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COLEAD

TECHNICAL BROCHURE

WHITEFLY FIELD MANAGEMENT BROCHURE

FOR GROWERS IN SURINAME

Funded by the European Union

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CONTENTS

Figure 1: Jute, *Cochorus oritorius* (Photo by V. Eziah, University of Ghana).

Background

This whiteflies field management brochure for leafy vegetables growers in Suriname is a part of a series of 4 brochures for the whiteflies management:

1. Whitefly management strategy dossier for the control bodies
2. Inspection and identification brochure for whiteflies in ACP countries for the inspectors and the extension workers
3. Whiteflies field management brochure for leafy vegetables growers in Suriname
4. Packhouse brochure for management of whiteflies in ACP countries for the packhouse managers

Suriname is among the ACP countries with an increasing number of interceptions due to whiteflies from leafy vegetables (e.g., *Solanum macrocarpon, Hibiscus, Ipomoea*, etc.) exported to the EU. Considering the new EU regulation already in force, much stringent guidelines are needed to be followed, to ensure interceptions of harmful organisms (specifically whitefly, *Bemisia tabaci*) do not rise to alarming levels that may warrant a ban.

This leaflet is designed to help growers in Suriname to check, identify, monitor, and control whiteflies in the field to ensure exported leafy vegetables are free from whiteflies and other Union quarantine pests, leading to a rise in the volume of leafy vegetables exported. Commonly exported leafy vegetables that may be associated with the sweet potato whitefly, *Bemisia tabaci* are shown below (Photos by KO Fening)

a. Cassava (*Manihot esculenta*)

b. 'Alefu' (*Amaranthus* sp.)

c. 'Gboma' (*Solanum macrocarpon*)

d. Sweet potato (*Ipomoea batatas*)

Figure 2. Examples of commonly exported leafy vegetables with high potential for sweet potato whitefly, *Bemisia tabaci* infestation (Photos a-d is by KO Fening and e. by V. Eziah, University of Ghana)

e. Jute, (*Cochorus oritorius*).

Figure 2. *(bis)* Figure 2. Examples of commonly exported leafy vegetables with high potential for sweet potato whitefly, *Bemisia tabaci* infestation (Photos a-d is by KO Fening and e. by V. Eziah, University of Ghana)

Description of whitefly and its lifecycle

Bemisia tabaci goes through six developmental stages, namely egg, first, second, third and fourth larval or nymphal stages and adult (Fig. 3). The duration of the egg to the adult stage depends on the climatic conditions and the host plant. For example, the duration of the egg-to-adult period of *B. tabaci* under laboratory conditions (25°C, 70 ± 10% RH, 14-hour photophase) was 19.8 days on collard, 21.2 days on soybean and 22.0 days on tomato (Takahashi et al. 2008).

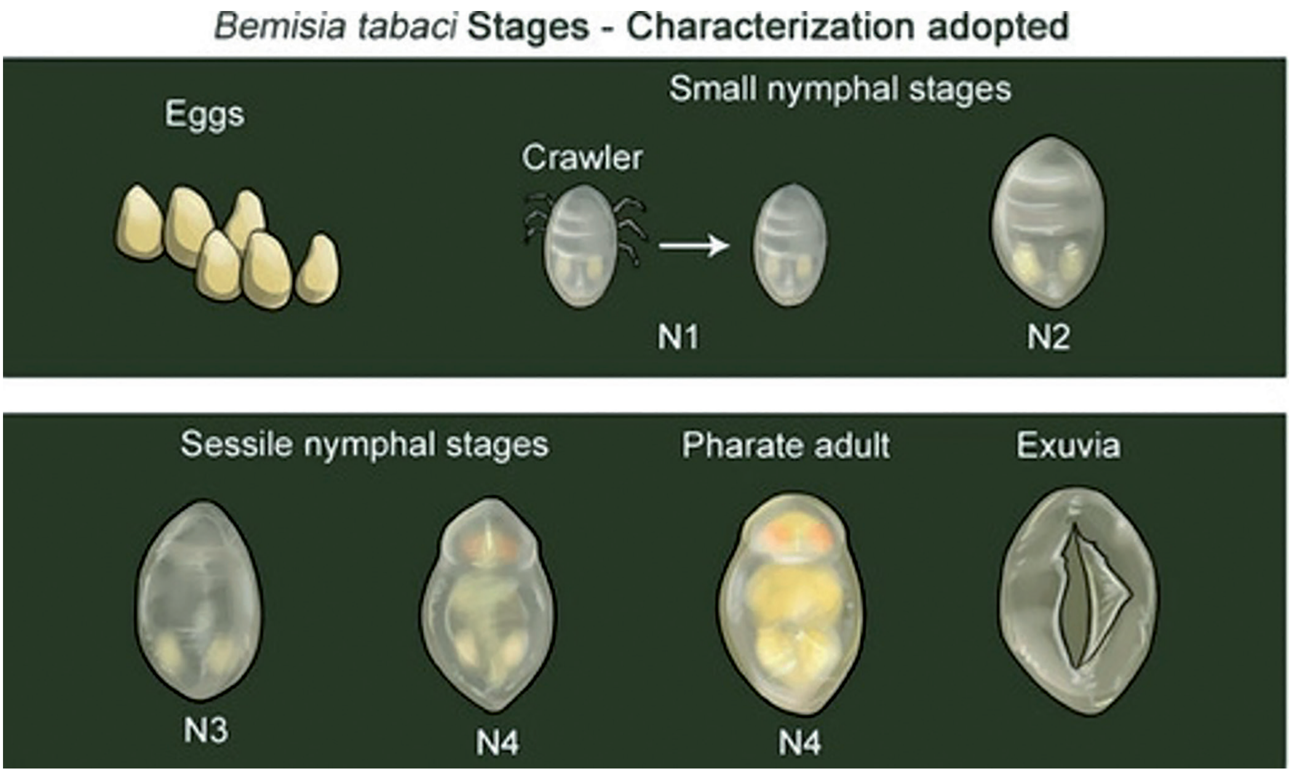


Figure 3: *Bemisia tabaci* developmental stages - illustration by Gabriella Czepak Caston. Adapted from Czepak *et al.* 2018.

Eggs:

Female whiteflies deposit pear-shaped eggs (Figs.3- 4) into the mesophyll or inner tissue of the leaf from the lower surface. Eggs are attached to the leaf by a stalk-like process. Eggs are white when first laid and become brown prior to hatching (Fig. 4). They are generally laid on the underside surface into the inner tissue of the younger upper leaves of the plant (Fig. 4). Females lay from 28-300 eggs depending on host and temperature.

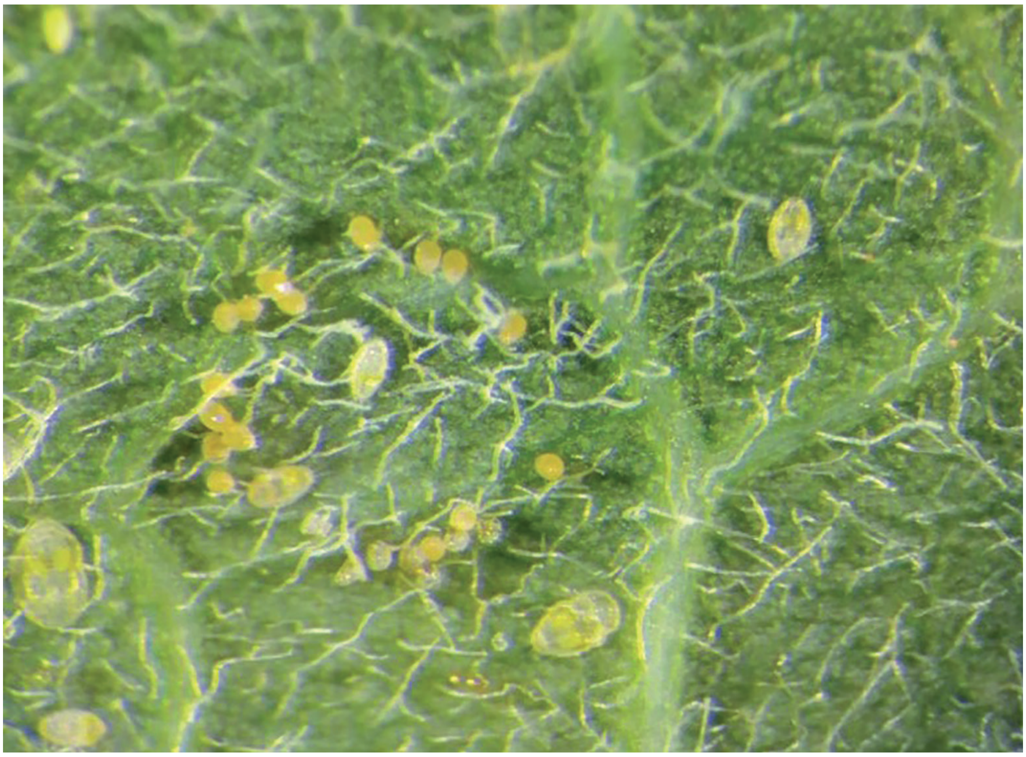
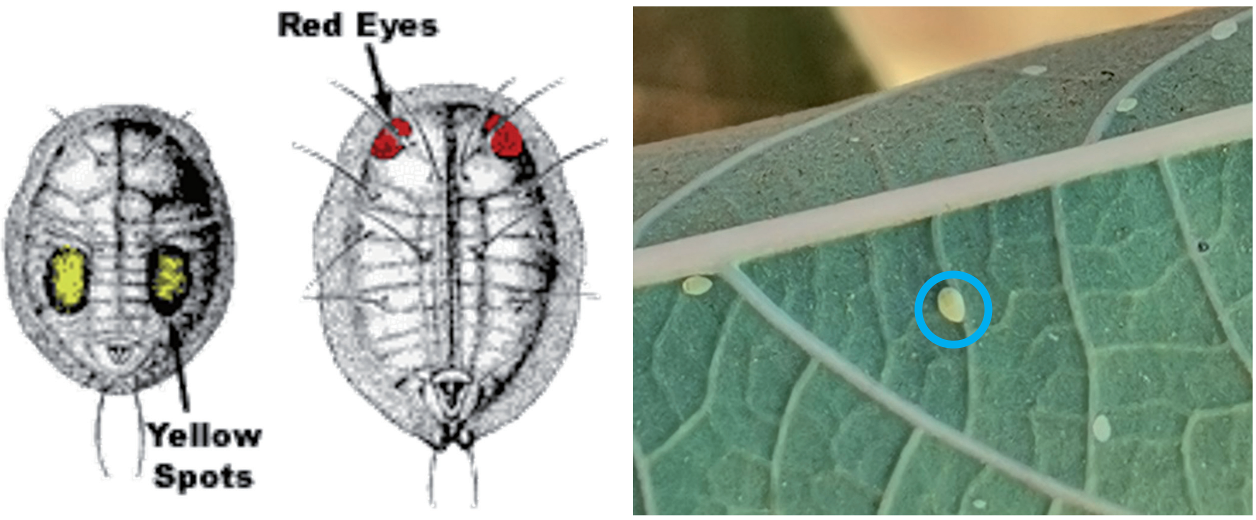


Figure 4: Sweetpotato whitefly, *Bemisia tabaci* eggs laid in a circle with a 1st instar crawler in the middle and older nymphs nearby. Photo by Erfan Vafaie, Texas A&M AgriLife Extension.

Larvae/nymphs:

The first nymphal stage is called crawler (Figs. 3-4) and the last stage is often referred to as the pupa. After hatching the crawlers move a short distance and settle to feed. Once settled, the subsequent three nymphal stages are scale-like and sedentary. **Nymphs are creamy white to light green and oval in outline** (Fig. 5b).



a. b.

Figure 5: a. 3rd (left) & 4th (right) instar nymphs called crawlers. (Photo by Tong-Xian Liu).
b. *Bemisia tabaci* nymphs on cassava leaf – Photo by KO Fening.

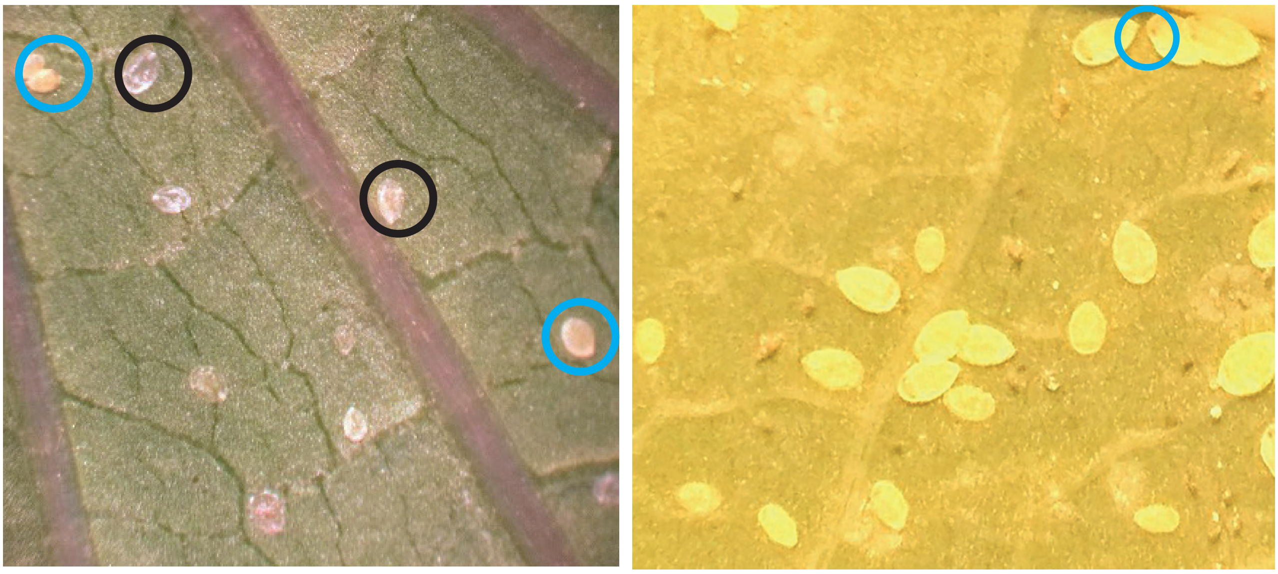


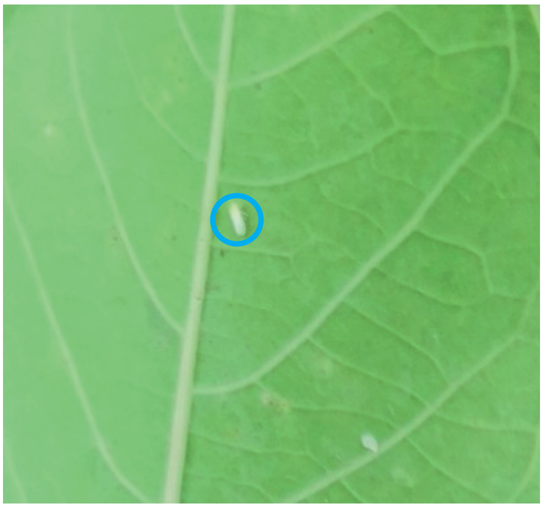
Figure 6: *Bemisia tabaci* nymphs (blue arrows) and shed skin (exuvia) (black arrows) on cassava and sweet potato, respectively as observed under the light microscope. Photos by KO Fening.

The eggs and early nymphal stages (1st and 2nd instars) might be difficult to observe with the naked eye, unless aided by a magnifying lens. Count large nymphs (3rd and 4th instars), those that are visible to the naked eye (Figs. 5-6). The 3rd & 4th instar nymphs appear as flattened, egg-shaped disks or 'scales (Figs.5-6). Although the 3rd & 4th instar nymphs should be visible to the naked eye, some of them may blend in with the leaf surface (Fig. 5). So, look for the two yellow spots on the 3rd and young 4th instars and the developing red "eye" spots on the matured or largest 4th instar (sometimes referred to as the pupae) (Fig. 5).

Adults:

Adult sweetpotato whiteflies are small, approximately 1mm in length, with a pale-yellow body and two pairs of white wings and covered with a white waxy powder. At rest, wings are held in an inverted V position. Their compound eyes are red.

a.



b.

Figure 7: a. Adult *B. tabaci*- Photo from Public Domain - Released by the USDA-ARS/original image by Stephen Ausmus. b. Adult *B. tabaci* on cassava leaf- Photo by KO Fening.

Avoid confusion of *Bemisia tabaci* with other whiteflies

The adult of the of the sweet potato whitefly (*Bemisia tabaci*) closely resembles the greenhouse whitefly (*Trialeurodes vaporariorum*) but is slightly smaller and yellower. More distinctively, the wings of *B. tabaci* are held vertical and parallel along the body compared to *Trialeurodes vaporariorum* where the wings are held horizontal along the body (Figure 8).

Figure 8: Adults of the greenhouse whitefly, *Trialeurodes vaporariorum*. (Unlike, *B. tabaci*, the fourth-instar nymphs have very long waxy filaments and a marginal fringe). (see photo above). Photo from University of California.

Symptoms of whitefly damage

Whiteflies use their stylets in sucking sap from the phloem of plant stems and leaves. High populations of whiteflies cause leaves to turn yellow, appear dry, distorted, discoloured, or fall off (Figure 9). Whiteflies also excrete honeydew (sugary liquid). Leaves get sticky and covered with black sooty mould (Fig. 10) that grows on honeydew as a result. Honeydew attracts ants, which may interfere with the activities of natural enemies that control whiteflies and other pests.

Figure 9: Damage symptoms and adults of *B. tabaci* on cotton leaf.
Photo by David Riley, University of Georgia (CC BY)

Figure 10. Sooty mould on leaf. (Source https://morningchores.com/sooty-mold/, 2021).

Figure 11. Damage symptoms and adults of *B. tabaci* on French bean leaf. Photo from A.M. Varela, *icipe*.

Monitoring of whitefly populations

It is important to monitor and inspect whiteflies population at the farm level for informed decision making on their management or to determine if management interventions were effective. Regular or daily scouting and examination of crops will lead to early detection and timely management of whiteflies, their natural enemies (predators and parasitoid) and other pests.

The monitoring system should include the following measures:

- Ensure all operators involved in the field activities can recognize whiteflies and whiteflies symptoms, and know what to do when they find it.
- Have procedures in place, in the field, to inspect for whiteflies presence
- and damage at all produces handling, packing and storage sites. This involves visual
- checks. This procedure should be available to operators at any time.
- Initiate a whiteflies Alert system and put intervention and isolation procedures in place when whiteflies infested produce is identified.
- Maintain a system for keeping records of field inspections. This detection log should include observations and control measures applied and should be available for audit/NPPO inspections.
- Ensure practices and facilities are in place for the management of all waste, including pest-damaged produces.
- Use refrigerated storage facilities where possible.
- Apply post-harvest treatments, when necessary, using plant protection products:
  - as in the case of field applications, the national authorities should be able to provide guidance on which products to use and how to use them (e.g. application method, dose rate, pre-harvest interval);
  - these must be in accordance with the registration status in the country of origin and the maximum residue level (MRL) of the active ingredient in the EU.
- Ensure harvested produce is never exposed to pest attack during packing, storage (including temporary storage), or transport (road, port or airport). This includes physical screening of transported consignments and packing areas to prevent pest entry. Use of pest-proof packaging is also an option.
- Train all people involved in post-harvest handling so they are aware of and apply good practices at all times to reduce the risk of pest damages. This will reduce the chance of infested produces reaching the packhouse. As mentioned above, it is essential to have a strict procedure in place in the field to inspect all produce and identify infested produces.

At the farm level, the scouting could be done on the crop by:

- Looking at the underside of the leaves for the presence of the nymphs (Figs. 2-5) and adults' (Figs. 6-7) whiteflies, *B. tabaci*, early in the morning (6-7am), where they are still inactive and easily noticeable. Note that the flying whiteflies are seen when the crop is disturbed. For early detection, scouting is done for adults and eggs that are usually found on young leaves (refer to Figs. 3-8)
- Counting the large nymphs (3^{rd} and 4^{th} instars), (Figs. 4-5) that are visible to the naked eye.
- Checking the presence of sooty mould and ants on host plants which are symptoms of the presence of the whiteflies (see section symptoms of whitefly damage) (Fig. 8-10).
- Using yellow sticky traps (Fig.12) in the vicinity or crop canopy (1 trap per $100m^2$).

Note during the inspection that:

- The eggs (Figs. 2-3) and early nymphal stages (1^{st} and 2^{nd} instars) (Figs. 2-5) might be difficult to observe with the naked eye, unless aided by a magnifying hand lens.
- The 3^{rd} & 4^{th} instar nymphs appear as flattened, egg-shaped disks or 'scales'. Some of them may blend in with the leaf surface. So, look for the two yellow spots on the 3^{rd} and young 4^{th} instars and the developing red "eye" spots on the matured or largest 4^{th} instar (sometimes referred to as the pupae).
- Adult whiteflies (Figs. 6-7) easily fly away when the leaf is disturbed, especially when there is sunshine.

Inspection tool recommended:

- Hand lens to examine leaves and other areas for better visibility of eggs and nymphal stages. A threshold of one (1) whitefly may warrant control measures due to its potential as a vector for the transmission of plant viruses.

At the country level, the National Plant Protection Organization should institute a monitoring programme to establish occurrence and spread of whiteflies species especially those of quarantine importance:

- Detection or delimiting surveys can be undertaken as guided by ISPM 6 (Guidelines for Surveillance)
- A good surveillance programme should be incorporated with a management framework (see COLEAD Whiteflies strategy management Dossier).

Control measures against whiteflies

The control measures for whiteflies could be classified into integrated pest management (IPM) interventions at the field level and postharvest or phytosanitary treatment of produce in the pack house. There is the need for surveillance and monitoring of whiteflies all along the supply chain, involving the checks and use of yellow sticky traps in both the field and the pack house to ensure produce sent to the exit point for export is free from whiteflies and other quarantine pests.

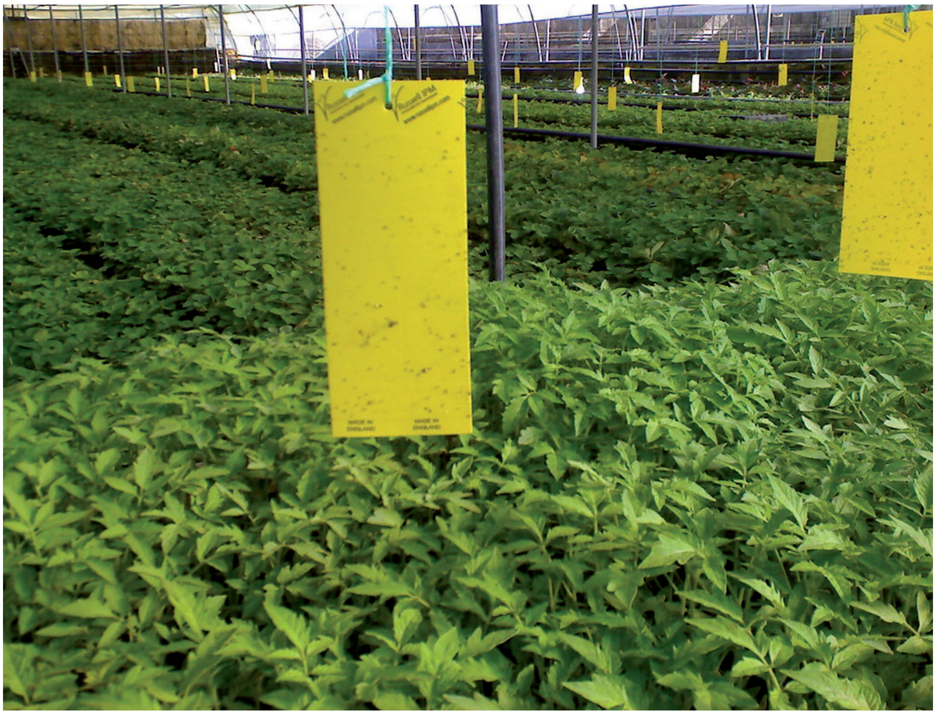


Figure 12. Monitoring and mass trapping of whiteflies and other insects (e.g., thrips) in a greenhouse using yellow sticky traps (Photo adopted from Russell IPM).

The diagram below summarises the IPM interventions for control of pests in the field, including whiteflies. These include **preventive** measures, **monitoring** and making the decision to **control** the pests, normally using environmentally friendly strategies.

Intervention - **Intervene when control measures are needed** - reducing pests to acceptable levels may involve cultural, physical, biological and chemical control measures individually or in combination. Its necessary to consider costs, benefits, timing, labour force and equipment as well as economic, environmental and social impacts of such interventions.

Monitoring - **Monitor crops for both pests and natural control mechanisms** - involves routine inspections through scouting for pests, non-pests and beneficials, use of monitoring tools (yellow sticky traps, pheromones traps) . The presence of any of the developing stages of whitefly on the plant or their presence in traps calls for control measures, as they serve as vectors for plant viral diseases.

Prevention -**prevent build up of pests – includes a range of practical strategies that suit local conditions** (variety selection, Crop management (soil/water), optimizing plant nutrition, preserving biodiversity).

Figure 13 : IPM competency areas (Adopted and modified from Crop life IPM guide).

The detailed information on the various whitefly management strategies are discussed below:

Crop management

Water and fertility management play important roles as cultural tactics in whitefly management. To optimize soil health, mineral and organic amendments should be applied at the right time and in the correct amounts. Overuse of both water and nitrogen fertilizer can greatly exacerbate damage from *B. tabaci* infestations by increasing whitefly numbers and honeydew production. Proper nutrition is essential; hence, high doses of nitrogen fertilizers that favour development and survival of whiteflies should be avoided.

Use of clean planting material is recommended. Inspection of seedlings for the presence of whiteflies before transplanting can help prevent or delay whitefly infestation on the field. Appropriate or recommended plant spacing should be adopted to allow air movement; this reduces ideal conditions for whiteflies to develop and increases the ease of detection. Protection of natural habitats near farmlands is recommended as it helps conserve biodiversity including many natural enemies.

Physical control

Physical control of whiteflies includes the use of methods that lead to exclusion or trapping of whiteflies using physical barriers and mechanisms. The physical methods that have proven to be effective in whitefly management include use of sticky traps, use of plastic covers and reflective mulches and covering.

Use of yellow sticky traps

Monitoring whitefly populations is an important part of an IPM programme. Yellow sticky traps attract adult whiteflies hence used to monitor and detect presence of whiteflies, for timely implementation of interventions. Although traps will not eliminate damaging populations but could be very useful for monitoring the whitefly population for timely and informed decision making, and is an integral component of an IPM, relying on multiple tactics. Yellow sticky traps have also been used to control low density infestations of whiteflies, especially in enclosed environments such as greenhouses and shade nets. Traps (100-300cm^2) spaced at 1 per 6m^2 will assist in controlling up to 50-60% of the pests. Since whiteflies do not fly very well, the best catches are on traps hung at 30 cm from the ground.

Use of plastic covers, reflective mulches and nets

Preventing physical contact of the whiteflies with the plant can prevent the transmission of viral diseases. Some of the means that have shown to reduce whitefly damage include reflective plastic mulches (silver, yellow, and white/black) and plastic mulches. The whiteflies are attracted by the colour of the plastic mulch, while the heat of the plastic kills the whiteflies. This is effective if the plants are young and do not cover the mulch; the protection can last for 10 to 20 days after transplanting and about 30 days after direct seeding. However, when using plastic covers, care should be taken to avoid sunscald and before putting the reflective mulch it is advisable to remove all weeds. The mulch should be placed on the plant beds and the edges buried with soil to hold them down. Cut 3- to 4-inch diameter holes and plant several seeds or single transplants in each hole. If a coated construction paper or other porous mulch that can tolerate sprinkling is used, the beds can be irrigated using furrow or sprinkle while on the other hand, plastic mulches require drip irrigation.

If the plants require to be established in a seedbed and later transplanted, it is critical to protect the seedlings under a properly closed fine-meshed insect netting or nylon nets until they are ready for transplanting to avoid infestation. It is also advisable to use tunnels for 3 to 5 weeks to protect seedlings from whiteflies infestation. To prevent whiteflies from entering production sites such as the greenhouse, openings should be sealed or screened with appropriate screening material. Whiteflies are small, so screens with a hole size of 0.27 x 0.82 mm are recommended. Use of these methods has reported reduced transmission of the Tomato Yellow Leaf Curl Virus in several countries.

Limiting movement in the infested areas

Movement of infested plants into areas known to be free from whiteflies should be restricted. This is to avoid spread of whiteflies from infested areas by humans, plants, and clothing. It is important to wear protective clothing before entry, and these must be left or removed before leaving the infested areas.

Cultural control

Use of clean planting material

Growers should obtain planting material from certified sources to avoid introducing whiteflies into growing sites. If producing own planting material/seedlings, good nursery management should be undertaken to get crops that are healthy and vigorous. New planting material should be examined carefully, particularly host plant species that are prone to regular infestation with whiteflies.

Farm sanitation/hygiene

Weeds play an important role in harbouring whiteflies between cropping seasons. They also often harbour whitefly-transmitted viruses. Growers should clear weeds early in advance before planting to reduce hideouts for whitefly developing stages. During active crop growth, the crop fields should be maintained to be weed free. Control of weed species that harbour *B. tabaci* in non-crop areas including head rows and fallow fields may also be helpful. Old crops with high levels of whitefly represent a threat to newly planted crops hence crop residues should be destroyed promptly after harvest, and the time between harvest and planting of subsequent host crops should be maximized. Good sanitation practices are also key components for establishment of host-free periods and for reducing whitefly adult intercrop migration.

Use of trap crops

Certain plants, such as tobacco, eggplant and okra are particularly attractive to whitefly. These could be used as "trap crops" in organic agriculture, to be destroyed before pupation occurs, or used as "banker plants" for the breeding of parasitic wasps.

Use of Resistant Varieties

Plant host resistance is the ability of a plant to resist or tolerate infestation by a pest. Growing resistant varieties is useful for the management of viral diseases transmitted by whiteflies, *B. tabaci*. Certain crop varieties have resistance and tolerance that is either natural or through selective breeding. For example, many varieties of cassava in East Africa have been bred particularly for resistance to cassava mosaic virus (CMV).

Early or delayed planting

Growers should plan planting dates to avoid the dry season when whiteflies are most prevalent. Whiteflies multiply rapidly in warm climate/conditions, quickly growing to overwhelming numbers that can cause severe damage to plants. Adjusting planting and harvest dates to avoid the heaviest migration periods and crop overlap has been a successful strategy and a key component in establishment of a host-free period for management of *B. tabaci* and its vectored virus pathogens. Geographic manipulation of crops has been used to avoid heavy periods of *B. tabaci* migrations. Adjusted planting and harvest dates are also key.

Crop rotation

Crop rotation is a practice of growing different crops (crops in different families or groups) on the same land in a regular recurring sequence. One of the main important reasons for crop rotation is to hinder development of weeds, insect pests and soil-borne diseases by reducing their population levels. Farmers should practice planting crops from different families in each season to break the lifecycle of whiteflies hence prevent them from multiplying. Developing a rotation plan involves dividing the farm for instance into 4 plots and allocating a crop per season for each plot. The crops are rotated on the plots making sure the same family of crop is not planted repeatedly on the same plot.

The Table below lists crop families and their common names that farmers can consider for integration into a crop rotation programme.

Table 1 Crop families for consideration in a crop rotation programme.

Family	Common names
Allium	Chive, garlic, leek, onion, shallot
Cucurbit (Gourd family)	Bitter gourd, bottle gourd, chayote cucumber, ivy gourd, luffa gourd, melons pumpkins, snake gourd, squash, wax gourd
Crucifer (*Brassica*)	Bok choy (petchay), broccoli, brussels sprouts, cabbage, Chinese cabbage, cauliflower, collard, kale, kohlrabi, mustard, radish, turnip, watercress
Legume	Common beans, black bean, broad bean (Fava), clover, cowpea, garbanzo, hyacinth bean, kidney bean, Lima bean, lintel, mungbean, peanut, pigeon pea, pinto bean, runner bean, snap pea, snow pea, soybean, string bean, white bean
Aster	Lettuce, artichoke
Solanaceous (Nightshade family)	Potato, tomato, pepper, eggplant
Grains and cereals	Corn, rice, sorghum, wheat, oat, barley, millet
Carrot family	Carrot, celery, dill, parsnip, parsley
Root crops	Cassava, sweet potato, taro, yam, water chestnut
Mallow family	Cotton, okra

Source : (Biovision, 2021b) https://infonet-biovision.org/PlantHealth/Crop-rotation

Examples of crop rotation involving some leafy vegetables and other crops (Source : Biovision, 2021b)

- **First season:**

Plot 1: Maize / garlic / onions / or leeks

Plot 2: Eggplant / chillies / potato / or tomato

Plot 3: Broccoli / cabbage / cauliflower / or kale

Plot 4: Beans / cowpeas / grams / or peas

- **Second season:**

Plot 1: Beans / cowpeas / grams or peas

Plot 2: Broccoli / cabbage / cauliflower / or kale

Plot 3: Eggplant / chillies / potato / or tomato

Plot 4: Maize / garlic / onions / or leeks

- **Third season:**

Plot 1: Broccoli / cabbage / cauliflower / or kale

Plot 2: Beans / cowpeas / grams / or peas

Plot 3: Maize / garlic / onions / or leeks

Plot 4: Eggplant / chillies / potato / or tomato

- **Fourth season**

Plot 1: Eggplant / chillies / potato / or tomato

Plot 2: Maize / garlic / onions / or leeks

Plot 3: Beans / cowpeas / grams / or peas

Plot 4: Broccoli / cabbage / cauliflower / or kale

Use of intercropping

Intercropping is an effective means of managing whitefly populations. Inter-planting tomatoes with capsicum or cucumber reduces whiteflies numbers when compared with tomatoes alone or tomatoes planted with eggplant or okra. Planting of border rows with coriander and fenugreek (which are not hosts of *B. tabaci*) favour establishment of natural enemies and as well as repelling whiteflies. Planting African marigolds around the boundary of the field has proven to repel whiteflies. Susceptible crops such as lettuce and *Brassica* spp. should not be sown near infestation sources such as cotton or melon, which themselves should not be sown near each other.

Use of oils, soap and starch

Spraying with soap and water has proven effective against whiteflies. Soaps work by partially removing the waxy layer from the scales and causing them to desiccate and die. Liquid soap sprayed at rate of 3 tablespoons (30ml) per litre of water is recommended for control of *B. tabaci* on tomatoes. Spraying 10 tablespoons (100ml) of liquid soap per 10 litres of water weekly is recommended for control whiteflies on cabbage. Oils and starch when sprayed onto scales of whitefly can act as suffocants. Various products are marketed around the world that are based on these ingredients.

Biological control

Biological control of whitefly constitutes use of natural enemies (parasitoids and predators) and use of products derived from plant extracts (neem, pyrethrum, etc.) and microorganisms which include fungi which are the only disease-causing organisms currently known to attack whiteflies. Biological control products are usually only efficient at low pest intensities and other interventions are often required. A key precaution to consider is that biological beneficial have a very short life expectancy and therefore introduction to the crop should be done as soon as possible after receipt. Use of bio-controls provides an option for growers to replace use of chemical applications by 50%, thus helping overcome the challenge of pesticide resistance and chemical residues. Although limited studies have been conducted, a comprehensive cost benefit analysis of using bio-controls, the approach has been termed as the most cost-effective method because of the sustainability it offers coupled with social and economic benefits. While this strategy may not provide the actual cost of the biocontrol options, growers are advised that the cost may depend on the specific option, geographical location and the manufacturers or producers costing.

Use of parasitoids

Parasitoids lower the population of whitefly species (*B. tabaci* and *T. vaporariorum*) via parasitism and host feeding. The most and widely used parasitoids are of genera, *Encarsia* and *Eretmocerus* with several successful cases on the efficacy of *Encarsia formosa* and *Eretmocerus eremicus* reported (Stansly P.A and Naranjo S.E. (eds.)). The *Encarsia* species occur naturally and can either be introduced right at the beginning of the crop before appearance of whitefly or on its first appearance. However, it is very sensitive to pesticides, hence careful attention should be paid to the spray programme for both insecticides and fungicides. *E. Formosa* should be introduced routinely on a preventative basis. *E. eremicus* has proven very effective in controlling both *B. tabaci* and *T. vaporariorum* and its thus useful for controlling mixed infestations of the two whiteflies (Stansly P.A and Naranjo S.E. (eds.); van Driesche et al. 2001). *E. formosa* and *E. eremicus* formulations are commercially available. More details on the usage, mode of action, application and dosage rates can be obtained from the product's label as well as manufacturer's information sheets.

Use of predators

Predators are being used to control *B. tabaci* principally under greenhouse conditions. Majority of the predators are ladybird beetles, predaceous bugs, lacewings, phytoseiid mites, and spiders. The predatory mite, *Amblyseius swirskii* is one of the most effective natural enemies, being active on most vegetable species, except tomatoes, with extensive use in pepper, cucumber and eggplant (Calvo et al., 2008; Nomikou et al., 2001). Use of additional predator species and parasitoids has helped in solving the incompatibility of *A. swirskii* with tomato plants. Several *A. swirskii* based microbial pesticides formulations are available and registered in many countries for management of whiteflies in horticultural crops. Several studies have reported a reduction in *B. tabaci* populations in plots treated with *A. swirskii* compared with controls (Calvo et al., 2008; Bolckmans et al., 2005; Namikou et al., 2001). In Spain *A. swirskii* has played a major role in controlling *B. tabaci* in pepper with elimination of whitefly populations from pepper crop that received eight whitefly adults per week over a 3-week period followed by a single release or either 25 or 50 mites per plant (Calvo et al., 2008). Effectiveness, host range and compatibility of *A. swirskii* with other natural enemies has led to its widespread adoption in greenhouse pepper and other protected vegetable crops in Spain and elsewhere (Stansly P.A and Naranjo S.E. (eds.). Moreover, *A. swirskii* can be released preventively when the crop is flowering and remains present in the crop throughout the entire growing season, even while pests' levels are very low (Bolckmans et al., 2005).

In Africa, *A. swirskii* has been recorded in Cabo Verde and Egypt (Figure 13). *Amblyseius swirskii* is native to Israel, Italy, Cyprus, Turkey, Greece and Egypt, and can be found on various crops including apples, apricot, citrus, vegetables and cotton (EPPO 2013). Since 2005, *Amblyseius swirskii* has been released or tested as a biological control agent in many European countries, as well as North America, North Africa, China, Japan and Argentina (Arthurs et al. 2009, Cedola and Polack 2011, EPPO 2013, Kade et al. 2011, Sato and Mochizuki 2011, Chen et al. 2011). Hence, in recent years, the range of *A. swirskii* may have expanded considerably in areas with suitable climatic conditions for its survival, including Senegal (Kade et al., 2011).

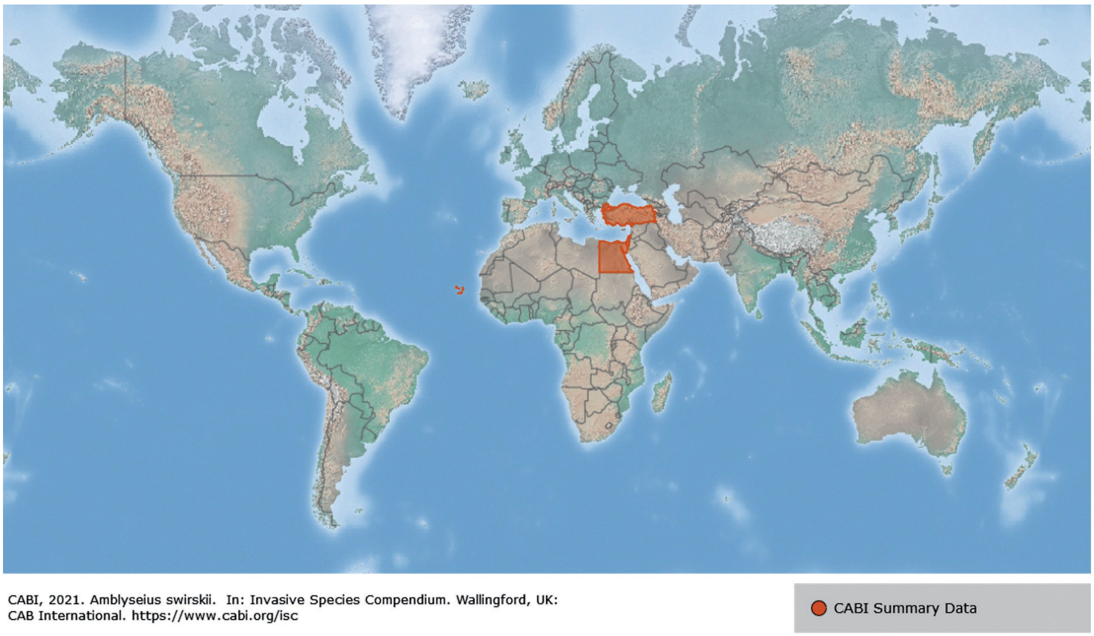


Figure 14: *Amblyseius swirskii distribution (Invasive Species Compendium, CABI, UK).*

Macrolophus pygmaeus is a reputed predator of the whiteflies *B. tabaci* and *Trialeurodes vaporariorum* and recently has also reported its efficacy in reduction of tomato leaf miner (*Tuta absosuta*). Better control of *T. absoluta* and *B. tabaci* was achieved at the higher abundance of the predator. Other authors have also reported the ability of this mirid to reduce the abundance of these two pests when they were present at the same time.

The dusty lacewing (***Conwentzia Africana***) is considered an important predator of *B. tabaci* in East and southern Africa and has been observed feeding directly on nymphs in Malawi and Kenya.

Predatory mite (***Amblydromalus limonicus***) is registered in some countries for control of whiteflies under greenhouses production. *Amblydromalus limonicus* is distributed widely in temperate to subtropical regions of North, Central and South America, and present in Hawaii, New Zealand (Moraes et al., 2004) and Australia (Steiner *et al.*, 2003; Steiner and Goodwin 2005).

Use of Entomopathogenic Fungi

Entomopathogenic fungi (EPF) infect and kill development stages of the whitefly species. Some of the commercial preparations available include ***Metarhizium anisopliae, Verticillium lecanii, Paecilomyces fumosoroseus*** and ***Beauveria bassiana*** (Stansly P.A and Naranjo S.E. (eds.)). Several biopesticide formulations of the EPF are available commercially and registered in several countries for management of whiteflies in horticultural crops.

B. bassiana infects whiteflies when applied as part of a formulation and has a broad range of targets including whitefly, thrips, mealybugs and aphids. It can be tank mixed with adjuvants, insecticidal soaps or oils. No residual harmful effect has been observed on beneficial insects. However, under dry conditions fungi may have limited activity, as they prefer humid conditions to infect the target insects (Abdelghany, 2015).

Use of Neem based bio-pesticides

Neem-based pesticides inhibit growth and development of immature stages, repel whitefly adults and reduce egg laying. They also significantly reduce the risk of Tomato Yellow Leaf Curl Virus transmission. Adding 0.1 to 0.5% of soft soap can enhance the efficacy of neem-based pesticides (Biovision, 2021a). Although all parts of neem tree possess botanical properties for pest control, the most potent results have been obtained with neem seed or oil, because of the high concentration of azadirachtin (Rovest and Deseo, 1991; Dimetry et al., 1996). A field experiment conducted by Nzanza and Mashela (2012) showed that fermented plant extracts of neem had insecticidal properties to maintain lower population densities of whitefly in tomatoes.

Note that, even if it is a natural biopesticide, some good agricultural practices (recommended dose rate, number and frequency of applications, and the pre-harvest interval) should be applied to avoid residues and toxicity on the produce.

Chemical control

Whiteflies are difficult to control once established, as they are often tolerant to chemical pesticides. In designing an IPM programme, farmers should consider proper selection and application to avoid overuse of pesticides with the same mode of action (Horowitz et al., 2011; Gyeltshen and Hodges, 2010). A systems approach to insecticide resistance management should be used. Rotation between active ingredients from at least three different modes of action groups (i.e. contact, systemic, translaminar) is recommended to avoid development of resistance to a particular active ingredient (EPPO, 2003).

Growers should observe proper application, responsible use and good handling practices of the products, which would help maximize their benefits, limit potential pesticide residues in crops and the environment as well as help avoid pest resurgence and resistance. Application should be made at the appropriate time in the cycle (e.g. adult and/or nymphal stage). Application should be initiated before the whitefly population increases to damage levels otherwise inappropriate timing of sprays may contribute to increased severity of whitefly infestation. Many pesticides have residual activity, hence specific reapplication intervals should be checked as per the product label (EPPO, 2003).

Proper selection of pesticides is necessary to review product characteristics, applications, and costs, then select the ones that provide the most cost-effective treatment with minimal undesirable effects (EPPO, 2003). It is advisable to consider compatibility of the active ingredients with the bio-control agents or biopesticide while focusing on use of selective substances rather than broad-spectrum products to avoid impact on the bio-control agents (Cioffi, 2013). Some products can be active against predators for months after application but have limited or negligible impact on pest populations after the initial application. Therefore, it is important to consider whether it is necessary to apply chemical pesticides particularly if they have a long residual impact on beneficial populations.

Which insecticides that are not banned in Suriname and could be used for the control of whiteflies:

The national authorities should provide guidance on which products to use, and how to use them (including application method, dose rate, pre-harvest interval). These must be in accordance with the registration status in the country of origin, and the maximum residue level (MRL) of the active ingredient in the EU.

Plant protection products currently not banned for use in Suriname on fruit and vegetables, are presented in Table 2.

Pesticide approvals are regularly changed, so their current status should be checked before any application. The conditions on pesticide product labels must be read and followed and their impact on any biological control agents should be considered.

Note that the list of Suriname indicates the banned products. We therefore built the above table based on the products suitable and efficient against whiteflies, from our review of the literature and field experience, that were not banned in Suriname.

Table 2. Insecticides not banned in Suriname and suitable for use against whiteflies:

Active ingredient	Group (s)	WHO Class[a]	Mode of action	EU Status
Abamectin	6: Avermectin	Ib	Glutamate-gated chloride channel	Approved
Acetamiprid	4A: Neonicotinoid	II	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Approved
Alpha-cypermethrin	3A: Pyrethroid	II	Sodium channel modulators	Not-approved
Amblydromalus limonicus	Predator	/	/	/
Amblyseius swirskii	Predator	/	/	/
Azadirachtin	UN: unknown mode of action	/	/	Approved
Beauveria bassiana	UNF: fungal agent of unknown or uncertain MOA	/	/	Approved
Beta-cyflutrin	3A: Pyrethroid	Ib	Sodium channel modulators	Not-approved
Bifenthrin	3A: Pyrethroid	II	Sodium channel modulators	Not-approved
Buprofezin	16	III	Inhibitors of chitin biosynthesis type 1	Approved
Chlorantraniliprole	28	U	Ryanodine receptor modulators	Approved
Chlorpyrifos-ethyl[b]	1B: Organophosphates	III	Acetylcholinesterase (ACHE) inhibitors	Not-approved
Cyantraniliprole	28	U	Ryanodine receptor modulators	Approved
Cypermethrin	3A: Pyrethroid	II	Sodium channel modulators	Approved
Cyromazin	17	III	Moulting disruptor, dipteran	Not-approved
Deltamethrin	3A: Pyrethroid	II	Sodium channel modulators	Approved
Diafenthiuron	12A	III	Inhibitors of mitochondrial ATP synthase	Not-approved
Diazinon	1B: Organophosphates	II	Acetylcholinesterase inhibitors	Not-approved
Dinotefuran	4A: Neonicotinoid	III	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Not-approved
Emamectin benzoate	6	II	Glutamate-gated chloride channel allosteric modulators	Approved
Encarsia formosa	/	/	/	/
Etofenprox	3A: Pyrethroid	U	Sodium channel modulators	Approved
Eretmocerus eremicus	/	/	/	/
Extraits de Chenopodium ambrosioides 16,75% - terpenoid Blend QRD 460	/	/	/	/
Fenpropathrin	3A: Pyrethroid	II	Sodium channel modulators	Not-approved
Flonicamid	29	II	Chordotonal organ modulators – undefined target sites	Approved
Flubendiamid	28	III	Ryanodine receptor modulators	Approved
Flupyradifurone	4D: Butenolides	II	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Approved
Paraffine oil	/	/	/	Approved
Imidacloprid[c]	4A: Neonicotinoid	II	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Not-approved
Indoxacarb	22A	II	Voltage-dependent sodium channel blockers	Not-approved
Isothiocyanate	8	II	Miscellaneous non-specific (multi-site) inhibitors	Not-approved
Lactone : aromatic extract of *Trichoderma harzianum* (!-lactones) : 1% ; Bore (B) : 2%; D-limonène : 6%	/	/	/	/
Lambda-cyhalothrin	3A: Pyrethroid	II	Sodium channel modulators	Approved

Active ingredient	Group (s)	WHO Class[a]	Mode of action	EU Status
Lecanicillium muscarium	/	/	/	Approved
Lufenuron	15	III	Inhibitors of chitin biosynthesis affecting CHS1	Not-approved
Geraniol	/	/	/	/
Malathion	1B: Organophosphates	III	Acetylcholinesterase inhibitors	Approved
Maltodextrin	/	/	/	Approved
Metarhizium anisopliae	/	/	/	Approved
Methomyl	1A: Carbamates	Ib	Acetylcholinesterase inhibitors	Not-approved
Monosultap	/	/	/	/
Novaluron	15: Benzoylureas	U	Inhibitors of chitin biosynthesis affecting CHS1	Not-approved
Orange oil	/	/	/	Approved
Oxymathrin (matrin)	/	/	/	Not-approved
Paecilomyces fumosoroseus	/	/	/	/
Pirimicarb	1A: Carbamates	II	Acetylcholinesterase inhibitors	Approved
Profenofos	1B: Organophosphates	II	Acetylcholinesterase inhibitors	Not-approved
Propylene glicol alginate	/	/	/	Approved
Pymetrozin	9B: Pyridine azomethine derivatives	III	Chordotonal organ TRPV channel modulators	Not-approved
Pyrethrin	3A: Pyrethroid	II	Sodium channel modulators	Approved
Pyriproxyfen	7C: Pyriproxyfen	U	Juvenile hormone mimcs	Approved
Spinetoram	5: Spinosyns	U	Nicotinic acetylcholine receptor (NACHR) allosteric modulators – site I	Approved
Spiromesifen	23	/	Inhibitors of acetyl coa carboxylase	Not-approved
Spirotetramate	23	III	Inhibitors of acetyl coa carboxylase	Not-approved
Sulfoxaflor	4C	II	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Approved
Terpenoid blend	/	/	/	Approved
Thiacloprid	4A: Neonicotinoid	II	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Not-approved
Thiamethoxam	4A: Neonicotinoid	II	Nicotinic acetylcholine receptor (nAChR) competitive modulators	Not-approved
Verticillium lecannii	/	/	/	Approved
Zeta-cypermethrin	3A: Pyrethroid	Ib	Sodium channel modulators	Not-approved

a WHO hazard Class II = moderately hazardous, Class III = slightly hazardous, Class U = unlikely to pose an acute hazard in normal use.

b Chlorpyrifos-ethyl is banned in the EU since July 2020 (due to neurotoxicity and persistence criteria). The maximum residue limit (MRL) has therefore been reduced to the limit of determination (0.01 mg/kg) [1]

c Imidacloprid is banned in the European Union since December 2020, the change of the European MRLs will take place in May 2022. The maximum residue limit will be reduced to the limit of determination 0.01 mg/kg[2].

1 Regulation (EU) 2020/1085 on maximum residue levels of chlorpyrifos and chlorpyrifos-methyl in or on certain products.

2 Regulation (EU) 2021/1881 of 26 October 2021 amending Annexes II and III to Regulation (EC) No 396/2005 of the European Parliament and of the Council as regards maximum residue levels for imidacloprid in or on certain products

Growers should only use products that are locally registered for use on their produce. Before spraying, the label should be read carefully, and the sprayer calibrated. The spray operator should ensure that the pesticide reaches the target but without run-off. An excessively high volume will cause run-off, which means a waste of product and incur an unnecessary cost. Please see COLEAD documents on the safe use of pesticides here.

It is important to follow the recommendations for use to avoid the risk of pesticide residues on the harvested product. The permitted maximum residue levels (MRLs) may vary according to the destination market. For produce that will be exported to the European Union (EU) MRLs apply. To comply with EU MRLs for leafy vegetables (Regulation (EC) No 396/2005), users should follow the Good Agricultural Practices (GAPs) provided by the manufacturer or based on relevant residue trials. The GAP recommendations include the dose rate, the maximum number of applications, the minimum interval between applications, and the pre-harvest interval (PHI). The PHI specifies the minimum number of days between the last application and harvest. In general, this information can be found on the product label.[3] As MRLs are often revised is it recommended to check up-to-date information on MRLs on EU Pesticide Database and CODEX websites or COLEAD crop protection (also includes recommended GAPs).

COLEAD's crop protection database is an online service for members and beneficiaries, which compiles GAPs for a variety of crop–active substance combinations using data available from manufacturers, the scientific literature, and COLEAD's trials. [4] The database contains information on GAPs that ensure compliance with current EU and Codex Alimentarius MRLs. Additional information includes the type of pesticide, the status of an active substance in the EU, the World Health Organization (WHO) recommended classification by hazard, and the resistance group. The crop protection database can be accessed at https://resources.colead.link/en/vue-substance-active-culture.

3 COLEAD highlights the importance of following the label but accepts no responsibility for any efficacy or residue problems that may result.

4 Before application of any plant protection product, it is advisable to check the latest regulatory changes in the EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=homepage&language=EN).

Future possibilities: products that could be effective but are not yet available in Suriname

While the active ingredients currently recommended and used for the control of whiteflies on various horticultural crops in Suriname are known to be effective, other substances with alternative modes of action are registered for use to control whiteflies in other countries including Europe. A review of solutions known to be effective against whiteflies is presented in Annex 1.

Table 3 presents a list of alternatives including low-risk substances that do not require an MRL in the EU and that could be of interest for future registrations. It also includes entomopathogenic fungi (EPF) that infect and kill development stages of the whitefly species. Some of the commercial preparations available include *Metarhizium anisopliae, Verticillium lecanii, Paecilomyces fumosoroseus* and *Beauveria bassiana* (Stansly P.A and Naranjo S.E. (eds.)). Several biopesticide formulations of the EPF are available commercially and registered in several countries for management of whiteflies in horticultural crops.

B. bassiana infects whiteflies when applied as part of a formulation and has a broad range of targets including whitefly, thrips, mealybugs and aphids. It can be tank mixed with adjuvants, insecticidal soaps or oils. No residual harmful effect has been observed on beneficial insects. However, under dry conditions fungi may have limited activity, as they prefer humid conditions to infect the target insects (Abdelghany, 2015).

Table 3 List of active ingredients interesting for future registrations on whiteflies on horticultural crops:

Active ingredient	EU Status	Efficacy	EU MRL [mg/kg]	Resistance group
Fatty acid	Approved	+++	No MRL required	UNE
Garlic (extract)	Approved	+	No MRL required	/
Azadirachtine	Approved	++++	Check EU Pesticide Database	UN
Beauveria bassiana	Approved*	++++	No MRL required	UNF
Buprofezin	Approved	++++	Check EU Pesticide Database	16
Clitoria ternatea	Not in EU Pesticide Database	+	0.01*	/
Cyantraniliprole	Approved	+++	Check EU Pesticide Database	28
Lecanicillium muscarium	Approved	+++	No MRL required	/
Maltodextrine	Approved	+++	No MRL required	/
Metarhizium anisopliae	Approved	+++	Check EU Pesticide Database	UNF
Orange oil (D-limonene)	Approved	++	No MRL required	/
Paecilomyces fumosoroseus	Approved	+++	No MRL required	UNF
Pymetrozine	Not Approved	++++	Check EU Pesticide Database	9B
Pyrethrine	Approved	++	Check EU Pesticide Database	3A
Pyriproxyfen	Approved	++++	Check EU Pesticide Database	7C
Terpenoid Blend QRD 460	Approved	++	No MRL required	/

*=LOQ
UNE = BOTANICAL ESSENCE INCLUDING SYNTHETIC, EXTRACTS AND UNREFINED OILS WITH UNKNOWN OR UNCERTAIN MOA
UN = COMPOUNDS OF UNKNOWN OR UNCERTAIN MOA
UNF = FUNGAL AGENTS OF UNKNOWN OR UNCERTAIN MOA
/ = unavailable information

Specific interventions during harvest

Phytosanitary treatment

- Care should be taken during harvesting such that plants or plant commodities infested with whiteflies are not harvested or are subjected to a phytosanitary treatment accordingly.
- Some of the treatments that can be applied include cold storage, controlled atmosphere, washing, brushing, waxing, dipping and heating.

Sanitation

- Rejects during harvesting should be put in sealed bags or containers and discarded appropriately. Because whiteflies may be dispersed via transport, infested plant material should not be transported in unsealed or open trucks and containers.

Laboratory testing

- Other than visual examinations to determine presence of whiteflies in plant materials, laboratory diagnostics should also be undertaken for confirmatory purposes.
- This is important especially in determining the type of species monitored.
- Official diagnostic protocols should be applied in laboratory testing.

Working together: stakeholder engagement and national action plans

- The risk for exporters is that continued presence of whiteflies in exported produces could threaten access to the European market.
- If further shipments are found to contain the pest, it is possible that imports of produces might be disallowed.
- This means that growers, exporters, and Ministry officials, such as inspectors and phytosanitary experts, must act together to protect the industry.
- Companies and growers must also work together, in particular by informing each other about whiteflies numbers.
- If adult whiteflies are discovered in the field/traps, or nymphs are found in produces, this information must be shared with other growers.
- It is important to remember that if only one exporter sends infested consignments to the EU, it could bring down the entire export sector.
- Along the supply chain, a series of protective measures and checks should be put in place to ensure whitefly is not present in exported produce.
- These cover six stages:
  1. Farmers growing produces for export should be registered by their NPPO.

2. Growers should monitor their fields for whiteflies and, when necessary, treatments should be applied. Growers must keep records of all monitoring and control operations, including: date, reason for applying pesticides, product applied, rate used, and preharvest interval. These records can be inspected by their NPPO.
3. Produces should be inspected before they leave the farm. If even a single fruit with a whitefly is found, sale to an exporter should be stopped.
4. During transport to the pack house, batches from individual farms/plots must be labelled and kept separate.
5. In the pack house, each individual batch of produces must be examined. Batches must be kept separate until they have been inspected and found to be clean, and only then they can be packed for shipment. The presence of even a single whitefly in a batch means that the batch must not be exported.
6. At the airport, phytosanitary inspectors must carry out official inspections. They should issue a phytosanitary certificate only if there isn't any presence of whitefly, insect frass, or signs of infestation on the produce.

Experience has shown that meeting the new EU rules requires effective dialogue and engagement between public and private sectors. All stakeholders must agree on the actions needed to ensure that exported produce is free of the designated pests. This means identifying and agreeing on actions to be taken by private sector operators at all stages, from production to export. It also means agreeing to the responsibilities of the public sector authorities, in particular the National Plant Protection Organization (NPPO). The different stakeholders must periodically meet to review the interventions approved by the NPPO in managing whiteflies on various export commodities (mainly leafy vegetables and other crops) to ensure that both local and international interceptions are minimal due to effective control of quarantine pests.

COLEAD recommends the establishment of committees or task forces that bring all major stakeholders around the table to develop (and oversee the implementation of) a national whitefly action plan. To be effective, this national action plan must be appropriate to the local context, and usable by the range of different producers and exporters concerned (large and small). It is essential that all stakeholders (growers, export companies and airport inspectors) agree to and implement the national action plan. Evidence of this good practice will need to be demonstrated to the European Food and Veterinary Office (FVO) if an inspection visit is conducted in an exporting country.

Annex 1: Plant Protection Products

The following table lists active substances that are known to be effective against whiteflies. It was compiled from multiple sources (efficacy trials, scientific literature, etc.)

ACTIVE INGREDIENT	EU STATUS	REFERENCE MENTIONING EFFICACY
Abamectin	Approved	7,8,10,24
Acephate	Not approved	8
Acetamiprid	Approved	6,7,8,10,11,13,19
Citric acid	/	
Fatty acid	Approved*	8,12,19
Afidopyropen	Not approved	13
Alpha-cypermethrin	Not approved	
Garlic (extract)	Approved	22
Amitraze	Not approved	4
Azadirachtin	Approved	4,7,8,12, 22,24
Beauveria bassiana	Approved*	2,4,7,8,12,19
Beta-cyflutrin	Not approved	
Bifenthin	Not approved	4,7,8,11,13
Buprofezin	Approved	1,4,6,8,10,11,12
Carapa procera (oil)	/	
Chlorantraniliprole	Approved	7
Chlorpyrifos-ethyl	Not approved	8
Clitoria ternatea (Natural extract from the Butterfly Pea)	/	13
Cypermethrin	Approved	
Cyantraniliprole	Approved	7,8,10,13
Cyromazine	Not approved	
Deltamethrine	Approved	4,19
Dimethoate	Not approved	
Diafenthiuron	Not approved	3,6,13
Diazinon	Not approved	
Dinotefuran	Not approved	8,10,11,12,13
Emamectin benzoate	Approved	13
Etofenprox	Approved	
Fenoxycarb	Not approved	4
Fenpropathrin	Not approved	4
Fenproximate	/	12
Flonicamide	Approved	15,19
Flubendiamid	Approved	
Flupyradifurone	Approved	10
Geraniol	Approved	
Paraffine oil	Approved*	8,13

ACTIVE INGREDIENT	EU STATUS	REFERENCE MENTIONING EFFICACY
Mineral oil	Approved*	12
Imidacloprid	Not approved	1,4,6,7,8,10,12
Kinoprene	Not approved	8
Lambda-cyhalothrin	Approved	7
Lecanicillium muscarium = Verticillium lecannii	Approved*	5,16,19
Lufenuron	Not approved	
Malathion	Approved	7
Maltodextrin	Approved	9,19,23
Metarhizium anisopliae	Approved*	5,7,19
Methomyl	Not approved	
Monosultap	/	
Novaluron	Not approved	6,8
Orange oil (D-limonene)	Approved	14,19
Oxymathrin (matrin)	Not approved	18
Piment (extrait)	Not approved	
Paecilomyces fumosoroseus	Approved*	2,8,12,19
Profenofos	Not approved	
Pymetrozin	Not approved	4,6,7,8,10,19
Pyrethrin	Approved	12,19
Pyridaben	Approved	8
Pyriproxyfen	Approved	6,8,10,11,12,13,19
Pyrifluquinazon	Not approved	8,10
Spinetoram	Approved	17
Spirodiclofen	Not approved	
Spiromesifen	Not approved	8,10,11,19
Spirotetramate	Not approved	8,10,12,13
Sulfoxaflor	Approved	7
Tagetes oil	Not approved	8
Terpenoid Blend QRD 460	Approved	20, 21
Thiacloprid	Not approved	6,19
Thiamethoxam	Not approved	7,6,8,10,12,19
Zeta-cypermethrin	Not approved	

* approval by type or strain

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Notes

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