N. tenuis* is only introduced in the tomato greenhouses in the South of Spain. Release rates of *M. caliginosus* range from 0.5 to 4 adults/m² while *N. tenuis* is released at a rate of 1 adult/m². The fact that *N. tenuis* can cause damage to the tomato plants when prey is scarce probably results in lower recommended release rates.

The parasitoid species used for whitefly control are tightly correlated to the whitefly species present in the different crop cycles and growing areas. *Eretmocerus mundus* only parasitizes *B. tabaci* and it is widely used in the Mediterranean basin in the tomato growing cycles when this whitefly is the predominant species. *Encarsia formosa* is used in Germany and the South of France, principally for *T. vaporariorum* control. Release rates of both parasitoid species are very variable: from 3 to 9 individuals/m² in the case of *E. mundus*, and from 4 to 55 individuals/m² in the case of *E. formosa*. It is noteworthy, that in the South of France *E. eremicus* is released when no *E. mundus* is available.

Table 7. Natural enemies and release rates (individuals/m²) used in the different European areas studied in TCS-Q2. Mc: *M. caliginosus*, Nt: *N. tenuis*, Em: *E. mundus* and Ef: *E. formosa*. See page 9 for cycle description.

Area	Cycle	Mc	Nt	Em	Ef
Germany	A	1.5	-	-	4-8
	C	0.5-2.5	-	-	7.5-9
South France	A	4	-	-	25-55
	C	3	-	10	10
North Spain-1	A	2-3	-	3-9	-
	B	2	-	-	-
North Spain-2	A	1.5	-	-	-
	B	2	-	3-9	-
South Spain	A	-	0.75	10	-
	B	-	1	10	-

Biological control is used mainly within the framework of IPM programs as a method to control some pests. In those programs, selective pesticides are applied for other pests lacking biological solutions or when biological control fails to maintain the target pest under the economic threshold. Natural enemies are also used in organic production although the acreage of tomatoes under this production system is very limited.

Decisions relating to beneficial species and rates usually rely on the experience of advisors who work, in many cases, for natural enemy producers or distributors. Releases of parasitoids are based on adult whitefly thresholds (1-2 whitefly adult /plant), whereas in the case of predators they are often calendar based. This is probably due to both predator availability and their slow installation on the crop, forcing the release of predators from the

outset. In the North of Spain, *M. caliginosus* release rates are configured according to natural populations of the predator at the start of the crop.

7.3. Other control tools to control whitefly

Important components of IPM strategies are the physical control tactics and virus plant resistance. TCS-Q2 data revealed that the use of nets in vents and double-door entry systems to reduce the movement of *B. tabaci* into greenhouses, and the use of tomato varieties tolerant to TYLCD, were used most extensively in areas with high pest pressure and TYLCD incidence. These areas are the South of Spain, the North of Spain-2 and South of France. Yellow sticky traps were also used in some areas as a whitefly control method. Their use was not correlated with *B. tabaci* pressure but was more related to the tomato growing area.

Genes that confer tolerance to TYLCV have been identified in various wild relatives of tomato and tolerant tomato lines having been developed by breeding. Most tolerant commercial cultivars to TYLCD have the *Ty-1* gene. The best cultivars and breeding lines available show tolerance to the virus rather than resistance. Moreover, as the yield of these tolerant cultivars may be affected by early infections, they need additional protection from viruliferous insects with insect control strategies or nets during the first months after planting.

Considering the fact that so many different viruses are transmitted by whiteflies it becomes an attractive strategy not to look for plant based resistance to the virus, but instead focus on plant based resistance to the vector. At present there are not varieties fully resistant to whiteflies. In tomato, resistance towards *B. tabaci* is found in wild relatives of the cultivated tomato (Muigai et al., 2003). Whitefly plant defence is at least partly based on the glandular trichomes. Tomatoes contain glandular and non-glandular trichomes: Both types can hinder insects in their movements and thus may have an effect on their susceptibility towards whiteflies. Several groups have studied the effect of trichome density. It was found that there is a small but significant negative correlation between the densities of type IV trichomes and whiteflies. The effect of the exudates of the trichomes is much stronger, secondary metabolites with insecticidal activity are present in wild relatives of the cultivated tomato and are responsible for the observed insect resistance. However, until now breeding efforts have been without success. This is probably due to the fact that several resistance conferring metabolites exist in parallel and are determined by a number of independent genes, hampering their combined transfer to a single variety of cultivated tomato.

The thrips vectored TSWV has also been reported to be an important disease in several tomato growing areas. Tomato cultivars resistant to TSWV have been obtained through the use of the single viral resistance gene Sw-5. The use of TSWV resistant cultivars in the different areas and crop cycles it is not correlated with the incidence of the virus nor the vector.

8. Recommendations to manage *B. tabaci* and TYLCD in tomato crops

The information collected within the TCS has permitted to establish a database with up-to-date information on the state of art of *B. tabaci* and whitefly transmitted viruses in EU and neighbouring countries and the tools that are available to manage this pest in tomato. This information will provide valuable input to contribute to the ENDURE Information Centre (SA4), to design innovative cropping systems that include tomato crop (RA2) and a multi-

criterion assessment of crop protection methods and cropping systems (RA3). Also the information collected will contribute to the IA2.4 and IA2.5 sub-activities for continuing refinement of decision support systems.

The key information will be collated in a leaflet and disseminated amongst farmers, pest advisors and plant protection services, in conjunction with SA1 activity, to transfer the available techniques and the knowledge on IPM-BC strategy for a wider, efficient and successful implementation.

In a sustainable agriculture scenario, IPM-BC is the most suitable control strategy for improving *B.tabaci* and TYLCD control on tomato greenhouses. Potential limitations for a wider adoption of IPM-BC programs in tomato crops have been identified within the TCS-Q2 (Table 8).

Table 8. Information on the limitation topics for IPM-BC strategy implementation in the different scenarios surveyed (TCS: Q2). A1:Lack of information; A2:Lack of information in my language; A3:There is information but the access to it is not easy; B1: Lack of biological solution for some pests; B2: Low pest injuries threshold; B3:Protocols available do not work in my climate; B4: Lack of trained advisors; B5:Lack of experience; B6: No availability of commercial natural enemies; B7: Low acceptance of the method on behalf of the farmer; C1: Natural enemies are expensive; C2: Increase costs due the need for technical advice.

Area	Cycle	Information			Method							Costs	
		A1	A2	A3	B1	B2	B3	B4	B5	B6	B7	C1	C2
Germany	A	1	1	1	2	2	1	3	2	1	2	3	3
	C	1	1	1	1	1	1	1	1	1	1	2	2
South France	A	1	1	1	1	1	1	1	1	1	1	3	1
	B	1	1	1	1	4	1	1	1	1	4	1	1
	C	1	1	1	3	1	1	1	1	1	1	1	1
North Spain-1	A	1	1	1	4	1	3	1	1	4	3	3	1
	B	1	1	1	4	1	1	1	1	1	4	4	1
North Spain-2	A&B	3	4	4	4	3	3	4	4	1	3	3	1
South Spain	A&B	3	1	1	4	4	1	2	2	1	3	1	4

The most extensive limitation was represented by the category “lack of a biological solution for some pests”, especially in Spain and South of France. This area is increasingly affected by a harmful mite, *A. lycopersici*, which does not have any efficient biological control agent. In addition, the “cost of the natural enemies” is considered high in all surveyed areas. A significant limitation, especially around the Mediterranean basin, is the “low acceptance of the method on behalf of the farmer” and may be related to the field surface according to some advisors opinion. This limitation will be overcome by an efficient training of farmers and advisors (SA1 activity) that will help to improve the knowledge on BC strategy and will increase the confidence in this control method on behalf of the end-user. The “Increase of costs associated with technical advice” is considered an important limitation to the implementation of IPM-BC in the South of Spain and in Germany. In South of France and South of Spain the low “pest injury thresholds” makes farmers reticent to initiate an IPM control program and this is probably due to high incidence of TYLCD in these areas.

9. Research priorities

To enhance a wider adoption of IPM programs in tomato crops some knowledge gaps have to be approached, thus research in the following domains were purposed: (i) whitefly-transmitted viruses, (ii) insecticide-resistance in whitefly populations and *B. tabaci* biotypes, (iii) host plant resistance to whiteflies, (iv) economic thresholds and sampling techniques for whitefly populations, and (v) whitefly natural enemies and biological control.

Within each of these domains several topics have been identified as important gaps of the current knowledge and that need to be included in a list of priorities in the EU research on pest control.

(i) On whitefly-transmitted viruses. A specific knowledge gap that can require ongoing continuous/periodical support is the risk associated to new geminiviruses and their potential recombination that could be studied by the sub-activity “Invading an emerging pest” RA4.4. Four geminiviruses species have been identified in Europe and there are 50 more distinct geminiviruses around the world that were all identified on tomato. Some non-European tomato geminiviruses could be introduced into Europe, and these viruses may recombine with European viruses to produce new species. To assess such a risk, the impact of recombination on virulence and fitness should be studied. Preliminary results indicate that most of them are infectious, but is not known how frequently a recombinant genome is more virulent and fitter than its parental viruses. Moreover it is not known if cultivars that were bred for resistance to TYLCV are resistant to the other tomato geminiviruses (Lapidot and Friedmann 2002).

(ii) On insecticide-resistance in whitefly populations and *B. tabaci* biotypes. There are two specific knowledge gaps that continue to limit more effective, efficient, and selective chemical control of whiteflies. Both require ongoing continuous/periodical research and will interface very effectively with the sub-activity RA4.1 “Pesticide resistance management”.

ii.a. Resistance assessments. Levels of insecticide resistance are dynamic and can be localised or more widespread. Contemporary monitoring data is necessary to make appropriate and informed insecticide choices. The relevance of *B. tabaci* biotypes to insecticide resistance in Europe is unknown. If, as has been the case for some years, a differential exists between the resistance status of biotypes B and Q, then control strategies would be most efficient if tailored to suit the biotype in question. Conversely, if little or no differential exists, as in some other global regions, biotype status will have minimal impact upon insecticide efficacy.

ii.b. Biotype assessments. Building on the previous point, biotype assessments may be an effective means of predicting the likely resistance expressed by local populations and if so, should be monitored accordingly. Updated knowledge on the status of European *B. tabaci* biotypes may give complementary information on *B. tabaci* invasiveness, whitefly infectivity of viral diseases, and several aspects of *B. tabaci* biology.

(iii) On host plant resistance to whiteflies and whitefly-transmitted viruses. Tomato has several closely related relatives that can be a source of resistance/tolerance traits in relation to whitefly populations and TYLCD. Some of those traits are being studied but several aspects of the mechanisms involved are still poorly understood. Other traits and mechanisms should be investigated with the aim of improving resistance of commercial tomato varieties. The following fields have been identified as requiring further research efforts and could be covered by the sub-activity RA4.2.

iii.a. Resistance mechanisms. Identification of the resistance mechanisms in different wild relatives of tomato and the active compounds involved. Interactions between *B. tabaci* biotypes and resistance mechanisms in the host plant.

iii.b. Biochemistry and genetics of resistance. Identification of the underlying biosynthetic pathways for the active compounds. Identification and tagging of genes involved.

(iv) On the economic thresholds and sampling techniques for whitefly populations. One of the conclusions raised from questionnaires in the case study dealt with the various methods applied for whitefly population sampling. Sampling techniques are closely related to economic thresholds and limitations complicate the efficient and selective application of control strategies. Two research priorities are proposed to alleviate these limitations.

iv.a. Sampling for decision making on whitefly control. Consistent protocols for the efficient estimation of whitefly populations, identification of the optimal sampling unit and the design of a sampling plan (size, frequency and timing of sampling).

iv.b. Economic thresholds for decision making. Economic thresholds *per se* are too static parameters to be considered as universal for making decisions on whitefly control. Economic thresholds as a function of whitefly population dynamics, in addition to insect density and damage relationships, would likely be more applicable to a range of situations.

(v) On whitefly natural enemies and biological control. One of the conclusions of the TCS-Q2 is that IPM-BC is the best control strategy to reduce pesticide residues on tomato crops. However, some important factors limit a wider uptake and highlight the need of increment research in next fields.

v.a. Improvement of whitefly biological control based on natural enemies conservation. In Mediterranean areas natural enemies are abundant and their conservation has demonstrated to efficiently control whitefly populations. To develop conservation tactics for enhancement of natural enemies in the tomato crops would lead to (a) reduce natural enemies release rates that are currently being used and, consequently, the cost of IPM-BC programs and (b) identify new native potential biological control agents.

v.b. Improve biological control of other key pest. Lack of effective natural enemies to control *Aculops lycopersici*, *Helicoverpa armigera*, *Frankliniella occidentalis* and leafminers is considered an important limitation for the implementation of IPM-BC especially in the Mediterranean where the larger surface of tomato production is located. To develop biological control strategies to manage these pests are crucial to increase the use of IPM-BC programs and reduce the insecticide use.

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ANNEX 1**QUESTIONNAIRE: TOMATO GROWING AREAS WHERE WHITEFLIES AND WHITEFLY TRANSMITTED VIRUSES ARE MAJOR CONSTRAINTS.**

Please return the filled questionnaire before 10 of May 2007.

1.- Professional that fills the questionnaire?

Advisor ☐ Plant Protection Service ☐ Scientist ☐ Company ☐

Others ☐.....

2.- Geographical identification:

Country

Specify the area to which information relates (i.e. county, region, etc.)....

Please indicate production area and/or number of growers involved:

Hectares

N. of growers

3.- Which crop systems are present in the area?

Tomatoes are produced in:

Greenhouses ☐ Glasshouses ☐ Open field crops ☐

Other vegetables and/or ornamentals are produced on:

Greenhouses ☐ Glasshouses ☐ Open field crops ☐

4.- Are whiteflies the key pest in tomato cultivation?

Yes ☐ No ☐

5.- If not, what is/are the pest/s limiting implementation of non chemical methods (or IPM systems) in tomato in your area?.

Lepidoptera ☐ Leafminers ☐ Thrips ☐

Mites ☐ Aphids ☐ Others ☐

6. What whitefly species and Bemisia biotypes are more abundant?

Bemisia tabaci ☐ *B. tabaci* biotype B ☐ *B. tabaci* biotype Q ☐
Trialeurodes vaporariorum ☐ Whitefly species unknown ☐

7.- If Bemisia is not present in your area, how do you estimate risks of having Bemisia/ Bemisia-transmitted viruses problems in the coming years?

High ☐ Medium ☐ Low ☐ No risk ☐

8.- Other crops damaged by whiteflies and whitefly transmitted virus?

Crop	WF transmitted virus		Identify virus
	yes	no	
Cucurbits <input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Eggplants <input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Peppers <input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Ornamentals <input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>

Others ☐

9.- Control methods currently used for whitefly control?

Insecticide application ☐ Biological control ☐ Cultural control ☐ Nets ☐
 Others ☐

10. Has Bemisia pesticide resistance been observed?

Yes ☐ No ☐ Not verified ☐

If yes, to which insecticide or group of compounds:

11.- What natural enemies species are used for Bemisia biological control?

Eretmocerus mundus ☐ *Eretmocerus eremicus* ☐
Macrolophus caliginosus ☐ *Nesidiocoris tenuis* ☐ *Dicyphus hesperus* ☐
Typhlodromips swirskii (= *Amblyseius swirskii*) ☐ Others ☐

On what crops:

Tomato ☐ Cucurbits ☐ Peppers ☐ Eggplants ☐ Ornamentals ☐ Others ☐

12.- Decision making on Bemisia control is based on:

Calendar ☐ or Thresholds ☐

13. Which Bemisia sampling method is used for decision making?

Species identification

Bemisia ☐ *Trialeurodes* ☐ Both ☐

Counts on:

Plants ☐ Yellow traps ☐ Others ☐

Stage

Adults ☐ Larvae ☐

ANNEX 2**ENDURE NETWORK TOMATO CASE-STUDY****QUESTIONNAIRE: CONTROL STRATEGIES USED TO CONTROL WHITEFLIES ON TOMATO CROPS****A-**

Identification of the geographical area	
Country:	<input type="text"/>
Area:	<input type="text"/>
Name of the person interviewed:	<input type="text"/>
In which group can you be classified:	<input type="checkbox"/> Advisor <input type="checkbox"/> Plant Protection Service <input type="checkbox"/> Other <input type="text"/>

The information that is detailed next refers to only one crop cycle taking place in a certain season. In the case that in your area tomatoes are grown in more than one crop cycle it will be necessary to answer one questionnaire for each crop cycle.

B-

Growing cycle:	<input type="checkbox"/> Greenhouse <input type="checkbox"/> Plastic <input type="checkbox"/> Glass Heating: <input type="checkbox"/> Yes <input type="checkbox"/> No
	<input type="checkbox"/> Open field
Area:	<input type="text"/> ha ; <input type="text"/> plots
Grown on	<input type="text"/>
Transplanting date (month):	<input type="text"/>
End of the crop (month):	<input type="text"/>
Origin of tomato seedlings:	
	<input type="checkbox"/> Local Seedling Company <input type="checkbox"/> Non local Seedling Company <input type="checkbox"/> Own production <input type="checkbox"/> Others <input type="text"/>

C- In what system would you frame the whitefly control strategy that is applied in your area? If more than one is applied, please indicate the percentage or surface of area where it is applied.

ha	%	
<input type="text"/>	<input type="text"/>	<input type="checkbox"/> IPM-Insecticides; based on the rationalized application of pesticides (IPM-insec)
<input type="text"/>	<input type="text"/>	<input type="checkbox"/> IPM-Biological; based on the use of natural enemies and selective pesticides (IPM-BC)
<input type="text"/>	<input type="text"/>	<input type="checkbox"/> IPM-Chemical
<input type="text"/>	<input type="text"/>	<input type="checkbox"/> IPM-Biological; based on the use of natural enemies and selective pesticides (IPM-BC)

In the case that in your area more than one control strategy is applied it will be necessary to answer the sections that correspond.

D- RANKING OF THE MAIN PESTS IN TOMATO

Please, rank the main **pests** in tomato according to their importance in your area (0: absent; 1: not very important; 2: important; 3: very important)

	0	1	2	3
<i>Trialeurodes vaporariorum</i> (greenhouse whitefly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Bemisia tabaci</i> (tobacco whitefly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Helicoverpa armigera</i> (tomato fruitworm)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Liriomyza spp.</i> (leafminers)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Macrosiphum euphorbiae</i> , <i>Myzus persicae</i> ,... (aphids)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Leptinotarsa decemlineata</i> (colorado potato beetle)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Frankliniella occidentalis</i> (western flower trips)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Aculops lycopersici</i> (tomato russet mite)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Tetranychus urticae</i> , <i>T. turkestan</i> (spidermites)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Agrotis spp.</i> (cutworm)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Agriotes sp.</i> (wireworm)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
*	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
*	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

* Please, identify other important pests not listed above

E- RANKING OF THE MAIN INSECT TRANSMITTED VIRUSES IN TOMATO

Please, rank the main **insect transmitted viruses** in tomato according to their importance in your area (0: absent; 1: not very important; 2: important; 3: very important)

	0	1	2	3
TYLCV <i>Tomato yellow leaf curl virus (all strains)</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
ToCV <i>Tomato chlorosis virus</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TICV <i>Tomato infectious chlorosis virus</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TSWV <i>Tomato spotted wilt virus</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CMV <i>Cucumber mosaic virus</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
PVY <i>Potato virus Y</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
**	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
**	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Please, identify other important viruses not listed above

F. PREVENTIVE AND CULTURAL CONTROL STRATEGIES APPLIED

1.1 Which other strategies are currently used for whitefly control?

- ☐ Use of whitefly screening in vents in side walls and double-door entry system in greenhouses
- ☒ Use of TYLCV tolerant varieties
- ☒ Use of other viruses resistant or tolerant plants
- ☐ Use of yellow sticky traps as a control strategy
- ☐ Crop rotation with plants that are not hosts of whiteflies
- ☐ Others,
- ☐ None

G-CONTROL STRATEGY FOR WHITEFLY ON TOMATO

	IPM-Insec	IPM-BC	Chemical	Ecological
Do you have a sampling plan for decision making?	Yes <input type="checkbox"/> No <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/>

If 'YES' please proceed to answer Section 1

If 'NO' please proceed to answer Section 2 and/or 3 according what you have answered at section C

1. SAMPLING

In the following questions we would like to define the sampling plan used for whitefly.

	IPM-Insec	IPM-BC	Chemical	Ecological
In which stage is whitefly sampled?	<input type="checkbox"/> Larvae <input type="checkbox"/> young <input type="checkbox"/> old <input type="checkbox"/> Adults	<input type="checkbox"/> Larvae <input type="checkbox"/> young <input type="checkbox"/> old <input type="checkbox"/> Adults	<input type="checkbox"/> Larvae <input type="checkbox"/> young <input type="checkbox"/> old <input type="checkbox"/> Adults	<input type="checkbox"/> Larvae <input type="checkbox"/> young <input type="checkbox"/> old <input type="checkbox"/> Adults
Do you count <i>s. separately B. tabaci</i> and <i>T. vaporariorum</i> ?	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
The sampling is done on:	<input type="checkbox"/> Plant <input type="checkbox"/> Yellow sticky traps	<input type="checkbox"/> Plant <input type="checkbox"/> Yellow sticky traps	<input type="checkbox"/> Plant <input type="checkbox"/> Yellow sticky traps	<input type="checkbox"/> Plant <input type="checkbox"/> Yellow sticky traps
If plants				
no of plants counted/area	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Entire plant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Apical shoot	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Leaf	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Which ones?	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
no of leaves	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Leaflets	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Which ones?	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
no of leaflets	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
no of leaves	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
If yellow sticky traps				
Number of traps/ha	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Trap area	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Frequency of sampling	<input type="checkbox"/> Less than one week <input type="checkbox"/> Weekly <input type="checkbox"/> Fortnightly <input type="checkbox"/> Monthly <input type="checkbox"/> Over one month	<input type="checkbox"/> Less than one week <input type="checkbox"/> Weekly <input type="checkbox"/> Fortnightly <input type="checkbox"/> Monthly <input type="checkbox"/> Over one month	<input type="checkbox"/> Less than one week <input type="checkbox"/> Weekly <input type="checkbox"/> Fortnightly <input type="checkbox"/> Monthly <input type="checkbox"/> Over one month	<input type="checkbox"/> Less than one week <input type="checkbox"/> Weekly <input type="checkbox"/> Fortnightly <input type="checkbox"/> Monthly <input type="checkbox"/> Over one month

2. BIOLOGICAL CONTROL

2.1 What strategy does the advisor recommend?

IPM-BC		Ecological	
<input type="checkbox"/> Conservation	<input type="checkbox"/> Release	<input type="checkbox"/> Conservation	<input type="checkbox"/> Release

2.2 In case of release, how does the advisor decide to recommend a release of natural enemies?

	IPM-BC	Ecological
Presence of whitefly on plants or on yellow traps	<input type="checkbox"/>	<input type="checkbox"/>
Whitefly over a threshold/ per plant sampling unit	<input type="text"/>	<input type="text"/>
Whitefly over a threshold / per yellow trap	<input type="text"/>	<input type="text"/>
Schedule on a calendar basis	<input type="checkbox"/>	<input type="checkbox"/>
According to the advisor's experience	<input type="checkbox"/>	<input type="checkbox"/>
According to natural enemies' availability	<input type="checkbox"/>	<input type="checkbox"/>

2.3 What natural enemy species are used for biological control of whiteflies? If other natural enemies not listed are used, please add to the list.

	Conservation *		Release					
			Rates ^a		Introductions ^b		Interval	
	IPM-BC	Ecological	IPM-BC	Ecological	IPM-BC	Ecological	IPM-BC	Ecological
<i>Eretmocerus mundus</i>	<input type="checkbox"/>	<input type="checkbox"/>						
<i>Macrolophus caliginosus</i>	<input type="checkbox"/>	<input type="checkbox"/>						
<i>Nesidiocoris tenuis</i>	<input type="checkbox"/>	<input type="checkbox"/>						
<i>Eretmocerus eremicus</i>	<input type="checkbox"/>	<input type="checkbox"/>						
<i>Encarsia formosa</i>	<input type="checkbox"/>	<input type="checkbox"/>						
<i>Dicyphus hesperus</i>	<input type="checkbox"/>	<input type="checkbox"/>						
	<input type="checkbox"/>	<input type="checkbox"/>						
	<input type="checkbox"/>	<input type="checkbox"/>						

* Conservation: No releases of natural enemies but conservation of natural enemies that colonize the crops spontaneously

^a Rates: Total number of individuals released per m² in each release

^b Introductions: Number of times that natural enemies are released per crop cycle

^c Interval: Interval between releases of natural enemies

3. CHEMICAL TREATMENT

3.1 How does the advisor decide to recommend a treatment?

	IPM-BC	IPM-Insec	Chemical
Presence of whitefly on plants or on yellow traps	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Whitefly over a threshold/ per plant sampling unit	<input type="text"/>	<input type="text"/>	<input type="text"/>
Whitefly over a threshold / per yellow trap	<input type="text"/>	<input type="text"/>	<input type="text"/>
Schedule on a calendar basis	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
According to the advisor's experience	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Presence of plants with virus symptoms	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3.2. Which are the active insecticide ingredients used? Please, add to the list any other active ingredient used and not listed below.

	IPM-BC	IPM-insec	Chemical
OPs, carbamates	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pyrethroids	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Neonicotinoids	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Abamectin	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pyriproxyfen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pymetrozine	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Diafenthiuron	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Novaluron	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Buprofezin	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pyridaben	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spiromesifen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3.3. For the treatments applied to control whiteflies specify:

	IPM-BC	IPM-insec	Chemical
Average number of applications per crop cycle	<input type="text"/>	<input type="text"/>	<input type="text"/>
Average no of active ingredients used per application	<input type="text"/>	<input type="text"/>	<input type="text"/>
If soil treatments are used, please indicate	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
No. Treatments/crop cycle	<input type="text"/>	<input type="text"/>	<input type="text"/>
Product	<input type="text"/>	<input type="text"/>	<input type="text"/>

H- POTENTIAL LIMITATIONS FOR IPM IMPLEMENTATION AND DEVELOPMENT IN TOMATO CROPS IN YOUR AREA*(1: unimportant limitation; 4:very important limitation)*

	1	2	3	4
<i>Limitations related to information accessibility</i>				
Lack of information	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of information in my language	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
There is information but the access to it is not easy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Limitations related to the method or technique</i>				
A biological solution is missing for some pests	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Very low pest injuries threshold	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Available protocols do not work in my climate/ agronomic situation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of trained advisors in the area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of experience in the area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
No availability of commercial natural enemies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Low acceptance of the method on behalf of the farmer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Economic limitations</i>				
The natural enemies that I could use are expensive	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Increased costs due to the need for technical advice	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Other limitations</i>				
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Comments:

I-

Which of the following sources have been used to answer the questionnaire (mark those that correspond):

- ☐ Personal experience
- ☐ Personal communication with advisers in the area
- ☐ Personal communication with farmers in the area
- ☐ Others,