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BS1847: Biology and management of South American fruit fly, *Anastrepha fraterculus*

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March 2019















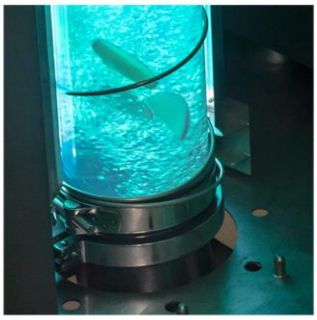


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EXECUTIVE SUMMARY

BS1847: Biology and management of South American fruit fly, *Anastrepha fraterculus*

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This aim of this report is to review the biology and management of the South American fruit fly (SAFF), *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae), and to discuss options for its management should it become established in the kiwifruit growing regions of New Zealand.

Biology and ecology

SAFF is considered the most economically damaging species of fruit fly in fruit production areas of Peru, Uruguay, and southern Brazil with complete crop loss possible. Fruit losses occur as a result of oviposition wounds causing deformation and inducing fruit decay, and from larval feeding within fruit, which often leads to rots. Further economic costs are those associated with control, quarantine compliance, and restriction or loss of markets.

SAFF is a relatively morphologically variable species present in Central and much of South America. The adult is 12–14 mm long and predominantly yellow to yellow-brown with markings on the wings. It is a polyphagous species with over 90 plant hosts reported. Native South American and commercial Myrtaceae are preferred hosts. Other hosts include crops such as apples, stone fruit, berries and grapes.

There are multiple generations each year with adults being the longest-lived and overwintering stage. Mating occurs in non-host trees and females migrate into crops to lay eggs just below the surface of fruit. Larvae feed within the fruit pulp and at maturity pupate in soil. Late instar larvae and pupae can be heavily parasitised.

Pest management

Adults are the only stage for which monitoring is routinely carried out. McPhail Trap® are used to survey and collect adults. The yellow colour of the McPhail Trap® is attractive to SAFF, however there is no specific pheromone lure and only food lures are used.

SAFF is managed in Brazilian orchards using a combination of toxic baits and insecticide applications to trunks, foliage and soil. Mass trapping may also occur. Hygiene in orchards and during processing for market is important as SAFF will breed in ripe fruit.

Research on SAFF pheromones for mating disruption and improved trapping and on Sterile Insect Technology (SIT) is in progress and these technologies are not commercially available yet.

Postharvest treatment of SAFF and related species is generally by cold treatment; the exception is mangos which may be heat-treated.

Risks to kiwifruit

Kiwifruit is not a preferred host but may be attacked either when fruit are young or when ripe. Susceptibility may vary among cultivars. While some insecticides in the current Crop Protection Standard (pyrethrum, spinosad, bifenthrin) are likely to be important in managing SAFF in New Zealand, successful management will require substantial change.

Summary

- Kiwifruit-growing areas in New Zealand are likely to have suitable climates for SAFF, and this could be confirmed by species distribution modelling.
- SAFF may damage at least some kiwifruit cultivars by laying eggs in fruit, and there may be some breeding in fallen ripe fruit. However most SAFF are likely to breed in other fruit such as feijoas, stonefruit, some citrus, guavas and grapes.
- Adults can be monitored using McPhail Traps baited with food lures and insecticides; there is no sex pheromone available yet.
- Monitoring and management will require a co-ordinated area-wide approach including urban and rural areas.
- Available control measures are mass trapping and toxic bait sprays; additional methods such as SIT and mating disruption are yet to be developed.

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1 BIOLOGY AND ECOLOGY OF *ANASTREPHA FRATERCULUS*

1.1 Classification/nomenclature

Anastrepha fraterculus Wiedemann (Diptera: Tephritidae)

Synonyms:

Dacus fraterculus Wiedemann, 1830 (original designation)
Tephritis mellea Walker, 1837
Trypeta unicolor Loew, 1862
Anthomyia frutalis Weyenbergh, 1874
Anastrepha peruviana Townsend, 1913
Anastrepha braziliensis Greene, 1934
Anastrepha costarukmanii Capoor, 1954
Anastrepha scholae Capoor, 1955
Anastrepha pseudofraterculus Capoor, 1955
Anastrepha lambayecae Korytkowski & Ojeda, 1968

The South American fruit fly (SAFF) is relatively morphologically variable and is considered to be a species complex of eight morphotypes (Hernandez-Ortiz et al. 2015). Genetic variability of the mitochondrial COI gene precludes DNA barcoding as an option for identification (Barr et al. 2018).

1.2 Geographical distribution

SAFF occurs throughout Central America, Trinidad and Tobago, Columbia, Venezuela, Guyana, Suriname, Ecuador, Peru, Paraguay, Bolivia, Brazil, Uruguay and northern Argentina (White & Elson-Harris 1992, Kovaleski et al. 2000, Hernandez-Ortiz et al. 2015) (Figure 1). It was also reported from Santa Cruz Island in the Galapagos in 1987 (Harper et al. 1989). SAFF is the most commonly found tephritid fruitfly species in monitoring traps in southern Brazil (Garcia & Corseuil 1998, Garcia et al. 2003a); it is less common than Mediterranean fruit fly, *Ceratitis capitata*, in northern Argentina (Segura et al. 2006) and is absent from Southern Argentina and Chile. An incursion occurred in Chile in 1930 (Volosky 2010) and a second was reportedly eradicated in 1964 (Enkerlin et al. 1989).

Figure 1. Countries and some specific localities within Brazil from which *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (South American fruit fly) has been reported (CABI 2019).

1.3 Description of life stages

Adults are predominantly yellow to yellow-brown with red-brown to brown setae and are 12–14 mm long; wings contain markings in a variable pattern that is not diagnostic (Figure 2) (Dias and Lucky 2017). Eggs are creamy white, elongate, and about 1.4 mm long with sculpturing around the micropylar end (Dutra et al. 2011). Larvae are of a typical tephritid shape being legless and tapering from a blunt posterior to the anterior end containing a pair of sharp mandibles or mouth hooks. There are three larval instars with the third and final instar being approximately 8–10 mm in length. The pupa is sclerotised, ovoid in shape, and approximately 5 mm in length (Figure 3).

Figure 2. **Female (left) and male (right) of *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (South American fruit fly). Both specimens are from the Brazilian-1 morphotype. Photograph by Vanessa Dias, University of Florida. http://entnemdept.ufl.edu/creatures/fruit/tropical/south_american_fruit_fly.htm**

Figure 3. (**A) Pupae of *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (South American fruit fly) *Anastrepha fraterculus* (Wiedemann). (B) Puparium with a pharate adult (fully formed fly) inside. Photograph by Vanessa Dias, University of Florida. http://entnemdept.ufl.edu/creatures/fruit/tropical/south_american_fruit_fly.htm**

Figure 4. Larvae of *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (South American fruit fly). Source https://www.viarural.com.ar/viarural.com.ar/agricultura/aa-insectos/anastrepha-fraterculus-02.htm

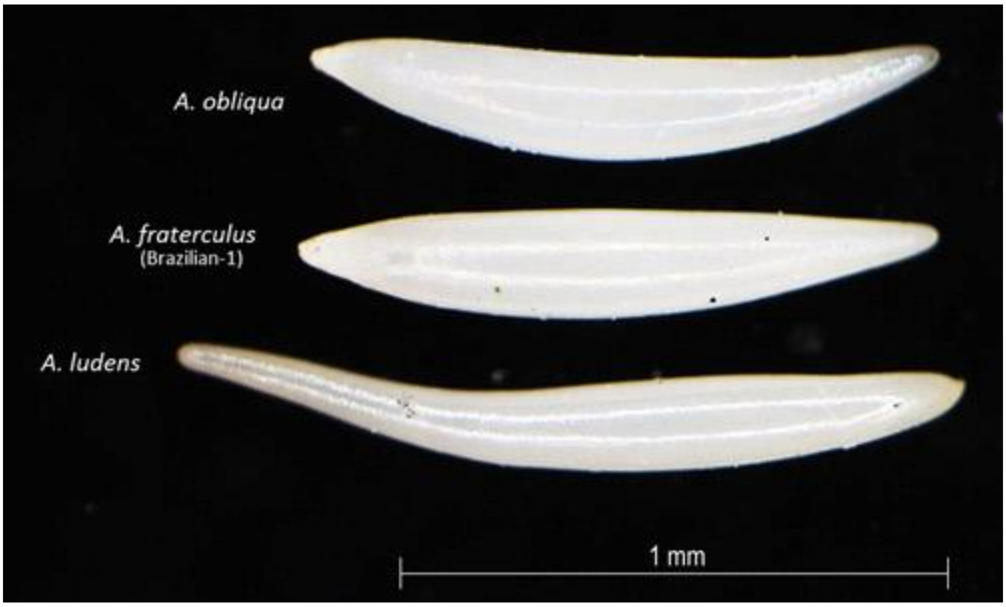

Figure 5. Egg of *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (South American fruit fly) *Anastrepha fraterculus* (Wiedemann) compared with those of two other *Anastrepha* species. Photograph by Vanessa Dias, University of Florida. http://entnemdept.ufl.edu/creatures/fruit/tropical/south_american_fruit_fly.htm

1.4 Host plants

SAFF is a polyphagous species. White and Elson-Harris (1992), Zucchi (2007) and CABI (2019) reported 47, >90 and 71 plant hosts for SAFF, respectively. Not all these plant species are likely to be of equal value as hosts. Plant species with fruit that are selected for oviposition under field conditions and that can support the development of SAFF from egg to healthy adults are host plants (Table 1). Some plant species (e.g. avocado and some citrus) are reported as hosts in field surveys but not in experimental studies (i.e. larvae did not complete development to adults). Other plant species attract egg-laying but do not support larval development, for example, kiwifruit (Table 2). In Brazil and Argentina SAFF prefer native and commercial Myrtaceace over introduced fruit species (Ovruski et al*.* 2003, Segura et al*.* 2006).

Table 1. Primary host plants of the South American fruit fly, *Anastrepha fraterculus*, defined as those that support the complete development from egg to adult.

Host species	Scientific name	Family	Comments	Reference
Aguay	*Chrysophyllum gonocarpum*	Sapotaceae	A rainforest species native to South America with grape-sized berries; host status based on adults reared from field-collected fruit	Oroño et al. 2006
Almond	*Prunus dulcis*	Rosaceae	Adults reared from field-collected fruit	Oroño et al. 2006
Apple	*Malus domestica*	Rosaceae	Data on host suitability are not consistent. Early-infested fruit may fall. Less suitable for larval development than guava (*Psidium guajava*)	Sugayama et al. 1998, Oroño et al. 2006
Apricot	*Prunus armeniaca*	Rosaceae	Adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Bitter or sour orange	*Citrus aurantium*	Rutaceae	Data on host suitability are not consistent. According to some authors, complete development is possible, while others claim that oviposition occurs but larvae fail to complete development.	Putruele 1996, Oroño et al. 2006
Blackberry	*Rubus fruticosus*	Rosaceae	Adults reared from field-collected fruit	Bisognin et al. 2015, Funes et al. 2017
Cherry of the Rio Grande	*Eugenia involucrate*	Myrtaceae	Preferred native host	Santos and Guimaraes 2018
Common passion flower	*Passiflora caerulea*	Passifloraceae	Adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Damson plum	*Prunus institia*	Rosaceae	Adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Feijoa	*Acca sellowiana*	Myrtaceae	Based on adults reared from field-collected fruit;	Salles and Leonel 1996, Oroño et al. 2006
Fig	*Ficus carica*	Moraceae	Based on adults reared from field-collected fruit	Oroño et al. 2006
Gabiroba	*Campomanesia xanthocarpa*	Myrtaceae	Preferred native host	Oroño et al. 2006 (as *C. crenta*), Santos and Guimaraes 2018
Grapes	*Vitis vinifera*	Vitaceae	Not all varieties equally preferred	Oroño et al. 2006, Zart et al. 2011, Machota et al. 2016
Grapefruit	*Citrus x paradisi*	Rutaceae	Data on host suitability are not consistent. Complete development possible or oviposition occurs but larvae fail to complete development; most preferred citrus for oviposition	Putruele 1996; Aluja et al. 2003, Oroño et al. 2006, Ruiz et al. 2015
Guabiyú	*Myrcianthes pungens*	Myrtaceae	Based on adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Guava	*Psidium guajava*	Myrtaceae	Based on adults reared from field-collected fruit. Preferred cultivated host	Putruele 1996, Segura et al. 2006, Oroño et al. 2006
Jua	*Ziziphus joazeiro*	Rhamnaceae	Based on adults reared from field-collected fruit	Sa et al. 2008
Kumquat	*Fortunella japonica*	Rutaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006
Loquat	*Eriobotrya japonica*	Rosaceae	Based on adults reared from field-collected fruit	Putruele 1996, Oroño *et al.* 2006

Host species	Scientific name	Family	Comments	Reference
Mandarin (Clementine)	*Citrus reticulata*	Rutaceae	Data on host suitability are not consistent. Complete development possible. Some authors claim that oviposition occurs but larvae fail to complete development.	Putruele 1996, Oroño et al. 2006, Segura et al. 2006, Ruiz et al. 2015, Dias et al. 2017
Mango	*Mangifera indica*	Anacardiaceae	Based on adults reared from field-collected fruit	Putruele 1996; Hernandez-Ortiz 1992, Ovruski et al. 2003
Orange	*Citrus sinensis*	Rutaceae	Data on host suitability are not consistent. Complete development possible or oviposition occurs but larvae fail to complete development	Putruele 1996, Aluja et al. 2003, Oroño et al. 2006, Ruiz et al. 2015
Pacay	*Inga marginata*	Fabaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006
Papaya	*Carica papaya*	Caricaceae	Based on adults reared from field-collected fruit	Putruele 1996
Peach	*Prunus persica*	Rosaceae	Based on adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006, Segura et al. 2006, Alberti et al. 2012
Pear	*Pyrus communis*	Rosaceae	Data on host suitability are not consistent. Suitable for larval development in laboratory trials but not preferred in the field	Oroño et al. 2006, Segura et al. 2006, Nunes et al. 2015
Persimmon	*Diospyros kaki*	Ebenaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006, Segura et al. 2006
Plum	*Prunus domestica*	Rosaceae	Based on adults reared from field-collected fruit	Goncalves et al. 2005, Oroño et al. 2006
Plum	*Prunus insititia*	Rosaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006
Pomegranate	*Punica granatum*	Punicaceae	Based on adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Prune	*Prunus saliciara*	Rosaceae	Fruit drops may occur before larvae complete development	Salles 1999, Putruele 1996
Quince	*Cydonia oblonga*	Rosaceae	Based on adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Raspberry	*Rubus idaeus*	Rosaceae	Based on adults reared from field-collected fruit	Funes et al. 2017, Santos and Guimaraes 2018
Spanish prune	*Spondias purpurea*	Anacardiaceae	Based on adults reared from field-collected fruit	Sa et al. 2008
Strawberry guava	*Psidium cattleianum*	Myrtaceae	Preferred native host in southern Brazil	Bisognin et al. 2015, Santos and Guimaraes 2018
Surinam cherry	*Eugenia uniflora*	Myrtaceae	Based on adults reared from field-collected fruit; preferred native host	Oroño et al. 2006, Bisognin et al. 2015, Santos and Guimaraes 2018
Ubajay	*Hexachlamys edulis*	Myrtaceae	Based on adults reared from field-collected fruit	Putruele 1996, Oroño et al. 2006
Umbu	*Spondias tuberosa*	Anacardiaceae	Based on adults reared from field-collected fruit	Sa et al. 2008
Unknown	*Eugenia retusa*	Myrtaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006
Wild plum	*Ximenia americana*	Olacaceae	Based on adults reared from field-collected fruit	Segura et al. 2006
Wild walnut	*Juglans australis*	Juglandaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006
Yellow Mombin	*Spondias mombim*	Anacardiaceae	Based on adults reared from field-collected fruit	Oroño et al. 2006

Table 2. Secondary and non-host plants of the South American fruit fly, *Anastrepha fraterculus*, defined as those that may be attract oviposition but do not support the complete development from egg to adult.

Host species	Scientific name (Family)	Family	Comments	Reference
Avocado	*Persea americana*	Lauraceae	Based on experimental studies and absence from field-collected fruit	Liquido et al. 2011
Blueberry	*Vaccinium* sp.	Ericaceae	Poor or non host	Bisognin et al. 2015
Kiwifruit	*Actinidia chinensis*	Actinidiaceae	Oviposition may occur rarely in mature fruit, but more likely in fallen fruit	Hickel and Schuck 1993, Lorscheiter et al. 2012
Lemon	*Citrus limon*	Rutaceae	Oviposition occurs but larvae fail to complete development	Ruiz et al. 2015
Mandarin (Satsuma)	*Citrus unshiu*	Rutaceae	Oviposition occurs but larvae fail to complete development	Oroño et al. 2006
Tangerine	*Citrus tangerina*	Rutaceae	Oviposition occurs but larvae fail to complete development	Dias et al. 2017, Segura et al. 2006, Ruiz et al. 2015

1.5 Damage

SAFF is considered the most economically damaging species of fruit fly in fruit production areas of Peru, Uruguay, and southern Brazil with complete crop loss possible (Rupp et al. 2006, Lorscheitter et al. 2012). Fruit losses occur as a result of oviposition wounds causing deformation and inducing fruit decay, and from larval feeding within fruit, which often leads to rots (e.g. Machota et al*.* 2016). While fruit loss can be serious, the loss of entire markets is possible through trade restriction. The presence of SAFF would require the implementation of a monitoring and control programme, and a postharvest treatment for export to occur (e.g. Willink et al. 2006).

1.5.1 Damage to kiwifruit

Hickel and Schuck (1993) recorded that SAFF emerged from *Actinidia* fruit of 'Hayward', Monty, 'Bruno', 'Allison' and 'Abbott' collected from the floor of commercial orchards and a research orchard near Campo Belo do Sul in Southern Brazil. 'Hayward' fruit were most infested with an average of five larvae/fruit; larvae tended to be found in the pericarp near the peduncle. Hickel and Schuck (1993) speculated that areas of the fruit with fewest hairs were preferred for oviposition, and that infestation of kiwifruit was due to high local populations of fruit flies with few alternative options for egg-laying. Lorscheiter et al. (2012) suggested that the larvae observed by Hickel and Schuck (1993) in fruit collected from the orchard floor were the result of oviposition after fruit drop, not before.

Lorscheiter et al*.* (2012) caged SAFF with fruit of two cultivars, 'Bruno' and a local selection known as MG06, for short periods on vines. Fruit were exposed at three different times of the season (30 and 90% of final fruit size and just prior to harvest). Eggs were found in 80% of MG06 fruit exposed at 30% of their final size. Crystalline exudate was also present on the surface of 80% of these fruit and presumed to be the result of oviposition wounds. No fruit drop associated with SAFF was observed during fruit growth, and damage at harvest was described as depressed areas and cracks in the fruit epidermis, and damage to pulp resulting from early larval feeding. No larvae were recorded. There was no damage to fruit exposed late in their development (90% of full size and fruit just prior to harvest), although eggs were found in one fruit. Fruit of 'Bruno' were not damaged. In laboratory trials, larvae of SAFF were able to complete development in fruit of MG06 after °Brix had reached 6.4%. In a separate laboratory trial da Silveira et al. (2010) found that SAFF could complete development in mature fruit of 'Bruno' and 'Hayward'.

1.6 Biology and ecology

1.6.1 Life-cycle length and seasonality

Adults are the longest lived stage (Figure 6) and are present at all times of the year. Machado et al. (1995) reported minimum threshold temperatures and day-degree sums for development (Table 3). Development was fastest at 25°C (Salles 1993) and the temperature range for survival was estimated to be between 10 and 35°C (Salles et al*.* 1995).

In southern Brazil there may be four generations a year dependent on temperature and food availability with flies most abundant in summer (Garcia *et al.* 2003b). Based on day-degree summation, a summer generation in the Bay of Plenty may take 45 d, an autumn generation may take 70 d and there may be no successful overwintering except as adult flies.

Table 3. Minimum temperature thresholds and day-degree sums for the temperature-dependent development rate of different lifestages of the South American fruit fly, *Anastrespha fraterculus* from Machado et al. (1995).

Life stage	Temperature threshold (°C)	Day-degree sum
Egg	9.25	52.25
Larva	10.27	161.45
Pupa	10.78	227.79
Complete life cycle	10.72	430.58

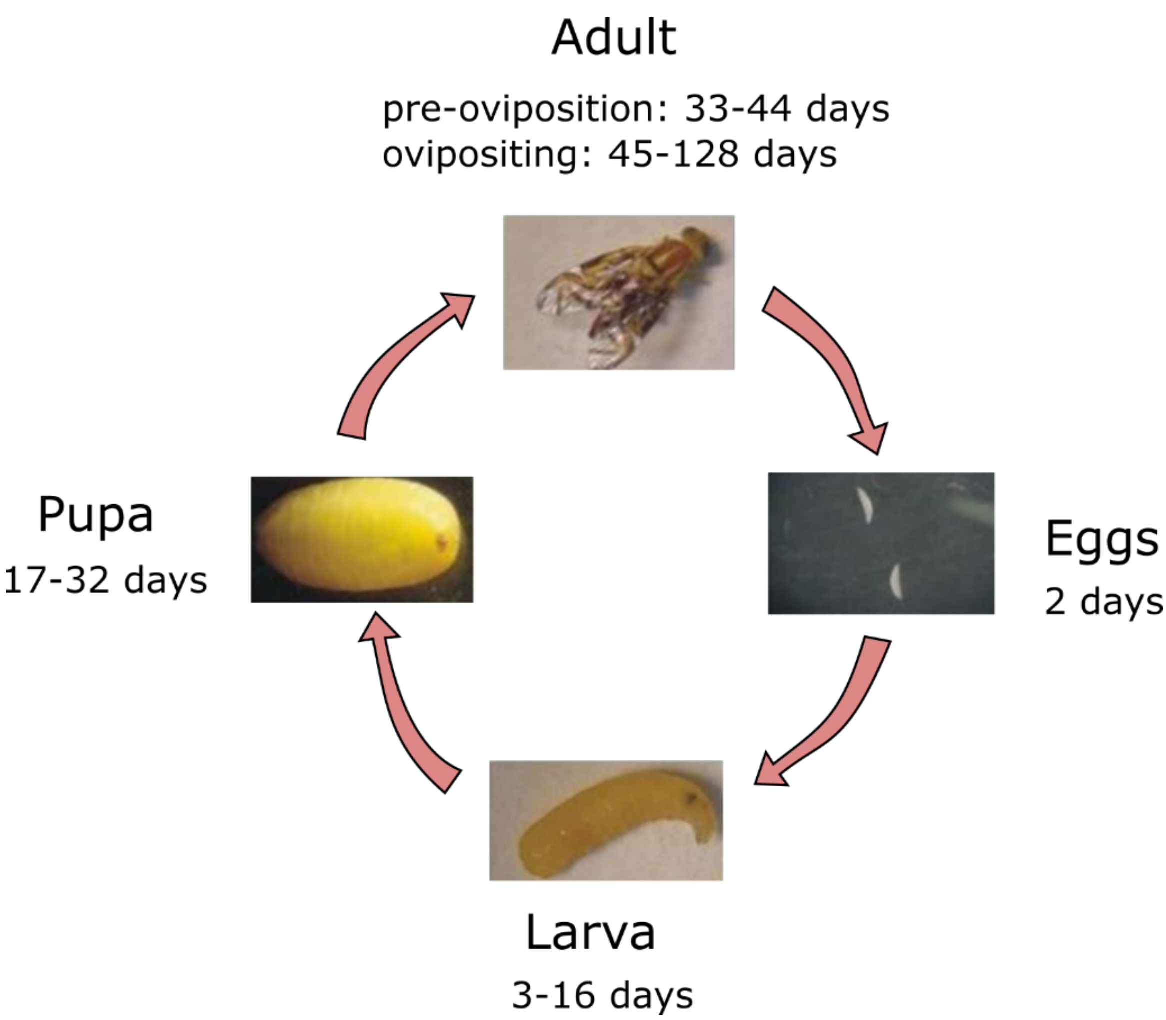

Figure 6. Life cycle of *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (SAFF) with development times for each stage when reared at 24°C according to Jaldo et al. (2007).

1.6.2 Adult

Adults mate in the foliage of non-host trees and mated females disperse to find suitable fruit for oviposition. Males have a relatively variable pre-mating period of 3–10 d before they establish and defend a mating territory, which is usually on the underside of a leaf. Mating is preceded by a complex courtship that includes release of pheromones and singing by vibrating wings (Morgante et al. 1983, Aluja 1994; Cladera et al. 2014). Analysis of the male sex pheromone indicated that there are at least 14 volatile compounds consisting of terpenoids, alcohols and aldehydes, the ratio of which can vary between populations (Brizova et al. 2013). Some of the volatiles are recognised by males and others by females, consistent with the defence of mating territories on the one hand and courtship behaviour on the other (Lima-Mendonca et al. 2014). A comparison between *Anastrepha* species suggests that mixtures are species-specific (Lima-Mendonca et al. 2014).

Breeding occurs all year round where climate allows. Taufer et al. (2000) found that ovarian development occurred at constant temperatures of 20 and 25°C, but not at 9 or 13°C. The average longevity for the longest-lived females was 153.9 days at 13°C. Females had shorter lives when kept at 9 and 25°C (51.0 and 68.4 d respectively). Mating occurs once and females may lay 400–800 eggs (Stibick 2004, Volosky 2010).

In Brazil adults were found to readily colonise peach orchards and, less frequently, apple orchards from surrounding native forest (Sugayama et al. 1998, Kovaleski et al. 1999, Salles 1999). However most flies remained within 200 m of the release point, suggesting they may remain aggregated around food sources in the landscape.

1.6.3 Larvae and pupae

All three stages of larvae feed within the fruit pulp. Feeding damage often leads to fruit drop, assisting mature larvae to leave fruit and enter soil where they pupate up to 10 cm deep dependent on compaction (Salles and Carvalho 1993). Successful pupation occurs in the temperature range 10–35°C (Salles et al. 1995).

1.6.4 Eggs

Eggs are laid singly below the fruit surface. In citrus eggs were found just below the fruit surface (<0.5 mm deep) while in other fruit such as mango and guava, eggs were laid >2 mm deep (Dias et al. 2018). The number of eggs laid differs according to fruit with more eggs laid in mango than in citrus (Dias et al. 2018).

1.7 Natural enemies

At least 13 parasitoids are known for SAFF (Table 4). The most abundant parasitoid of SAFF is the Figitid *Aganaspis pelleranoi* (Wiedemann) which occurs widely in Brazil and has parasitism rates ranging between 26 and 90% (Guimarães et al. 2000, Nunes et al. 2012) and has also been reared from a wide range of hosts in northern Argentina (Schlisermann et al. 2010).

Table 4. Parasitoids recorded from South American fruit fly *Anastrepha fraterculus*.

Parasitoid species	Parasitoid Family	Host stage	Reference
Aceratoneuromyia indica	Eulophidae	Late instar larvae and pupae	Schliserman et al. 2010
Aganaspis nordlanderi	Figitidae	Larvae/ Pupae	Santos and Guimaraes 2018
Aganaspis pelleranoi	Figitidae	Larvae/ Pupae	Santos and Guimaraes 2018, Goncalves et al. 2016, Schliserman et al. 2010
Asobara anastrephae	Braconidae	Late instar larvae and pupae	Schliserman et al. 2010
Coptera haywardi	Diaprididae	Pupae	Ovruski et al. 2000
Diachasmimorpha longicaudata	Braconidae	Late instar larvae and pupae	Schliserman et al. 2010
Doryctobracon areolatus	Braconidae	Puparia Late instar larve and pupae	Santos and Guimaraes 2018, Schliserman et al. 2010, Marinho et al. 2009
D. brasiliensis	Braconidae	Puparia	Schliserman et al. 2010, Santos and Guimaraes 2018, Marinho et al. 2009
Lopheucoila anastrephae	Braconidae	Puparia Late instar larve and pupae	Schliserman et al. 2010
Odontosema anastrephae	Braconidae	Puparia Late instar larvae and pupae	Schliserman et al. 2010
Opius bellus	Braconidae	Puparia Late instar larvae and pupae	Schliserman et al. 2010
Trichopria anastrephae	Diaprididae	Pupae	Ovruski et al. 2000
Utetes anastrephae	Braconidae	Puparia Late instar larvae and pupae	Schliserman et al. 2010

2 PEST MANAGEMENT

2.1 Monitoring techniques

Adults are the only stage for which monitoring is routinely carried out. The McPhail Trap® is used to survey and collect adults. The yellow colour of McPhail Traps is attractive to SAFF (Aluja 1994, Cytrynowicz et al. 1982) however there is no specific pheromone lure and only food lures are used. Recommendations of the USDA are that McPhail Traps be hung in a favoured host tree and baited with torula yeast pellets or protein hydrolysate and water (Stibick 2004).

The success of baiting is influenced by the host crop and the developmental stage of the fruit with traps in preferred host crops such as ripe guavas capturing relatively high numbers of flies (Jahnke et al. 2014). Da Rosa et al. (2017) tested four lures for trapping and monitoring SAFF in plum, pear and feijoa orchards in Brasil. Lures made of hydrolysed animal proteins (CeraTrap, BioIberica, Barcelona) were the most effective for plum and pear orchards but results were more variable for a feijoa orchard.

2.2 Management

2.2.1 Chemical control

SAFF is managed in Brazilian orchards using a combination of toxic baits and insecticide applications when a threshold of 0.5 flies per trap per day is exceeded (Sugayama et al. 1998, Cladera et al. 2014). Malathion has been the standard insecticide used with food lures (Stibick 2004) but recently spinosyns (spinosad or spinetoram) have been tested (Harter et al. 2015, Schutze et al. 2018). Both spinosad and spinetoram were effective in killing adult SAFF with their efficacy being modified by the type of bait they were combined with. The commercial bait (Success 0.02 CB®, a.i. 0.24 g/L spinosad) was the only combination of toxin and lure to provide at least 80% mortality for 21 days (Schutze et al. 2018). Harter et al. (2015) found that traps with malathion were superior to spinosad formulations, including Success 0.02 CB. Rain significantly reduced the efficacy of all formulations (Harter et al. 2015). Research on kairomones and phagostimulants to improve the consumption of baits and bait/insecticide combinations is a focus for tephritid fruit fly management in general, however this research is still in its infancy for SAFF (Cladera et al. 2014).

When a fly is trapped in an otherwise fruit-fly-free area, foliage and ground bait sprays, fruit stripping and soil treatment is a minimum recommended response (Stibick 2004). The Animal & Plant Health Inspection Service (APHIS) of the USDA, which regulates the import of fruit from South America, recommends treatment if one mated female or two or more unmated females are trapped. Area freedom is deemed to be verified after no flies are captured for three generations within a detection zone of 8 km radius (Stibick 2004).

Mass trapping is recommended at a density of 150 traps/ha (Stibick 2004). Foliage and ground sprays of spinosad formulated with sugars, attractants and water are recommended within 366 m (400 yards) of a positive trap catch (Stibick 2004). Soil treatment to a depth of 50 mm with diazinon is also recommended where there are confirmed larval infestations (Stibick 2004).

2.2.2 Cultural control

Removal of ripe, fallen fruit in orchards and protection of stored and rejected fruit at postharvest facilities are recommended hygiene measures.

Mating disruption (MD) is not yet commercially used but has been tested successfully in commercial peach orchards near Pelotas, Brazil (Harter et al. 2010). A synthetic pheromone formulation, Splat® Grafo (Isca Tecnologias Ltd, Brazil), was applied at a rate of 1 kg/ha using 1000 dispensers together with a toxic bait containing malathion. The number of SAFF captured in traps was reduced by 90%. Damage to fruit was also reduced to 0.1% in treated blocks compared with 8.3% when blocks were untreated. Splat Grafo is formulated to contain 4.4% of the pheromones (E) -8-Dodecenyl Acetate, (Z) -8-Dodecenyl Acetate, and Z-8-dodecenol; the remainder being inert waxes and oils. It can be applied by caulking gun to branches, tree trunks and posts.

The development of Sterile Insect Technology (SIT) for SAFF was initiated in the late 1990s. Progress has been impeded by the uncertain species status of SAFF, incomplete biological knowledge required to rear it and the lack of a management structure to implement it (Vera et al*.* 2007, Cladera et al. 2014).

2.2.3 Biological control

Biological control programmes are in an early development phase in Argentina. The braconid *Diachasmimorpha longicaudata*, a larval-pepupal koinobiont endoparasitoid, and *Coptera haywardi*, an idiobiont pupal endoparasitoid, are being considered for release in northern Argentina (Van Nieuwenhove et al. 2016). Separately they had 75 and 56% parasitism rates and together parasitised about 93% of all hosts. A number of other species are also be considered to have potential as biological control agents including *Aganaspis pelleranoi* (Goncalves et al. 2016) and *Doryctobracon brasiliensis* (Poncio et al*.* 2016). The latter has an estimated optimum temperature of 21°C, making it suitable for warm temperate regions.

Nematodes and fungal entomopathogens have been screened successfully in laboratory trials (e.g. Destefano et al*.* 2005, Heve et al*.* 2017) and may provide options for reducing survival of mature larvae and pupae in soil.

2.2.4 Post-harvest control

Postharvest treatment is required to ensure market access for fruit from areas where SAFF is established (Willink et al. 2006). APHIS of the USDA regulates the import of fruit from South America. It has requirements for packaging, containment, inspection and certification, and treatment to probit 9 (99.997% mortality). SAFF and other *Anastrepha* species are managed by cold treatment (APHIS schedule T107) which includes preconditioning of fruit and then applying cold (≤0.6°C for 18 d or ≤1.1°C for 20 d or ≤1.7°C for 22 d) (Stibick 2004, Willink et al. 2006).

Hot water treatment is a common option used by the mango industry of Latin America to gain entry to US markets. Treatment is based on the study by Nascimento et al*.* (1992) who found that hot water treatment at 45.9-46.3°C for 39.7 and 68.5 min achieved probit 9 mortality of eggs and larvae of SAFF respectively.

3 PEST MANAGEMENT IN KIWIFRUIT

3.1 Chemical control

SAFF may be managed in kiwifruit orchards by mass trapping and by foliage and trunk bait sprays during the high-risk period in summer and autumn (Tables 5 and 6). A commercial toxic bait made in Brazil (Success 0.02 CB®) is available. Soil treatments with bifenthrin may provide sustained control of emerging fruit flies as it is strongly bound to organic matter and is more persistent (half-life of 97–250 d in soil) than some other insecticides such as diazinon (half-life of 34.8 d in soil) (Fecko 1999, Singh and Singh 2005).

3.2 Cultural control

Ripe, fallen fruit can be attractive to SAFF so that hygiene measures are likely to be important to prevent the build-up of local populations of flies on orchards and at packhouses.

As SAFF is able to use a wide range of hosts, its management will require an area-wide approach throughout the year. Known hosts are common in the Bay of Plenty and other kiwifruit-growing regions in New Zealand (Figure 7). Area-wide monitoring in both rural and urban areas, together with orchard and packhouse hygiene and grower and community engagement are likely to be important.

Substantial further research is needed before area-wide management can include technologies such as mating disruption, SIT or other new methods such as gene drives (McFarlane et al. 2018). The latter technology is in development and involves the use of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR/Cas9) genome editing to replace an existing genetic sequence with a designed sequence that distorts inheritance in its favour.

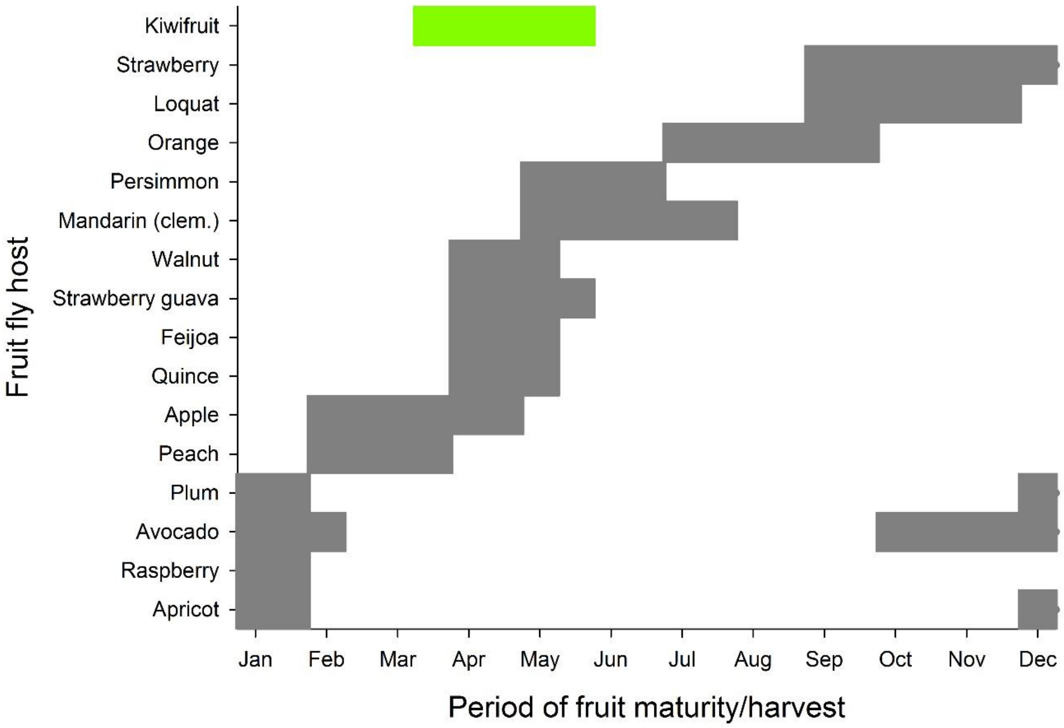

Figure 7. Monthly availability of suitable hosts of the South American fruit fly, *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) (SAFF) based on approximate harvest periods for fruit in New Zealand.

3.3 Biological control

There may be some biological control of soil-dwelling pupae and adult flies by existing predators in New Zealand. However more effective but not necessarily economically acceptable control may come from introduced parasitoids. Parasitism rates are likely to vary according to the fruit host, season and at the local block level, and classical biological control is best seen as an adjunct to other measures (Ovrusiu et al*.* 2007, Ovruski and Schliserman 2012). The selection, introduction, rearing and release of one or more parasitoids is likely to be a medium- to long-term research programme and of considerable cost. Whether the use of entomopathogens for control of soil-dwelling late instar larvae and pupal requires is worthwhile is reliant on further research.

3.4 Summary

- Kiwifruit-growing areas in New Zealand are likely to have suitable climates for SAFF, and this could be confirmed by species distribution modelling.
- SAFF may damage at least some kiwifruit cultivars by laying eggs in fruit, and there may be some breeding in fallen ripe fruit. However most SAFF are likely to breed in other fruit such as feijoas, stonefruit, some citrus, guavas and grapes.
- Adults can be monitored using McPhail Traps baited with food lures and insecticides; there is no sex pheromone available yet.
- Monitoring and management will require a co-ordinated area-wide approach including urban and rural areas.
- Available control measures are mass trapping and toxic bait sprays; additional methods such as sterile insect release and mating disruption are yet to be developed.

Table 5. Current and potential methods for pre and postharvest management of South American Fruit Fly (SAFF), *Anastrepha fraterculus*.

Type	Method	Expected outcomes(s)	Likely impact on SAFF populations	Used elsewhere	Key limitation(s)	On orchard implement-ation	Technical difficulty of research	Relative development costs	Develop-mental time
Monitoring	Food lure and insecticide traps for adults	Identifying SAFF densities and distribution	Low (depending on trap density)	Argentina, Brazil, Chile, Mexico	Labour intensive	easy	easy	low	short
	New attractants	More efficient trapping	Low-medium (depending on trap density)	No	Replacement/cost of attractant	easy	difficult	high	long
	Automated traps	Improved monitoring; less labour intensive	Low (depending on trap density)	No	Establishment and maintenance costs may be higher than manual traps	easy	difficult	medium	medium
Chemical	Mass trapping with insecticide and food lure	Reduced local populations	High in local area	Chile?	Labour intensive	easy	easy	low	short
	Soil sprays	Reduced emergence of adults	High in local area	Argentina, Brazil, Mexico	Not compatible with CPS	easy	easy	low	short
	Bait sprays for foliage and trunk application	Reduced adult densities	High in local area	Argentina, Brazil, Mexico	Expensive as repeated sprays required; rainfall limits persistence	easy	easy	low	short
	New insecticides	New products available in CPS for use in traps or as soil and foliage sprays	High in local area	No	Availability is uncertain	easy	moderate	medium	medium

Type	Method	Expected outcomes(s)	Likely impact on SAFF populations	Used elsewhere	Key limitation(s)	On orchard implement-ation	Technical difficulty of research	Relative development costs	Develop-mental time
Cultural	Mating disruption	Reduced local populations	High in local area	One experiment in Brazil	Technical aspects such as availability of pheromones and dispenser technology	moderate	moderate	medium	medium
	Sterile Insect technique	Reduced local populations	high	No	Requires a mass-rearing, an irradiation facility and supporting research	easy	moderate	high	long
	Fruit removal	Removal of eggs, larvae and pupae	medium	Argentina, Brazil, Mexico	Labour intensive	easy	easy	low	short
	Removal of host plants	Reduction in SAFF abundance	medium	No	Requires social licence	easy	easy	low	short
	Gene drive	Reduction or elimination of SAFF	high	No	Many technological, legal and social barriers	easy	high	high	long
Biological	Classical biocontrol - introduction of new parasitoids	Ongoing population suppression	medium	Natural enemies known in South America	Regulatory approval, time and costs to introduce and test against SAFF	easy	moderate	high	long
	Biopesticides including nematodes	Reduced survival of late instar larvae and pupae in soil	medium	No	Time to test and formulate against SAFF	easy	moderate	moderate	long
Post-harvest	Cold treatment	Reduce fruit infestation to probit 9	low	Yes	Requires research to confirm a protocol for kiwifruit	NA	moderate	low	short
	Heat treatment	Reduce fruit infestation to probit 9	low	No. One experiment on mangos	Possible fruit damage	NA	moderate	medium	medium
	Irradiation or fumigation treatments	Mortality of eggs and larvae in fruit	low	No	Social licence, possible fruit damage	NA	difficult	high	long

Table 6. A potential management plan for South American Fruit fly, *Anastrepha fraterculus*, in kiwifruit blocks (based on methods currently available). Note, bifenthrin would not be suitable for use in organic orchards.

Period	Method	Active Ingredient	Product name (available in Zealand)	Allowed in CPP	Adverse impact risk	Comments
Dormancy	Adult bait traps with insecticide	spinosad, bifenthrin	Success Naturalyte, Entrust™ SC Naturalyte, Talstar 100EC	No	None	Rainfall reduces efficacy of bait traps
	Host plant removal on orchard	NA	NA	Yes	Low	Fruit trees in rural home gardens are likely to be reservoirs if not removed
Bud Phase	Adult bait traps with insecticide	spinosad, bifenthrin	Success Naturalyte, Entrust™ SC Naturalyte, Talstar 100EC	No	None	
Flower-ing	Adult bait traps with insecticide	spinosad, bifenthrin	Success Naturalyte, Entrust™ SC Naturalyte, Talstar 100EC	No	None	
Fruit-set to monitoring	Adult bait traps with insecticide; Canopy sprays of spinosad up to 120 days before harvest; canopy sprays of pyrethrum up to 14 days before harvest	spinosad, bifenthrin, pyrethrum	Success Naturalyte, Entrust™ SC Naturalyte, Talstar 100EC	No	None	
Monitoring	Mass trapping of adults	spinosad, bifenthrin	Success Naturalyte, Entrust™ SC Naturalyte, Talstar 100EC	No	None	
	Orchard hygiene – removal of thinned/fallen fruit	NA	NA	Yes	None	
	Ground bait sprays	bifenthrin	Talstar 100EC	No	Moderate	Multiple sprays assumes modification of CPS
	Canopy sprays	pyrethrum	Pyganic, ZETaPY, Pylon	Yes	None	Multiple sprays assumes modification of CPS
Postharvest	Adult bait traps with insecticide	spinosad, bifenthrin	Success Naturalyte, Entrust™ SC Naturalyte, Talstar 100EC	Yes	None	
	Orchard hygiene – removal of unharvested/fallen fruit	NA	NA	Yes	None	
	Ground sprays to prevent fly emergence	bifenthrin	Talstar 100EC	No	Moderate	Multiple sprays assumes modification of CPS
	Canopy sprays	pyrethrum	Pyganic, ZETaPY, Pylon	Yes	None	If fruit remain on vines after harvest
	Host plant removal on orchard	NA	NA	Yes	None	

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